Exhibit A - U.S. Patent No. 7,924,802 ("'802 Patent")

Accused Instrumentalities: cellular base stations, mobile products, and services that support 3GPP carrier aggregation, including without limitation Apple mobile products, and all versions and variations thereof since the issuance of the asserted patent.

For each and every claim identified below, the Accused Products include Defendant's current, past, and future 3GPP 4G and 5G NR Radio Access Network (RAN) solutions and cellular base stations supporting 4G and 5G carrier aggregation capable radios and basebands compliant with the 3GPP 4G and 5G Standards, that are provided to Defendant from Nokia, Ericsson, and Samsung. The charts below describe 4G and 5G base stations and UEs compliant with carrier aggregation technologies supported in the eNups anteB/gNB infrastructure and UEs that are provided to the defendant by the infrastructure and UE vendors.

The following charts apply to each Accused Product because, as described below, each Accused Product implements carrier aggregation wireless technology, including but not limited to functionality set forth in the 3GPP 4G and 5G NR Standard (a communications Standard to which each Accused Product is advertised as compliant) in a manner that causes each Accused Product to function in substantially the same manner with respect to the Asserted Claims.

Claim 1

Claim 1	Public Documentation
[1pre] A method of transmitting information in a wireless communication channel comprising:	To the extent the preamble is found to be limiting, the Accused Instrumentalities perform a method of transmitting information in a wireless communication channel. For example, Defendant deploys and uses 4G and 5G RAN Solutions by vendors Ericsson and Nokia. These 4G and 5G RAN Solutions are 4G and 5G NR cellular radio access network systems supporting carrier aggregation, and the accused systems include all the installed components for the 4G and 5G NR RAN solution systems deployed by Defendant. *See, e.g.*: 5.2 Downlink 5.2.1 Downlink transmission scheme A closed loop Demodulation Reference Signal (DMRS) based spatial multiplexing is supported for Physical Downlink Shared Channel (PDSCH). Up to 8 and 12 orthogonal DL DMRS ports are supported for type 1 and type 2 DMRS respectively. Up to 8 orthogonal DL DMRS ports per UE are supported for SU MIMO and up to 4 orthogonal DL DMRS ports per UE are supported for MU-MIMO. The number of SU-MIMO code words is one for 1-4 layer transmissions and two for 5-8 layer transmissions.

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Claim 1	Public Documentation
	The DMRS and corresponding PDSCH are transmitted using the same precoding matrix and the UE does not need to know the precoding matrix to demodulate the transmission. The transmitter may use different precoder matrix for different parts of the transmission bandwidth, resulting in frequency selective precoding. The UE may also assume that the same precoding matrix is used across a set of Physical Resource Blocks (PRBs) denoted Precoding Resource Block Group (PRG). Transmission durations from 2 to 14 symbols in a slot is supported. Aggregation of multiple slots with Transport Block (TB) repetition is supported. (3GPP TS 38.300 V17.4.0) 5.4 Carrier aggregation 5.4.1 Carrier aggregation In Carrier Aggregation (CA), two or more Component Carriers (CCs) are aggregated. A UE may simultaneously receive or transmit on one or multiple CCs depending on its capabilities: - A UE with single timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells sharing the same timing advance (multiple serving cells grouped in one TAG); - A UE with multiple timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells with different timing advances (multiple serving cells grouped in multiple TAGs). NG-RAN ensures that each TAG contains at least one serving cell; - A non-CA capable UE can receive on a single CC and transmit on a single CC corresponding to one serving cell only (one serving cell in one TAG). CA is supported for both contiguous and non-contiguous CCs. When CA is deployed frame timing and SFN are aligned across cells that can be aggregated, or an offset in multiples of slots between the PCell/PSCell and an SCell is configured to the UE. The maximum number of configured CCs for a UE is 16 for DL and 16 for UL. (3GPP TS 38.300 V17.4.0) 6.7 Carrier Aggregation In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below:

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Claim 1	Public Documentation
	- In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell. (3GPP TS 38.300 V17.4.0)

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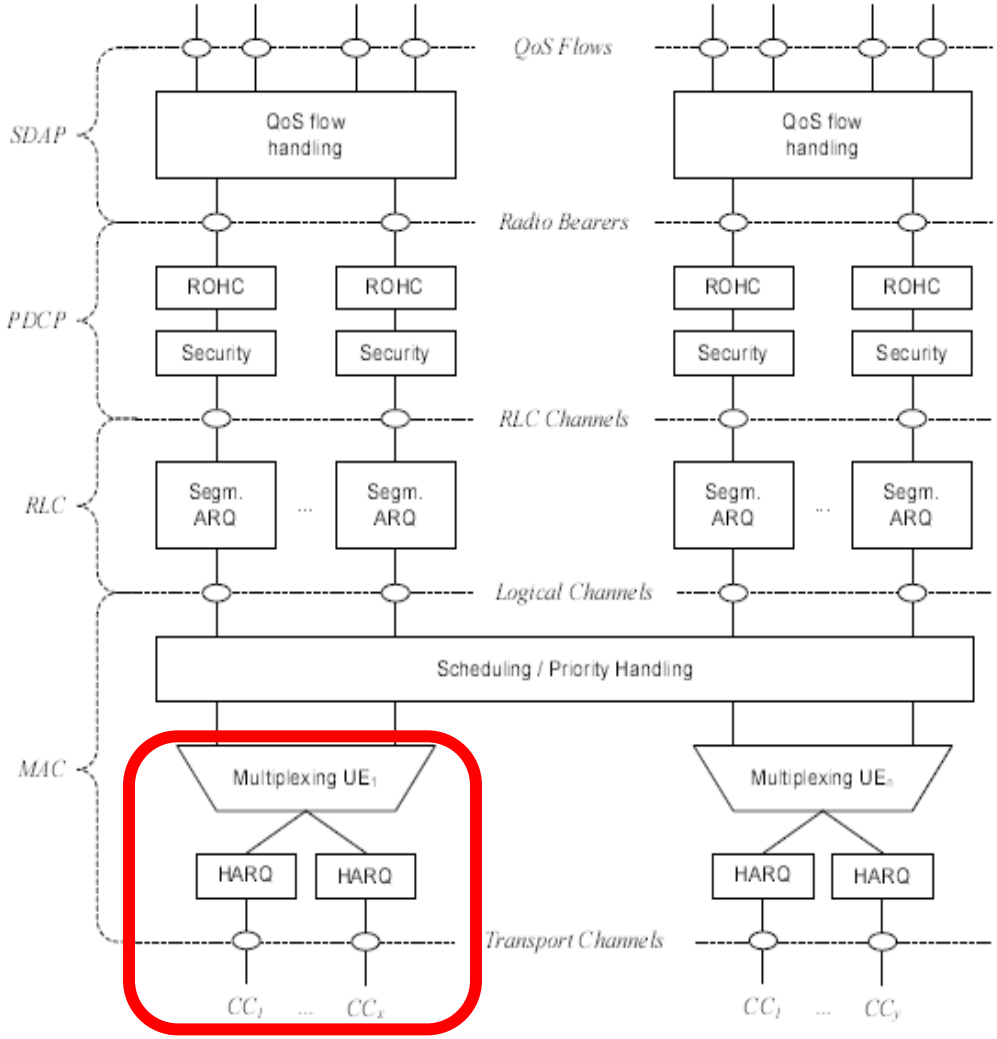
Claim 1	Public Documentation
	 **Figure 6.7-1: Layer 2 Structure for DL with CA configured** (3GPP TS 38.300 V17.4.0)

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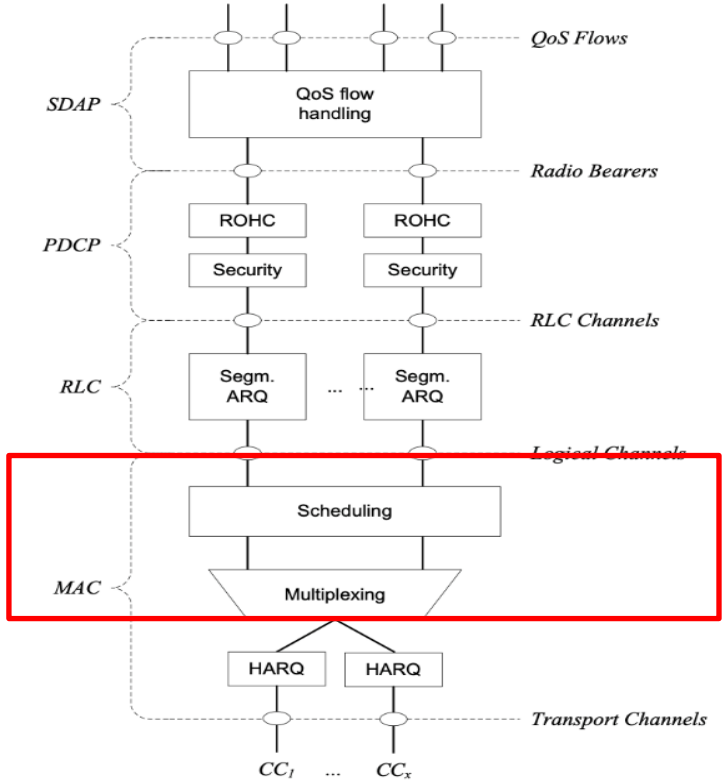
Claim 1	Public Documentation
	 **Figure 6.7-2: Layer 2 Structure for UL with CA configured** (3GPP TS 38.300 V17.4.0)

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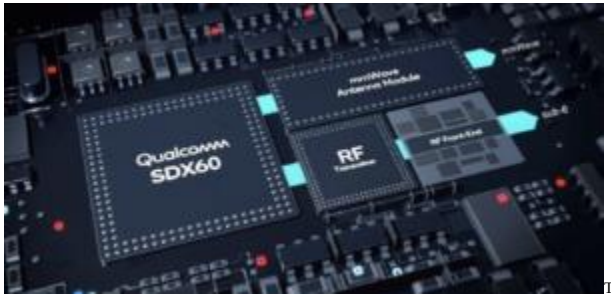
Ex.1028.0005

Claim 1	Public Documentation
	5G Carrier Aggregation is set to deliver a significant performance boost to mobile users but what is it and how does it work? The ongoing rollout of commercial 5G networks has significantly improved the experience for mobile subscribers around the world. As the ecosystem matures, a growing number of more advanced 5G Standalone (5G SA) networks will be central to delivering the speed and ultra-low latency to support cutting-edge applications. 5G Carrier Aggregation will play a vital role in underpinning the significant performance boost promised by 5G SA, representing an important milestone in the evolution of wireless infrastructure. Carrier Aggregation is a software functionality in Radio Access Networks and user devices which allows Mobile Network Operators (MNOs) to combine the capabilities of radio cells at distinct frequency allocations to enhance the end user experience. A key technology already in the LTE-Advanced networks, Carrier Aggregation enabled the evolution to Gigabit-LTE, achieving user data rates of more than 1 Gbps. However, in 5G networks, Carrier Aggregation will enable the evolution to multi-Gigabit-5G, reaching user data rates of about 4 Gbps and above. 5G Carrier Aggregation is also capable of improving the geographic availability, more commonly referred to as coverage, of high data rates. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/)

Claim 1	Public Documentation
	Carrier Aggregation in 5G Networks To accelerate rollout, the initial commercial 5G networks relied on the LTE infrastructure in radio access and the core network, referred to as 5G non-Standalone (5G NSA). 5G NSA allows MNOs to increase the bandwidth available to end users by bundling 4G and 5G carriers through 4G-5G Dual Connectivity. This allowed 5G users to benefit from existing LTE Carrier Aggregation capabilities with up to two 5G carriers aggregated alongside LTE carriers. To unlock the full capability of 5G, including ultra-low latency, reliability, and efficiency, MNOs are introducing 5G Standalone (5G SA) with a dedicated 5G Core and highly efficient 5G air interface, without dependency on existing LTE networks. The number of specified 5G SA Carrier Aggregation band combinations is increasing with each quarterly revision of the 3GPP specifications, enabling further options to achieve multi-Gigabit 5G data rates. These specifications are important to ensure interoperability between user equipment, such as smartphones, and networks. Between 2021 to 2022, the focus of the specifications for Carrier Aggregation in 5G SA in FR1 shifted from two component carriers to three and four component carriers. As the number of 5G frequency bands exceeds that of LTE-A, the possible Carrier Aggregation band combinations are greatly expanded, offering increased deployment options and flexibility for MNOs in different markets. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/)

Claim 1	Public Documentation
	Key benefits of 5G Carrier Aggregation Improved data speeds and throughput 5G Carrier Aggregation will boost the network performance to meet the requirements of data-hungry applications, such as augmented and virtual reality services, for both industrial and consumer use cases. Greater cell coverage As operators are looking to maximize the use of their available spectrum assets in different FDD and TDD bands, Carrier Aggregation is the key to reaching extended coverage range. This helps reduce the need to deploy new cell sites, bringing cost savings to operators. It also improves mobile user experience with consistent level of service across the network. Enhanced energy efficiency In 2019, the mobile industry made a milestone commitment to transform the sector and reach net zero carbon emissions by 2050. Carrier Aggregation has been demonstrated to reduce overall power consumption levels while increasing throughput and maintaining high service levels. This indicates that the technology could contribute to reducing overall energy usage and the mobile industry's carbon footprint. Improved coverage can also contribute to longer battery life for individual devices, requiring less frequent charging. Greater ROI According to data from GSA, the total amount raised in 2021 from spectrum auctions and assignments reached at least $140.1Bn. Radio spectrum is a finite and extremely valuable resource, representing a considerable financial burden for most MNOs. Therefore, with ever increasing demands for bandwidth, utilising this spectrum in the most efficient way becomes a top operational priority. 5G CA represents one of the most effective methods for MNOs to get the most from their outlay by maximising spectral efficiency. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/) SEE WHAT CARRIER AGGREGATION CAN DO FOR YOUR NETWORK 5G Carrier Aggregation -with Coverage Boost- powered by Advanced RAN Coordination is a versatile and blended solution for high-performing 5G networks. It is a game-changer for delivering extended coverage and increased network capacity while supporting

Claim 1	Public Documentation
	• Higher peak rates • Flexible band combinations • Intra and inter RAN Compute • Both platforms, Ericsson Radio System and Cloud RAN (https://www.ericsson.com/en/ran/carrier-aggregation) THE BIG FEATURE: ENHANCED 5G CARRIER AGGREGATION ON IPHONE 13  The Qualcomm X60 is the first 5G modem capable of combining different types of 5G signals together. The additional 5G bands are actually not the biggest cellular change with the iPhone 13. **Assuming the speculation proves true and Apple is indeed using the Qualcomm X60 modem - the real key cellular feature of the iPhone 13 is support for enhanced 5G carrier aggregation.** In addition to being much more power efficient, the big jump between the X55 and X60 modems revolves around improved 5G carrier aggregation - allowing the modem to better combine multiple signals on different frequency bands. To get deeper into the nitty gritty of why this is (and why we've encouraged many to consider waiting for the X60), see our featured story from June 2021: **5G Industry Update: 5G Routers, Hotspots & Antennas Are Here – But Should You Wait?** In a nutshell - the X60 is just more adept at combining long range and short range 5G signals. For example, the X60 can combine super short range mmWave with longer range mid-band or low-band 5G, helping to compensate for mmWave's range limitations.

Claim 1	Public Documentation
	A more specific example: the X60 will allow T-Mobile's long-range low-band band n71 and super-fast mid-band n41 to be used by the modem simultaneously. This will give many T-Mobile customers the range of n71, without sacrificing the speed of n41. And another example - Verizon or AT&T will be able to combine their upcoming C-Band deployments (n77) with their longer range Sub-6 GHz 5G signals in ways that the X55 is just not capable of. (https://www.rvmobileinternet.com/apples-fall-2021-cellular-updates-new-iphone-13-modem-analysis-ipad-mini-goes-5g/#The_Big_Feature_Enhanced_5G_Carrier_Aggregation_on_iPhone_13) # AT&T Quietly Lights Up Carrier Aggregation in Chicago ***Mar 6, 2014, 12:10 PM by Eric M. Zeman*** ***updated Mar 7, 2014, 7:32 AM*** AT&T has improved its LTE network in Chicago and several other markets by using an LTE-Advanced technique called Carrier Aggregation. GigaOm confirmed the soft launch with AT&T SVP of Network Technologies Kris Rinne. With Carrier Aggregation, AT&T has combined the channels of its existing spectrum to double the capacity. AT&T is running LTE in both the 700MHz and AWS bands in Chicago. By aggregating the channels together, AT&T can deliver theoretical peak download speeds of 110Mbps to devices with the proper radio support. At the moment, AT&T is selling only one device with Carrier Aggregation, the Unite mobile hotspot. The Samsung Galaxy S5 is expected to be the first smartphone to support Carrier Aggregation in the U.S. AT&T did not name the other two markets that have access to Carrier Aggregation, but said that more markets on are on the way. Sprint, T-Mobile, and Verizon Wireless are all in various stages of deploying Carrier Aggregation in their own LTE networks.

(https://www.phonescoop.com/articles/article.php?a=13751)

AT&T: We are deploying 3-channel carrier aggregation on LTE network

By **Mike Dano** . Sep 14, 2016 3:37pm

AT&T confirmed to *FierceWireless* that it too is deploying three-channel carrier aggregation on its LTE network. The news indicates AT&T is joining the rest of the nation's Tier 1 carriers in deploying the technology.

"We're currently in the process of deploying 3-way carrier aggregation on our network," said AT&T spokesman Steven Schwadron. "AT&T started strategically deploying LTE-A in early 2014 and now we cover with LTE-A the vast majority of our customers in our LTE coverage area. We're also adding also additional spectrum and equipment on an ongoing basis to further boost our network performance."

Schwadron added that AT&T currently sells 26 devices that are "LTE-A capable," and that the carrier lists them on its website. Schwadron added that, while LTE-Advanced peak speeds can be significantly higher than LTE speeds, "performance will depend on many factors including location and network traffic."

Importantly, though, Schwadron declined to provide any further details, including what spectrum bands AT&T is combining through carrier aggregation and where the service is available. He said only that AT&T is deploying the technology into "high-density, high-traffic areas."

AT&T's acknowledgement that it is deploying carrier aggregation isn't much of a surprise. AT&T's John Donovan said in 2014 that the operator would deploy carrier aggregation technology where it can, depending on how much spectrum it has available to meld together. Further, in 2015, AT&T's Tom Keathley told *FierceWireless* that AT&T had expanded its use of carrier aggregation to include major markets such as New York, San Francisco and Dallas.

However, AT&T's admission that it is deploying three-channel carrier aggregation is noteworthy since much of the industry's discussion on the topic has so far focused on two-channel carrier aggregation. Carrier aggregation technology allows wireless network operators to essentially glue together transmissions across different spectrum bands in order to provide faster download speeds. For example, AT&T could use the technology to meld transmissions across its 700 MHz and AWS spectrum bands via two-channel carrier aggregation. Three-channel aggregation would add another chuck of spectrum, such as transmissions over PCS spectrum, to the transmission.

Of course, AT&T isn't alone in deploying three-channel carrier aggregation: Verizon, Sprint and T-Mobile have all said they too are either deploying it or will soon. Sprint last week confirmed to *FierceWireless* that it launched three-channel carrier aggregation in Chicago and Kansas City, merging transmissions across three different channels of its 2.5 GHz

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Claim 1	Public Documentation
	spectrum and providing speeds up to 200 Mbps. And T-Mobile has said it too is already offering three-channel carrier aggregation, though it did not say where. For its part, Verizon has said it is currently offering two-channel carrier aggregation in the 461 cities, and Verizon's Mike Haberman said the operator will also offer three-channel carrier aggregation in locations where it has sufficient spectrum. To be clear, though, three-channel carrier aggregation must be enabled both in the network and on the users' device. (https://fiercewireless.com/wireless/at-t-we-are-deploying-3-channel-carrier-aggregation-lte-network) # AT&T Pushing Toward Four Carrier Aggregation, LAA in Second Half of This Year **By Diana Goovaerts | March 2, 2017** BARCELONA – U.S. wireless carrier AT&T is pushing toward the launch of four carrier aggregation in the second half of this year, including some configurations that utilize unlicensed spectrum via License Assisted Access (LAA). AT&T Vice President of RAN and Device Design Gordon Mansfield on Thursday told Wireless Week the carrier is eyeing deployment of four carrier aggregation in the early second part of the year. The advancement will be made via a software upgrade to the carrier's network, he said, and is part of the carrier's push toward gigabit speeds. "With the spectrum positions that the operators have in the U.S., you've got to bring together some unlicensed spectrum as well (to hit gigabit speeds)," Mansfield said. "You can get close, you can get up to several hundred with just the macro network and the licensed spectrum, but the way you get to a gigabit is you use licensed spectrum with 4×4 MIMO and 256-QAM and you bring in LAA with unlicensed carriers. And in that case it will actually be 4CA." According to Mansfield, four carrier aggregation will be used in conjunction with technologies like 256-QAM and 4×4 MIMO to help reach 1 Gbps or more on the network. In areas where the carrier has a densely built network with small cells, Mansfield said four carrier aggregation with LAA will be used. But in the macro network, he said, four carrier aggregation will be on licensed bands. While devices today currently only support one of the three aforementioned technologies at a time, Mansfield indicated devices are headed down the pipe as soon as in the second quarter that will have baseband modems capable of supporting all simultaneously. Mansfield declined to name the vendors who are planning such releases. Mansfield specified, though, that some capabilities will be available on the device right out of the box. Others, like LAA, will be added via an over the air software update pushed out over the network later in the year, he said.

Claim 1	Public Documentation
	(https://www.5gtechnologyworld.com/att-pushing-toward-four-carrier-aggregation-laa-in-second-half-of-this-year/) # AT&T in early 2020: results show excellent speeds on both 5G and LTE Dave Andersen, Apr 23, 2020 **AT&T delivered faster speeds in 51 out of 55 markets tested to date in the first half of 2020.** With our testing efforts currently on hold due to the COVID-19 pandemic, we thought now would be a perfect time to take a look at how the carriers have performed across the 55 markets we've tested so far in the first half of 2020. We'll soon publish carrier-specific reports with overviews of performance for both 5G and 4G LTE in 1H 2020, and to kick things off, we'll start with AT&T. AT&T has deployed its 5G using 850 MHz low-band spectrum in several cities across the US, and the carrier has shown particularly impressive gains since our last round of testing in the second half of 2019. While AT&T's median download speeds on 4G LTE were already fast in most metros across the country in 2019, the carrier stepped up even more in the first half of 2020. We found excellent and improved download speeds on the carrier's 4G LTE network in the 55 markets we completed testing before we paused our scouting efforts, and AT&T's low-band 5G is also providing generally fast speeds (though not as fast as Verizon's mmWave 5G). This strong showing by AT&T can't entirely be chalked up to its 5G service, however. AT&T has been investing heavily over the past 18 months to bolster its already robust 4G LTE network. AT&T erected new cell sites in cities across the country, added more spectrum layers, and utilized 5-carrier aggregation (5CA) on a wide scale paired with 4x4 MIMO technology to maximize its vast spectrum holdings and provide faster speeds. AT&T also reallocated some of the spectrum reserved for its FirstNet Public Safety network and began using it for general customers while still satisfying its commitments to first responders. In short, AT&T has taken numerous steps to upgrade its network as 5G deployments continue, and AT&T subscribers are reaping the rewards in the form of faster connectivity that should only get better as the carrier's 5G continues to expand and mature.

Claim 1	Public Documentation
	AT&T's advantage: widespread 5-carrier aggregation and 4x4 MIMO technology A primary reason for AT&T's improved speed results in 2020 is the carrier's widespread usage of 5-carrier aggregation (5CA) technology. In short, 5CA allows AT&T to combine five separate channels to increase bandwidth and provide faster speeds. On top of its capacity gains from 5CA, the efficiency of each of those five channels is maximized by AT&T's utilization of 4x4 MIMO (Multiple Input Multiple Output) technology. MIMO refers to using multiple radio antennas at both the tower and the device, which helps improve capacity, coverage, and speed. In a 4x4 system, there are four antennas on both the tower and device, whereas with 2x2 MIMO, there are two antennas on the tower and device. If you think of each channel with 4x4 MIMO as utilizing four independent data streams, 5CA allows 20 independent streams to be combined, which results in greater bandwidth and, in turn, faster speeds. However, in order for a carrier to utilize 5CA, it's imperative to hold spectrum in five channels, and AT&T is in a unique position as the only carrier with the spectrum necessary for wide scale use of 5CA. In addition, AT&T also utilizes 256QAM, a spectrum modulation method that provides the highest possible level of spectral efficiency, and the carrier has expanded the reach of its Band 2 spectrum (the biggest of the five channels in 5CA) by adding new cell towers in cities across the US. AT&T has an advantage over the competition as the only carrier that can utilize 5-carrier aggregation on a wide scale in the US. Sprint and T-Mobile use 3-carrier aggregation, while Verizon uses 4-carrier aggregation technology. **The results: broad use of 5CA and 4x4 MIMO lead to much faster speeds** AT&T's speeds took a significant step forward during our first-half 2020 testing. Among the 55 cities we tested, AT&T's speeds improved in a whopping 51 of those markets, which was more than any other carrier (Sprint was the closest, with improvements in 47 markets). Even more impressive is that AT&T's median download speeds jumped by at least 15 Mbps in 22 of those markets, with increases of at least 10 Mbps in 37 out of 55 cities. Considering that 15 Mbps is generally fast by itself, an increase of 15 Mbps from a speed that was already fast can profoundly change the end-user experience. (https://rootmetrics.com/en-US/content/att-early-2020-performance-review) # 5-carrier aggregation gives AT&T network edge – RootMetrics By **Bevin Fletcher** . Apr 24, 2020 4:45pm

Claim 1	Public Documentation
	AT&T delivered speed gains across 51 markets in the early part of 2020, with its wide-scale use of 5-component carrier aggregation and 4x4 MIMO giving it an edge over competition, according to RootMetrics. RootMetrics temporarily suspended its network testing but in the meantime is publishing carrier-specific reports on 4G LTE and 5G performance in the first half of 2020. AT&T's speeds improved significantly in 51 out of 55 markets in RootMetrics' testing, outpacing every other carrier. Speed performance on AT&T's network jumped more than 30 Mbps in four cities at the start of 2020, compared to the end of 2019. RELATED: Verizon grabs RootMetrics awards in Los Angeles The biggest increase was seen in Ogden, Utah, where median download speeds spiked 37 Mbps from 38.2 Mbps in 2019 to 75.2 Mbps in early 2020. Markets rounding out the top five for AT&T's most improved speeds include Minneapolis, Cincinnati, Charleston, South Carolina, and Allentown, Pennsylvania. In 37 of the 55 markets tested, speeds jumped at least 10 Mbps compared to 2019, and at least 15 Mbps in 22 markets. "Considering that 15 Mbps is generally fast by itself, an increase of 15 Mbps from a speed that was already fast can profoundly change the end-user experience," the report noted. RootMetrics' tests done last year only connected to AT&T's 4G LTE, while the 2020 results connected to the carrier's low-band 5G where available. In the latest test period, AT&T's network recorded median download speeds above 50 Mbps in 23 markets, compared to just three markets in the second half of 2019. At the start of this year, only two cities registered speeds under 20 Mbps. AT&T is moving forward with its low-band 5G rollouts, just this week expanding to 90 additional cities, but RootMetrics called out the carrier's heavy investment over the last 18 months to enhance its already strong 4G LTE network. RELATED: 5G a 'mixed bag' as Verizon gets high speeds, T-Mobile offers better coverage – RootMetrics "AT&T erected new cell sites in cities across the country, added more spectrum layers, and utilized 5-carrier aggregation (5CA) on a wide scale paired with 4x4 MIMO technology to maximize its vast spectrum holdings and provide faster speeds," RootMetrics reported. "AT&T also reallocated some of the spectrum reserved for its FirstNet Public Safety network and began using it for general customers while still satisfying its commitments to first responders." AT&T is in a unique position to use five-component carrier aggregation (5CA), according to the testing company, a technology which requires and enables it to combine five separate channels for increased capacity.

Claim 1	Public Documentation
	"AT&T has an advantage over the competition as the only carrier that can utilize 5-carrier aggregation on a wide scale in the U.S.," according the report. That compares to Sprint and T-Mobile's use of 3-carrier aggregation, while Verizon uses 4-component carrier aggregation. While 5-carrier aggregation is helping enhance AT&T's speeds over low-band spectrum, 8-component carrier aggregation (8CC) has been cited in work to hit record 5G speeds using millimeter wave spectrum. In lab tests in February, Ericsson alongside Qualcomm, used 8CC to aggregate 800 MHz of millimeter wave spectrum and achieve a record 5G speed of 4.3 Gbps. RELATED: Verizon works with Samsung, Qualcomm to achieve 4.2 Gbps on its 5G network Verizon, meanwhile, worked with Samsung and Qualcomm earlier this year, using the technology to aggregate 800 MHz of 28 GHz mmWave spectrum and hit speeds of 4.2 Gbps on its live 5G network in Texas. Verizon SVP of Technology Planning Adam Koeppe said at the time that 8-channel carrier aggregation using mmWave would be widely available on the carrier's network this year. In terms of RootMetrics' latest report, the company didn't test AT&T's 5G+ network, which was just recently opened up to consumers and leans on high-band millimeter wave instead of low-band spectrum. Out of the 55 markets, AT&T's low-band flavor of 5G still delivered strong results. That includes Philadelphia, which ranked the fastest with median 5G download speeds of 94.5 Mbps – though limited availability of just 1.6%. "AT&T's network investments have clearly paid dividends for its subscribers on both 5G and 4G LTE," RootMetrics concluded. "As more and more 5G devices become available, consumers will find even faster speeds thanks not only to 5G, but also because some 5G-ready smartphones can take advantage of AT&T's pairing of wide-scale 5CA with 4x4 MIMO." (https://www.fiercewireless.com/operators/widespread-5-carrier-givesat-t-network-edge-rootmetric) **April 18, 2023** Taking 5G to the Next Level with Standalone 5G By Jason Sikes, AVP Device Architecture *AT&T Labs makes industry-first 5G SA Uplink 2-CA data connection in the U.S. to improve upload speeds, with additional speed and other upgrades in the works*

Claim 1	Public Documentation
	AT&T is architecting tomorrow's wireless network to ***connect people to greater possibility***. As engineers, we design, build, test, refine and repeat so that you can get more out of your 5G connection and developers can build and deploy the next generation of apps and services. A key part of this evolution is the critical transition phase we are entering in scaling from 5G non-standalone (NSA) to 5G standalone (SA). **How does Standalone take 5G to the next level?** Unlike 5G NSA that still relies on a 4G LTE core, 5G SA uses a dedicated 5G core that can unlock capabilities like faster upload speeds, ultra-low latency, ultra-high reliability and edge functions. This technology will be key to business opportunities like the next generation of connected cars. We have said that we plan to deploy Standalone 5G when the ecosystem is ready, and AT&T is charging forward to advance SA ecosystem readiness. Businesses and developers will be some of the first to take advantage of the new technologies standalone 5G enables as we continue to move from research & development to their deployment. **Uplink: where challenge meets opportunity** This new age of connectivity is not only about consuming more content but also generating more content than ever before. Demand for uplink capacity and speed continues to increase, about 30% a year in AT&T's mobility network. Whether you are uploading large files, on a video call with family, live streaming, cloud gaming or using extended reality applications, the network is facing surging upstream traffic demands it never has before. Our latest network innovations are complex but are all about helping meet this new demand. Just a few weeks ago, we completed the **first 5G SA Uplink 2-carrier aggregation data call in the U.S.** Carrier aggregation (CA) means we are combining or "aggregating" different frequency bands to give you more bandwidth and capacity. For you, this means faster uplink transmission speeds. *Think of this as adding more lanes in the network traffic highway*. No one in the U.S market has successfully aggregated two carriers in 5G SA uplink – until now. This is part of our ongoing effort to provide greater reliability for our customers. The test was conducted in our labs with Nokia's 5G AirScale portfolio and MediaTek's 5G M80 mobile test platform. We aggregated our low-band n5 and our mid-band n77 spectrum. Compared to our low-band n5 alone, we saw a 100% increase in uplink throughput by aggregating our low-band n5 with 40MHz of our mid-band n77. Taking it a step further, we achieved a 250% increase aggregating 100MHz of n77. The bottom line? We achieved incredible upload speeds of over 70 Mbps on n5 with 40MHz of n77 and over 120 Mbps on n5 with 100MHz of n77. While carrier aggregation is like adding more traffic lanes in the highway, adding another vehicle to carry traffic is another way we are managing surging uplink demand. We are doing this via a **two-layer uplink MIMO** on time division duplex (TDD) in our mid-band n77. MIMO combines signals and data streams from multiple antennas ("vehicles") to improve

Claim 1	Public Documentation
	signal quality and data rates. This feature will not only improve uplink throughput but also enhance cell capacity and spectrum efficiency. **Network design and device readiness go hand in hand** Although we continue to make progress in enhancing uplink coverage, we haven't forgotten about the downlink. Enhanced downlink and uplink carrier aggregation capabilities work together to bring the 5G SA performance today's technologies need. Last fall, we completed a **5G SA four component carrier downlink** call by combining two FDD carriers and two TDD carriers. These capabilities allow AT&T devices to aggregate our mid-band n77 in the C-Band and 3.45GHz spectrum ranges. Compared with low band and mmWave spectrum, mid-band n77 provides a good balance between coverage and speed. This follows the **5G SA three component carrier downlink feature** that we introduced last year to 2022 AT&T Flagship devices which combines one frequency division duplex (FDD) carrier and two TDD carriers. In the coming months, AT&T will also enable **5G New Radio Dual Connectivity (NR-DC)**, aggregating our low and mid-band spectrum with our high-band mmWave spectrum on 5G SA. Our labs have achieved 5G NR-DC downlink throughput speeds of up to 5.3Gbps and uplink throughput speeds of up to 670Mbps. This technology will help provide high-speed mobile broadband for both downlink and uplink in stadiums, airports, and other high-density venues. The 5G SA ecosystem is rapidly evolving, with new technologies and capabilities being introduced to provide differentiated experiences. Here are some features that are on the horizon for 5G SA: • Specialized Network Services – think network slicing, precision location, private routing, etc. – for tailored network solutions to meet specific user requirements; • Non-terrestrial network solutions to supplement coverage in remote locations ; and • Reduced capability 5G (RedCap) for a new generation of 5G capable wearables, industrial IoT or wireless sensors and other small form factor consumer devices. AT&T is dedicated to being the best connectivity provider. The 5G SA ecosystem is rapidly evolving, with new technologies and capabilities being introduced to set the foundation for next generation applications and services. (https://about.att.com/blogs/2023/standalone-5g-innovations.html)

AT&T spectrum aggregation industry first ups 5G ante

Dan Meyer | Executive Editor. April 19, 2023 1:00 PM

AT&T tested spectrum aggregation models on the oft-overlooked uplink channel that the carrier claimed was an industry first and resulted in network speeds that could help meet growing 5G traffic demands.

Jason Sikes, AVP for device architecture at AT&T, explained in a blog post that the carrier completed an uplink data call running on its 5G standalone (SA) network core that aggregated two different spectrum frequency bands. The test was in AT&T's labs using Nokia's 5G AirScale equipment running on MediaTek's mobile test platform.

Sikes explained in an email to SDxCentral that the test used 10-megahertz of AT&T's low-band 850 MHz spectrum combined with varying amounts of the carrier's C-band spectrum. With 40-megahertz of C-band spectrum the carrier was able to increase uplink speeds by 100% to more than 70 Mb/s compared with just the base 850 MHz spectrum. It witnessed a 250% increase in speed to more than 120 Mb/s using 100-megahertz of C-band spectrum.

"Think of this as adding more lanes in the network traffic highway," Sikes wrote in the blog. "No one in the U.S market has successfully aggregated two carriers in 5G SA uplink – until now."

Sikes added that AT&T's mobile network has witnessed a 30% increase in uplink capacity demand per year.

"This new age of connectivity is not only about consuming more content but also generating more content than ever before," he noted of the increase. "Whether you are uploading large files, on a video call with family, live streaming, cloud gaming or using extended reality applications, the network is facing surging upstream traffic demands it never has before."

The latest test followed one conducted by the carrier last fall that involved a four-channel downlink call that traversed its 5G SA network. That call aggregated a pair of frequency division duplex (FDD) carriers and a pair of time division duplex (TDD) carriers running in the C-band and the 3.45 GHz spectrum bands.

FDD is where different bands of frequency are used by users; one for uplink and the other for downlink. TDD is where one frequency band will be used for uplink and downlink, switching between the two from moment to moment.

Sikes also noted that AT&T was deploying a "two-layer uplink" multiple-input, multiple output (MINO) technology on TDD across its C-band spectrum. "This feature will not only improve uplink throughput but also enhance cell capacity and spectrum efficiency," he wrote, though he further added that the carrier did not use MIMO during the most recent uplink test.

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	The carrier is planning to launch 5G New Radio Dual Connectivity (NR-DC) capabilities "in the coming months." This will allow for the aggregation of low- and mid-band spectrum with AT&T's millimeter-wave (mmWave) spectrum using the 5G SA core. Sikes noted this capability has resulted in lab test downlink speeds up to 5.3 Gb/s and uplink speeds up to 670 Mb/s. "This technology gives customers high-speed mobile broadband for both downlink and uplink in stadiums, airports and other high-density venues," Sikes wrote. In the follow-up email, Sikes added that "over time, private 5G and fixed wireless will benefit from these uplink and downlink enhancements." (https://www.sdxcentral.com/articles/analysis/att-spectrum-aggregation-industry-first-ups-5g-ante/2023/04/) WHY CHOOSE NOKIA 5G CARRIER AGGREGATION? Together with the leading mobile network operators across the world and the user equipment ecosystem, we have commercially introduced two component, three component and four component 5G Carrier Aggregation to enable Multi-Gigabit 5G on sub-6 GHz frequency allocations. We also have Carrier Aggregation commercially available for high-band. On millimeter wave spectrum, Carrier Aggregation with eight component carriers in downlink and four component carriers in uplink enables reaching even higher data rates. Nokia 5G Carrier Aggregation: • Works in 5G Non-Standalone and 5G Standalone in the same cells for smooth migration from NSA to SA • Boosts 5G performance • By aggregating low-band carriers for coverage and mid-band carriers for capacity, helps deliver Multi-Gigabit user data speeds already today.

Claim 1	Public Documentation
	5G Carrier Aggregation is software running on the baseband unit, easy to activate in Nokia 5G networks. The supported Carrier Aggregation band combinations are following the quarterly 3GPP specification updates. Our quarterly software updates ensure the best possible band combination support, and bring more flexibility for mobile operators to optimize their network coverage and capacity. Nokia 5G Carrier Aggregation works with massive MIMO and dynamic spectrum sharing, enabling a further capacity boost on mid-band and more flexibility for low-band aggregation. Nokia AirScale ensures uncompromised RF bandwidth for efficient multi-carrier sub-6 GHz Carrier Aggregation. Additionally, our AirScale baseband is optimized for providing the processing capacity and scalability for multi-carrier, large bandwidth Carrier Aggregation. (https://www.nokia.com/networks/mobile-networks/carrier-aggregation/) # Ericsson spearheads 5G carrier aggregation milestones with key partners Ericsson has achieved groundbreaking milestones for carrier aggregation in 5G New Radio (NR) technology together with key customers and ecosystem partners. Ericsson has recently pushed 5G carrier aggregation (5G CA) technology to new levels after a series of successful interoperability tests with customers including T-Mobile and Optus, and ecosystem partners such as Qualcomm and MediaTek. The interoperability tests use carrier aggregation to extend the coverage of 5G, boost network capacity, and increase data speeds. Ericsson's collaboration with partners has so far resulted in several 5G firsts: • World's first 5G standalone (SA) data session with 5G CA on a commercial smartphone completed with T-Mobile, LG and MediaTek. With 5G CA, T-Mobile can combine its different 5G spectrum bands – starting with 2.5 GHz mid-band and 600 MHz low-band – boosting speeds and increasing the footprint of T-Mobile's mid-band 5G. It's also a key step in expanding T-Mobile's nationwide standalone architecture 5G network by increasing SA 5G capacity and speeds. (October 2020)

Claim 1	Public Documentation
	• A 2300 + 3500MHz 5G Non-Standalone Carrier Aggregation call made by Optus using Ericsson technology and Samsung's Galaxy S20 5G handset range. The call showed the benefit of using both spectrum frequencies simultaneously, namely, a significant increase in the average and peak 5G speeds that customers, with an eligible handset, will benefit from as the capability becomes available. (August 2020) • First to complete all three combinations of NR time division duplex (TDD) and frequency division duplex (FDD) carrier aggregation (CA) together with MediaTek. The companies carried out a 5G SA data call by aggregating 20MHz on FDD spectrum and 100MHz on TDD spectrum with MediaTek's Dimensity 1000+ chipset at the Ericsson Lab in Kista. (September 2020) • Completed pioneering interoperability tests for 5G SA carrier aggregation across both FDD/TDD and TDD/TDD bands together with Qualcomm Technologies. 5G CA allows service providers to use multiple sub-6 GHz spectrum channels simultaneously to transfer data between base stations and a 5G mobile device. (August 2020) Per Narvinger, Head of Product Area Networks, Ericsson says: "From technology development to wider area deployments, Ericsson continues to spearhead 5G innovation with customers and industry partners. To maximize the full potential of the mid-band spectrum, we've developed 5G NR carrier aggregation solutions that will help our customers deploy a better 5G with greater coverage, increased capacity and higher data speeds. These solutions will extend the coverage of the high capacity mid-band spectrum. By enabling peak speeds, coverage and capacity, 5G carrier aggregation will be a real game-changer." Ericsson's 5G NR carrier aggregation solution will be commercially available in the fourth quarter of 2020 with a global rollout expected during 2021. (https://www.ericsson.com/en/news/2020/10/5g-carrier-aggregation) Ericsson ups the tempo on 5G Carrier Aggregation with world's first downlink 6CC data call Available in English 日本語 Ericsson revs up the tempo on 5G Carrier Aggregation by combining six component carriers to set a record download speed of 5.7Gbps for the world's first 6CC (component carrier) data call.

Claim 1	Public Documentation
	NEWS AUG 17, 2023 The data call was achieved using three FDD (frequency division duplex) bands combined with three TDD (time division duplex) bands in sub-6GHz, enabled by Ericsson RAN Compute hardware, state-of the-art carrier aggregation software, and innovative Advanced RAN Coordination functionality. The 3FDD + 3TDD carrier aggregation testing was carried out in an Ericsson lab with a user equipment (UE) simulator. By combining FDD spectrum with TDD spectrum, more users can benefit from carrier aggregation gains. In total, 400MHz of bandwidth was aggregated with FDD bandwidths ranging 20MHz to 50MHz to achieve the 5.7Gbps throughput. With six-component carrier capability, communications service providers can optimize use of network and spectrum assets to deliver higher data speeds and capacity that improve the experience of downlink-heavy applications. This can mean better audio and video quality for streaming users, faster file downloads, and a better working environment for digital nomads. Sibel Tombaz, Head of Product Line 5G RAN at Ericsson Networks, says: "We are keeping the momentum on carrier aggregation by continuously stretching its potential to boost capacity and speed. Our successful 6CC data call shows how versatile our solution is and that we are poised to work with ecosystem partners to make this new band combination a reality. Our goal, as always, is to help customers meet end users' growing appetite for high-capacity, ultrahigh-speed 5G." "Carrier Aggregation is crucial to getting the best possible 5G performance out of scattered spectrum assets," Tombaz adds. "And with 6CC, service providers will be able to maximize use of allocated spectrum and optimize the combined bandwidth for superior mobile experience." (https://www.ericsson.com/en/news/2023/8/ericsson-ups-the-tempo-on-5g-carrier-aggregation-with-worlds-first-downlink-6cc-data-call)

Claim 1	Public Documentation
	Samsung Galaxy S20 Released 2020, March 06 163g, 7.9mm thickness Android 10, up to Android 13, One UI 5 128GB storage, microSDXC 18% 6,985,860 HITS 456 BECOME A FAN 6.2" 1440x3200 pixels 64MP 4320p 8GB RAM Exynos 990 4000mAh Li-Ion REVIEW OPINIONS COMPARE PICTURES Also available with 5G NETWORK Technology GSM / CDMA / HSPA / EVDO / LTE COLLAPSE 2G bands GSM 850 / 900 / 1800 / 1900 - SIM 1 & SIM 2 (Dual SIM model only) CDMA 800 / 1900 & TD-SCDMA 3G bands HSDPA 850 / 900 / 1700(AWS) / 1900 / 2100 CDMA2000 1xEV-DO 4G bands 1, 2, 3, 4, 5, 7, 8, 12, 13, 17, 18, 19, 20, 25, 26, 28, 32, 38, 39, 40, 41, 66 Speed HSPA 42.2/5.76 Mbps, LTE-A (7CA) Cat20 2000/200 Mbps (https://www.gsmarena.com/samsung_galaxy_s20-10081.php)

Claim 1	Public Documentation
	5G Carrier Aggregation is set to deliver a significant performance boost to mobile users but what is it and how does it work? The ongoing rollout of commercial 5G networks has significantly improved the experience for mobile subscribers around the world. As the ecosystem matures, a growing number of more advanced 5G Standalone (5G SA) networks will be central to delivering the speed and ultra-low latency to support cutting-edge applications. 5G Carrier Aggregation will play a vital role in underpinning the significant performance boost promised by 5G SA, representing an important milestone in the evolution of wireless infrastructure. Carrier Aggregation is a software functionality in Radio Access Networks and user devices which allows Mobile Network Operators (MNOs) to combine the capabilities of radio cells at distinct frequency allocations to enhance the end user experience. A key technology already in the LTE-Advanced networks, Carrier Aggregation enabled the evolution to Gigabit-LTE, achieving user data rates of more than 1 Gbps. However, in 5G networks, Carrier Aggregation will enable the evolution to multi-Gigabit-5G, reaching user data rates of about 4 Gbps and above. 5G Carrier Aggregation is also capable of improving the geographic availability, more commonly referred to as coverage, of high data rates. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/)

Claim 1	Public Documentation
	Carrier Aggregation in 5G Networks To accelerate rollout, the initial commercial 5G networks relied on the LTE infrastructure in radio access and the core network, referred to as 5G non-Standalone (5G NSA). 5G NSA allows MNOs to increase the bandwidth available to end users by bundling 4G and 5G carriers through 4G-5G Dual Connectivity. This allowed 5G users to benefit from existing LTE Carrier Aggregation capabilities with up to two 5G carriers aggregated alongside LTE carriers. To unlock the full capability of 5G, including ultra-low latency, reliability, and efficiency, MNOs are introducing 5G Standalone (5G SA) with a dedicated 5G Core and highly efficient 5G air interface, without dependency on existing LTE networks. The number of specified 5G SA Carrier Aggregation band combinations is increasing with each quarterly revision of the 3GPP specifications, enabling further options to achieve multi-Gigabit 5G data rates. These specifications are important to ensure interoperability between user equipment, such as smartphones, and networks. Between 2021 to 2022, the focus of the specifications for Carrier Aggregation in 5G SA in FR1 shifted from two component carriers to three and four component carriers. As the number of 5G frequency bands exceeds that of LTE-A, the possible Carrier Aggregation band combinations are greatly expanded, offering increased deployment options and flexibility for MNOs in different markets. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/)

Claim 1	Public Documentation
	Key benefits of 5G Carrier Aggregation Improved data speeds and throughput 5G Carrier Aggregation will boost the network performance to meet the requirements of data-hungry applications, such as augmented and virtual reality services, for both industrial and consumer use cases. Greater cell coverage As operators are looking to maximize the use of their available spectrum assets in different FDD and TDD bands, Carrier Aggregation is the key to reaching extended coverage range. This helps reduce the need to deploy new cell sites, bringing cost savings to operators. It also improves mobile user experience with consistent level of service across the network. Enhanced energy efficiency In 2019, the mobile industry made a milestone commitment to transform the sector and reach net zero carbon emissions by 2050. Carrier Aggregation has been demonstrated to reduce overall power consumption levels while increasing throughput and maintaining high service levels. This indicates that the technology could contribute to reducing overall energy usage and the mobile industry's carbon footprint. Improved coverage can also contribute to longer battery life for individual devices, requiring less frequent charging. Greater ROI According to data from GSA, the total amount raised in 2021 from spectrum auctions and assignments reached at least $140.1Bn. Radio spectrum is a finite and extremely valuable resource, representing a considerable financial burden for most MNOs. Therefore, with ever increasing demands for bandwidth, utilising this spectrum in the most efficient way becomes a top operational priority. 5G CA represents one of the most effective methods for MNOs to get the most from their outlay by maximising spectral efficiency. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/) Samsung Galaxy users in the United States will now enjoy faster 5G speeds, all thanks to T-Mobile's carrier aggregation technology. At the Mobile World Congress 2023 event in Barcelona, T-Mobile announced the successful deployment of 5G carrier aggregation on its standalone 5G network.

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	Ericsson, Nokia, Qualcomm Technologies, Inc., and Samsung teamed up with T-Mobile in the completion of the 5G Carrier Aggregation tech. The phone used for the project was a Samsung Galaxy S23 series model. Consequently, T-Mobile customers with a Galaxy S23, Galaxy S23+, or Galaxy S23 Ultra will be the first to benefit from four-carrier aggregations later this year. (https://www.sammobile.com/news/t-mobile-carrier-aggregation-5g-samsung-galaxy-s23/)
[1a] transmitting first information across a first frequency range using a wireless transmitter, the first frequency range having a first center frequency, a first highest frequency, and a first lowest frequency; and	The Accused Instrumentalities perform a method including transmitting first information across a first frequency range using a wireless transmitter, the first frequency range having a first center frequency, a first highest frequency, and a first lowest frequency. For example, the Accused Instrumentalities transmit uplink information on a first component carrier with a frequency range with a first center frequency (labeled $F_{C,low}$ in the excerpt from 3GPP TS 38.101 V17.9.0 below), first highest frequency (highlighted in red below), and first lowest frequency (highlighted in blue below). This applies in the cases of intra-band contiguous, intra-band non-contiguous, and inter-band CA. *See, e.g.*: 5.2 Downlink 5.2.1 Downlink transmission scheme A closed loop Demodulation Reference Signal (DMRS) based spatial multiplexing is supported for Physical Downlink Shared Channel (PDSCH). Up to 8 and 12 orthogonal DL DMRS ports are supported for type 1 and type 2 DMRS respectively. Up to 8 orthogonal DL DMRS ports per UE are supported for SU MIMO and up to 4 orthogonal DL DMRS ports per UE are supported for MU-MIMO. The number of SU-MIMO code words is one for 1-4 layer transmissions and two for 5-8 layer transmissions. The DMRS and corresponding PDSCH are transmitted using the same precoding matrix and the UE does not need to know the precoding matrix to demodulate the transmission. The transmitter may use different precoder matrix for different parts of the transmission bandwidth, resulting in frequency selective precoding. The UE may also assume that the same precoding matrix is used across a set of Physical Resource Blocks (PRBs) denoted Precoding Resource Block Group (PRG). Transmission durations from 2 to 14 symbols in a slot is supported. Aggregation of multiple slots with Transport Block (TB) repetition is supported. (3GPP TS 38.300 V17.4.0)

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5.3 Uplink

5.3.1 Uplink transmission scheme

Two transmission schemes are supported for PUSCH: codebook based transmission and non-codebook based transmission.

For codebook based transmission, the gNB provides the UE with a transmit precoding matrix indication in the DCI. The UE uses the indication to select the PUSCH transmit precoder from the codebook. For non-codebook based transmission, the UE determines its PUSCH precoder based on wideband SRI field from the DCI.

A closed loop DMRS based spatial multiplexing is supported for PUSCH. For a given UE, up to 4 layer transmissions are supported. The number of code words is one. When transform precoding is used, only a single MIMO layer transmission is supported.

Transmission durations from 1 to 14 symbols in a slot is supported.

Aggregation of multiple slots with TB repetition is supported.

(3GPP TS 38.300 V17.4.0)

5.4 Carrier aggregation

5.4.1 Carrier aggregation

In Carrier Aggregation (CA), two or more Component Carriers (CCs) are aggregated. A UE may simultaneously receive or transmit on one or multiple CCs depending on its capabilities:

- A UE with single timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells sharing the same timing advance (multiple serving cells grouped in one TAG);
- A UE with multiple timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells with different timing advances (multiple serving cells grouped in multiple TAGs). NG-RAN ensures that each TAG contains at least one serving cell;
- A non-CA capable UE can receive on a single CC and transmit on a single CC corresponding to one serving cell only (one serving cell in one TAG).

CA is supported for both contiguous and non-contiguous CCs. When CA is deployed frame timing and SFN are aligned across cells that can be aggregated, or an offset in multiples of slots between the PCell/PSCell and an SCell is configured to the UE. The maximum number of configured CCs for a UE is 16 for DL and 16 for UL.

(3GPP TS 38.300 V17.4.0)

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	## 6.7 Carrier Aggregation In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below: - In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell. (3GPP TS 38.300 V17.4.0)

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	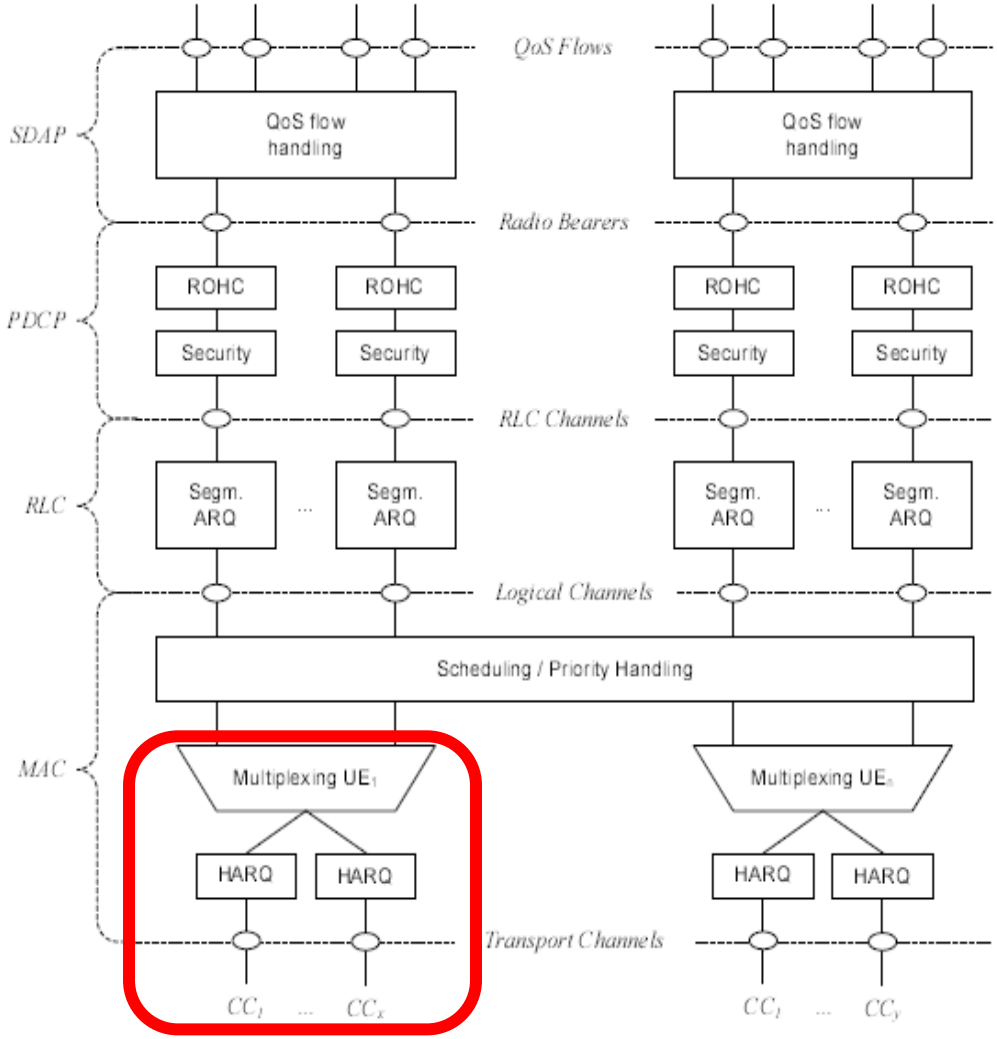 **Figure 6.7-1: Layer 2 Structure for DL with CA configured** (3GPP TS 38.300 V17.4.0)

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	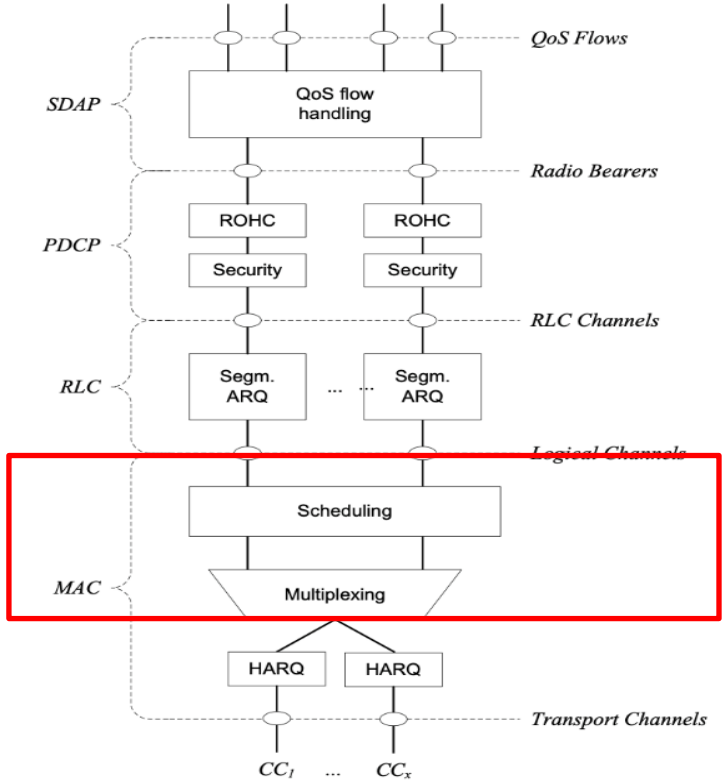 **Figure 6.7-2: Layer 2 Structure for UL with CA configured** (3GPP TS 38.300 V17.4.0)

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5.3A.2 Maximum transmission bandwidth configuration for CA

For carrier aggregation, the maximum transmission bandwidth configuration is defined per component carrier and the requirement is specified in clause 5.3.2.

5.3A.3 Minimum guardband and transmission bandwidth configuration for CA

For intra-band contiguous carrier aggregation, *Aggregated Channel Bandwidth* and *Guard Bands* are defined as follows, see Figure 5.3A.3-1.

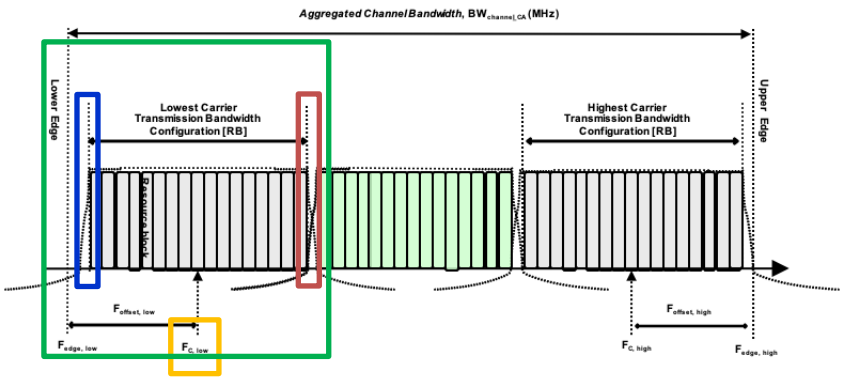

Figure 5.3A.3-1: Definition of *Aggregated Channel Bandwidth* for intra-band carrier aggregation

The *aggregated channel bandwidth*, $BW_{Channel_CA}$, is defined as

$$BW_{Channel_CA} = F_{edge,high} - F_{edge,low} \text{ (MHz)}.$$

The lower bandwidth edge $F_{edge,low}$ and the upper bandwidth edge $F_{edge,high}$ of the aggregated channel bandwidth are used as frequency reference points for transmitter and receiver requirements and are defined by

$$F_{edge,low} = F_{C,low} - F_{offset,low}$$

$$F_{edge,high} = F_{C,high} + F_{offset,high}$$

The lower and upper frequency offsets depend on the transmission bandwidth configurations of the lowest and highest assigned edge component carrier and are defined as

$$F_{offset,low} = (N_{RB,low}*12 + 1)*SCS_{low}/2 + BW_{GB} \text{ (MHz)}$$

$$F_{offset,high} = (N_{RB,high}*12 - 1)*SCS_{high}/2 + BW_{GB} \text{ (MHz)}$$

$$BW_{GB} = \max(BW_{GB,Channel(k)})$$

$N_{RB,low}$ and $N_{RB,high}$ are the transmission bandwidth configurations according to Table 5.3.2-1 for the lowest and highest assigned component carrier, SCS_{low} and SCS_{high} are the sub-carrier spacing for the lowest and highest assigned component carrier respectively. SCS_{low}, SCS_{high}, $N_{RB,low}$, $N_{RB,high}$, and $BW_{GB,Channel(k)}$ use the largest μ value among the subcarrier spacing configurations supported in the operating band for both of the channel bandwidths according to Table 5.3.5-1 and $BW_{GB,Channel(k)}$ is the minimum guard band for carrier k according to Table 5.3.3-1 for the said μ value.

In case there is no common μ value for both of the channel bandwidths, μ=1 is used for SCS_{low}, SCS_{high}, $N_{RB,low}$, $N_{RB,high}$ and $BW_{GB,Channel(k)}$.

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Petitioners' Ex. 1028
Ex.1028.0033

Claim 1	Public Documentation

5.5A.1 Configurations for intra-band contiguous CA

Power class 3 is supported for all uplinks. Power classes other than power class 3 are supported as indicated in Table 5.5A.1-1.

Table 5.5A.1-1: NR CA configurations and bandwidth combination sets defined for intra-band contiguous CA

NR CA configuration / Bandwidth combination set								
NR CA configuration	Uplink CA configurations or single uplink carrier[5]	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Maximum aggregated bandwidth (MHz)	Bandwidth combination set
CA_n1B	-	10	10,15				40	0
		15	15,20					
		20	20					
CA_n2B	-	5	15				20	0
		10	10					
CA_n3B	-	5	15, 20, 25, 30				60	0
		10	10, 15, 20, 25, 30					
		15, 20, 25, 30	5, 10, 15, 20, 25, 30					
CA_n5B	CA_n5B	5, 10, 15	5, 10, 15				20	0
CA_n7B	CA_n7B	10	10, 15, 20, 30, 40				50	0
		15	15, 20, 30					
		20	20, 30					
CA_n25B	-	5	15				20	0
		10	10					
CA_n38B	-	5	15, 20, 25				50	0
		10	10, 15, 20, 25					
		15, 20, 25	5, 10, 15, 20, 25					
CA_n40B	-	20	80				100	0
		50	50					
	CA_n40B	10,15, 20, 30, 40, 50, 60, 80	10, 15, 20, 30, 40, 50, 60, 80				100	1
CA_n41B	n41[3] CA_n41B	10, 20, 30, 40, 50	10, 20, 30, 40, 50				100	0
CA_n41C	n41[3,4] CA_n41C[3]	40	80, 100				180	0
		50, 60, 80	60, 80, 100					
		10	100				190	1
		15, 20	90, 100					
		40	80, 90, 100					
		50, 60, 80, 90	60, 80, 90, 100					
		10	100				190	2
		15, 20	90, 100					
		30, 40	80, 90, 100					
		50, 60, 80, 90	60, 80, 90, 100					
		See n41 channel bandwidths in Table 5.3.5-1 for each carrier[2]					190	4 and 5
CA_n46B	-	20, 40, 60	20, 40				100	0
CA_n46C	-	60, 80	60, 80				160	0
CA_n46D	-	60, 80	80	80			240	0
CA_n46M	-	20, 40, 60	20, 40	20, 40			140	0
CA_n46N		Void						0
	-	20, 40, 60	20, 40	20, 40	20, 40		180	1
CA_n46Q	-	20, 60	20, 40	20, 40	20, 40	20, 40	220	0
CA_n48B	CA_n48B	5	15, 20				40	0
		10, 15, 20	10, 15, 20					
		15, 20	15, 20					
	-	10	50, 60, 80, 90				100	1

(3GPP TS 38.101 V17.9.0)

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Claim 1	Public Documentation

5.5A.2 Configurations for intra-band non-contiguous CA

Table 5.5A.2-1: NR CA configurations and bandwidth combination sets defined for intra-band non-contiguous CA

NR CA Configuration	Uplink CA Configurations or single uplink carrier[5]	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Maximum Aggregated bandwidth (MHz)	Bandwidth combination set
CA_n1(2A)	-	5, 10, 15, 20	5, 10, 15, 20			40	0
CA_n2(2A)	-	5, 10, 15, 20	5, 10, 15, 20			40	0
CA_n3(2A)	-	5, 10, 15, 20	5, 10, 15, 20			40	0
	-	5, 10, 15, 20, 25, 30	5, 10, 15, 20, 25, 30			60	1
CA_n5(2A)	-	5, 10, 15, 20	5, 10, 15, 20			25	0
CA_n7(2A)	-	5, 10, 15, 20	5, 10, 15, 20			40	0
CA_n12(2A)	-	5	5			10	0
CA_n25(2A)	-	5, 10, 15, 20	5, 10, 15, 20			40	0
		5, 10, 15, 20, 25, 30, 40	5, 10, 15, 20, 25, 30, 40			60	1
		See n25 channel bandwidths in Table 5.3.5-1 for each carrier				60	4 and 5
CA_n25(3A)	-	5, 10, 15, 20, 25, 30, 40	5, 10, 15, 20, 25, 30, 40	5, 10, 15, 20, 25, 30, 40		55	0
		See n25 channel bandwidths in Table 5.3.5-1 for each carrier				55	4 and 5
CA_n41(2A)	n41[3,4] CA_n41(2A)	40, 50, 60, 80, 100	40, 50, 60, 80, 100			180	0
		10, 15, 20, 40, 50, 60, 80, 90, 100	10, 15, 20, 40, 50, 60, 80, 90, 100			190	1
	-	10, 15, 20, 30, 40, 50, 60, 80, 90	15, 20, 30, 40, 50, 60, 80, 90, 100			190	2
		10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100			190	3
		See n41 channel bandwidths in Table 5.3.5-1 for each carrier				190	4 and 5
CA_n41(3A)	n41[3,4]	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100		190	0
		See n41 channel bandwidths in Table 5.3.5-1 for each carrier				190	4 and 5
CA_n41(4A)	n41[3]	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	190	0
		See n41 channel bandwidths in Table 5.3.5-1 for each carrier				190	4 and 5
CA_n48(2A)		10, 15, 20, 40, 50, 60, 80. 90. 100	10, 15, 20, 40, 50, 60, 80. 90. 100			140[2]	0
		10, 15, 20, 30, 40, 50, 60, 70, 80, 90. 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90. 100			140[2]	1
CA_n48(3A)	-	10, 15, 20, 40,50, 60, 80. 90. 100	10, 15, 20, 40,50, 60, 80. 90. 100	10, 15, 20, 40,50, 60, 80. 90. 100		140[2]	0
		10, 15, 20, 30, 40, 50, 60, 70, 80, 90. 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90. 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90. 100		140[2]	1

(3GPP TS 38.101 V17.9.0)

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Ex.1028.0035

Claim 1	Public Documentation
[1b] simultaneously transmitting second information across a second frequency range using the same wireless transmitter, the second frequency range having a second center frequency greater than the first center frequency, a second highest frequency, and a second lowest frequency.	The Accused Instrumentalities perform a method including simultaneously transmitting second information across a second frequency range using the same wireless transmitter, the second frequency range having a second center frequency greater than the first center frequency, a second highest frequency, and a second lowest frequency. For example, the Accused Instrumentalities transmit uplink information on a second component carrier with a frequency range with a second center frequency (labeled $F_{C,high}$ in the excerpt from 3GPP TS 38.101 V17.9.0 below), second highest frequency (highlighted in red below), and second lowest frequency (highlighted in blue below). This applies in the cases of intra-band contiguous, intra-band non-contiguous, and inter-band CA. The transmission is performed simultaneously using the same wireless transmitter, as set out in section 5.4 of 3GPP TS 38.300 V17.4.0. *See, e.g.*: 5.2 Downlink 5.2.1 Downlink transmission scheme A closed loop Demodulation Reference Signal (DMRS) based spatial multiplexing is supported for Physical Downlink Shared Channel (PDSCH). Up to 8 and 12 orthogonal DL DMRS ports are supported for type 1 and type 2 DMRS respectively. Up to 8 orthogonal DL DMRS ports per UE are supported for SU MIMO and up to 4 orthogonal DL DMRS ports per UE are supported for MU-MIMO. The number of SU-MIMO code words is one for 1-4 layer transmissions and two for 5-8 layer transmissions. The DMRS and corresponding PDSCH are transmitted using the same precoding matrix and the UE does not need to know the precoding matrix to demodulate the transmission. The transmitter may use different precoder matrix for different parts of the transmission bandwidth, resulting in frequency selective precoding. The UE may also assume that the same precoding matrix is used across a set of Physical Resource Blocks (PRBs) denoted Precoding Resource Block Group (PRG). Transmission durations from 2 to 14 symbols in a slot is supported. Aggregation of multiple slots with Transport Block (TB) repetition is supported. (3GPP TS 38.300 V17.4.0) 5.3 Uplink 5.3.1 Uplink transmission scheme Two transmission schemes are supported for PUSCH: codebook based transmission and non-codebook based transmission.

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Petitioners' Ex. 1028
Ex.1028.0036

Claim 1	Public Documentation
	For codebook based transmission, the gNB provides the UE with a transmit precoding matrix indication in the DCI. The UE uses the indication to select the PUSCH transmit precoder from the codebook. For non-codebook based transmission, the UE determines its PUSCH precoder based on wideband SRI field from the DCI. A closed loop DMRS based spatial multiplexing is supported for PUSCH. For a given UE, up to 4 layer transmissions are supported. The number of code words is one. When transform precoding is used, only a single MIMO layer transmission is supported. Transmission durations from 1 to 14 symbols in a slot is supported. Aggregation of multiple slots with TB repetition is supported. (3GPP TS 38.300 V17.4.0) 5.4 Carrier aggregation 5.4.1 Carrier aggregation In Carrier Aggregation (CA), two or more Component Carriers (CCs) are aggregated. A UE may simultaneously receive or transmit on one or multiple CCs depending on its capabilities: - A UE with single timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells sharing the same timing advance (multiple serving cells grouped in one TAG); - A UE with multiple timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells with different timing advances (multiple serving cells grouped in multiple TAGs). NG-RAN ensures that each TAG contains at least one serving cell; - A non-CA capable UE can receive on a single CC and transmit on a single CC corresponding to one serving cell only (one serving cell in one TAG). CA is supported for both contiguous and non-contiguous CCs. When CA is deployed frame timing and SFN are aligned across cells that can be aggregated, or an offset in multiples of slots between the PCell/PSCell and an SCell is configured to the UE. The maximum number of configured CCs for a UE is 16 for DL and 16 for UL. (3GPP TS 38.300 V17.4.0) 6.7 Carrier Aggregation In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below:

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Ex.1028.0037

Claim 1	Public Documentation
	- In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell. (3GPP TS 38.300 V17.4.0)

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Petitioners' Ex. 1028
Ex.1028.0038

Claim 1	Public Documentation

5.3A.2 Maximum transmission bandwidth configuration for CA

For carrier aggregation, the maximum transmission bandwidth configuration is defined per component carrier and the requirement is specified in clause 5.3.2.

5.3A.3 Minimum guardband and transmission bandwidth configuration for CA

For intra-band contiguous carrier aggregation, *Aggregated Channel Bandwidth* and *Guard Bands* are defined as follows, see Figure 5.3A.3-1.

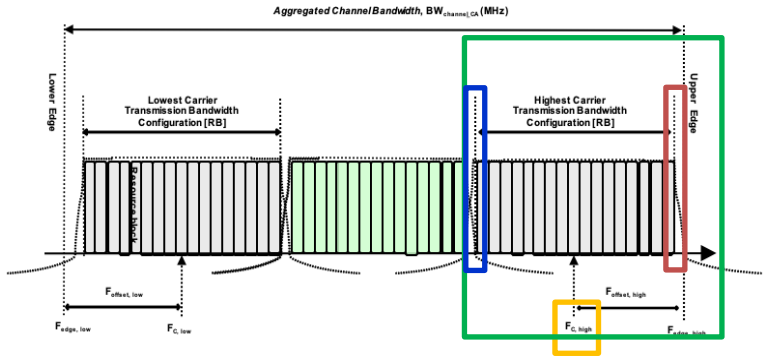

Figure 5.3A.3-1: Definition of *Aggregated Channel Bandwidth* for intra-band carrier aggregation

The *aggregated channel bandwidth*, $BW_{Channel_CA}$, is defined as

$$BW_{Channel_CA} = F_{edge,high} - F_{edge,low} \text{ (MHz)}.$$

The lower bandwidth edge $F_{edge,low}$ and the upper bandwidth edge $F_{edge,high}$ of the aggregated channel bandwidth are used as frequency reference points for transmitter and receiver requirements and are defined by

$$F_{edge,low} = F_{C,low} - F_{offset,low}$$

$$F_{edge,high} = F_{C,high} + F_{offset,high}$$

The lower and upper frequency offsets depend on the transmission bandwidth configurations of the lowest and highest assigned edge component carrier and are defined as

$$F_{offset,low} = (N_{RB,low}*12 + 1)*SCS_{low}/2 + BW_{GB} \text{ (MHz)}$$

$$F_{offset,high} = (N_{RB,high}*12 - 1)*SCS_{high}/2 + BW_{GB} \text{ (MHz)}$$

$$BW_{GB} = \max(BW_{GB,Channel(k)})$$

$N_{RB,low}$ and $N_{RB,high}$ are the transmission bandwidth configurations according to Table 5.3.2-1 for the lowest and highest assigned component carrier, SCS_{low} and SCS_{high} are the sub-carrier spacing for the lowest and highest assigned component carrier respectively. SCS_{low}, SCS_{high}, $N_{RB,low}$, $N_{RB,high}$, and $BW_{GB,Channel(k)}$ use the largest μ value among the subcarrier spacing configurations supported in the operating band for both of the channel bandwidths according to Table 5.3.5-1 and $BW_{GB,Channel(k)}$ is the minimum guard band for carrier k according to Table 5.3.3-1 for the said μ value.

In case there is no common μ value for both of the channel bandwidths, μ=1 is used for SCS_{low}, SCS_{high}, $N_{RB,low}$, $N_{RB,high}$ and $BW_{GB,Channel(k)}$.

(3GPP TS 38.101 V17.9.0)

Claim 1	Public Documentation

5.5A.1 Configurations for intra-band contiguous CA

Power class 3 is supported for all uplinks. Power classes other than power class 3 are supported as indicated in Table 5.5A.1-1.

Table 5.5A.1-1: NR CA configurations and bandwidth combination sets defined for intra-band contiguous CA

NR CA configuration / Bandwidth combination set								
NR CA configuration	Uplink CA configurations or single uplink carrier[5]	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Maximum aggregated bandwidth (MHz)	Bandwidth combination set
CA_n1B	-	10	10,15				40	0
		15	15,20					
		20	20					
CA_n2B	-	5	15				20	0
		10	10					
CA_n3B	-	5	15, 20, 25, 30				60	0
		10	10, 15, 20, 25, 30					
		15, 20, 25, 30	5, 10, 15, 20, 25, 30					
CA_n5B	CA_n5B	5, 10, 15	5, 10, 15				20	0
CA_n7B	CA_n7B	10	10, 15, 20, 30, 40				50	0
		15	15, 20, 30					
		20	20, 30					
CA_n25B	-	5	15				20	0
		10	10					
CA_n38B	-	5	15, 20, 25				50	0
		10	10, 15, 20, 25					
		15, 20, 25	5, 10, 15, 20, 25					
CA_n40B	-	20	80				100	0
		50	50					
	CA_n40B	10,15, 20, 30, 40, 50, 60, 80	10, 15, 20, 30, 40, 50, 60, 80				100	1
CA_n41B	n41[3] CA_n41B	10, 20, 30, 40, 50	10, 20, 30, 40, 50				100	0
CA_n41C	n41[3,4] CA_n41C[3]	40	80, 100				180	0
		50, 60, 80	60, 80, 100					
		10	100				190	1
		15, 20	90, 100					
		40	80, 90, 100					
		50, 60, 80, 90	60, 80, 90, 100					
		10	100				190	2
		15, 20	90, 100					
		30, 40	80, 90, 100					
		50, 60, 80, 90	60, 80, 90, 100					
		See n41 channel bandwidths in Table 5.3.5-1 for each carrier[2]					190	4 and 5
CA_n46B	-	20, 40, 60	20, 40				100	0
CA_n46C	-	60, 80	60, 80				160	0
CA_n46D	-	60, 80	80	80			240	0
CA_n46M	-	20, 40, 60	20, 40	20, 40			140	0
CA_n46N		Void						0
	-	20, 40, 60	20, 40	20, 40	20, 40		180	1
CA_n46O	-	20, 60	20, 40	20, 40	20, 40	20, 40	220	0
CA_n48B	CA_n48B	5	15, 20				40	0
		10, 15, 20	10, 15, 20					
		15, 20	15, 20					
	-	10	50, 60, 80, 90				100	1

(3GPP TS 38.101 V17.9.0)

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Ex.1028.0040

Claim 1	Public Documentation

5.5A.2 Configurations for intra-band non-contiguous CA

Table 5.5A.2-1: NR CA configurations and bandwidth combination sets defined for intra-band non-contiguous CA

NR CA Configuration	Uplink CA Configurations or single uplink carrier[5]	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Maximum Aggregated bandwidth (MHz)	Bandwidth combination set
CA_n1(2A)	-	5, 10, 15, 20	5, 10, 15, 20			40	0
CA_n2(2A)	-	5, 10, 15, 20	5, 10, 15, 20			40	0
CA_n3(2A)	-	5, 10, 15, 20	5, 10, 15, 20			40	0
	-	5, 10, 15, 20, 25, 30	5, 10, 15, 20, 25, 30			60	1
CA_n5(2A)	-	5, 10, 15, 20	5, 10, 15, 20			25	0
CA_n7(2A)	-	5, 10, 15, 20	5, 10, 15, 20			40	0
CA_n12(2A)	-	5	5			10	0
CA_n25(2A)	-	5, 10, 15, 20	5, 10, 15, 20			40	0
		5, 10, 15, 20, 25, 30, 40	5, 10, 15, 20, 25, 30, 40			60	1
		See n25 channel bandwidths in Table 5.3.5-1 for each carrier				60	4 and 5
CA_n25(3A)	-	5, 10, 15, 20, 25, 30, 40	5, 10, 15, 20, 25, 30, 40	5, 10, 15, 20, 25, 30, 40		55	0
		See n25 channel bandwidths in Table 5.3.5-1 for each carrier				55	4 and 5
CA_n41(2A)	n41[3,4] CA_n41(2A)	40, 50, 60, 80, 100	40, 50, 60, 80, 100			180	0
		10, 15, 20, 40, 50, 60, 80, 90, 100	10, 15, 20, 40, 50, 60, 80, 90, 100			190	1
	-	10, 15, 20, 30, 40, 50, 60, 80, 90	15, 20, 30, 40, 50, 60, 80, 90, 100			190	2
		10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100			190	3
		See n41 channel bandwidths in Table 5.3.5-1 for each carrier				190	4 and 5
CA_n41(3A)	n41[3,4]	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100		190	0
		See n41 channel bandwidths in Table 5.3.5-1 for each carrier				190	4 and 5
CA_n41(4A)	n41[3]	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	190	0
		See n41 channel bandwidths in Table 5.3.5-1 for each carrier				190	4 and 5
CA_n48(2A)		10, 15, 20, 40, 50, 60, 80. 90. 100	10, 15, 20, 40, 50, 60, 80. 90. 100			140[2]	0
		10, 15, 20, 30, 40, 50, 60, 70, 80, 90. 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90. 100			140[2]	1
CA_n48(3A)	-	10, 15, 20, 40,50, 60, 80. 90. 100	10, 15, 20, 40,50, 60, 80. 90. 100	10, 15, 20, 40,50, 60, 80. 90. 100		140[2]	0
		10, 15, 20, 30, 40, 50, 60, 70, 80, 90. 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90. 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90. 100		140[2]	1

(3GPP TS 38.101 V17.9.0)

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Petitioners' Ex. 1028
Ex.1028.0041

Claim 1	Public Documentation
	5.4 Carrier aggregation 5.4.1 Carrier aggregation In Carrier Aggregation (CA), two or more Component Carriers (CCs) are aggregated. A UE may simultaneously receive or transmit on one or multiple CCs depending on its capabilities: - A UE with single timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells sharing the same timing advance (multiple serving cells grouped in one TAG); - A UE with multiple timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells with different timing advances (multiple serving cells grouped in multiple TAGs). NG-RAN ensures that each TAG contains at least one serving cell; - A non-CA capable UE can receive on a single CC and transmit on a single CC corresponding to one serving cell only (one serving cell in one TAG). CA is supported for both contiguous and non-contiguous CCs. When CA is deployed frame timing and SFN are aligned across cells that can be aggregated, or an offset in multiples of slots between the PCell/PSCell and an SCell is configured to the UE. The maximum number of configured CCs for a UE is 16 for DL and 16 for UL. (3GPP TS 38.300 V17.4.0)

Claim 2

Claim 2	Public Documentation
[2] The method of claim 1 wherein frequency difference between the first	The Accused Instrumentalities perform a method wherein the frequency difference between the first center frequency and the second center frequency is greater than the sum of one-half the first frequency range and one-half the second frequency range.

Claim 2	Public Documentation
center frequency and the second center frequency is greater than the sum of one-half the first frequency range and one-half the second frequency range.	For example, the bandwidth from the center of the first carrier component ("first frequency") to the second carrier component ("second frequency") comprising half of the first carrier component and half of the second carrier component plus the guard band between the two carrier component, is greater than the half of the first frequency and half of the second frequency. *See, e.g.*: 5.3A.2 Maximum transmission bandwidth configuration for CA For carrier aggregation, the maximum transmission bandwidth configuration is defined per component carrier and the requirement is specified in clause 5.3.2. 5.3A.3 Minimum guardband and transmission bandwidth configuration for CA For intra-band contiguous carrier aggregation, *Aggregated Channel Bandwidth* and *Guard Bands* are defined as follows, see Figure 5.3A.3-1.

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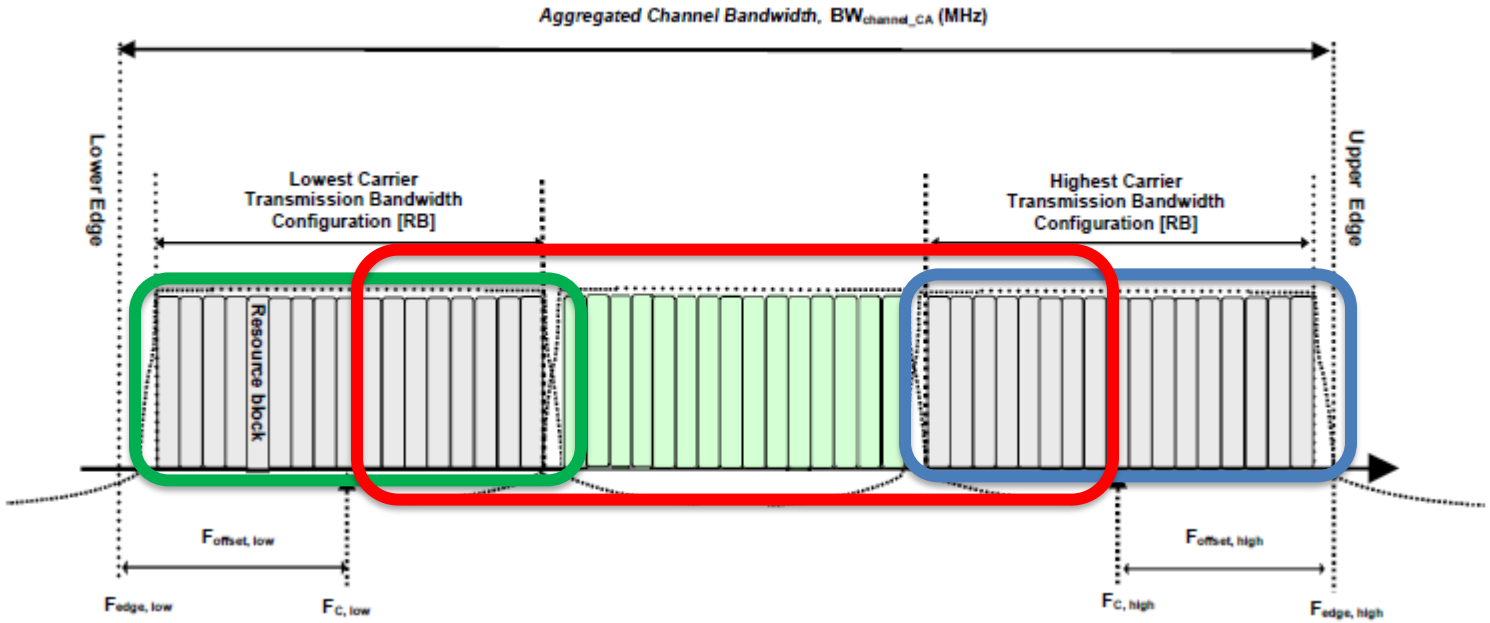
Claim 2	Public Documentation
	 **Figure 5.3A.3-1: Definition of *Aggregated Channel Bandwidth* for intra-band carrier aggregation** BWChannel_CA = Fedge,high - Fedge,low (MHz). The lower bandwidth edge Fedge, low and the upper bandwidth edge Fedge,high of the aggregated channel bandwidth are used as frequency reference points for transmitter and receiver requirements and are defined by Fedge,low = FC,low - Foffset,low Fedge,high = FC,high + Foffset,high The lower and upper frequency offsets depend on the transmission bandwidth configurations of the lowest and highest assigned edge component carrier and are defined as Foffset,low = (NRB,low*12 + 1)*SCSlow/2 + BWGB (MHz)

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Petitioners' Ex. 1028
Ex.1028.0044

Claim 2	Public Documentation
	$F_{offset,high} = (N_{RB,high}*12 - 1)*SCS_{high}/2 + BW_{GB}$ (MHz) $BW_{GB} = \max(BW_{GB,Channel(k)})$ $N_{RB,low}$ and $N_{RB,high}$ are the transmission bandwidth configurations according to Table 5.3.2-1 for the lowest and highest assigned component carrier, SCS_{low} and SCS_{high} are the sub-carrier spacing for the lowest and highest assigned component carrier respectively. SCS_{low}, SCS_{high}, $N_{RB,low}$, $N_{RB,high}$, and $BW_{GB,Channel(k)}$ use the largest μ value among the subcarrier spacing configurations supported in the operating band for both of the channel bandwidths according to Table 5.3.5-1 and $BW_{GB,Channel(k)}$ is the minimum guard band for carrier k according to Table 5.3.3-1 for the said μ value. In case there is no common μ value for both of the channel bandwidths, μ=1 is used for SCS_{low}, SCS_{high}, $N_{RB,low}$, $N_{RB,high}$, and $BW_{GB,Channel(k)}$. (3GPP TS 38.101-1 V17.5.0)

Claim 3

Claim 3	Public Documentation
[3] The method of claim 1 wherein the first and second information are transmitted using the same power amplifier in said wireless transmitter.	The Accused Instrumentalities perform a method wherein the first and second information are transmitted using the same power amplifier in said wireless transmitter. *See, e.g.*:

Claim 3	Public Documentation
	11.3.2.1 Transmitter architecture Figure 11.3.2.1-1 illustrates various TX architectures options according to where the component carriers are combined, i.e., at digital baseband, or in analog waveforms before RF mixer, or after mixer but before the PA, or after the PA. Option A - In an adjacent *contiguous common carrier* aggregation scenario, the UE very likely has one PA. Connected to the PA can be a single RF chain (a zero-IF mixer, a wideband DAC, and a wideband IFFT) Option-B - Combines analog baseband waveforms from component Carrier first (e.g., via a mixer operating at an IF of roughly the bandwidth of the other component carrier in the example of 2-component carrier aggregation). Then the resulting wideband signal is up-converted to RF. Option-C - Does ZIF up-conversion of each component carrier before combining and feeding into a single PA. Option-D - Employs multiple RF chains and multiple PAs after which the high-power signals are combined and fed into a single antenna. PA coupling at the UE can be challenging for option-D. (3GPP TR 36.912 version 15.0.0 Release 15)

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Ex.1028.0046

Claim 3	Public Documentation

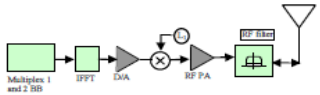
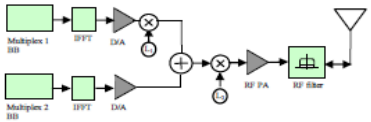
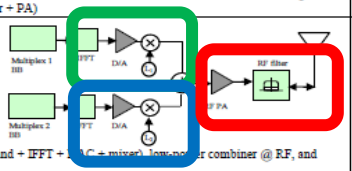
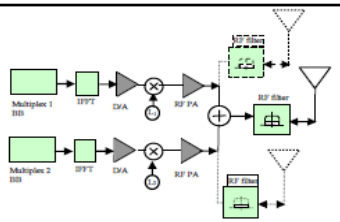
Tx Characteristics				
Option	Description (Tx architecture)	Intra Band aggregation		Inter Band aggregation
		Contiguous (CC)	Non contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes		
B	 Multiple (baseband + IFFT + DAC), single (stage-1 IF mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes	
C	 Multiple (baseband + IFFT + DAC + mixer), low-power combiner @ RF, and single PA	Yes	Yes	
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes	Yes + (depending on the specific EUTRA bands being aggregated),
X	*OTHERS*			

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios

(3GPP TR 36.912 version 15.0.0 Release 15)

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Ex.1028.0047

Claim 4

Claim 4	Public Documentation
[4] The method of claim 3 wherein the bandwidth of said power amplifier is greater than the difference between the first lowest frequency and the second highest frequency.	The Accused Instrumentalities perform a method wherein the bandwidth of said power amplifier is greater than the difference between the first lowest frequency and the second highest frequency. For example, as shown below, the bandwidth of an exemplary power amplifier meets the claimed conditions. *See, e.g.*:

Claim 4	Public Documentation
	SKYWORKS PRODUCT SUMMARY **SKY77786-11 High Band Multimode Multiband Power Amplifier Module Supporting LTE Advanced Applications** **Applications** • Multiband 4G / LTE handsets • FDD LTE Bands 7 and 30 • TDD LTE Band 38, 40, 41 **Features** • Two T/R (RX) port and 3 outputs • Industry-leading PAE for 4G • Optimized for APT DCDC operation • Fully programmable Mobile Industry Processor Interface (MIPI) control • MIPI programmable bias modes optimize best 4G efficiency/linearity performance. • Small, low profile package: - 3.0 x 3.0 x 0.71 mm - 20-pad configuration Skyworks Green™ products are compliant with all applicable legislation and are halogen-free. For additional information, refer to Skyworks *Definition of Green™*, document number SQ04-0074. **Description** Skyworks SKY77786-11 Skyl iFE™ is a multimode multiband (MMMB) Power Amplifier Module (PAM) that supports 4G handsets and operates efficiently in LTE bands from 2.3 GHz to 2.7 GHz. The module is fully programmable through a Mobile Industry Processor Interface (MIPI®). The PAM consists of a single high band LTE block, a Multi-Function Control (MFC) block, and a T/R switch block. RF input/output ports internally matched to 50 Ω to reduce the number of external components. A CMOS integrated circuit uses standard MIPI controls to provide the internal MFC interface and operation. Extremely low leakage current maximizes handset standby time. The InGaP die and the silicon die and passive components are mounted on a multi-layer laminate substrate. The assembly is encapsulated in a 3.0 mm x 3.0 mm x 0.71 mm, 20-pad MCM, SMT package which is a more highly manufacturable, low cost solution. **4G:** The SKY77786-11 supports 1.4, 3, 5, 10, 15, 20, 30, 35, 40 MHz channel bandwidths. Similar to 3G operation, output power is controlled by varying the input power and V_{CC} is adjusted using a DCDC converter to maximize efficiency for each power level. 4G Modulation scheme includes: - FDD LTE - TDD LTE - Uplink Carrier Aggregation (CA) support for Bands 40/41 (up to 40 MHz)

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Petitioners' Ex. 1028
Ex.1028.0049

Claim 6

Claim 6	Public Documentation
[6] The method of claim 1 wherein the first information corresponds to a first wireless protocol and the second information corresponds to a second wireless protocol.	The Accused Instrumentalities perform a method wherein the first information corresponds to a first wireless protocol and the second information corresponds to a second wireless protocol. *See, e.g.*: Cellular operators, for example AT&T, have deployed Dynamic Spectrum Sharing (DSS) and carrier aggregation technology that provides service using both LTE and 5G by sharing the same spectrum and using carrier aggregation, using two different protocols. Operators, for example AT&T, have also used carrier aggregation using a combination of FDD and TDD protocols, using two different protocols. # AT&T Touts Standalone 5G Breakthrough Posted on April 18, 2023 6:25pm by Carl Weinschenk In a blog post today, AT&T touted its achievements involving 5G standalone technology, including the completion several weeks ago of what the company said was the first 5G standalone uplink two-carrier aggregation data call in the United States. Like most carriers, AT&T initially deployed 5G in non-standalone mode, which relies on previous-generation technology in the core network. As the blog post notes, standalone 5G uses a dedicated core, which can help support faster upload speeds, lower latency, and edge functions, as well as enhancing reliability. The 5G standalone uplink two-carrier aggregation data call was conducted at AT&T's Labs with Nokia's 5G AirScale portfolio and MediaTek's 5G M80 mobile test platform. AT&T aggregated low band n5 and mid-band n77 spectrum. When the n5 was aggregated with 40 MHz of the n77 mid-band, the test generated a 100% increase in uplink throughput compared to the n5 low-band alone. A 250% increase was seen when 100 MHz of n77 was aggregated with the n5 spectrum. "The bottom line? We achieved incredible upload speeds of over 70 Mbps on n5 with 40MHz of n77 and over 120 Mbps on n5 with 100MHz of n77," said Jason Sikes, AT&T's Associate Vice President of Device Architecture, in today's blog post.

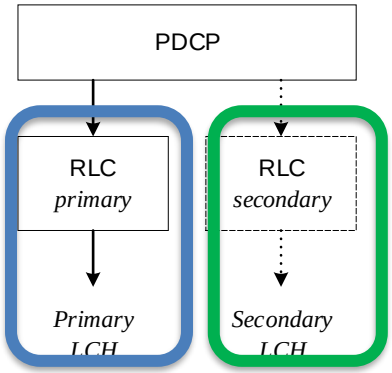
Claim 6	Public Documentation
	AT&T also said that it completed a standalone 5G four component carrier downlink call several months ago. The call combined two frequency division duplex (FDD) and two time division duplex (TDD) carriers. AT&T was able to aggregate mid-band n77 in the C-band and 3.45 GHz spectrum ranges. The blog post also references AT&T's use of two-layer uplink multiple in multiple out (MIMO) on TDD in the n77 band. MIMO combines signals and data streams from multiple antennas to improve signal quality and data rates, the carrier said. "This feature ill not only improve uplink throughput but also enhance cell capacity and spectrum efficiency," Sikes said, although the post doesn't indicate the status of that development Looking ahead, AT&T plans to enable 5G new radio dual connectivity (NR-DC), which will involve the aggregation of low and mid-band spectrum with high-frequency mmWave spectrum on 5G SA. So far, AT&T's labs achieved 5G NR-DC downlink throughput speeds as high as 5.3 Gbps and uplink throughput speeds as fast as 670 Mbps. (https://www.telecompetitor.com/att-touts-standalone-5g-breakthrough/) # AT&T spectrum aggregation industry first ups 5G ante **Dan Meyer** | Executive Editor. April 19, 2023 1:00 PM AT&T tested spectrum aggregation models on the oft-overlooked uplink channel that the carrier claimed was an industry first and resulted in network speeds that could help meet growing 5G traffic demands. Jason Sikes, AVP for device architecture at AT&T, explained in a blog post that the carrier completed an uplink data call running on its 5G standalone (SA) network core that aggregated two different spectrum frequency bands. The test was in AT&T's labs using Nokia's 5G AirScale equipment running on MediaTek's mobile test platform. Sikes explained in an email to SDxCentral that the test used 10-megahertz of AT&T's low-band 850 MHz spectrum combined with varying amounts of the carrier's C-band spectrum. With 40-megahertz of C-band spectrum the carrier was able to increase uplink speeds by 100% to more than 70 Mb/s compared with just the base 850 MHz spectrum. It witnessed a 250% increase in speed to more than 120 Mb/s using 100-megahertz of C-band spectrum. "Think of this as adding more lanes in the network traffic highway," Sikes wrote in the blog. "No one in the U.S market has successfully aggregated two carriers in 5G SA uplink – until now." Sikes added that AT&T's mobile network has witnessed a 30% increase in uplink capacity demand per year.

Claim 6	Public Documentation
	"This new age of connectivity is not only about consuming more content but also generating more content than ever before," he noted of the increase. "Whether you are uploading large files, on a video call with family, live streaming, cloud gaming or using extended reality applications, the network is facing surging upstream traffic demands it never has before." The latest test followed one conducted by the carrier last fall that involved a four-channel downlink call that traversed its 5G SA network. That call aggregated a pair of frequency division duplex (FDD) carriers and a pair of time division duplex (TDD) carriers running in the C-band and the 3.45 GHz spectrum bands. FDD is where different bands of frequency are used by users; one for uplink and the other for downlink. TDD is where one frequency band will be used for uplink and downlink, switching between the two from moment to moment. Sikes also noted that AT&T was deploying a "two-layer uplink" multiple-input, multiple output (MINO) technology on TDD across its C-band spectrum. "This feature will not only improve uplink throughput but also enhance cell capacity and spectrum efficiency," he wrote, though he further added that the carrier did not use MIMO during the most recent uplink test. The carrier is planning to launch 5G New Radio Dual Connectivity (NR-DC) capabilities "in the coming months." This will allow for the aggregation of low- and mid-band spectrum with AT&T's millimeter-wave (mmWave) spectrum using the 5G SA core. Sikes noted this capability has resulted in lab test downlink speeds up to 5.3 Gb/s and uplink speeds up to 670 Mb/s. "This technology gives customers high-speed mobile broadband for both downlink and uplink in stadiums, airports and other high-density venues," Sikes wrote. In the follow-up email, Sikes added that "over time, private 5G and fixed wireless will benefit from these uplink and downlink enhancements." (https://www.sdxcentral.com/articles/analysis/att-spectrum-aggregation-industry-first-ups-5g-ante/2023/04/) # AT&T to deploy dynamic spectrum sharing in second half of 2020 By **Bevin Fletcher** . May 28, 2020 11:42am Verizon has probably been the carrier most vocal about benefits of dynamic spectrum sharing (DSS) technology, but rival AT&T is also a fan and SVP Igal Elbaz said Thursday that the carrier expects to deploy DSS later this year.

Claim 6	Public Documentation
	"You should expect us to have DSS introduced in our network in the second half of 2020," said Elbaz, AT&T's senior vice president of Wireless Technology, speaking this morning to investment analysts at the virtual Cowen and Company Technology, Media & Telcom Conference. Elbaz called DSS a very important technology in terms of enabling both AT&T and other carriers to scale 5G rollouts. The timeline is similar to that of rival Verizon, which has pointed to dynamic spectrum sharing as key to its strategy for introducing broad nationwide 5G coverage this year using existing spectrum. Last month CEO Hans Vestberg indicated Verizon's plans to commercially deploy DSS in the second half of this year are still on track, with no COVID-19-related supply chain issues affecting the carrier's ability to do so. RELATED: AT&T 4G LTE connects IoT robots to kill germs, keep shelves stocked Dynamic spectrum sharing allows carriers to operate both 5G New Radio (NR) and LTE using the same spectrum channel by shifting or allocating resources between the two, based on the number of users or traffic needs. This is different from previous technology generation shifts, where carriers usually had to carve out or take away a portion of their existing spectrum and dedicate it to the new technology. Elbaz used the example of having four channels for LTE, and then needing to take away one channel, clean it, and use it only for 5G. That leaves an operator with only three channels instead of four for the vast majority of its users who are still on LTE. Meanwhile, there's a free channel for 5G, but it has very little usage because it takes time for new 5G users with capable devices to accumulate and generate traffic. "That's not an efficient way to manage your spectrum in the transition," Elbaz said. AT&T and T-Mobile have each already rolled out low-band 5G service that's not much speedier, or in some cases slower, than 4G LTE. Verizon, which is seen as lacking in low- and mid-band spectrum that it can dedicate to 5G, has stuck to 5G deployments using millimeter wave spectrum limited to small pockets of urban areas. Verizon is expected to participate for mid-band spectrum at the C-band auction set for December, but it will take time before that can be put to use. While DSS will let the carriers use existing spectrum to roll out 5G more quickly, it's been observed that the technology doesn't add extra capacity. RELATED: Charter talks with AT&T about wholesale MVNO agreement Analysts at LightShed Partners have said they expect Verizon will deliver broad 5G coverage enabled by a combination of DSS and carrier aggregation. As the firm explained, despite the confusing name, carrier aggregation enables operators to combine spectrum blocks, both blocks adjacent and non-adjacent, and from other bands to deliver faster speeds to end users. Although AT&T is pursuing a $6 billion cost-cutting initiative, Elbaz reiterated that AT&T will continue to invest in its core products, which include 5G, fiber and HBO Max (which just launched yesterday). That includes likely participation

Claim 6	Public Documentation
	for C-band spectrum. Still, Cowen analysts today suggested DSS could mean the carrier doesn't need to invest in as much new spectrum as it would otherwise. RELATED: AT&T 'not backing off' $6B cost cutting initiative While preparing for its 5G deployments, AT&T has bolstered its 4G LTE network, adding capacity with nearly 160 MHz of sub-6 GHz spectrum alongside its FirstNet public safety build. Network testing results tracked significant 4G LTE performance increases following enhancements that included additional spectrum and LTE-Advanced technologies such as carrier aggregation. AT&T stands out as the only carrier able to utilize 5-carrier aggregation on a wide scale for 4G LTE. According to RootMetrics, that helped boost AT&T's speed performance significantly in 51 out of 55 markets tested in the first half of 2020, compared to the end of 2019. Comparatively, for 4G LTE, Sprint and T-Mobile use 3-carrier aggregation, while Verizon uses 4-component carrier aggregation. Support for 5G carrier aggregation is expected in June with 3GPP Release 16. With DSS, AT&T can use existing channels for 5G, sharing instead of sacrificing 4G LTE spectrum resources. As more 5G devices come online, carriers can deploy DSS on additional, or eventually all, existing channels to serve both 4G LTE and 5G users. "[DSS] is a profound technology and really allows us to do that transition very efficiently," Elbaz said. RELATED: Ericsson defends dynamic spectrum sharing That said, there is at least one carrier that has cast some doubt on DSS. Last month T-Mobile President of Technology Neville Ray reiterated that one vendor was still trailing in a DSS product; T-Mobile doesn't depend DSS for its nationwide 5G network thanks to its 600 MHz portfolio. Ericsson led the charge on dynamic spectrum sharing technology, and its product is already being commercially used by global operators, including Swisscom, Telstra, and Play. Nokia, meanwhile, launched DSS in April, with volume shipments anticipated in July in line with availability of DSS-capable handsets. While Ray called DSS "still bumpy", he acknowledged T-Mobile will still deploy it. Verizon and AT&T executives have refuted problems with DSS, including Verizon's Vestberg, who last month said tests were going "very well." (https://www.fiercewireless.com/tech/at-t-to-deploy-dynamic-spectrum-sharing-second-half-2020)

Claim 7

Claim 7	Public Documentation
[7] The method of claim 1 wherein the first information and the second information are the same data transmitted across two different frequencies.	The Accused Instrumentalities perform a method wherein the first information and the second information are the same data transmitted across two different frequencies. For example, the packet duplication feature of 5G release 15 transmits the same data on two carrier components of carrier aggregation transmission method, i.e., the first and second data destined to two carriers are the same. (3GPP TS 38.300 version 16.2.0) *See, e.g.*: **16.1.3 Packet Duplication** When duplication is configured for a radio bearer by RRC, at least one secondary RLC entity is added to the radio bearer to handle the duplicated PDCP PDUs as depicted on Figure 16.1.3-1, where the logical channel corresponding to the primary RLC entity is referred to as *the primary logical channel*, and the logical channel corresponding to the secondary RLC entity(ies), the *secondary logical channel(s)*. All RLC entities have the same RLC mode. Duplication at PDCP therefore consists in submitting the same PDCP PDUs multiple times: once to each activated RLC entity for the radio bearer. With multiple independent transmission paths, packet duplication therefore increases reliability and reduces latency and is especially beneficial for URLLC services.  **Figure 16.1.3-1: Packet Duplication**

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Petitioners' Ex. 1028
Ex.1028.0055

Claim 7	Public Documentation
	When configuring duplication for a DRB, RRC also sets the state of PDCP duplication (either activated or deactivated) at the time of (re-)configuration. After the configuration, the PDCP duplication state can then be dynamically controlled by means of a MAC control element and in DC, the UE applies the MAC CE commands regardless of their origin (MCG or SCG). When duplication is configured for an SRB the state is always active and cannot be dynamically controlled. When configuring duplication for a DRB with more than one secondary RLC entity, RRC also sets the state of each of them (i.e. either activated or deactivated). Subsequently, a MAC CE can be used to dynamically control whether each of the configured secondary RLC entities for a DRB should be activated or deactivated, i.e. which of the RLC entities shall be used for duplicate transmission. Primary RLC entity cannot be deactivated. When duplication is deactivated for a DRB, all secondary RLC entities associated to this DRB are deactivated. When a secondary RLC entity is deactivated, it is not re-established, the HARQ buffers are not flushed, and the transmitting PDCP entity should indicate to the secondary RLC entity to discard all duplicated PDCP PDUs. When activating duplication for a DRB, NG-RAN should ensure that at least one serving cell is activated for each logical channel of the DRB; and when the deactivation of SCells leaves no serving cells activated for a logical channel of the DRB, NG-RAN should ensure that duplication is also deactivated. When duplication is activated, the original PDCP PDU and the corresponding duplicate(s) shall not be transmitted on the same carrier. The primary and secondary logical channels can either belong to the same MAC entity (referred to as CA duplication) or to different ones (referred to as DC or DC+CA duplication). CA duplication can be configured together with DC duplication when duplication over more than two legs is configured in the UE. In CA duplication, logical channel mapping restrictions are used in MAC to ensure that the primary and secondary logical channels are not sent on the same carrier. When CA duplication is configured for an SRB, one of the logical channels associated to the SRB is mapped to SpCell. When CA duplication is deactivated for a DRB, the logical channel mapping restrictions of the primary and secondary logical channels are lifted for as long as duplication remains deactivated. When an RLC entity acknowledges the transmission of a PDCP PDU, the PDCP entity shall indicate to the other RLC entity(ies) to discard it. In addition, in case of CA duplication, when an RLC entity restricted to only SCell(s) reaches the maximum number of retransmissions for a PDCP PDU, the UE informs the gNB but does not trigger RLF.

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Petitioners' Ex. 1028
Ex.1028.0056

Claim 7	Public Documentation
	(3GPP TS 38.300 version 16.2.0)

Claim 8

Claim 8	Public Documentation

[8] The method of claim 1 wherein the first information and the second information are from the same data stream.	The Accused Instrumentalities perform a method wherein the first information and the second information are from the same data stream.
	
	For example, the packet duplication may be deactivated. When packet duplication is deactivated, the same data stream is multiplexed onto the multiple component carriers (CCs) of carrier aggregation method. The data transmitted on the first component carrier ("first information") and the data transmitted on the second component carrier ("second information") are from multiplexing the same data stream for transmission onto the two carriers.
	
	See, e.g.:
	
	5.11.1 ACTIVATION/DEACTIVATION OF PDCP DUPLICATION
	
	For the PDCP entity configured with *pdcp-Duplication*, the transmitting PDCP entity shall:
	- for SRBs:
	  - activate the PDCP duplication;
	- for DRBs:
	  - if the activation of PDCP duplication is indicated for the DRB:
	    - activate the PDCP duplication for the DRB;
	  - if the activation of PDCP duplication is indicated for at least one associated RLC entities:
	    - activate the PDCP duplication for the indicated associated RLC entities;
	    - activate the PDCP duplication for the DRB;
	  - if the deactivation of PDCP duplication is indicated for the DRB:
	    - deactivate the PDCP duplication for the DRB;
	  - <u>if the deactivation of PDCP duplication is indicated for at least one associated RLC entities</u>:
	    - <u>deactivate the PDCP duplication for the indicated associated RLC entities;</u>
	    - <u>if all associated RLC entities other than the primary RLC entity are deactivated for PDCP duplication:</u>
	      - <u>deactivate the PDCP duplication for the DRB</u>.

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Petitioners' Ex. 1028
Ex.1028.0057

(3GPP TS 38.323 V17.4.0)

6.7 CARRIER AGGREGATION

In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below:

- In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell.

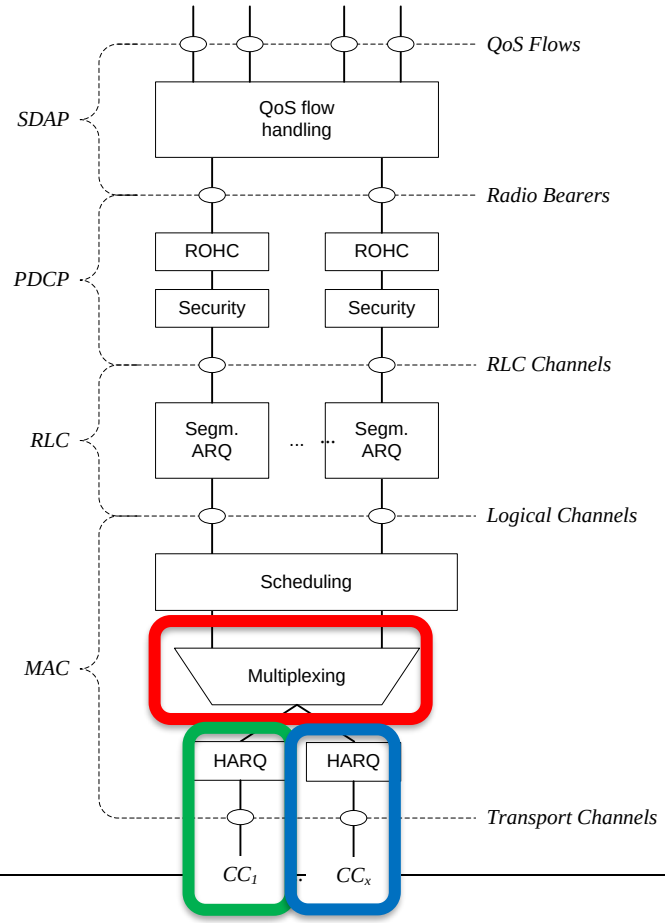

Figure 6.7-2: Layer 2 Structure for UL with CA configured.

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Petitioners' Ex. 1028
Ex.1028.0058

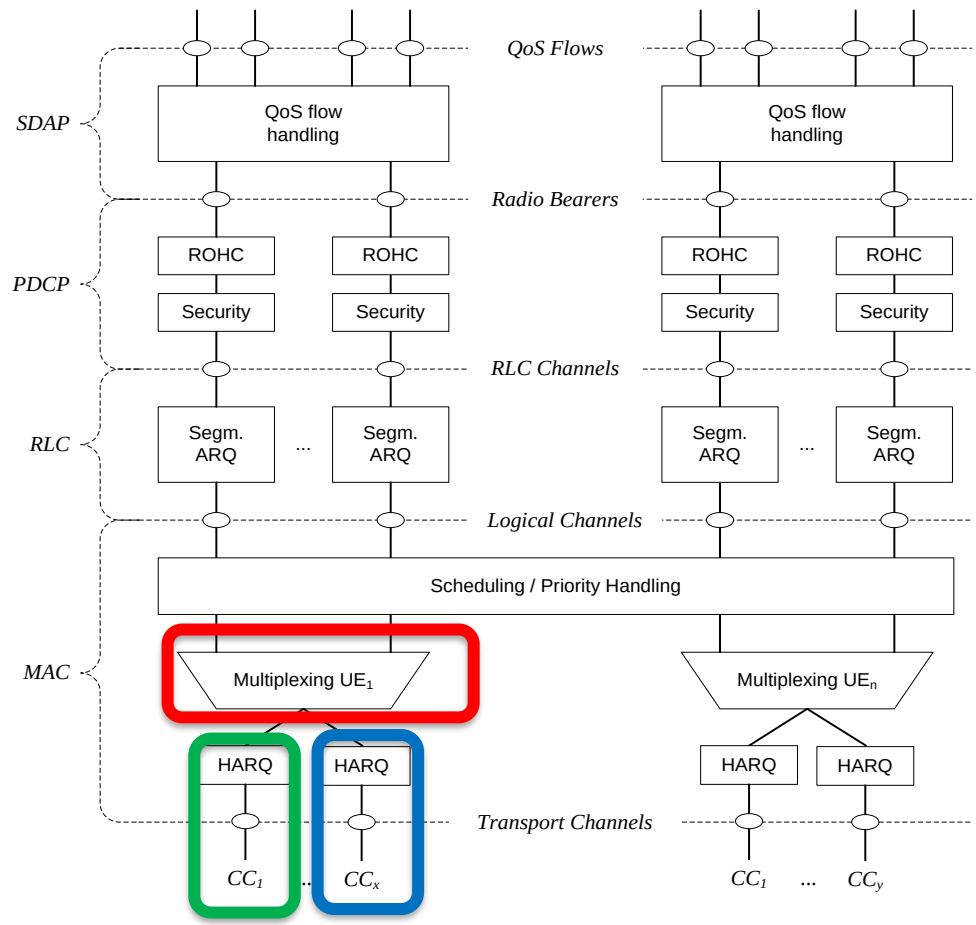

Figure 6.7-1: Layer 2 Structure for DL with CA configured.

IPR2024-00946
Petitioners' Ex. 1028
Ex.1028.0059

Claim 8	Public Documentation
	(3GPP TS 38.300 V17.4.0)

Claim 9

Claim 9	Public Documentation
[9] The method of claim 1 wherein first information and second information comprise a plurality of OFDM symbols, wherein a first symbol is transmitted during a first time slot across the first frequency range and a second symbol is trans- mitted during the first time slot across the second frequency range, and wherein a third symbol is transmitted during a second time slot across the first frequency range and a fourth symbol is transmitted during the second time slot across a second frequency range.	The Accused Instrumentalities perform a method wherein first information and second information comprise a plurality of OFDM symbols, wherein a first symbol is transmitted during a first time slot across the first frequency range and a second symbol is trans- mitted during the first time slot across the second frequency range, and wherein a third symbol is transmitted during a second time slot across the first frequency range and a fourth symbol is transmitted during the second time slot across a second frequency range. For example, the 5G frame structure comprises frames of length 10 msec long, each frame comprises 10 sub-frames, each subframe comprises at least two time slots, and each frame comprises at least 20 time slots. Each time slot comprises a multitude of OFDM symbols. A transport block, data payload, in 5G is divided into a set of code blocks, each code block is transmitted on frequency resources of OFDM symbols that comprise a time slot. In a Carrier Aggregation (CA) method, a data stream is multiplexed onto multiple Component Carriers (CCs), e.g., onto a first and a second data stream. The first and second data ("information") streams are transmitted on a first and a second CC, respectively. The first data stream is transmitted on a first CC, on frequency resources of an OFDM symbol in a time slot of the first CC, and the second data stream is transmitted on a second CC, on frequency resources of an OFDM symbol in the time slot of the second CC. The code blocks of the transport block (payload, data stream) are multiplexed onto the CCs and transmitted in consecutive time slots. *See, e.g.*: **6.7 CARRIER AGGREGATION** In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below: - In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell.

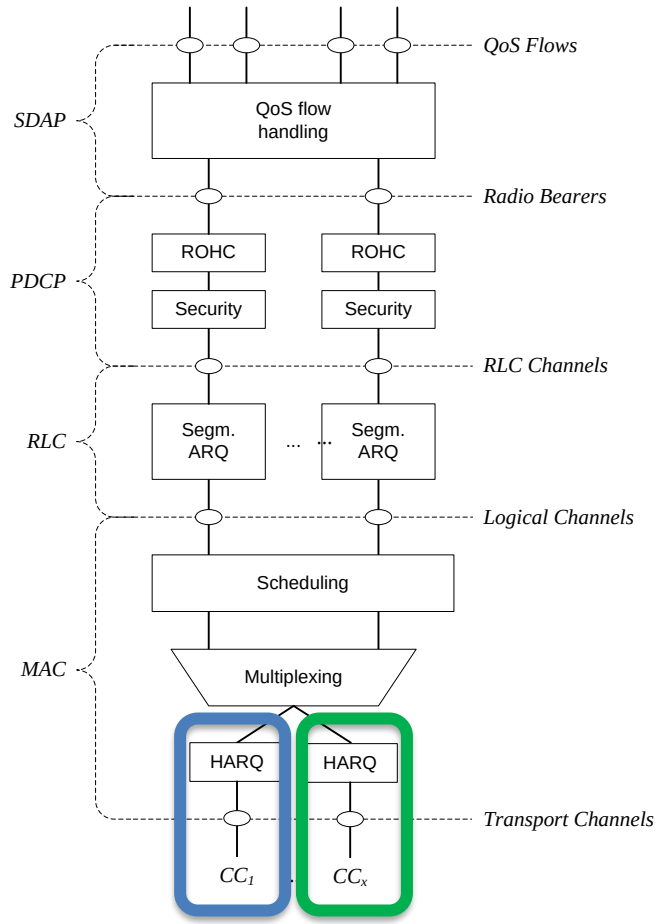

Figure 6.-2: Layer 2 Structure for UL with CA configured.

(3GPP TS 38.300 V17.4.0)

Frame structure and physical resources

4.1 GENERAL

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Petitioners' Ex. 1028
Ex.1028.0061

Claim 9	Public Documentation
	Throughout this specification, unless otherwise noted, the size of various fields in the time domain is expressed in time units $T_c = 1/(\Delta f_{max} \cdot N_f)$ where $\Delta f_{max} = 480 \cdot 10^3$ Hz and $N_f = 4096$. The constant $\kappa = T_s/T_c = 64$ where $T_s = 1/(\Delta f_{ref} \cdot N_{f,ref})$, $\Delta f_{ref} = 15 \cdot 10^3$ Hz and $N_{f,ref} = 2048$. Throughout this specification, unless otherwise noted, statements using the term "UE" in clauses 4, 5, 6, or 7 are equally applicable to the IAB-MT part of an IAB node. **4.2 NUMEROLOGIES** Multiple OFDM numerologies are supported as given by Table 4.2-1 where μ and the cyclic prefix for a downlink or uplink bandwidth part are obtained from the higher-layer parameter *subcarrierSpacing* and *cyclicPrefix*, respectively. **Table 4.2-1: Supported transmission numerologies.** μ | $\Delta f = 2^{\mu} \cdot 15$ [kHz] | **Cyclic prefix** 0 | 15 | Normal 1 | 30 | Normal 2 | 60 | Normal, Extended 3 | 120 | Normal 4 | 240 | Normal **4.3 FRAME STRUCTURE** **4.3.1 FRAMES AND SUBFRAMES** Downlink, uplink, and sidelink transmissions are organized into frames with $T_f = (\Delta f_{max} N_f / 100) \cdot T_c = 10$ms duration, each consisting of ten subframes of $T_{sf} = (\Delta f_{max} N_f / 1000) \cdot T_c = 1$ms duration. The number of consecutive OFDM symbols per subframe is $N_{symb}^{subframe,\mu} = N_{symb}^{slot} N_{slot}^{subframe,\mu}$. Each frame is divided into two equally-sized half-frames of five subframes each with half-frame 0 consisting of subframes 0 – 4 and half-frame 1 consisting of subframes 5 – 9. There is one set of frames in the uplink and one set of frames in the downlink on a carrier.

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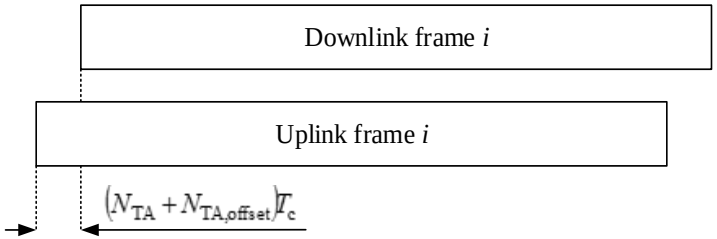
Petitioners' Ex. 1028
Ex.1028.0062

Claim 9	Public Documentation
	Uplink frame number i for transmission from the UE shall start $T_{TA} = (N_{TA} + N_{TA,offset})T_c$ before the start of the corresponding downlink frame at the UE where $N_{TA,offset}$ is given by [5, TS 38.213], except for msgA transmission on PUSCH where $T_{TA} = 0$ shall be used.  **Figure 4.3.1-1: Uplink-downlink timing relation.** **4.3.2 SLOTS** For subcarrier spacing configuration μ, slots are numbered $n_s^\mu \in \{0, \ldots, N_{slot}^{subframe,\mu} - 1\}$ in increasing order within a subframe and $n_{s,f}^\mu \in \{0, \ldots, N_{slot}^{frame,\mu} - 1\}$ in increasing order within a frame. There are N_{symb}^{slot} consecutive OFDM symbols in a slot where N_{symb}^{slot} depends on the cyclic prefix as given by Tables 4.3.2-1 and 4.3.2-2. The start of slot n_s^μ in a subframe is aligned in time with the start of OFDM symbol $n_s^\mu N_{symb}^{slot}$ in the same subframe. OFDM symbols in a slot in a downlink or uplink frame can be classified as 'downlink', 'flexible', or 'uplink'. Signaling of slot formats is described in clause 11.1 of [5, TS 38.213]. (3GPP TS 38.211 V16.1.0) **5G NR Transport Block Size (TBS) Calculation** August 16, 2020Author3GPP Specification, 5G MAC Layer, 5G NR, 5G Physical Layer Frame structure and physical resources Transport Block in 5G NR, is nothing but the payload, which is passed between the MAC and Phy Layers, specifically for the shared data channel such as PDSCH and PUSCH. A Transport Block undergoes Phy layer

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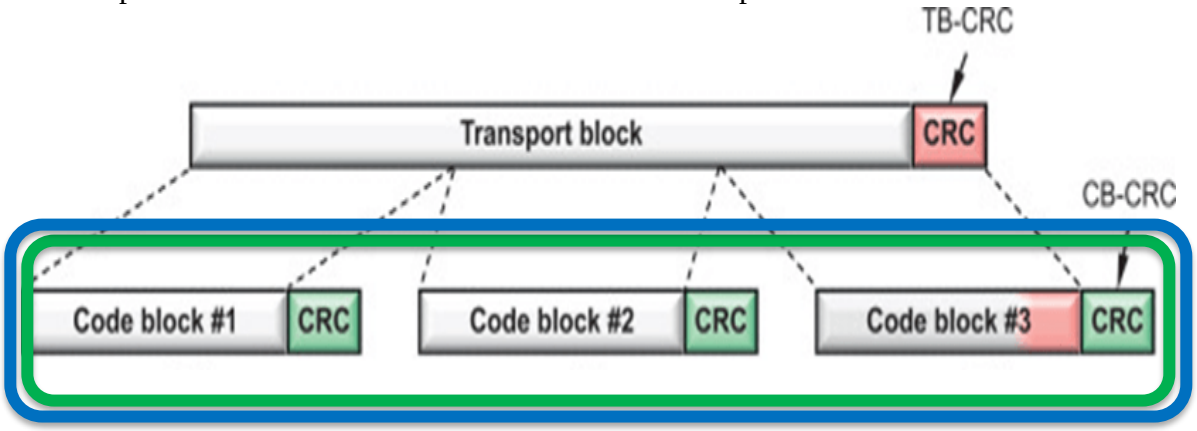
	processing at the transmitter before being mapped onto the PDSCH for transmission over the air interface. A Transport block is added with CRC and segmented into code blocks as shown as below. The transport block consists of up to million bits and the code block consists of up to 8448 bits.  (https://www.techplayon.com/5g-nr-transport-block-size-tbs-calculatin) **TIME-FREQUENCY RESOURCE** A ***resource element*** is the smallest time-frequency resource over one subcarrier of a single OFDM symbol. It is identified as $(k,l)_{p,\mu}$ where k is the index of the subcarrier in the frequency domain, l is the OFDM symbol position in time domain, p is the antenna port and μ is the subcarrier spacing configuration defined in Table 1 above. A ***resource block*** (a.k.a ***physical resource block*** – ***PRB***) is a block of $N^{RB}_{sc} = 12$ subcarriers over which the transmissions are scheduled. 5G NR physical layer uses time-frequency resource (***physical resource block***) for transmission.

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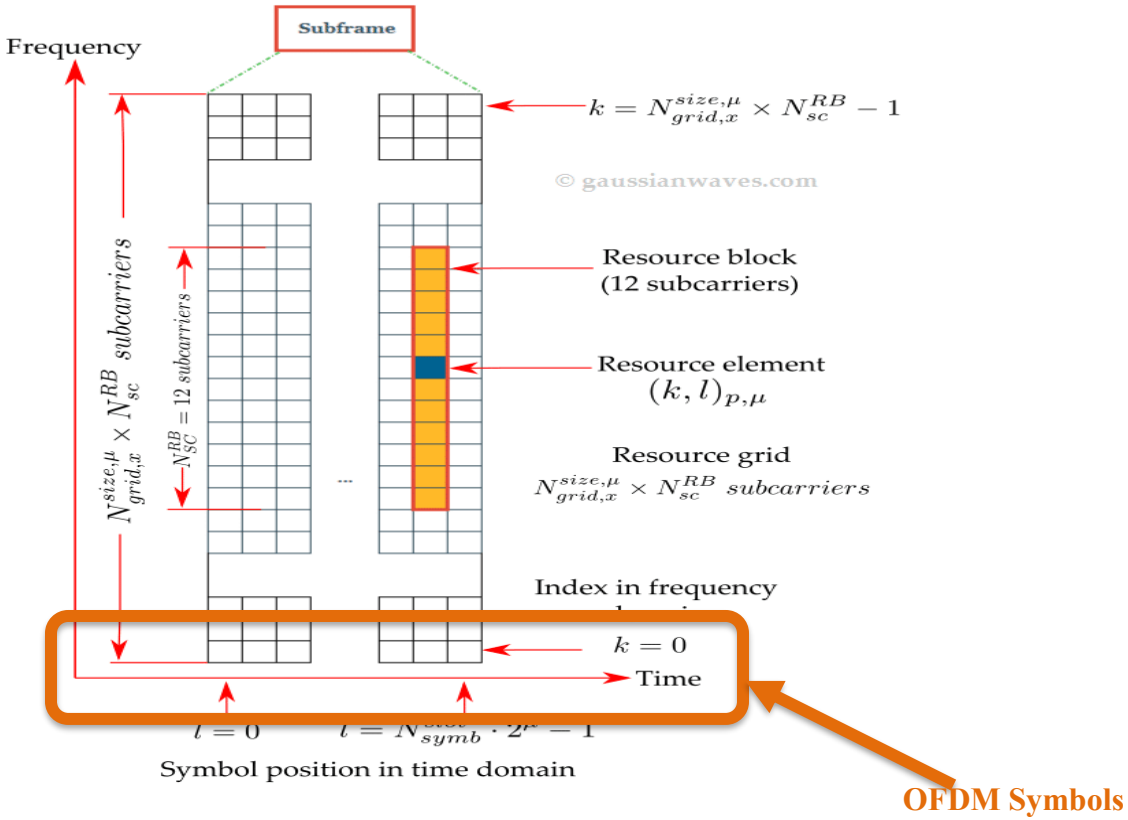
	A resource grid consists of $N^{size,\mu}_{grid,x}$ subcarriers and $N^{subframe,\mu}_{symb}$ number of OFDM symbols (***Table 2 and 3***).  ***Figure 3: Resource element, Resource block, Resource grid in 5G NR*** (https://www.gaussianwaves.com/2022/02/5g-nr-resource-block)

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[10pre] A method of transmitting information in a wireless communication channel comprising:	To the extent the preamble is found to be limiting, the Accused Instrumentalities perform a method of transmitting information in a wireless communication channel. For example, Defendant deploys and uses 4G and 5G RAN Solutions by vendors Ericsson and Nokia. These 4G and 5G RAN Solutions are 4G and 5G NR cellular radio access network systems supporting carrier aggregation, and the accused systems include all the installed components for the 4G and 5G NR RAN solution systems deployed by Defendant. *See, e.g.*: 5.4 Carrier aggregation 5.4.1 Carrier aggregation In Carrier Aggregation (CA), two or more Component Carriers (CCs) are aggregated. A UE may simultaneously receive or transmit on one or multiple CCs depending on its capabilities: - A UE with single timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells sharing the same timing advance (multiple serving cells grouped in one TAG); - A UE with multiple timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells with different timing advances (multiple serving cells grouped in multiple TAGs). NG-RAN ensures that each TAG contains at least one serving cell; - A non-CA capable UE can receive on a single CC and transmit on a single CC corresponding to one serving cell only (one serving cell in one TAG). CA is supported for both contiguous and non-contiguous CCs. When CA is deployed frame timing and SFN are aligned across cells that can be aggregated, or an offset in multiples of slots between the PCell/PSCell and an SCell is configured to the UE. The maximum number of configured CCs for a UE is 16 for DL and 16 for UL. (3GPP TS 38.300 V17.4.0) 6.7 Carrier Aggregation In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below:

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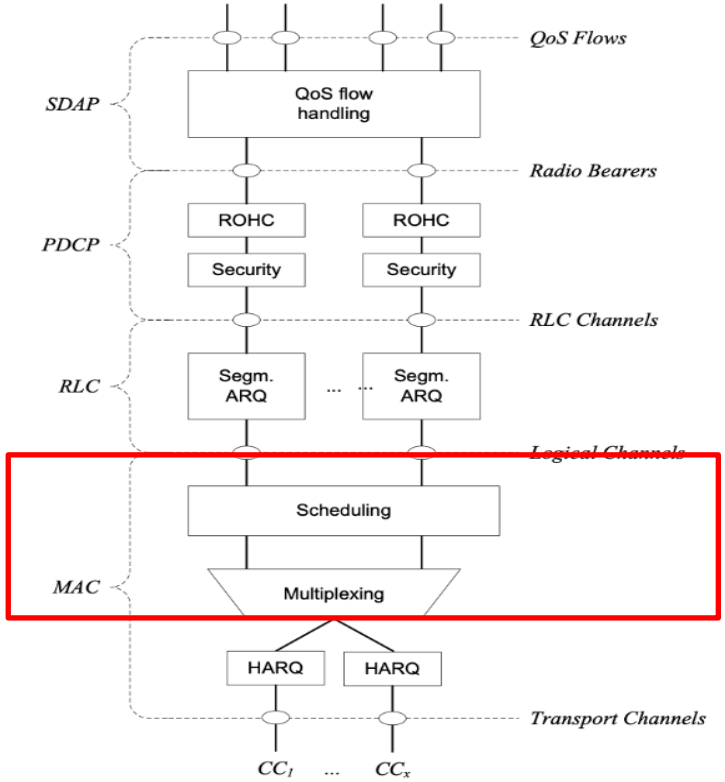
	- In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell. (3GPP TS 38.300 V17.4.0)  **Figure 6.7-2: Layer 2 Structure for UL with CA configured** (3GPP TS 38.300 V17.4.0)

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Claim 10	Public Documentation
	5G Carrier Aggregation is set to deliver a significant performance boost to mobile users but what is it and how does it work? The ongoing rollout of commercial 5G networks has significantly improved the experience for mobile subscribers around the world. As the ecosystem matures, a growing number of more advanced 5G Standalone (5G SA) networks will be central to delivering the speed and ultra-low latency to support cutting-edge applications. 5G Carrier Aggregation will play a vital role in underpinning the significant performance boost promised by 5G SA, representing an important milestone in the evolution of wireless infrastructure. Carrier Aggregation is a software functionality in Radio Access Networks and user devices which allows Mobile Network Operators (MNOs) to combine the capabilities of radio cells at distinct frequency allocations to enhance the end user experience. A key technology already in the LTE-Advanced networks, Carrier Aggregation enabled the evolution to Gigabit-LTE, achieving user data rates of more than 1 Gbps. However, in 5G networks, Carrier Aggregation will enable the evolution to multi-Gigabit-5G, reaching user data rates of about 4 Gbps and above. 5G Carrier Aggregation is also capable of improving the geographic availability, more commonly referred to as coverage, of high data rates. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/)

Claim 10	Public Documentation
	Carrier Aggregation in 5G Networks To accelerate rollout, the initial commercial 5G networks relied on the LTE infrastructure in radio access and the core network, referred to as 5G non-Standalone (5G NSA). 5G NSA allows MNOs to increase the bandwidth available to end users by bundling 4G and 5G carriers through 4G-5G Dual Connectivity. This allowed 5G users to benefit from existing LTE Carrier Aggregation capabilities with up to two 5G carriers aggregated alongside LTE carriers. To unlock the full capability of 5G, including ultra-low latency, reliability, and efficiency, MNOs are introducing 5G Standalone (5G SA) with a dedicated 5G Core and highly efficient 5G air interface, without dependency on existing LTE networks. The number of specified 5G SA Carrier Aggregation band combinations is increasing with each quarterly revision of the 3GPP specifications, enabling further options to achieve multi-Gigabit 5G data rates. These specifications are important to ensure interoperability between user equipment, such as smartphones, and networks. Between 2021 to 2022, the focus of the specifications for Carrier Aggregation in 5G SA in FR1 shifted from two component carriers to three and four component carriers. As the number of 5G frequency bands exceeds that of LTE-A, the possible Carrier Aggregation band combinations are greatly expanded, offering increased deployment options and flexibility for MNOs in different markets. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/)

Claim 10	Public Documentation
	Key benefits of 5G Carrier Aggregation Improved data speeds and throughput 5G Carrier Aggregation will boost the network performance to meet the requirements of data-hungry applications, such as augmented and virtual reality services, for both industrial and consumer use cases. Greater cell coverage As operators are looking to maximize the use of their available spectrum assets in different FDD and TDD bands, Carrier Aggregation is the key to reaching extended coverage range. This helps reduce the need to deploy new cell sites, bringing cost savings to operators. It also improves mobile user experience with consistent level of service across the network. Enhanced energy efficiency In 2019, the mobile industry made a milestone commitment to transform the sector and reach net zero carbon emissions by 2050. Carrier Aggregation has been demonstrated to reduce overall power consumption levels while increasing throughput and maintaining high service levels. This indicates that the technology could contribute to reducing overall energy usage and the mobile industry's carbon footprint. Improved coverage can also contribute to longer battery life for individual devices, requiring less frequent charging. Greater ROI According to data from GSA, the total amount raised in 2021 from spectrum auctions and assignments reached at least $140.1Bn. Radio spectrum is a finite and extremely valuable resource, representing a considerable financial burden for most MNOs. Therefore, with ever increasing demands for bandwidth, utilising this spectrum in the most efficient way becomes a top operational priority. 5G CA represents one of the most effective methods for MNOs to get the most from their outlay by maximising spectral efficiency. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/) Samsung Galaxy users in the United States will now enjoy faster 5G speeds, all thanks to T-Mobile's carrier aggregation technology. At the Mobile World Congress 2023 event in Barcelona, T-Mobile announced the successful deployment of 5G carrier aggregation on its standalone 5G network.

Claim 10	Public Documentation
	Ericsson, Nokia, Qualcomm Technologies, Inc., and Samsung teamed up with T-Mobile in the completion of the 5G Carrier Aggregation tech. The phone used for the project was a Samsung Galaxy S23 series model. Consequently, T-Mobile customers with a Galaxy S23, Galaxy S23+, or Galaxy S23 Ultra will be the first to benefit from four-carrier aggregations later this year. (https://www.sammobile.com/news/t-mobile-carrier-aggregation-5g-samsung-galaxy-s23/) *See, e.g.*: **AT&T Quietly Lights Up Carrier Aggregation in Chicago** ***Mar 6, 2014, 12:10 PM by Eric M. Zeman*** ***updated Mar 7, 2014, 7:32 AM*** AT&T has improved its LTE network in Chicago and several other markets by using an LTE-Advanced technique called Carrier Aggregation. GigaOm confirmed the soft launch with AT&T SVP of Network Technologies Kris Rinne. With Carrier Aggregation, AT&T has combined the channels of its existing spectrum to double the capacity. AT&T is running LTE in both the 700MHz and AWS bands in Chicago. By aggregating the channels together, AT&T can deliver theoretical peak download speeds of 110Mbps to devices with the proper radio support. At the moment, AT&T is selling only one device with Carrier Aggregation, the Unite mobile hotspot. The Samsung Galaxy S5 is expected to be the first smartphone to support Carrier Aggregation in the U.S. AT&T did not name the other two markets that have access to Carrier Aggregation, but said that more markets on are on the way. Sprint, T-Mobile, and Verizon Wireless are all in various stages of deploying Carrier Aggregation in their own LTE networks. (https://www.phonescoop.com/articles/article.php?a=13751) **AT&T: We are deploying 3-channel carrier aggregation on LTE network** By **Mike Dano** . Sep 14, 2016 3:37pm

Claim 10	Public Documentation
	AT&T confirmed to *FierceWireless* that it too is deploying three-channel carrier aggregation on its LTE network. The news indicates AT&T is joining the rest of the nation's Tier 1 carriers in deploying the technology. "We're currently in the process of deploying 3-way carrier aggregation on our network," said AT&T spokesman Steven Schwadron. "AT&T started strategically deploying LTE-A in early 2014 and now we cover with LTE-A the vast majority of our customers in our LTE coverage area. We're also adding also additional spectrum and equipment on an ongoing basis to further boost our network performance." Schwadron added that AT&T currently sells 26 devices that are "LTE-A capable," and that the carrier lists them on its website. Schwadron added that, while LTE-Advanced peak speeds can be significantly higher than LTE speeds, "performance will depend on many factors including location and network traffic." Importantly, though, Schwadron declined to provide any further details, including what spectrum bands AT&T is combining through carrier aggregation and where the service is available. He said only that AT&T is deploying the technology into "high-density, high-traffic areas." AT&T's acknowledgement that it is deploying carrier aggregation isn't much of a surprise. AT&T's John Donovan said in 2014 that the operator would deploy carrier aggregation technology where it can, depending on how much spectrum it has available to meld together. Further, in 2015, AT&T's Tom Keathley told *FierceWireless* that AT&T had expanded its use of carrier aggregation to include major markets such as New York, San Francisco and Dallas. However, AT&T's admission that it is deploying three-channel carrier aggregation is noteworthy since much of the industry's discussion on the topic has so far focused on two-channel carrier aggregation. Carrier aggregation technology allows wireless network operators to essentially glue together transmissions across different spectrum bands in order to provide faster download speeds. For example, AT&T could use the technology to meld transmissions across its 700 MHz and AWS spectrum bands via two-channel carrier aggregation. Three-channel aggregation would add another chuck of spectrum, such as transmissions over PCS spectrum, to the transmission. Of course, AT&T isn't alone in deploying three-channel carrier aggregation: Verizon, Sprint and T-Mobile have all said they too are either deploying it or will soon. Sprint last week confirmed to *FierceWireless* that it launched three-channel carrier aggregation in Chicago and Kansas City, merging transmissions across three different channels of its 2.5 GHz spectrum and providing speeds up to 200 Mbps. And T-Mobile has said it too is already offering three-channel carrier aggregation, though it did not say where. For its part, Verizon has said it is currently offering two-channel carrier aggregation in the 461 cities, and Verizon's Mike Haberman said the operator will also offer three-channel carrier aggregation in locations where it has sufficient spectrum. To be clear, though, three-channel carrier aggregation must be enabled both in the network and on the users' device.

(https://fiercewireless.com/wireless/at-t-we-are-deploying-3-channel-carrier-aggregation-lte-network)

AT&T Pushing Toward Four Carrier Aggregation, LAA in Second Half of This Year

By Diana Goovaerts | March 2, 2017

BARCELONA – U.S. wireless carrier AT&T is pushing toward the launch of four carrier aggregation in the second half of this year, including some configurations that utilize unlicensed spectrum via License Assisted Access (LAA).

AT&T Vice President of RAN and Device Design Gordon Mansfield on Thursday told Wireless Week the carrier is eyeing deployment of four carrier aggregation in the early second part of the year. The advancement will be made via a software upgrade to the carrier's network, he said, and is part of the carrier's push toward gigabit speeds.

"With the spectrum positions that the operators have in the U.S., you've got to bring together some unlicensed spectrum as well (to hit gigabit speeds)," Mansfield said. "You can get close, you can get up to several hundred with just the macro network and the licensed spectrum, but the way you get to a gigabit is you use licensed spectrum with 4×4 MIMO and 256-QAM and you bring in LAA with unlicensed carriers. And in that case it will actually be 4CA."

According to Mansfield, four carrier aggregation will be used in conjunction with technologies like 256-QAM and 4×4 MIMO to help reach 1 Gbps or more on the network.

In areas where the carrier has a densely built network with small cells, Mansfield said four carrier aggregation with LAA will be used. But in the macro network, he said, four carrier aggregation will be on licensed bands.

While devices today currently only support one of the three aforementioned technologies at a time, Mansfield indicated devices are headed down the pipe as soon as in the second quarter that will have baseband modems capable of supporting all simultaneously. Mansfield declined to name the vendors who are planning such releases.

Mansfield specified, though, that some capabilities will be available on the device right out of the box. Others, like LAA, will be added via an over the air software update pushed out over the network later in the year, he said.
(https://www.5gtechnologyworld.com/att-pushing-toward-four-carrier-aggregation-laa-in-second-half-of-this-year/)

Claim 10	Public Documentation
	# AT&T in early 2020: results show excellent speeds on both 5G and LTE Dave Andersen, Apr 23, 2020 **AT&T delivered faster speeds in 51 out of 55 markets tested to date in the first half of 2020.** With our testing efforts currently on hold due to the COVID-19 pandemic, we thought now would be a perfect time to take a look at how the carriers have performed across the 55 markets we've tested so far in the first half of 2020. We'll soon publish carrier-specific reports with overviews of performance for both 5G and 4G LTE in 1H 2020, and to kick things off, we'll start with AT&T. AT&T has deployed its 5G using 850 MHz low-band spectrum in several cities across the US, and the carrier has shown particularly impressive gains since our last round of testing in the second half of 2019. While AT&T's median download speeds on 4G LTE were already fast in most metros across the country in 2019, the carrier stepped up even more in the first half of 2020. We found excellent and improved download speeds on the carrier's 4G LTE network in the 55 markets we completed testing before we paused our scouting efforts, and AT&T's low-band 5G is also providing generally fast speeds (though not as fast as Verizon's mmWave 5G). This strong showing by AT&T can't entirely be chalked up to its 5G service, however. AT&T has been investing heavily over the past 18 months to bolster its already robust 4G LTE network. AT&T erected new cell sites in cities across the country, added more spectrum layers, and utilized 5-carrier aggregation (5CA) on a wide scale paired with 4x4 MIMO technology to maximize its vast spectrum holdings and provide faster speeds. AT&T also reallocated some of the spectrum reserved for its FirstNet Public Safety network and began using it for general customers while still satisfying its commitments to first responders. In short, AT&T has taken numerous steps to upgrade its network as 5G deployments continue, and AT&T subscribers are reaping the rewards in the form of faster connectivity that should only get better as the carrier's 5G continues to expand and mature. **AT&T's advantage: widespread 5-carrier aggregation and 4x4 MIMO technology** A primary reason for AT&T's improved speed results in 2020 is the carrier's widespread usage of 5-carrier aggregation (5CA) technology. In short, 5CA allows AT&T to combine five separate channels to increase bandwidth and provide faster speeds. On top of its capacity gains from 5CA, the efficiency of each of those five channels is maximized by AT&T's utilization of 4x4 MIMO (Multiple Input Multiple Output) technology. MIMO refers to using multiple radio antennas at both the tower and the device, which helps improve capacity, coverage, and speed. In a 4x4 system, there are four antennas on both the tower and device, whereas with 2x2 MIMO, there are two antennas on the tower and device.

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	If you think of each channel with 4x4 MIMO as utilizing four independent data streams, 5CA allows 20 independent streams to be combined, which results in greater bandwidth and, in turn, faster speeds. However, in order for a carrier to utilize 5CA, it's imperative to hold spectrum in five channels, and AT&T is in a unique position as the only carrier with the spectrum necessary for wide scale use of 5CA. In addition, AT&T also utilizes 256QAM, a spectrum modulation method that provides the highest possible level of spectral efficiency, and the carrier has expanded the reach of its Band 2 spectrum (the biggest of the five channels in 5CA) by adding new cell towers in cities across the US. AT&T has an advantage over the competition as the only carrier that can utilize 5-carrier aggregation on a wide scale in the US. Sprint and T-Mobile use 3-carrier aggregation, while Verizon uses 4-carrier aggregation technology. **The results: broad use of 5CA and 4x4 MIMO lead to much faster speeds** AT&T's speeds took a significant step forward during our first-half 2020 testing. Among the 55 cities we tested, AT&T's speeds improved in a whopping 51 of those markets, which was more than any other carrier (Sprint was the closest, with improvements in 47 markets). Even more impressive is that AT&T's median download speeds jumped by at least 15 Mbps in 22 of those markets, with increases of at least 10 Mbps in 37 out of 55 cities. Considering that 15 Mbps is generally fast by itself, an increase of 15 Mbps from a speed that was already fast can profoundly change the end-user experience. (https://rootmetrics.com/en-US/content/att-early-2020-performance-review) # 5-carrier aggregation gives AT&T network edge – RootMetrics By **Bevin Fletcher** . Apr 24, 2020 4:45pm AT&T delivered speed gains across 51 markets in the early part of 2020, with its wide-scale use of 5-component carrier aggregation and 4x4 MIMO giving it an edge over competition, according to RootMetrics. RootMetrics temporarily suspended its network testing but in the meantime is publishing carrier-specific reports on 4G LTE and 5G performance in the first half of 2020. AT&T's speeds improved significantly in 51 out of 55 markets in RootMetrics' testing, outpacing every other carrier. Speed performance on AT&T's network jumped more than 30 Mbps in four cities at the start of 2020, compared to the end of 2019. RELATED: Verizon grabs RootMetrics awards in Los Angeles

Claim 10	Public Documentation
	The biggest increase was seen in Ogden, Utah, where median download speeds spiked 37 Mbps from 38.2 Mbps in 2019 to 75.2 Mbps in early 2020. Markets rounding out the top five for AT&T's most improved speeds include Minneapolis, Cincinnati, Charleston, South Carolina, and Allentown, Pennsylvania. In 37 of the 55 markets tested, speeds jumped at least 10 Mbps compared to 2019, and at least 15 Mbps in 22 markets. "Considering that 15 Mbps is generally fast by itself, an increase of 15 Mbps from a speed that was already fast can profoundly change the end-user experience," the report noted. RootMetrics' tests done last year only connected to AT&T's 4G LTE, while the 2020 results connected to the carrier's low-band 5G where available. In the latest test period, AT&T's network recorded median download speeds above 50 Mbps in 23 markets, compared to just three markets in the second half of 2019. At the start of this year, only two cities registered speeds under 20 Mbps. AT&T is moving forward with its low-band 5G rollouts, just this week expanding to 90 additional cities, but RootMetrics called out the carrier's heavy investment over the last 18 months to enhance its already strong 4G LTE network. RELATED: 5G a 'mixed bag' as Verizon gets high speeds, T-Mobile offers better coverage – RootMetrics "AT&T erected new cell sites in cities across the country, added more spectrum layers, and utilized 5-carrier aggregation (5CA) on a wide scale paired with 4x4 MIMO technology to maximize its vast spectrum holdings and provide faster speeds," RootMetrics reported. "AT&T also reallocated some of the spectrum reserved for its FirstNet Public Safety network and began using it for general customers while still satisfying its commitments to first responders." AT&T is in a unique position to use five-component carrier aggregation (5CA), according to the testing company, a technology which requires and enables it to combine five separate channels for increased capacity. "AT&T has an advantage over the competition as the only carrier that can utilize 5-carrier aggregation on a wide scale in the U.S.," according the report. That compares to Sprint and T-Mobile's use of 3-carrier aggregation, while Verizon uses 4-component carrier aggregation. While 5-carrier aggregation is helping enhance AT&T's speeds over low-band spectrum, 8-component carrier aggregation (8CC) has been cited in work to hit record 5G speeds using millimeter wave spectrum. In lab tests in February, Ericsson alongside Qualcomm, used 8CC to aggregate 800 MHz of millimeter wave spectrum and achieve a record 5G speed of 4.3 Gbps. RELATED: Verizon works with Samsung, Qualcomm to achieve 4.2 Gbps on its 5G network

Claim 10	Public Documentation
	Verizon, meanwhile, worked with Samsung and Qualcomm earlier this year, using the technology to aggregate 800 MHz of 28 GHz mmWave spectrum and hit speeds of 4.2 Gbps on its live 5G network in Texas. Verizon SVP of Technology Planning Adam Koeppe said at the time that 8-channel carrier aggregation using mmWave would be widely available on the carrier's network this year. In terms of RootMetrics' latest report, the company didn't test AT&T's 5G+ network, which was just recently opened up to consumers and leans on high-band millimeter wave instead of low-band spectrum. Out of the 55 markets, AT&T's low-band flavor of 5G still delivered strong results. That includes Philadelphia, which ranked the fastest with median 5G download speeds of 94.5 Mbps – though limited availability of just 1.6%. "AT&T's network investments have clearly paid dividends for its subscribers on both 5G and 4G LTE," RootMetrics concluded. "As more and more 5G devices become available, consumers will find even faster speeds thanks not only to 5G, but also because some 5G-ready smartphones can take advantage of AT&T's pairing of wide-scale 5CA with 4x4 MIMO." (https://www.fiercewireless.com/operators/widespread-5-carrier-givesat-t-network-edge-rootmetric) **April 18, 2023** Taking 5G to the Next Level with Standalone 5G By Jason Sikes, AVP Device Architecture *AT&T Labs makes industry-first 5G SA Uplink 2-CA data connection in the U.S. to improve upload speeds, with additional speed and other upgrades in the works* AT&T is architecting tomorrow's wireless network to ***connect people to greater possibility***. As engineers, we design, build, test, refine and repeat so that you can get more out of your 5G connection and developers can build and deploy the next generation of apps and services. A key part of this evolution is the critical transition phase we are entering in scaling from 5G non-standalone (NSA) to 5G standalone (SA). **How does Standalone take 5G to the next level?** Unlike 5G NSA that still relies on a 4G LTE core, 5G SA uses a dedicated 5G core that can unlock capabilities like faster upload speeds, ultra-low latency, ultra-high reliability and edge functions. This technology will be key to business opportunities like the next generation of connected cars. We have said that we plan to deploy Standalone 5G when the ecosystem is ready, and AT&T is charging forward to advance SA ecosystem readiness. Businesses and developers will be some of the first to take advantage of the new technologies standalone 5G enables as we continue to move from research & development to their deployment.

Claim 10	Public Documentation
	Uplink: where challenge meets opportunity This new age of connectivity is not only about consuming more content but also generating more content than ever before. Demand for uplink capacity and speed continues to increase, about 30% a year in AT&T's mobility network. Whether you are uploading large files, on a video call with family, live streaming, cloud gaming or using extended reality applications, the network is facing surging upstream traffic demands it never has before. Our latest network innovations are complex but are all about helping meet this new demand. Just a few weeks ago, we completed the **first 5G SA Uplink 2-carrier aggregation data call in the U.S.** Carrier aggregation (CA) means we are combining or "aggregating" different frequency bands to give you more bandwidth and capacity. For you, this means faster uplink transmission speeds. *Think of this as adding more lanes in the network traffic highway*. No one in the U.S market has successfully aggregated two carriers in 5G SA uplink – until now. This is part of our ongoing effort to provide greater reliability for our customers. The test was conducted in our labs with Nokia's 5G AirScale portfolio and MediaTek's 5G M80 mobile test platform. We aggregated our low-band n5 and our mid-band n77 spectrum. Compared to our low-band n5 alone, we saw a 100% increase in uplink throughput by aggregating our low-band n5 with 40MHz of our mid-band n77. Taking it a step further, we achieved a 250% increase aggregating 100MHz of n77. The bottom line? We achieved incredible upload speeds of over 70 Mbps on n5 with 40MHz of n77 and over 120 Mbps on n5 with 100MHz of n77. While carrier aggregation is like adding more traffic lanes in the highway, adding another vehicle to carry traffic is another way we are managing surging uplink demand. We are doing this via a **two-layer uplink MIMO** on time division duplex (TDD) in our mid-band n77. MIMO combines signals and data streams from multiple antennas ("vehicles") to improve signal quality and data rates. This feature will not only improve uplink throughput but also enhance cell capacity and spectrum efficiency. **Network design and device readiness go hand in hand** Although we continue to make progress in enhancing uplink coverage, we haven't forgotten about the downlink. Enhanced downlink and uplink carrier aggregation capabilities work together to bring the 5G SA performance today's technologies need. Last fall, we completed a **5G SA four component carrier downlink** call by combining two FDD carriers and two TDD carriers. These capabilities allow AT&T devices to aggregate our mid-band n77 in the C-Band and 3.45GHz spectrum ranges. Compared with low band and mmWave spectrum, mid-band n77 provides a good balance between coverage and speed. This follows the **5G SA three component carrier downlink feature** that we introduced last year to 2022 AT&T Flagship devices which combines one frequency division duplex (FDD) carrier and two TDD carriers. In the coming months, AT&T will also enable **5G New Radio Dual Connectivity (NR-DC)**, aggregating our low and mid-band spectrum with our high-band mmWave spectrum on 5G SA. Our labs have achieved 5G NR-DC downlink throughput speeds of up

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	to 5.3Gbps and uplink throughput speeds of up to 670Mbps. This technology will help provide high-speed mobile broadband for both downlink and uplink in stadiums, airports, and other high-density venues. The 5G SA ecosystem is rapidly evolving, with new technologies and capabilities being introduced to provide differentiated experiences. Here are some features that are on the horizon for 5G SA: • Specialized Network Services – think network slicing, precision location, private routing, etc. – for tailored network solutions to meet specific user requirements; • Non-terrestrial network solutions to supplement coverage in remote locations ; and • Reduced capability 5G (RedCap) for a new generation of 5G capable wearables, industrial IoT or wireless sensors and other small form factor consumer devices. AT&T is dedicated to being the best connectivity provider. The 5G SA ecosystem is rapidly evolving, with new technologies and capabilities being introduced to set the foundation for next generation applications and services. (https://about.att.com/blogs/2023/standalone-5g-innovations.html) AT&T spectrum aggregation industry first ups 5G ante **Dan Meyer** | Executive Editor. April 19, 2023 1:00 PM AT&T tested spectrum aggregation models on the oft-overlooked uplink channel that the carrier claimed was an industry first and resulted in network speeds that could help meet growing 5G traffic demands. Jason Sikes, AVP for device architecture at AT&T, explained in a blog post that the carrier completed an uplink data call running on its 5G standalone (SA) network core that aggregated two different spectrum frequency bands. The test was in AT&T's labs using Nokia's 5G AirScale equipment running on MediaTek's mobile test platform. Sikes explained in an email to SDxCentral that the test used 10-megahertz of AT&T's low-band 850 MHz spectrum combined with varying amounts of the carrier's C-band spectrum. With 40-megahertz of C-band spectrum the carrier was able to increase uplink speeds by 100% to more than 70 Mb/s compared with just the base 850 MHz spectrum. It witnessed a 250% increase in speed to more than 120 Mb/s using 100-megahertz of C-band spectrum. "Think of this as adding more lanes in the network traffic highway," Sikes wrote in the blog. "No one in the U.S market has successfully aggregated two carriers in 5G SA uplink – until now." Sikes added that AT&T's mobile network has witnessed a 30% increase in uplink capacity demand per year.

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	"This new age of connectivity is not only about consuming more content but also generating more content than ever before," he noted of the increase. "Whether you are uploading large files, on a video call with family, live streaming, cloud gaming or using extended reality applications, the network is facing surging upstream traffic demands it never has before." The latest test followed one conducted by the carrier last fall that involved a four-channel downlink call that traversed its 5G SA network. That call aggregated a pair of frequency division duplex (FDD) carriers and a pair of time division duplex (TDD) carriers running in the C-band and the 3.45 GHz spectrum bands. FDD is where different bands of frequency are used by users; one for uplink and the other for downlink. TDD is where one frequency band will be used for uplink and downlink, switching between the two from moment to moment. Sikes also noted that AT&T was deploying a "two-layer uplink" multiple-input, multiple output (MINO) technology on TDD across its C-band spectrum. "This feature will not only improve uplink throughput but also enhance cell capacity and spectrum efficiency," he wrote, though he further added that the carrier did not use MIMO during the most recent uplink test. The carrier is planning to launch 5G New Radio Dual Connectivity (NR-DC) capabilities "in the coming months." This will allow for the aggregation of low- and mid-band spectrum with AT&T's millimeter-wave (mmWave) spectrum using the 5G SA core. Sikes noted this capability has resulted in lab test downlink speeds up to 5.3 Gb/s and uplink speeds up to 670 Mb/s. "This technology gives customers high-speed mobile broadband for both downlink and uplink in stadiums, airports and other high-density venues," Sikes wrote. In the follow-up email, Sikes added that "over time, private 5G and fixed wireless will benefit from these uplink and downlink enhancements." (https://www.sdxcentral.com/articles/analysis/att-spectrum-aggregation-industry-first-ups-5g-ante/2023/04/) WHY CHOOSE NOKIA 5G CARRIER AGGREGATION? Together with the leading mobile network operators across the world and the user equipment ecosystem, we have commercially introduced two component, three component and four component 5G Carrier Aggregation to enable Multi-Gigabit 5G on sub-6 GHz frequency allocations. We also have Carrier Aggregation commercially available for high-band. On millimeter wave spectrum, Carrier Aggregation with eight component carriers in downlink and four component carriers in uplink enables reaching even higher data rates.

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	Nokia 5G Carrier Aggregation: • Works in 5G Non-Standalone and 5G Standalone in the same cells for smooth migration from NSA to SA • Boosts 5G performance • By aggregating low-band carriers for coverage and mid-band carriers for capacity, helps deliver Multi-Gigabit user data speeds already today. 5G Carrier Aggregation is software running on the baseband unit, easy to activate in Nokia 5G networks. The supported Carrier Aggregation band combinations are following the quarterly 3GPP specification updates. Our quarterly software updates ensure the best possible band combination support, and bring more flexibility for mobile operators to optimize their network coverage and capacity. Nokia 5G Carrier Aggregation works with massive MIMO and dynamic spectrum sharing, enabling a further capacity boost on mid-band and more flexibility for low-band aggregation. Nokia AirScale ensures uncompromised RF bandwidth for efficient multi-carrier sub-6 GHz Carrier Aggregation. Additionally, our AirScale baseband is optimized for providing the processing capacity and scalability for multi-carrier, large bandwidth Carrier Aggregation. (https://www.nokia.com/networks/mobile-networks/carrier-aggregation/) # Ericsson spearheads 5G carrier aggregation milestones with key partners Ericsson has achieved groundbreaking milestones for carrier aggregation in 5G New Radio (NR) technology together with key customers and ecosystem partners. Ericsson has recently pushed 5G carrier aggregation (5G CA) technology to new levels after a series of successful interoperability tests with customers including T-Mobile and Optus, and ecosystem partners such as Qualcomm and MediaTek. The interoperability tests use carrier aggregation to extend the coverage of 5G, boost network capacity, and increase data speeds. Ericsson's collaboration with partners has so far resulted in several 5G firsts: • World's first 5G standalone (SA) data session with 5G CA on a commercial smartphone completed with T-Mobile, LG and MediaTek. With 5G CA, T-Mobile can combine its different 5G spectrum bands – starting with 2.5

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	GHz mid-band and 600 MHz low-band – boosting speeds and increasing the footprint of T-Mobile's mid-band 5G. It's also a key step in expanding T-Mobile's nationwide standalone architecture 5G network by increasing SA 5G capacity and speeds. (October 2020) • A 2300 + 3500MHz 5G Non-Standalone Carrier Aggregation call made by Optus using Ericsson technology and Samsung's Galaxy S20 5G handset range. The call showed the benefit of using both spectrum frequencies simultaneously, namely, a significant increase in the average and peak 5G speeds that customers, with an eligible handset, will benefit from as the capability becomes available. (August 2020) • First to complete all three combinations of NR time division duplex (TDD) and frequency division duplex (FDD) carrier aggregation (CA) together with MediaTek. The companies carried out a 5G SA data call by aggregating 20MHz on FDD spectrum and 100MHz on TDD spectrum with MediaTek's Dimensity 1000+ chipset at the Ericsson Lab in Kista. (September 2020) • Completed pioneering interoperability tests for 5G SA carrier aggregation across both FDD/TDD and TDD/TDD bands together with Qualcomm Technologies. 5G CA allows service providers to use multiple sub-6 GHz spectrum channels simultaneously to transfer data between base stations and a 5G mobile device. (August 2020) Per Narvinger, Head of Product Area Networks, Ericsson says: "From technology development to wider area deployments, Ericsson continues to spearhead 5G innovation with customers and industry partners. To maximize the full potential of the mid-band spectrum, we've developed 5G NR carrier aggregation solutions that will help our customers deploy a better 5G with greater coverage, increased capacity and higher data speeds. These solutions will extend the coverage of the high capacity mid-band spectrum. By enabling peak speeds, coverage and capacity, 5G carrier aggregation will be a real game-changer." Ericsson's 5G NR carrier aggregation solution will be commercially available in the fourth quarter of 2020 with a global rollout expected during 2021. (https://www.ericsson.com/en/news/2020/10/5g-carrier-aggregation) Ericsson ups the tempo on 5G Carrier Aggregation with world's first downlink 6CC data call Available in English 日本語

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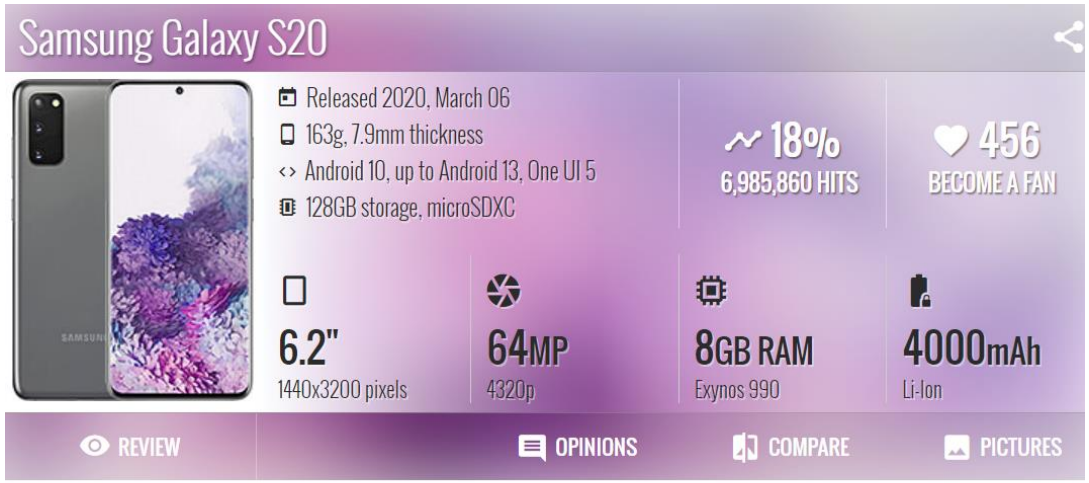
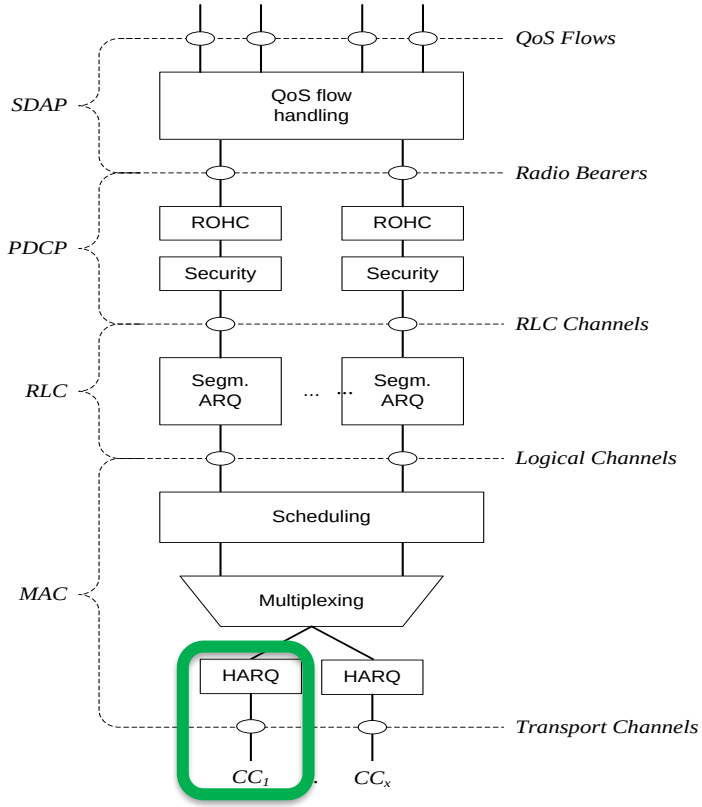
	Ericsson revs up the tempo on 5G Carrier Aggregation by combining six component carriers to set a record download speed of 5.7Gbps for the world's first 6CC (component carrier) data call. NEWS AUG 17, 2023 The data call was achieved using three FDD (frequency division duplex) bands combined with three TDD (time division duplex) bands in sub-6GHz, enabled by Ericsson RAN Compute hardware, state-of the-art carrier aggregation software, and innovative Advanced RAN Coordination functionality. The 3FDD + 3TDD carrier aggregation testing was carried out in an Ericsson lab with a user equipment (UE) simulator. By combining FDD spectrum with TDD spectrum, more users can benefit from carrier aggregation gains. In total, 400MHz of bandwidth was aggregated with FDD bandwidths ranging 20MHz to 50MHz to achieve the 5.7Gbps throughput. With six-component carrier capability, communications service providers can optimize use of network and spectrum assets to deliver higher data speeds and capacity that improve the experience of downlink-heavy applications. This can mean better audio and video quality for streaming users, faster file downloads, and a better working environment for digital nomads. Sibel Tombaz, Head of Product Line 5G RAN at Ericsson Networks, says: "We are keeping the momentum on carrier aggregation by continuously stretching its potential to boost capacity and speed. Our successful 6CC data call shows how versatile our solution is and that we are poised to work with ecosystem partners to make this new band combination a reality. Our goal, as always, is to help customers meet end users' growing appetite for high-capacity, ultrahigh-speed 5G." "Carrier Aggregation is crucial to getting the best possible 5G performance out of scattered spectrum assets," Tombaz adds. "And with 6CC, service providers will be able to maximize use of allocated spectrum and optimize the combined bandwidth for superior mobile experience." (https://www.ericsson.com/en/news/2023/8/ericsson-ups-the-tempo-on-5g-carrier-aggregation-with-worlds-first-down-link-6cc-data-call)

Claim 10	Public Documentation
	 Also available with 5G NETWORK — Technology: GSM / CDMA / HSPA / EVDO / LTE (COLLAPSE) 2G bands: GSM 850 / 900 / 1800 / 1900 - SIM 1 & SIM 2 (Dual SIM model only) CDMA 800 / 1900 & TD-SCDMA 3G bands: HSDPA 850 / 900 / 1700(AWS) / 1900 / 2100 CDMA2000 1xEV-DO 4G bands: 1, 2, 3, 4, 5, 7, 8, 12, 13, 17, 18, 19, 20, 25, 26, 28, 32, 38, 39, 40, 41, 66 Speed: HSPA 42.2/5.76 Mbps, LTE-A (7CA) Cat20 2000/200 Mbps (https://www.gsmarena.com/samsung_galaxy_s20-10081.php)
[10a] receiving a first digital signal comprising first data to be transmitted;	The Accused Instrumentalities perform a method that includes receiving a first digital signal comprising first data to be transmitted. For example: **6.7 CARRIER AGGREGATION** In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below: - In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell.

Claim 10	Public Documentation
	 **Figure 6.7-2: Layer 2 Structure for UL with CA configured** (3GPP TS 38.300 V17.5.0) The Accused Instrumentalities perform a method that includes receiving a second digital signal comprising second data to be transmitted. For example:

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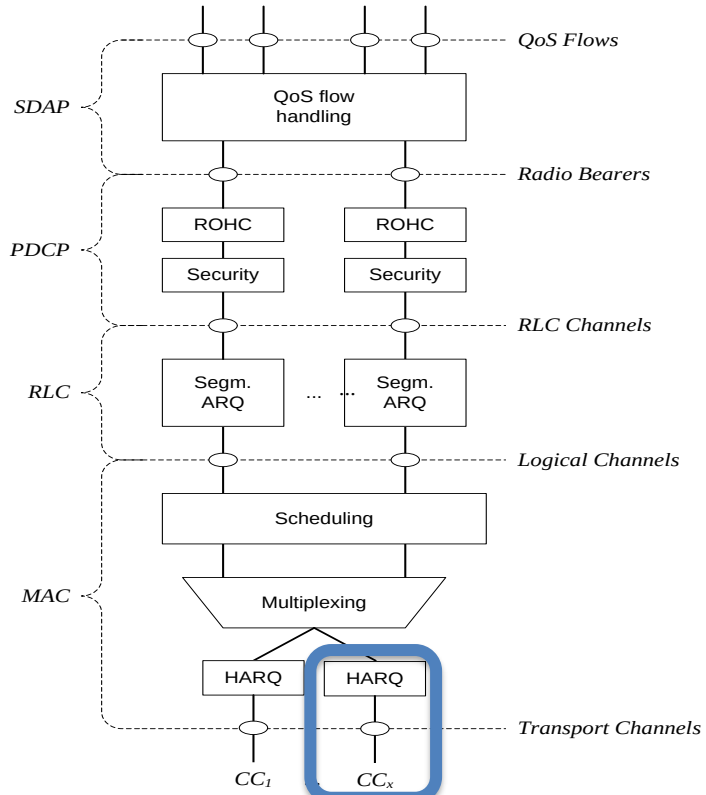
Claim 10	Public Documentation
[10b] receiving a second digital signal comprising second data to be transmitted;	**6.7 CARRIER AGGREGATION** In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below: - In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell.  **Figure 6.7-2: Layer 2 Structure for UL with CA configured** (3GPP TS 38.300 V17.5.0)

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Claim 10	Public Documentation
[10c] converting the first digital signal into a first analog signal using a first digital-to-analog converter, the first analog signal carrying the first data across a first frequency range;	The Accused Instrumentalities perform a method that includes converting the first digital signal into a first analog signal using a first digital-to-analog converter, the first analog signal carrying the first data across a first frequency range. For example: **11.3.2.1 Transmitter architecture** Figure 11.3.2.1-1 illustrates various TX architectures options according to where the component carriers are combined, i.e., at digital baseband, or in analog waveforms before RF mixer, or after mixer but before the PA, or after the PA. Option A - In an adjacent *contiguous common carrier* aggregation scenario, the UE very likely has one PA. Connected to the PA can be a single RF chain (a zero-IF mixer, a wideband DAC, and a wideband IFFT) Option-B - Combines analog baseband waveforms from component Carrier first (e.g., via a mixer operating at an IF of roughly the bandwidth of the other component carrier in the example of 2-component carrier aggregation). Then the resulting wideband signal is up-converted to RF. Option-C - Does ZIF up-conversion of each component carrier before combining and feeding into a single PA. Option-D - Employs multiple RF chains and multiple PAs after which the high-power signals are combined and fed into a single antenna. PA coupling at the UE can be challenging for option-D.

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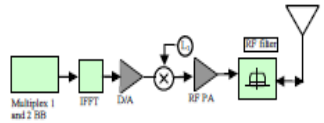
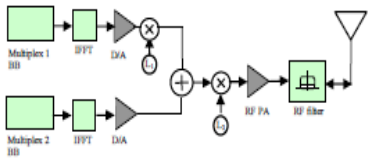
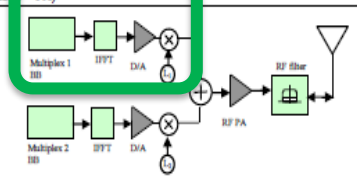
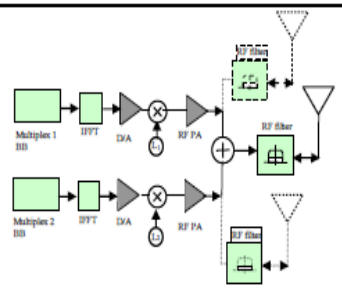
Tx Characteristics				
Option	Description (Tx architecture)	Intra Band aggregation		Inter Band aggregation
		Contiguous (CC)	Non contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes		
B	 Multiple (baseband + IFFT + DAC), single (stage-1 IF mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes	
C	 Multiple (baseband + IFFT + DAC + mixer), low-power combiner @ RF, and single PA	Yes	Yes	
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes	Yes + (depending on the specific EUTRA bands being aggregated),
X	*OTHERS*			

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios

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Claim 10	Public Documentation
[10d] converting the second digital signal into a second analog signal using a second digital-to-analog converter, the second analog signal carrying the second data across a second frequency range;	The Accused Instrumentalities perform a method that includes converting the second digital signal into a second analog signal using a second digital-to-analog converter, the second analog signal carrying the second data across a second frequency range. For example:

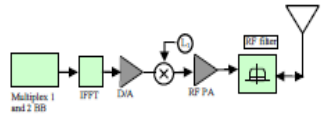
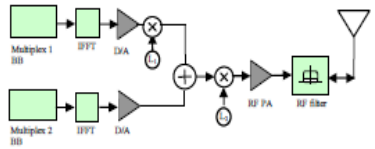
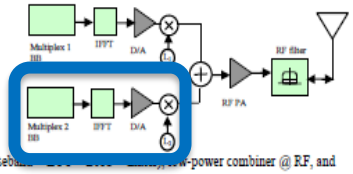
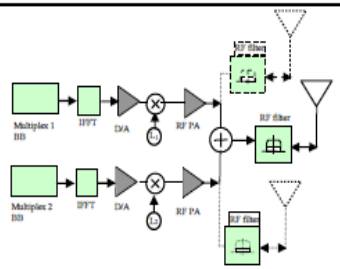
Tx Characteristics				
Option	Description (Tx architecture)	Intra Band aggregation		Inter Band aggregation
		Contiguous (CC)	Non contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes		
B	 Multiple (baseband + IFFT + DAC), single (stage-1 IF mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes	
C	 Multiple (baseb power combiner @ RF, and single PA	Yes	Yes	
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes	Yes + (depending on the specific EUTRA bands being aggregated),
X	*OTHERS*			

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios

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[10e] up-converting the first analog signal to a first RF center frequency to produce a first up-converted analog signal, wherein the first up-converted analog signal comprises a first up-converted frequency range from the first RF center frequency minus one-half the first frequency range to the first RF center frequency plus one-half the first frequency range;	The Accused Instrumentalities perform a method that includes up-converting the first analog signal to a first RF center frequency to produce a first up-converted analog signal, wherein the first up-converted analog signal comprises a first up-converted frequency range from the first RF center frequency minus one-half the first frequency range to the first RF center frequency plus one-half the first frequency range. For example:

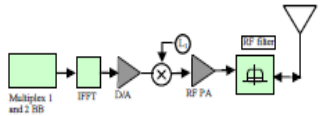
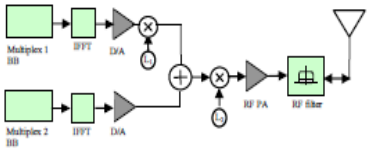
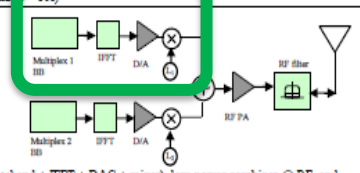
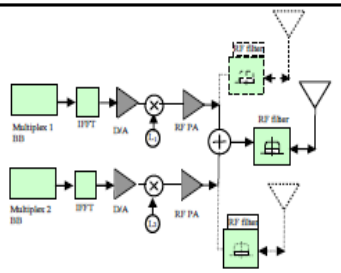
Tx Characteristics				
Option	Description (Tx architecture)	Intra Band aggregation		Inter Band aggregation
		Contiguous (CC)	Non contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes		
B	 Multiple (baseband + IFFT + DAC), single (stage-1 IF mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes	
C	 Multiple (baseband + IFFT + DAC + mixer), low-power combiner @ RF, and single PA	Yes	Yes	
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes	Yes + (depending on the specific EUTRA bands being aggregated),
X	*OTHERS*			

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios

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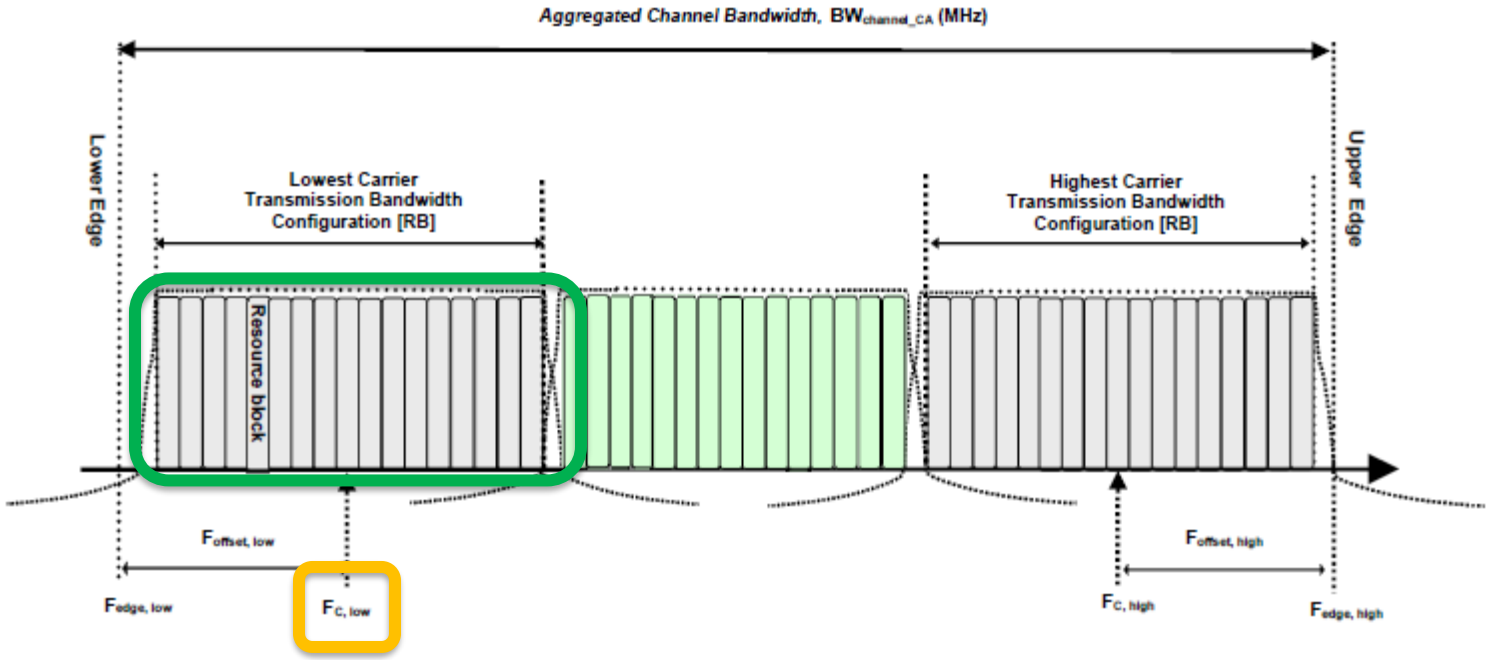
	For carrier aggregation, the maximum transmission bandwidth configuration is defined per component carrier and the requirement is specified in clause 5.3.2. 5.3A.3 Minimum guardband and transmission bandwidth configuration for CA For intra-band contiguous carrier aggregation, *Aggregated Channel Bandwidth* and *Guard Bands* are defined as follows, see Figure 5.3A.3-1.  **Figure 5.3A.3-1: Definition of *Aggregated Channel Bandwidth* for intra-band carrier aggregation** BWChannel_CA = Fedge,high - Fedge,low (MHz).

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Ex.1028.0091

Claim 10	Public Documentation
	The lower bandwidth edge $F_{edge,\ low}$ and the upper bandwidth edge $F_{edge,high}$ of the aggregated channel bandwidth are used as frequency reference points for transmitter and receiver requirements and are defined by $F_{edge,low} = F_{C,low} - F_{offset,low}$ $F_{edge,high} = F_{C,high} + F_{offset,high}$ The lower and upper frequency offsets depend on the transmission bandwidth configurations of the lowest and highest assigned edge component carrier and are defined as $F_{offset,low} = (N_{RB,low}*12 + 1)*SCS_{low}/2 + BW_{GB}$ (MHz) $F_{offset,high} = (N_{RB,high}*12 - 1)*SCS_{high}/2 + BW_{GB}$ (MHz) $BW_{GB} = \max(BW_{GB,Channel(k)})$ $N_{RB,low}$ and $N_{RB,high}$ are the transmission bandwidth configurations according to Table 5.3.2-1 for the lowest and highest assigned component carrier, SCS_{low} and SCS_{high} are the sub-carrier spacing for the lowest and highest assigned component carrier respectively. SCS_{low}, SCS_{high}, $N_{RB,low}$, $N_{RB,high}$, and $BW_{GB,Channel(k)}$ use the largest μ value among the subcarrier spacing configurations supported in the operating band for both of the channel bandwidths according to Table 5.3.5-1 and $BW_{GB,Channel(k)}$ is the minimum guard band for carrier k according to Table 5.3.3-1 for the said μ value. In case there is no common μ value for both of the channel bandwidths, μ=1 is used for SCS_{low}, SCS_{high}, $N_{RB,low}$, $N_{RB,high}$, and $BW_{GB,Channel(k)}$. (3GPP TS 38.101-1 V17.5.0)

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Ex.1028.0092

Claim 10	Public Documentation
[10f] up-converting the second analog signal to a second RF center frequency greater than the first center RF frequency to produce a second up-converted analog signal, wherein the second up-converted analog signal comprises a second up-converted frequency range from the second RF center frequency minus one-half the second frequency range to the second RF center frequency plus one-half the second frequency range, and wherein a frequency difference between the first RF center frequency and the second RF center frequency is greater than the sum of one-half the first frequency range and one-half the second frequency range;	The Accused Instrumentalities perform a method that includes up-converting the second analog signal to a second RF center frequency greater than the first center RF frequency to produce a second up-converted analog signal, wherein the second up-converted analog signal comprises a second up-converted frequency range from the second RF center frequency minus one-half the second frequency range to the second RF center frequency plus one-half the second frequency range, and wherein a frequency difference between the first RF center frequency and the second RF center frequency is greater than the sum of one-half the first frequency range and one-half the second frequency range. For example:

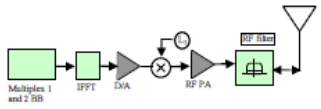
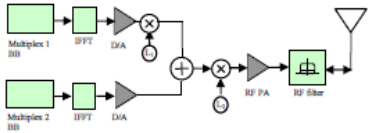
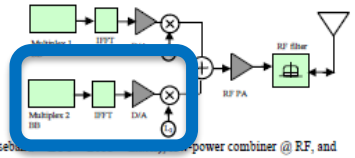
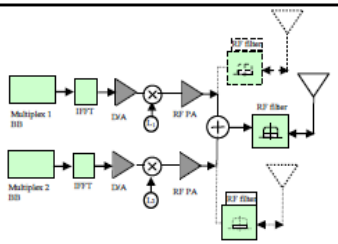
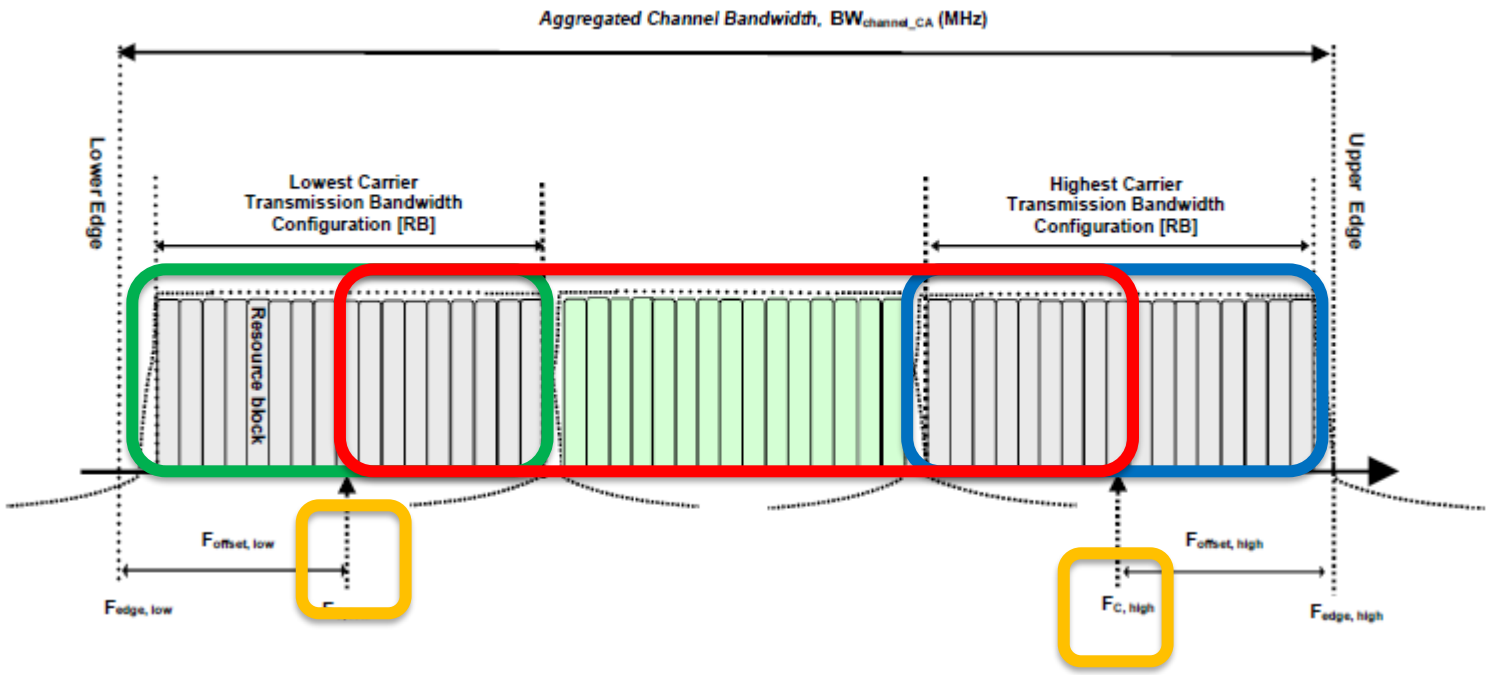
Tx Characteristics				
Option	Description (Tx architecture)	Intra Band aggregation		Inter Band aggregation
		Contiguous (CC)	Non contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes		
B	 Multiple (baseband + IFFT + DAC), single (stage-1 IF mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes	
C	 Multiple (baseb power combiner @ RF, and single PA	Yes	Yes	
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes	Yes + (depending on the specific EUTRA bands being aggregated),
X	*OTHERS*			

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios

(3GPP TR 36.912 version 15.0.0 Release 15)

Claim 10	Public Documentation
	For carrier aggregation, the maximum transmission bandwidth configuration is defined per component carrier and the requirement is specified in clause 5.3.2. 5.3A.3 Minimum guardband and transmission bandwidth configuration for CA For intra-band contiguous carrier aggregation, *Aggregated Channel Bandwidth* and *Guard Bands* are defined as follows, see Figure 5.3A.3-1.  **Figure 5.3A.3-1: Definition of *Aggregated Channel Bandwidth* for intra-band carrier aggregation** (3GPP TS 38.101-1 V17.5.0)

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Petitioners' Ex. 1028
Ex.1028.0094

Claim 10	Public Documentation
[10g] combining the first up-converted analog signal and the second up-converted analog signal to produce a combined up-converted signal;	The Accused Instrumentalities perform a method that includes combining the first up-converted analog signal and the second up-converted analog signal to produce a combined up-converted signal. For example:

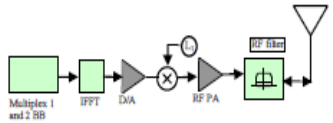
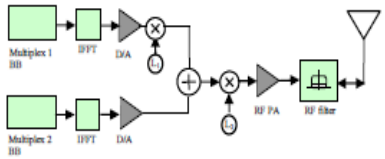
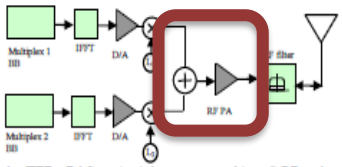
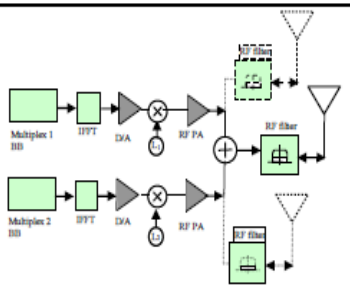
Tx Characteristics				
Option	Description (Tx architecture)	Intra Band aggregation		Inter Band aggregation
		Contiguous (CC)	Non contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes		
B	 Multiple (baseband + IFFT + DAC), single (stage-1 IF mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes	
C	 Multiple (baseband + IFFT + DAC + mixer), low-power combiner @ RF, and single PA	Yes	Yes	
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes	Yes + (depending on the specific EUTRA bands being aggregated),
X	*OTHERS*			

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios

(3GPP TR 36.912 version 15.0.0 Release 15)

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Ex.1028.0095

Claim 10	Public Documentation
[10h] amplifying the combined up-converted signal in a power amplifier resulting in an amplified combined up-converted signal; and	The Accused Instrumentalities perform a method that includes amplifying the combined up-converted signal in a power amplifier resulting in an amplified combined up-converted signal. For example:

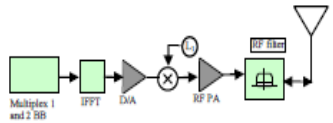
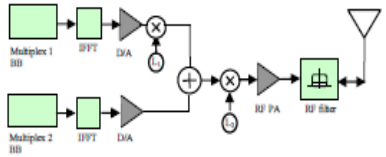
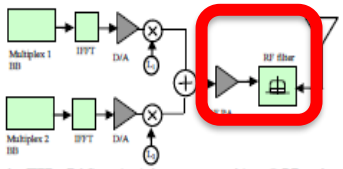
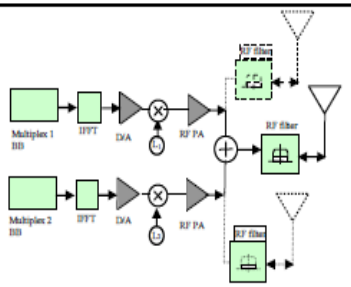
Tx Characteristics				
Option	Description (Tx architecture)	Intra Band aggregation		Inter Band aggregation
		Contiguous (CC)	Non contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes		
B	 Multiple (baseband + IFFT + DAC), single (stage-1 IF mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes	
C	 Multiple (baseband + IFFT + DAC + mixer), low-power combiner @ RF, and single PA	Yes	Yes	
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes	Yes + (depending on the specific EUTRA bands being aggregated),
X	*OTHERS*			

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios

(3GPP TR 36.912 version 15.0.0 Release 15)

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Petitioners' Ex. 1028
Ex.1028.0096

Claim 10	Public Documentation
[10i] transmitting the amplified combined up-converted signal on a first antenna,	The Accused Instrumentalities perform a method that includes transmitting the amplified combined up-converted signal on a first antenna. For example:

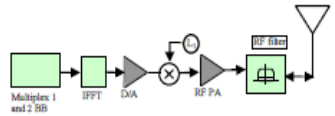
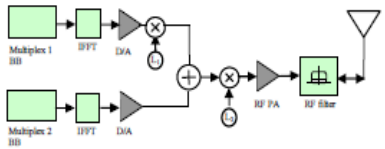
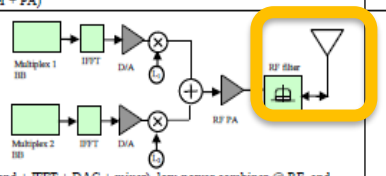
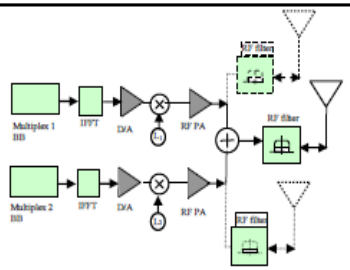
Tx Characteristics				
Option	Description (Tx architecture)	Intra Band aggregation		Inter Band aggregation
		Contiguous (CC)	Non contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes		
B	 Multiple (baseband + IFFT + DAC), single (stage-1 IF mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes	
C	 Multiple (baseband + IFFT + DAC + mixer), low-power combiner @ RF, and single PA	Yes	Yes	
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes	Yes + (depending on the specific EUTRA bands being aggregated),
X	*OTHERS*			

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios

(3GPP TR 36.912 version 15.0.0 Release 15)

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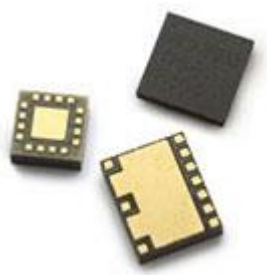
Ex.1028.0097

Claim 10	Public Documentation

[10j] wherein the bandwidth of said power amplifier is greater than the difference between a lowest frequency in the first up-converted frequency range and a highest frequency in the second up-converted frequency range.	The Accused Instrumentalities perform a method wherein the bandwidth of said power amplifier is greater than the difference between a lowest frequency in the first up-converted frequency range and a highest frequency in the second up-converted frequency range. For example, in power amplifier designs believed to be representative of those used in the Accused Instrumentalities:
	
	Mobile RF FEM
	
	 
	
	Broadcom provides custom RF frond end module (FEM) devices for mobile wireless applications. These devices incorporate multiband power amplifiers (PA), FBAR duplexers and multiplexers, SOI multi-mode LNAs and antenna switch, coupler and MIPI controller, designed to support various carrier aggregation (CA) for both FDD and TDD bands.
	Broadcom has shipped billions of RF FEM devices to the world's leading smartphone manufacturers.
	
	The Broadcom ACFM-2S13 is a quadplexer device that combines Band 1 and Band 3 duplexers into a single, miniature package. Band 4 duplexer is co-banded. The device features a single antenna connection, eliminating the need for antenna switching. High Isolation between bands enables the use of carrier aggregation.
	
	The ACFM-2S13 is designed with Broadcom's innovative filter capability which makes possible ultra-small, high-Q filters at a fraction of their usual size. Low Tx Insertion Loss of the ACFM-2S13 reduces power amplifier current, extending battery life. The device enhances receiver sensitivity and dynamic range with low Rx Insertion Loss and high rejection of Tx signals at the Rx ports.
	Features
	• Single antenna
	• High cross band isolation
	  • Enables carrier aggregation
	• Band 4 co-banding
	• Miniature size
	  • 2.0 x 2.5 mm footprint
	  • 0.710 mm typ. height
	• High Power Rating
	• Environmental
	  • RoHS 6 Compliant
	  • Halogen Free
	  • TBBPA Free
	
	(https://www.broadcom.com/products/wireless/demo-boards/acfm-2s13)

Claim 10	Public Documentation
	SKYWORKS PRODUCT SUMMARY **SKY77786-11 High Band Multimode Multiband Power Amplifier Module Supporting LTE Advanced Applications** **Applications** • Multiband 4G / LTE handsets • FDD LTE Bands 7 and 30 • TDD LTE Band 38, 40, 41 **Features** • Two T/R (RX) port and 3 outputs • Industry-leading PAE for 4G • Optimized for APT DCDC operation • Fully programmable Mobile Industry Processor Interface (MIPI) control • MIPI programmable bias modes optimize best 4G efficiency/linearity performance. • Small, low profile package: - 3.0 x 3.0 x 0.71 mm - 20-pad configuration Skyworks Green™ products are compliant with all applicable legislation and are halogen-free. For additional information, refer to Skyworks *Definition of Green*™, document number SQ04-0074. **Description** Skyworks SKY77786-11 SkyLiTE™ is a multimode multiband (MMMB) Power Amplifier Module (PAM) that supports 4G handsets and operates efficiently in LTE bands from 2.3 GHz to 2.7 GHz. The module is fully programmable through a Mobile Industry Processor Interface (MIPI®). The PAM consists of a single high band LTE block, a Multi-Function Control (MFC) block, and a T/R switch block. RF input/output ports internally matched to 50 Ω to reduce the number of external components. A CMOS integrated circuit uses standard MIPI controls to provide the internal MFC interface and operation. Extremely low leakage current maximizes handset standby time. The InGaP die and the silicon die and passive components are mounted on a multi-layer laminate substrate. The assembly is encapsulated in a 3.0 mm x 3.0 mm x 0.71 mm, 20-pad MCM, SMT package which is a more highly manufacturable, low cost solution. **4G:** The SKY77786-11 supports 1.4, 3, 5, 10, 15, 20, 30, 35, 40 MHz channel bandwidths. Similar to 3G operation, output power is controlled by varying the input power and V_{CC} is adjusted using a DCDC converter to maximize efficiency for each power level. 4G Modulation scheme includes: - FDD LTE - TDD LTE - Uplink Carrier Aggregation (CA) support for Bands 40/41 (up to 40 MHz)

Claim 13

Claim 13	Public Documentation
[13] The method of claim 10 wherein the first digital signal is encoded using a first wireless protocol and the second digital signal is encoded using a second wireless protocol.	The Accused Instrumentalities perform a method wherein the first digital signal is encoded using a first wireless protocol and the second digital signal is encoded using a second wireless protocol. For example: For example: Cellular operators, for example AT&T, have deployed Dynamic Spectrum Sharing (DSS) and carrier aggregation technology that provides service using both LTE and 5G by sharing the same spectrum and using carrier aggregation, using two different protocols. Operators, for example AT&T, have also used carrier aggregation using a combination of FDD and TDD protocols, using two different protocols. AT&T Touts Standalone 5G Breakthrough Posted on April 18, 2023 6:25pm by Carl Weinschenk In a blog post today, AT&T touted its achievements involving 5G standalone technology, including the completion several weeks ago of what the company said was the first 5G standalone uplink two-carrier aggregation data call in the United States. Like most carriers, AT&T initially deployed 5G in non-standalone mode, which relies on previous-generation technology in the core network. As the blog post notes, standalone 5G uses a dedicated core, which can help support faster upload speeds, lower latency, and edge functions, as well as enhancing reliability. The 5G standalone uplink two-carrier aggregation data call was conducted at AT&T's Labs with Nokia's 5G AirScale portfolio and MediaTek's 5G M80 mobile test platform. AT&T aggregated low band n5 and mid-band n77 spectrum. When the n5 was aggregated with 40 MHz of the n77 mid-band, the test generated a 100% increase in uplink throughput compared to the n5 low-band alone. A 250% increase was seen when 100 MHz of n77 was aggregated with the n5 spectrum. "The bottom line? We achieved incredible upload speeds of over 70 Mbps on n5 with 40MHz of n77 and over 120 Mbps on n5 with 100MHz of n77," said Jason Sikes, AT&T's Associate Vice President of Device Architecture, in today's blog post. AT&T also said that it completed a standalone 5G four component carrier downlink call several months ago. The call combined two frequency division duplex (FDD) and two time division duplex (TDD) carriers. AT&T was able to aggregate mid-band n77 in the C-band and 3.45 GHz spectrum ranges.

Claim 13	Public Documentation
	The blog post also references AT&T's use of two-layer uplink multiple in multiple out (MIMO) on TDD in the n77 band. MIMO combines signals and data streams from multiple antennas to improve signal quality and data rates, the carrier said. "This feature ill not only improve uplink throughput but also enhance cell capacity and spectrum efficiency," Sikes said, although the post doesn't indicate the status of that development Looking ahead, AT&T plans to enable 5G new radio dual connectivity (NR-DC), which will involve the aggregation of low and mid-band spectrum with high-frequency mmWave spectrum on 5G SA. So far, AT&T's labs achieved 5G NR-DC downlink throughput speeds as high as 5.3 Gbps and uplink throughput speeds as fast as 670 Mbps. (https://www.telecompetitor.com/att-touts-standalone-5g-breakthrough/) AT&T spectrum aggregation industry first ups 5G ante Dan Meyer | Executive Editor. April 19, 2023 1:00 PM AT&T tested spectrum aggregation models on the oft-overlooked uplink channel that the carrier claimed was an industry first and resulted in network speeds that could help meet growing 5G traffic demands. Jason Sikes, AVP for device architecture at AT&T, explained in a blog post that the carrier completed an uplink data call running on its 5G standalone (SA) network core that aggregated two different spectrum frequency bands. The test was in AT&T's labs using Nokia's 5G AirScale equipment running on MediaTek's mobile test platform. Sikes explained in an email to SDxCentral that the test used 10-megahertz of AT&T's low-band 850 MHz spectrum combined with varying amounts of the carrier's C-band spectrum. With 40-megahertz of C-band spectrum the carrier was able to increase uplink speeds by 100% to more than 70 Mb/s compared with just the base 850 MHz spectrum. It witnessed a 250% increase in speed to more than 120 Mb/s using 100-megahertz of C-band spectrum. "Think of this as adding more lanes in the network traffic highway," Sikes wrote in the blog. "No one in the U.S market has successfully aggregated two carriers in 5G SA uplink – until now." Sikes added that AT&T's mobile network has witnessed a 30% increase in uplink capacity demand per year. "This new age of connectivity is not only about consuming more content but also generating more content than ever before," he noted of the increase. "Whether you are uploading large files, on a video call with family, live streaming, cloud gaming or using extended reality applications, the network is facing surging upstream traffic demands it never has before." The latest test followed one conducted by the carrier last fall that involved a four-channel downlink call that traversed its 5G SA network. That call aggregated a pair of frequency division duplex (FDD) carriers and a pair of time division duplex (TDD) carriers running in the C-band and the 3.45 GHz spectrum bands.

Claim 13	Public Documentation
	FDD is where different bands of frequency are used by users; one for uplink and the other for downlink. TDD is where one frequency band will be used for uplink and downlink, switching between the two from moment to moment. Sikes also noted that AT&T was deploying a "two-layer uplink" multiple-input, multiple output (MINO) technology on TDD across its C-band spectrum. "This feature will not only improve uplink throughput but also enhance cell capacity and spectrum efficiency," he wrote, though he further added that the carrier did not use MIMO during the most recent uplink test. The carrier is planning to launch 5G New Radio Dual Connectivity (NR-DC) capabilities "in the coming months." This will allow for the aggregation of low- and mid-band spectrum with AT&T's millimeter-wave (mmWave) spectrum using the 5G SA core. Sikes noted this capability has resulted in lab test downlink speeds up to 5.3 Gb/s and uplink speeds up to 670 Mb/s. "This technology gives customers high-speed mobile broadband for both downlink and uplink in stadiums, airports and other high-density venues," Sikes wrote. In the follow-up email, Sikes added that "over time, private 5G and fixed wireless will benefit from these uplink and downlink enhancements." (https://www.sdxcentral.com/articles/analysis/att-spectrum-aggregation-industry-first-ups-5g-ante/2023/04/) # AT&T to deploy dynamic spectrum sharing in second half of 2020 By **Bevin Fletcher** . May 28, 2020 11:42am Verizon has probably been the carrier most vocal about benefits of dynamic spectrum sharing (DSS) technology, but rival AT&T is also a fan and SVP Igal Elbaz said Thursday that the carrier expects to deploy DSS later this year. "You should expect us to have DSS introduced in our network in the second half of 2020," said Elbaz, AT&T's senior vice president of Wireless Technology, speaking this morning to investment analysts at the virtual Cowen and Company Technology, Media & Telcom Conference. Elbaz called DSS a very important technology in terms of enabling both AT&T and other carriers to scale 5G rollouts. The timeline is similar to that of rival Verizon, which has pointed to dynamic spectrum sharing as key to its strategy for introducing broad nationwide 5G coverage this year using existing spectrum. Last month CEO Hans Vestberg indicated Verizon's plans to commercially deploy DSS in the second half of this year are still on track, with no COVID-19-related supply chain issues affecting the carrier's ability to do so.

Claim 13	Public Documentation
	RELATED: AT&T 4G LTE connects IoT robots to kill germs, keep shelves stocked Dynamic spectrum sharing allows carriers to operate both 5G New Radio (NR) and LTE using the same spectrum channel by shifting or allocating resources between the two, based on the number of users or traffic needs. This is different from previous technology generation shifts, where carriers usually had to carve out or take away a portion of their existing spectrum and dedicate it to the new technology. Elbaz used the example of having four channels for LTE, and then needing to take away one channel, clean it, and use it only for 5G. That leaves an operator with only three channels instead of four for the vast majority of its users who are still on LTE. Meanwhile, there's a free channel for 5G, but it has very little usage because it takes time for new 5G users with capable devices to accumulate and generate traffic. "That's not an efficient way to manage your spectrum in the transition," Elbaz said. AT&T and T-Mobile have each already rolled out low-band 5G service that's not much speedier, or in some cases slower, than 4G LTE. Verizon, which is seen as lacking in low- and mid-band spectrum that it can dedicate to 5G, has stuck to 5G deployments using millimeter wave spectrum limited to small pockets of urban areas. Verizon is expected to participate for mid-band spectrum at the C-band auction set for December, but it will take time before that can be put to use. While DSS will let the carriers use existing spectrum to roll out 5G more quickly, it's been observed that the technology doesn't add extra capacity. RELATED: Charter talks with AT&T about wholesale MVNO agreement Analysts at LightShed Partners have said they expect Verizon will deliver broad 5G coverage enabled by a combination of DSS and carrier aggregation. As the firm explained, despite the confusing name, carrier aggregation enables operators to combine spectrum blocks, both blocks adjacent and non-adjacent, and from other bands to deliver faster speeds to end users. Although AT&T is pursuing a $6 billion cost-cutting initiative, Elbaz reiterated that AT&T will continue to invest in its core products, which include 5G, fiber and HBO Max (which just launched yesterday). That includes likely participation for C-band spectrum. Still, Cowen analysts today suggested DSS could mean the carrier doesn't need to invest in as much new spectrum as it would otherwise. RELATED: AT&T 'not backing off' $6B cost cutting initiative While preparing for its 5G deployments, AT&T has bolstered its 4G LTE network, adding capacity with nearly 160 MHz of sub-6 GHz spectrum alongside its FirstNet public safety build. Network testing results tracked significant 4G LTE performance increases following enhancements that included additional spectrum and LTE-Advanced technologies such as carrier aggregation. AT&T stands out as the only carrier able to utilize 5-carrier aggregation on a wide scale for 4G LTE. According to RootMetrics, that helped boost AT&T's speed performance significantly in 51 out of 55 markets tested in the first half of 2020, compared to the

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	end of 2019. Comparatively, for 4G LTE, Sprint and T-Mobile use 3-carrier aggregation, while Verizon uses 4-component carrier aggregation. Support for 5G carrier aggregation is expected in June with 3GPP Release 16. With DSS, AT&T can use existing channels for 5G, sharing instead of sacrificing 4G LTE spectrum resources. As more 5G devices come online, carriers can deploy DSS on additional, or eventually all, existing channels to serve both 4G LTE and 5G users. "[DSS] is a profound technology and really allows us to do that transition very efficiently," Elbaz said. RELATED: Ericsson defends dynamic spectrum sharing That said, there is at least one carrier that has cast some doubt on DSS. Last month T-Mobile President of Technology Neville Ray reiterated that one vendor was still trailing in a DSS product; T-Mobile doesn't depend DSS for its nationwide 5G network thanks to its 600 MHz portfolio. Ericsson led the charge on dynamic spectrum sharing technology, and its product is already being commercially used by global operators, including Swisscom, Telstra, and Play. Nokia, meanwhile, launched DSS in April, with volume shipments anticipated in July in line with availability of DSS-capable handsets. While Ray called DSS "still bumpy", he acknowledged T-Mobile will still deploy it. Verizon and AT&T executives have refuted problems with DSS, including Verizon's Vestberg, who last month said tests were going "very well." (https://www.fiercewireless.com/tech/at-t-to-deploy-dynamic-spectrum-sharing-second-half-2020)

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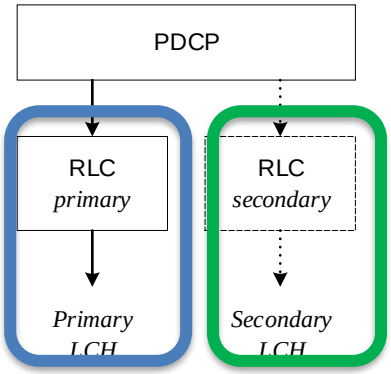
[14pre] The method of claim 10 wherein the second data is the same as the first data, the method further comprising:	The Accused Instrumentalities perform a method wherein the second data is the same as the first data. For example: **16.1.3 Packet Duplication** When duplication is configured for a radio bearer by RRC, at least one secondary RLC entity is added to the radio bearer to handle the duplicated PDCP PDUs as depicted on Figure 16.1.3-1, where the logical channel corresponding to the primary RLC entity is referred to as *the primary logical channel*, and the logical channel corresponding to the secondary RLC entity(ies), the *secondary logical channel(s)*. All RLC entities have the same RLC mode. Duplication at PDCP therefore consists in submitting the same PDCP PDUs multiple times: once to each activated RLC entity for the radio bearer. With multiple independent transmission paths, packet duplication therefore increases reliability and reduces latency and is especially beneficial for URLLC services.  **Figure 16.1.3-1: Packet Duplication** (3GPP TS 38.300 version 16.2.0)

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[14a] receiving the transmitted signal on a second antenna; [14b] amplifying the received signal in a low noise amplifier resulting in an amplified received up-converted signal, wherein the bandwidth of said low noise amplifier is greater than the difference between the lowest frequency in the first up-converted frequency range and the highest frequency in the second up-converted frequency range;	The Accused Instrumentalities perform a method that includes amplifying a signal received on a second antenna in a low noise amplifier resulting in an amplified received up-converted signal, wherein the bandwidth of said low noise amplifier is greater than the difference between the lowest frequency in the first up-converted frequency range and the highest frequency in the second up-converted frequency range. For example, in low noise amplifier designs believed to be representative of the kinds of power amplifiers used in the Accused Instrumentalities: SKYWORKS **PRODUCT SUMMARY** **SKY5™-8255-11 Front-End Module for LTE and NR** **Applications** • Multi-band 4G/5G handsets - Band B42, B48, n77, n78, and n79 **Features** • Full Baseband-Agnostic Design • Full Power APT support without DPD • UHB S-PAD covering B42, B48, n77, n78, n79, and separate Auxiliary TX • MIPI® v2.1 compliant 52 MHz RFFE bus - Two Tx control connections / one Rx control connection • Two ET/APT PA cores • Two LNA cores • Support 2x2 UL-MIMO using two TX placements • Support Fast SRS Hopping timing requirements • Supports system connectivity for: - MIMO-UL with single-feed or diplexed/separate-feed n77/n79 - SISO-UL with single-feed or diplexed/separate-feed n77/n79 • ASM switch with two selectable ANT ports and 6 AUX ports for seamless SRS Hopping support • Switchable LAA input • 50 ohm input/output impedance with internal DC-blocking • Continuous bias control via RFFE interface • Low Supply voltage • Low leakage current in power-down mode Skyworks Green™ products are compliant with all applicable legislation and are halogen-free. For additional information, refer to *Skyworks Definition of Green™*, document number SQ04-0074. **Features** • Supports full SRS connectivity with minimal external switches • SRS RX ports for sharing coax cables • Integrated Antenna and band select switches • Integrated LNA with MIPI® control features - up to seven gain modes - independent gain and bias control • Integrated wide bandwidth filters • Small, low profile package - 5.5 mm x 4.5 mm x 0.8 mm (Max) - 42-pad configuration (includes 15-pad ground array) **Description** SKY58255-11 is a recent addition to our Sky5™ portfolio of 5G Technology products. Packaged in a single 5.5 mm x 4.5 mm x 0.8 mm (Max) form factor, this versatile and fully matched Front-End Module (FEM) supports multi-band 4G/5G and LTE/NR applications. The 42-pad surface mount (SMT) module consists of PA blocks, input and output matching, a MIPI standard digital control block, single-ended filters, antenna and band-select switches and low Noise amplifier (LNA). Utilizing an enhanced architecture, SKY58255-11 covers multiple bands and meets the spectral linearity requirements of CP-OFDM and DFTS-OFDM modulations with up to 100 MHz bandwidth and up to 273 resource block allocations. Output power is controlled by varying input power and adjusting VCC maximizes efficiency. Extremely low leakage current maximizes handset stand-by time .

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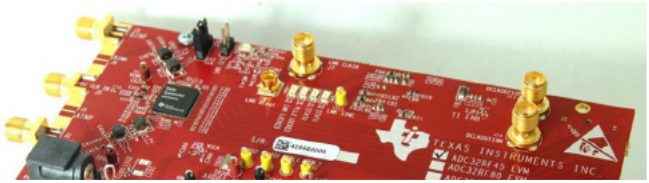
[14c] down-converting the amplified received up-converted signal using a first down-converter and a signal corresponding to the first RF center frequency to produce a fourth analog signal corresponding to the first analog signal; and	The Accused Instrumentalities perform a method that includes down-converting the amplified received up-converted signal using a first down-converter and a signal corresponding to the first RF center frequency to produce a fourth analog signal corresponding to the first analog signal. For example, in power amplifier designs believed to be representative of those used in the Accused Instrumentalities: ***TI Designs*** ***Multi-Band RF Sampling Receiver Solution*** TEXAS INSTRUMENTS **TI Designs** The RF sampling receiver captures signals directly in the radio frequency (RF) band. In a multi-band application, the desired signals do not have a very wide band, but they are spaced far apart within the spectrum. The ADC32RF80 is a dual-channel, 14-bit, 3-GSPS RF sampling telecom receiver. The 3-dB input bandwidth is 3 GHz, and it captures signals up to 4 GHz. The device includes two digital down converters (DDC) per channel. The DDC offers decimation values from 8 to 32 and includes a 16-bit numerically controlled oscillator to move the captured signal down to digital baseband. With the high sampling rate of the ADC32RF80, the device captures a large swatch of the RF spectrum, which contains signals in multiple bands and potentially undesired interferers. The DDC independently mixes the desired bands to digital baseband. Decimation reduces the output data rate to a lower level and provides digital filtering around the desired band to eliminate interference and to improve signal-to-noise ratio (SNR) performance. This feature is critical for high-end telecommunication receivers that require high dynamic range. **Design Features** • 3-GSPS RF Sampling Receiver Solution • Low Noise, High Dynamic Range RF Sampling Receiver Solution • Programmable Decimation from 8 to 32 • Dual Digital Down-Converter With Independent Numerically Controlled Oscillators **Featured Applications** • Wireless Base Station Multi-Band or Multi-Mode Receiver • Multi-carrier GSM Receiver • Digital Pre-Distortion Feedback Receiver • Telecommunications Receiver • Carrier Aggregation Receiver  (https://www.ti.com/lit/ug/tidubq3/tidubq3.pdf)

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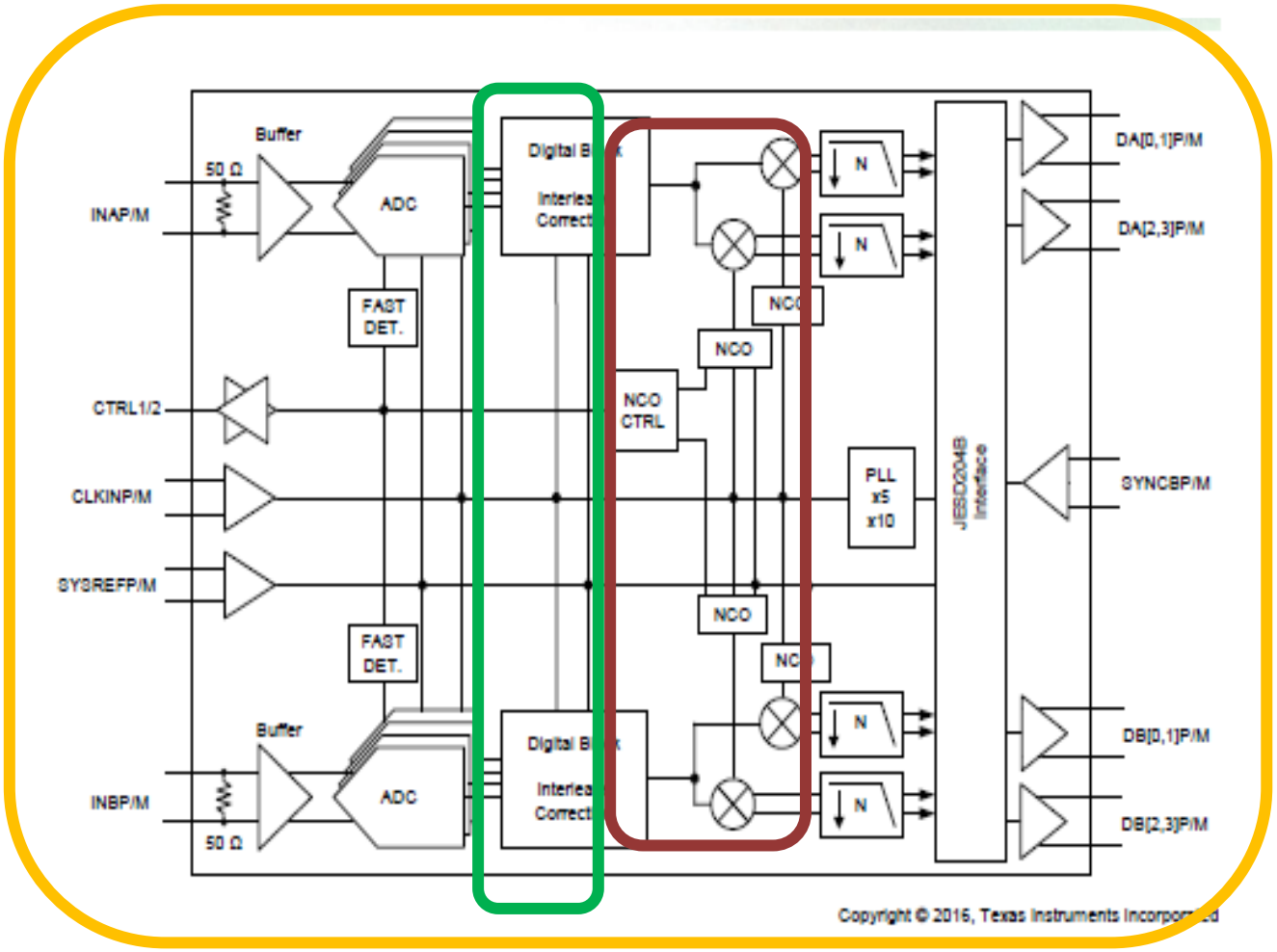
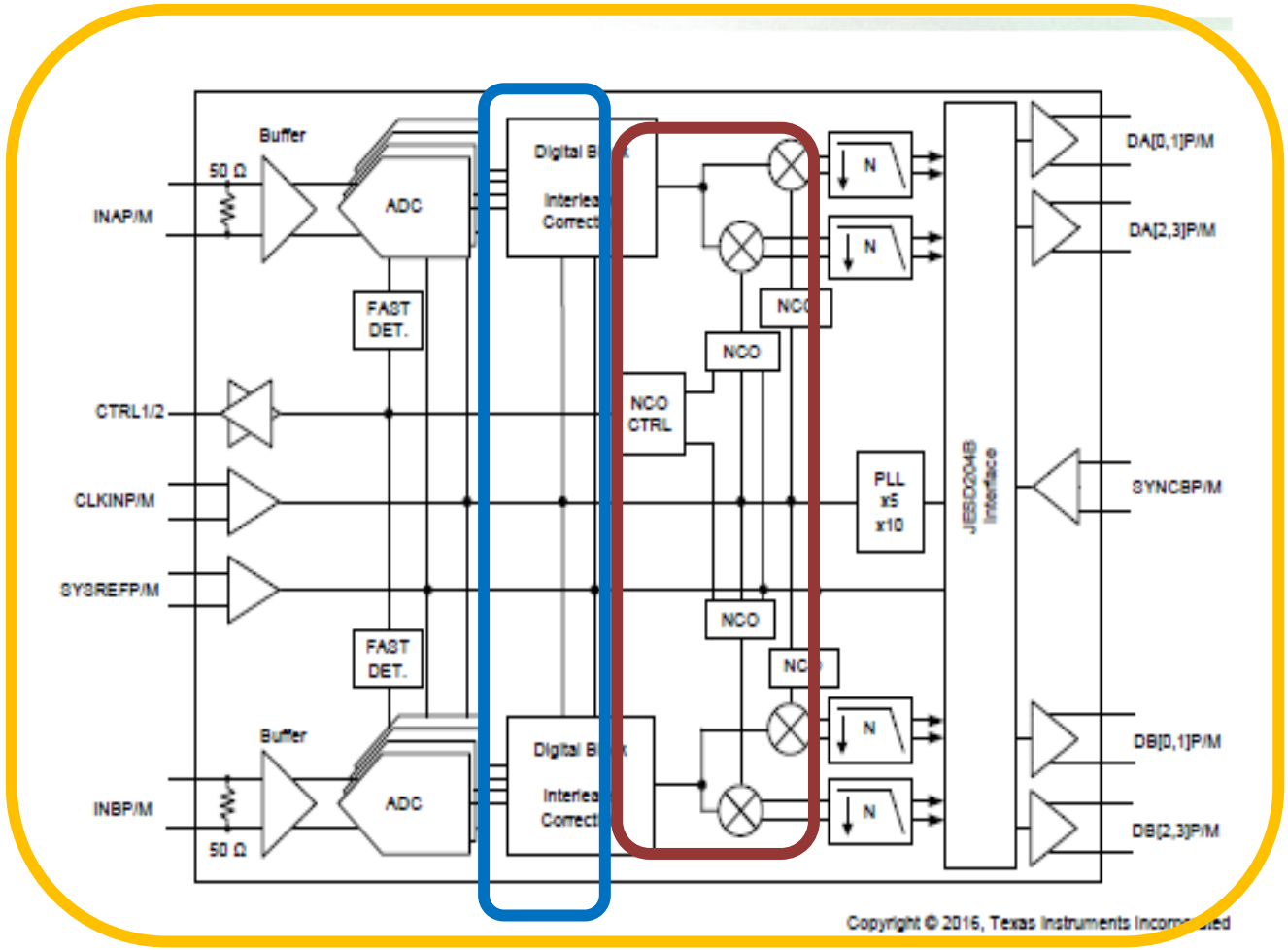
	 https://www.ti.com/lit/ug/tidubq3/tidubq3.pdf

Claim 14	Public Documentation
[14d] down-converting the amplified received up-converted analog signal using a second down-converter and a signal corresponding to the second RF center frequency to produce a fifth analog signal corresponding to the second analog signal.	The Accused Instrumentalities perform a method that includes down-converting the amplified received up-converted analog signal using a second down-converter and a signal corresponding to the second RF center frequency to produce a fifth analog signal corresponding to the second analog signal. For example:  https://www.ti.com/lit/ug/tidubq3/tidubq3.pdf

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[17pre] A wireless communication system comprising:	To the extent the preamble is found to be limiting, the Accused Instrumentalities perform a method of transmitting information in a wireless communication channel. For example, Defendant deploys and uses 4G and 5G RAN Solutions by vendors Ericsson and Nokia. These 4G and 5G RAN Solutions are 4G and 5G NR cellular radio access network systems supporting carrier aggregation, and the accused systems include all the installed components for the 4G and 5G NR RAN solution systems deployed by Defendant. *See, e.g.*: 5.4 Carrier aggregation 5.4.1 Carrier aggregation In Carrier Aggregation (CA), two or more Component Carriers (CCs) are aggregated. A UE may simultaneously receive or transmit on one or multiple CCs depending on its capabilities: - A UE with single timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells sharing the same timing advance (multiple serving cells grouped in one TAG); - A UE with multiple timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells with different timing advances (multiple serving cells grouped in multiple TAGs). NG-RAN ensures that each TAG contains at least one serving cell; - A non-CA capable UE can receive on a single CC and transmit on a single CC corresponding to one serving cell only (one serving cell in one TAG). CA is supported for both contiguous and non-contiguous CCs. When CA is deployed frame timing and SFN are aligned across cells that can be aggregated, or an offset in multiples of slots between the PCell/PSCell and an SCell is configured to the UE. The maximum number of configured CCs for a UE is 16 for DL and 16 for UL. (3GPP TS 38.300 V17.4.0) 6.7 Carrier Aggregation In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below:

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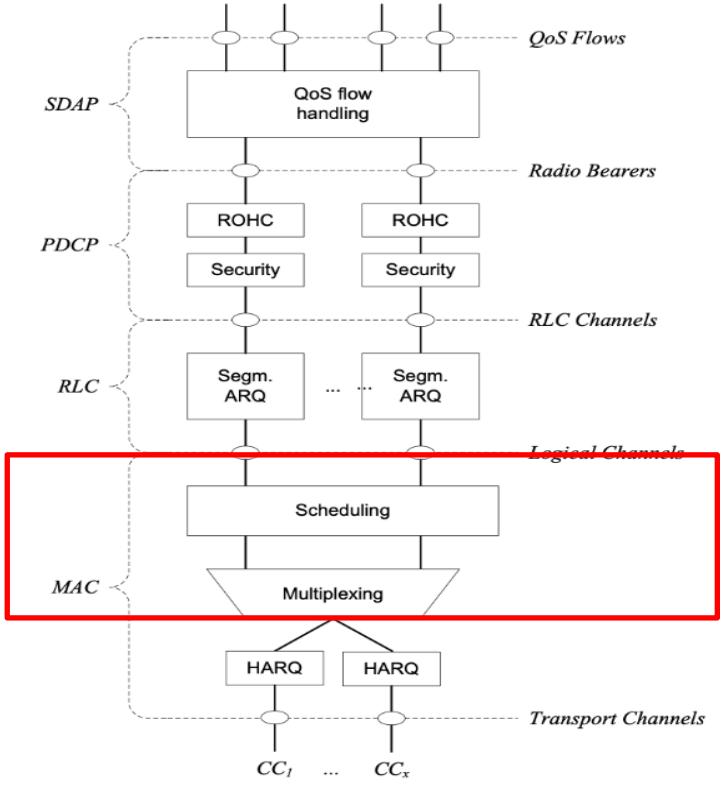
	- In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell. (3GPP TS 38.300 V17.4.0)  **Figure 6.7-2: Layer 2 Structure for UL with CA configured** (3GPP TS 38.300 V17.4.0)

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Claim 17	Public Documentation
	5G Carrier Aggregation is set to deliver a significant performance boost to mobile users but what is it and how does it work? The ongoing rollout of commercial 5G networks has significantly improved the experience for mobile subscribers around the world. As the ecosystem matures, a growing number of more advanced 5G Standalone (5G SA) networks will be central to delivering the speed and ultra-low latency to support cutting-edge applications. 5G Carrier Aggregation will play a vital role in underpinning the significant performance boost promised by 5G SA, representing an important milestone in the evolution of wireless infrastructure. Carrier Aggregation is a software functionality in Radio Access Networks and user devices which allows Mobile Network Operators (MNOs) to combine the capabilities of radio cells at distinct frequency allocations to enhance the end user experience. A key technology already in the LTE-Advanced networks, Carrier Aggregation enabled the evolution to Gigabit-LTE, achieving user data rates of more than 1 Gbps. However, in 5G networks, Carrier Aggregation will enable the evolution to multi-Gigabit-5G, reaching user data rates of about 4 Gbps and above. 5G Carrier Aggregation is also capable of improving the geographic availability, more commonly referred to as coverage, of high data rates. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/)

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	Carrier Aggregation in 5G Networks To accelerate rollout, the initial commercial 5G networks relied on the LTE infrastructure in radio access and the core network, referred to as 5G non-Standalone (5G NSA). 5G NSA allows MNOs to increase the bandwidth available to end users by bundling 4G and 5G carriers through 4G-5G Dual Connectivity. This allowed 5G users to benefit from existing LTE Carrier Aggregation capabilities with up to two 5G carriers aggregated alongside LTE carriers. To unlock the full capability of 5G, including ultra-low latency, reliability, and efficiency, MNOs are introducing 5G Standalone (5G SA) with a dedicated 5G Core and highly efficient 5G air interface, without dependency on existing LTE networks. The number of specified 5G SA Carrier Aggregation band combinations is increasing with each quarterly revision of the 3GPP specifications, enabling further options to achieve multi-Gigabit 5G data rates. These specifications are important to ensure interoperability between user equipment, such as smartphones, and networks. Between 2021 to 2022, the focus of the specifications for Carrier Aggregation in 5G SA in FR1 shifted from two component carriers to three and four component carriers. As the number of 5G frequency bands exceeds that of LTE-A, the possible Carrier Aggregation band combinations are greatly expanded, offering increased deployment options and flexibility for MNOs in different markets. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/)

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	Key benefits of 5G Carrier Aggregation Improved data speeds and throughput 5G Carrier Aggregation will boost the network performance to meet the requirements of data-hungry applications, such as augmented and virtual reality services, for both industrial and consumer use cases. Greater cell coverage As operators are looking to maximize the use of their available spectrum assets in different FDD and TDD bands, Carrier Aggregation is the key to reaching extended coverage range. This helps reduce the need to deploy new cell sites, bringing cost savings to operators. It also improves mobile user experience with consistent level of service across the network. Enhanced energy efficiency In 2019, the mobile industry made a milestone commitment to transform the sector and reach net zero carbon emissions by 2050. Carrier Aggregation has been demonstrated to reduce overall power consumption levels while increasing throughput and maintaining high service levels. This indicates that the technology could contribute to reducing overall energy usage and the mobile industry's carbon footprint. Improved coverage can also contribute to longer battery life for individual devices, requiring less frequent charging. Greater ROI According to data from GSA, the total amount raised in 2021 from spectrum auctions and assignments reached at least $140.1Bn. Radio spectrum is a finite and extremely valuable resource, representing a considerable financial burden for most MNOs. Therefore, with ever increasing demands for bandwidth, utilising this spectrum in the most efficient way becomes a top operational priority. 5G CA represents one of the most effective methods for MNOs to get the most from their outlay by maximising spectral efficiency. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/) Samsung Galaxy users in the United States will now enjoy faster 5G speeds, all thanks to T-Mobile's carrier aggregation technology. At the Mobile World Congress 2023 event in Barcelona, T-Mobile announced the successful deployment of 5G carrier aggregation on its standalone 5G network.

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	Ericsson, Nokia, Qualcomm Technologies, Inc., and Samsung teamed up with T-Mobile in the completion of the 5G Carrier Aggregation tech. The phone used for the project was a Samsung Galaxy S23 series model. Consequently, T-Mobile customers with a Galaxy S23, Galaxy S23+, or Galaxy S23 Ultra will be the first to benefit from four-carrier aggregations later this year. (https://www.sammobile.com/news/t-mobile-carrier-aggregation-5g-samsung-galaxy-s23/) # AT&T Quietly Lights Up Carrier Aggregation in Chicago ***Mar 6, 2014, 12:10 PM by Eric M. Zeman*** ***updated Mar 7, 2014, 7:32 AM*** AT&T has improved its LTE network in Chicago and several other markets by using an LTE-Advanced technique called Carrier Aggregation. GigaOm confirmed the soft launch with AT&T SVP of Network Technologies Kris Rinne. With Carrier Aggregation, AT&T has combined the channels of its existing spectrum to double the capacity. AT&T is running LTE in both the 700MHz and AWS bands in Chicago. By aggregating the channels together, AT&T can deliver theoretical peak download speeds of 110Mbps to devices with the proper radio support. At the moment, AT&T is selling only one device with Carrier Aggregation, the Unite mobile hotspot. The Samsung Galaxy S5 is expected to be the first smartphone to support Carrier Aggregation in the U.S. AT&T did not name the other two markets that have access to Carrier Aggregation, but said that more markets on are on the way. Sprint, T-Mobile, and Verizon Wireless are all in various stages of deploying Carrier Aggregation in their own LTE networks. (https://www.phonescoop.com/articles/article.php?a=13751) # AT&T: We are deploying 3-channel carrier aggregation on LTE network By **Mike Dano** . Sep 14, 2016 3:37pm

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	AT&T confirmed to *FierceWireless* that it too is deploying three-channel carrier aggregation on its LTE network. The news indicates AT&T is joining the rest of the nation's Tier 1 carriers in deploying the technology. "We're currently in the process of deploying 3-way carrier aggregation on our network," said AT&T spokesman Steven Schwadron. "AT&T started strategically deploying LTE-A in early 2014 and now we cover with LTE-A the vast majority of our customers in our LTE coverage area. We're also adding also additional spectrum and equipment on an ongoing basis to further boost our network performance." Schwadron added that AT&T currently sells 26 devices that are "LTE-A capable," and that the carrier lists them on its website. Schwadron added that, while LTE-Advanced peak speeds can be significantly higher than LTE speeds, "performance will depend on many factors including location and network traffic." Importantly, though, Schwadron declined to provide any further details, including what spectrum bands AT&T is combining through carrier aggregation and where the service is available. He said only that AT&T is deploying the technology into "high-density, high-traffic areas." AT&T's acknowledgement that it is deploying carrier aggregation isn't much of a surprise. AT&T's John Donovan said in 2014 that the operator would deploy carrier aggregation technology where it can, depending on how much spectrum it has available to meld together. Further, in 2015, AT&T's Tom Keathley told *FierceWireless* that AT&T had expanded its use of carrier aggregation to include major markets such as New York, San Francisco and Dallas. However, AT&T's admission that it is deploying three-channel carrier aggregation is noteworthy since much of the industry's discussion on the topic has so far focused on two-channel carrier aggregation. Carrier aggregation technology allows wireless network operators to essentially glue together transmissions across different spectrum bands in order to provide faster download speeds. For example, AT&T could use the technology to meld transmissions across its 700 MHz and AWS spectrum bands via two-channel carrier aggregation. Three-channel aggregation would add another chuck of spectrum, such as transmissions over PCS spectrum, to the transmission. Of course, AT&T isn't alone in deploying three-channel carrier aggregation: Verizon, Sprint and T-Mobile have all said they too are either deploying it or will soon. Sprint last week confirmed to *FierceWireless* that it launched three-channel carrier aggregation in Chicago and Kansas City, merging transmissions across three different channels of its 2.5 GHz spectrum and providing speeds up to 200 Mbps. And T-Mobile has said it too is already offering three-channel carrier aggregation, though it did not say where. For its part, Verizon has said it is currently offering two-channel carrier aggregation in the 461 cities, and Verizon's Mike Haberman said the operator will also offer three-channel carrier aggregation in locations where it has sufficient spectrum. To be clear, though, three-channel carrier aggregation must be enabled both in the network and on the users' device.

(https://fiercewireless.com/wireless/at-t-we-are-deploying-3-channel-carrier-aggregation-lte-network)

AT&T Pushing Toward Four Carrier Aggregation, LAA in Second Half of This Year

By Diana Goovaerts | March 2, 2017

BARCELONA – U.S. wireless carrier AT&T is pushing toward the launch of four carrier aggregation in the second half of this year, including some configurations that utilize unlicensed spectrum via License Assisted Access (LAA).

AT&T Vice President of RAN and Device Design Gordon Mansfield on Thursday told Wireless Week the carrier is eyeing deployment of four carrier aggregation in the early second part of the year. The advancement will be made via a software upgrade to the carrier's network, he said, and is part of the carrier's push toward gigabit speeds.

"With the spectrum positions that the operators have in the U.S., you've got to bring together some unlicensed spectrum as well (to hit gigabit speeds)," Mansfield said. "You can get close, you can get up to several hundred with just the macro network and the licensed spectrum, but the way you get to a gigabit is you use licensed spectrum with 4×4 MIMO and 256-QAM and you bring in LAA with unlicensed carriers. And in that case it will actually be 4CA."

According to Mansfield, four carrier aggregation will be used in conjunction with technologies like 256-QAM and 4×4 MIMO to help reach 1 Gbps or more on the network.

In areas where the carrier has a densely built network with small cells, Mansfield said four carrier aggregation with LAA will be used. But in the macro network, he said, four carrier aggregation will be on licensed bands.

While devices today currently only support one of the three aforementioned technologies at a time, Mansfield indicated devices are headed down the pipe as soon as in the second quarter that will have baseband modems capable of supporting all simultaneously. Mansfield declined to name the vendors who are planning such releases.

Mansfield specified, though, that some capabilities will be available on the device right out of the box. Others, like LAA, will be added via an over the air software update pushed out over the network later in the year, he said.
(https://www.5gtechnologyworld.com/att-pushing-toward-four-carrier-aggregation-laa-in-second-half-of-this-year/)

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	# AT&T in early 2020: results show excellent speeds on both 5G and LTE Dave Andersen, Apr 23, 2020 **AT&T delivered faster speeds in 51 out of 55 markets tested to date in the first half of 2020.** With our testing efforts currently on hold due to the COVID-19 pandemic, we thought now would be a perfect time to take a look at how the carriers have performed across the 55 markets we've tested so far in the first half of 2020. We'll soon publish carrier-specific reports with overviews of performance for both 5G and 4G LTE in 1H 2020, and to kick things off, we'll start with AT&T. AT&T has deployed its 5G using 850 MHz low-band spectrum in several cities across the US, and the carrier has shown particularly impressive gains since our last round of testing in the second half of 2019. While AT&T's median download speeds on 4G LTE were already fast in most metros across the country in 2019, the carrier stepped up even more in the first half of 2020. We found excellent and improved download speeds on the carrier's 4G LTE network in the 55 markets we completed testing before we paused our scouting efforts, and AT&T's low-band 5G is also providing generally fast speeds (though not as fast as Verizon's mmWave 5G). This strong showing by AT&T can't entirely be chalked up to its 5G service, however. AT&T has been investing heavily over the past 18 months to bolster its already robust 4G LTE network. AT&T erected new cell sites in cities across the country, added more spectrum layers, and utilized 5-carrier aggregation (5CA) on a wide scale paired with 4x4 MIMO technology to maximize its vast spectrum holdings and provide faster speeds. AT&T also reallocated some of the spectrum reserved for its FirstNet Public Safety network and began using it for general customers while still satisfying its commitments to first responders. In short, AT&T has taken numerous steps to upgrade its network as 5G deployments continue, and AT&T subscribers are reaping the rewards in the form of faster connectivity that should only get better as the carrier's 5G continues to expand and mature. **AT&T's advantage: widespread 5-carrier aggregation and 4x4 MIMO technology** A primary reason for AT&T's improved speed results in 2020 is the carrier's widespread usage of 5-carrier aggregation (5CA) technology. In short, 5CA allows AT&T to combine five separate channels to increase bandwidth and provide faster speeds. On top of its capacity gains from 5CA, the efficiency of each of those five channels is maximized by AT&T's utilization of 4x4 MIMO (Multiple Input Multiple Output) technology. MIMO refers to using multiple radio antennas at both the tower and the device, which helps improve capacity, coverage, and speed. In a 4x4 system, there are four antennas on both the tower and device, whereas with 2x2 MIMO, there are two antennas on the tower and device.

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	If you think of each channel with 4x4 MIMO as utilizing four independent data streams, 5CA allows 20 independent streams to be combined, which results in greater bandwidth and, in turn, faster speeds. However, in order for a carrier to utilize 5CA, it's imperative to hold spectrum in five channels, and AT&T is in a unique position as the only carrier with the spectrum necessary for wide scale use of 5CA. In addition, AT&T also utilizes 256QAM, a spectrum modulation method that provides the highest possible level of spectral efficiency, and the carrier has expanded the reach of its Band 2 spectrum (the biggest of the five channels in 5CA) by adding new cell towers in cities across the US. AT&T has an advantage over the competition as the only carrier that can utilize 5-carrier aggregation on a wide scale in the US. Sprint and T-Mobile use 3-carrier aggregation, while Verizon uses 4-carrier aggregation technology. **The results: broad use of 5CA and 4x4 MIMO lead to much faster speeds** AT&T's speeds took a significant step forward during our first-half 2020 testing. Among the 55 cities we tested, AT&T's speeds improved in a whopping 51 of those markets, which was more than any other carrier (Sprint was the closest, with improvements in 47 markets). Even more impressive is that AT&T's median download speeds jumped by at least 15 Mbps in 22 of those markets, with increases of at least 10 Mbps in 37 out of 55 cities. Considering that 15 Mbps is generally fast by itself, an increase of 15 Mbps from a speed that was already fast can profoundly change the end-user experience. (https://rootmetrics.com/en-US/content/att-early-2020-performance-review) # 5-carrier aggregation gives AT&T network edge – RootMetrics By **Bevin Fletcher** . Apr 24, 2020 4:45pm AT&T delivered speed gains across 51 markets in the early part of 2020, with its wide-scale use of 5-component carrier aggregation and 4x4 MIMO giving it an edge over competition, according to RootMetrics. RootMetrics temporarily suspended its network testing but in the meantime is publishing carrier-specific reports on 4G LTE and 5G performance in the first half of 2020. AT&T's speeds improved significantly in 51 out of 55 markets in RootMetrics' testing, outpacing every other carrier. Speed performance on AT&T's network jumped more than 30 Mbps in four cities at the start of 2020, compared to the end of 2019. RELATED: Verizon grabs RootMetrics awards in Los Angeles

Claim 17	Public Documentation
	The biggest increase was seen in Ogden, Utah, where median download speeds spiked 37 Mbps from 38.2 Mbps in 2019 to 75.2 Mbps in early 2020. Markets rounding out the top five for AT&T's most improved speeds include Minneapolis, Cincinnati, Charleston, South Carolina, and Allentown, Pennsylvania. In 37 of the 55 markets tested, speeds jumped at least 10 Mbps compared to 2019, and at least 15 Mbps in 22 markets. "Considering that 15 Mbps is generally fast by itself, an increase of 15 Mbps from a speed that was already fast can profoundly change the end-user experience," the report noted. RootMetrics' tests done last year only connected to AT&T's 4G LTE, while the 2020 results connected to the carrier's low-band 5G where available. In the latest test period, AT&T's network recorded median download speeds above 50 Mbps in 23 markets, compared to just three markets in the second half of 2019. At the start of this year, only two cities registered speeds under 20 Mbps. AT&T is moving forward with its low-band 5G rollouts, just this week expanding to 90 additional cities, but RootMetrics called out the carrier's heavy investment over the last 18 months to enhance its already strong 4G LTE network. RELATED: 5G a 'mixed bag' as Verizon gets high speeds, T-Mobile offers better coverage – RootMetrics "AT&T erected new cell sites in cities across the country, added more spectrum layers, and utilized 5-carrier aggregation (5CA) on a wide scale paired with 4x4 MIMO technology to maximize its vast spectrum holdings and provide faster speeds," RootMetrics reported. "AT&T also reallocated some of the spectrum reserved for its FirstNet Public Safety network and began using it for general customers while still satisfying its commitments to first responders." AT&T is in a unique position to use five-component carrier aggregation (5CA), according to the testing company, a technology which requires and enables it to combine five separate channels for increased capacity. "AT&T has an advantage over the competition as the only carrier that can utilize 5-carrier aggregation on a wide scale in the U.S.," according the report. That compares to Sprint and T-Mobile's use of 3-carrier aggregation, while Verizon uses 4-component carrier aggregation. While 5-carrier aggregation is helping enhance AT&T's speeds over low-band spectrum, 8-component carrier aggregation (8CC) has been cited in work to hit record 5G speeds using millimeter wave spectrum. In lab tests in February, Ericsson alongside Qualcomm, used 8CC to aggregate 800 MHz of millimeter wave spectrum and achieve a record 5G speed of 4.3 Gbps. RELATED: Verizon works with Samsung, Qualcomm to achieve 4.2 Gbps on its 5G network

Claim 17	Public Documentation
	Verizon, meanwhile, worked with Samsung and Qualcomm earlier this year, using the technology to aggregate 800 MHz of 28 GHz mmWave spectrum and hit speeds of 4.2 Gbps on its live 5G network in Texas. Verizon SVP of Technology Planning Adam Koeppe said at the time that 8-channel carrier aggregation using mmWave would be widely available on the carrier's network this year. In terms of RootMetrics' latest report, the company didn't test AT&T's 5G+ network, which was just recently opened up to consumers and leans on high-band millimeter wave instead of low-band spectrum. Out of the 55 markets, AT&T's low-band flavor of 5G still delivered strong results. That includes Philadelphia, which ranked the fastest with median 5G download speeds of 94.5 Mbps – though limited availability of just 1.6%. "AT&T's network investments have clearly paid dividends for its subscribers on both 5G and 4G LTE," RootMetrics concluded. "As more and more 5G devices become available, consumers will find even faster speeds thanks not only to 5G, but also because some 5G-ready smartphones can take advantage of AT&T's pairing of wide-scale 5CA with 4x4 MIMO." (https://www.fiercewireless.com/operators/widespread-5-carrier-givesat-t-network-edge-rootmetric) **April 18, 2023** Taking 5G to the Next Level with Standalone 5G By Jason Sikes, AVP Device Architecture *AT&T Labs makes industry-first 5G SA Uplink 2-CA data connection in the U.S. to improve upload speeds, with additional speed and other upgrades in the works* AT&T is architecting tomorrow's wireless network to ***connect people to greater possibility***. As engineers, we design, build, test, refine and repeat so that you can get more out of your 5G connection and developers can build and deploy the next generation of apps and services. A key part of this evolution is the critical transition phase we are entering in scaling from 5G non-standalone (NSA) to 5G standalone (SA). **How does Standalone take 5G to the next level?** Unlike 5G NSA that still relies on a 4G LTE core, 5G SA uses a dedicated 5G core that can unlock capabilities like faster upload speeds, ultra-low latency, ultra-high reliability and edge functions. This technology will be key to business opportunities like the next generation of connected cars. We have said that we plan to deploy Standalone 5G when the ecosystem is ready, and AT&T is charging forward to advance SA ecosystem readiness. Businesses and developers will be some of the first to take advantage of the new technologies standalone 5G enables as we continue to move from research & development to their deployment.

Claim 17	Public Documentation
	Uplink: where challenge meets opportunity This new age of connectivity is not only about consuming more content but also generating more content than ever before. Demand for uplink capacity and speed continues to increase, about 30% a year in AT&T's mobility network. Whether you are uploading large files, on a video call with family, live streaming, cloud gaming or using extended reality applications, the network is facing surging upstream traffic demands it never has before. Our latest network innovations are complex but are all about helping meet this new demand. Just a few weeks ago, we completed the **first 5G SA Uplink 2-carrier aggregation data call in the U.S.** Carrier aggregation (CA) means we are combining or "aggregating" different frequency bands to give you more bandwidth and capacity. For you, this means faster uplink transmission speeds. *Think of this as adding more lanes in the network traffic highway*. No one in the U.S market has successfully aggregated two carriers in 5G SA uplink – until now. This is part of our ongoing effort to provide greater reliability for our customers. The test was conducted in our labs with Nokia's 5G AirScale portfolio and MediaTek's 5G M80 mobile test platform. We aggregated our low-band n5 and our mid-band n77 spectrum. Compared to our low-band n5 alone, we saw a 100% increase in uplink throughput by aggregating our low-band n5 with 40MHz of our mid-band n77. Taking it a step further, we achieved a 250% increase aggregating 100MHz of n77. The bottom line? We achieved incredible upload speeds of over 70 Mbps on n5 with 40MHz of n77 and over 120 Mbps on n5 with 100MHz of n77. While carrier aggregation is like adding more traffic lanes in the highway, adding another vehicle to carry traffic is another way we are managing surging uplink demand. We are doing this via a **two-layer uplink MIMO** on time division duplex (TDD) in our mid-band n77. MIMO combines signals and data streams from multiple antennas ("vehicles") to improve signal quality and data rates. This feature will not only improve uplink throughput but also enhance cell capacity and spectrum efficiency. **Network design and device readiness go hand in hand** Although we continue to make progress in enhancing uplink coverage, we haven't forgotten about the downlink. Enhanced downlink and uplink carrier aggregation capabilities work together to bring the 5G SA performance today's technologies need. Last fall, we completed a **5G SA four component carrier downlink** call by combining two FDD carriers and two TDD carriers. These capabilities allow AT&T devices to aggregate our mid-band n77 in the C-Band and 3.45GHz spectrum ranges. Compared with low band and mmWave spectrum, mid-band n77 provides a good balance between coverage and speed. This follows the **5G SA three component carrier downlink feature** that we introduced last year to 2022 AT&T Flagship devices which combines one frequency division duplex (FDD) carrier and two TDD carriers. In the coming months, AT&T will also enable **5G New Radio Dual Connectivity (NR-DC)**, aggregating our low and mid-band spectrum with our high-band mmWave spectrum on 5G SA. Our labs have achieved 5G NR-DC downlink throughput speeds of up

Claim 17	Public Documentation
	to 5.3Gbps and uplink throughput speeds of up to 670Mbps. This technology will help provide high-speed mobile broadband for both downlink and uplink in stadiums, airports, and other high-density venues. The 5G SA ecosystem is rapidly evolving, with new technologies and capabilities being introduced to provide differentiated experiences. Here are some features that are on the horizon for 5G SA: • Specialized Network Services – think network slicing, precision location, private routing, etc. – for tailored network solutions to meet specific user requirements; • Non-terrestrial network solutions to supplement coverage in remote locations ; and • Reduced capability 5G (RedCap) for a new generation of 5G capable wearables, industrial IoT or wireless sensors and other small form factor consumer devices. AT&T is dedicated to being the best connectivity provider. The 5G SA ecosystem is rapidly evolving, with new technologies and capabilities being introduced to set the foundation for next generation applications and services. (https://about.att.com/blogs/2023/standalone-5g-innovations.html) AT&T spectrum aggregation industry first ups 5G ante **Dan Meyer** | Executive Editor. April 19, 2023 1:00 PM AT&T tested spectrum aggregation models on the oft-overlooked uplink channel that the carrier claimed was an industry first and resulted in network speeds that could help meet growing 5G traffic demands. Jason Sikes, AVP for device architecture at AT&T, explained in a blog post that the carrier completed an uplink data call running on its 5G standalone (SA) network core that aggregated two different spectrum frequency bands. The test was in AT&T's labs using Nokia's 5G AirScale equipment running on MediaTek's mobile test platform. Sikes explained in an email to SDxCentral that the test used 10-megahertz of AT&T's low-band 850 MHz spectrum combined with varying amounts of the carrier's C-band spectrum. With 40-megahertz of C-band spectrum the carrier was able to increase uplink speeds by 100% to more than 70 Mb/s compared with just the base 850 MHz spectrum. It witnessed a 250% increase in speed to more than 120 Mb/s using 100-megahertz of C-band spectrum. "Think of this as adding more lanes in the network traffic highway," Sikes wrote in the blog. "No one in the U.S market has successfully aggregated two carriers in 5G SA uplink – until now." Sikes added that AT&T's mobile network has witnessed a 30% increase in uplink capacity demand per year.

Claim 17	Public Documentation
	"This new age of connectivity is not only about consuming more content but also generating more content than ever before," he noted of the increase. "Whether you are uploading large files, on a video call with family, live streaming, cloud gaming or using extended reality applications, the network is facing surging upstream traffic demands it never has before." The latest test followed one conducted by the carrier last fall that involved a four-channel downlink call that traversed its 5G SA network. That call aggregated a pair of frequency division duplex (FDD) carriers and a pair of time division duplex (TDD) carriers running in the C-band and the 3.45 GHz spectrum bands. FDD is where different bands of frequency are used by users; one for uplink and the other for downlink. TDD is where one frequency band will be used for uplink and downlink, switching between the two from moment to moment. Sikes also noted that AT&T was deploying a "two-layer uplink" multiple-input, multiple output (MINO) technology on TDD across its C-band spectrum. "This feature will not only improve uplink throughput but also enhance cell capacity and spectrum efficiency," he wrote, though he further added that the carrier did not use MIMO during the most recent uplink test. The carrier is planning to launch 5G New Radio Dual Connectivity (NR-DC) capabilities "in the coming months." This will allow for the aggregation of low- and mid-band spectrum with AT&T's millimeter-wave (mmWave) spectrum using the 5G SA core. Sikes noted this capability has resulted in lab test downlink speeds up to 5.3 Gb/s and uplink speeds up to 670 Mb/s. "This technology gives customers high-speed mobile broadband for both downlink and uplink in stadiums, airports and other high-density venues," Sikes wrote. In the follow-up email, Sikes added that "over time, private 5G and fixed wireless will benefit from these uplink and downlink enhancements." (https://www.sdxcentral.com/articles/analysis/att-spectrum-aggregation-industry-first-ups-5g-ante/2023/04/) WHY CHOOSE NOKIA 5G CARRIER AGGREGATION? Together with the leading mobile network operators across the world and the user equipment ecosystem, we have commercially introduced two component, three component and four component 5G Carrier Aggregation to enable Multi-Gigabit 5G on sub-6 GHz frequency allocations. We also have Carrier Aggregation commercially available for high-band. On millimeter wave spectrum, Carrier Aggregation with eight component carriers in downlink and four component carriers in uplink enables reaching even higher data rates.

Claim 17	Public Documentation
	Nokia 5G Carrier Aggregation: • Works in 5G Non-Standalone and 5G Standalone in the same cells for smooth migration from NSA to SA • Boosts 5G performance • By aggregating low-band carriers for coverage and mid-band carriers for capacity, helps deliver Multi-Gigabit user data speeds already today. 5G Carrier Aggregation is software running on the baseband unit, easy to activate in Nokia 5G networks. The supported Carrier Aggregation band combinations are following the quarterly 3GPP specification updates. Our quarterly software updates ensure the best possible band combination support, and bring more flexibility for mobile operators to optimize their network coverage and capacity. Nokia 5G Carrier Aggregation works with massive MIMO and dynamic spectrum sharing, enabling a further capacity boost on mid-band and more flexibility for low-band aggregation. Nokia AirScale ensures uncompromised RF bandwidth for efficient multi-carrier sub-6 GHz Carrier Aggregation. Additionally, our AirScale baseband is optimized for providing the processing capacity and scalability for multi-carrier, large bandwidth Carrier Aggregation. (https://www.nokia.com/networks/mobile-networks/carrier-aggregation/) # Ericsson spearheads 5G carrier aggregation milestones with key partners Ericsson has achieved groundbreaking milestones for carrier aggregation in 5G New Radio (NR) technology together with key customers and ecosystem partners. Ericsson has recently pushed 5G carrier aggregation (5G CA) technology to new levels after a series of successful interoperability tests with customers including T-Mobile and Optus, and ecosystem partners such as Qualcomm and MediaTek. The interoperability tests use carrier aggregation to extend the coverage of 5G, boost network capacity, and increase data speeds. Ericsson's collaboration with partners has so far resulted in several 5G firsts:

Claim 17	Public Documentation
	• World's first 5G standalone (SA) data session with 5G CA on a commercial smartphone completed with T-Mobile, LG and MediaTek. With 5G CA, T-Mobile can combine its different 5G spectrum bands – starting with 2.5 GHz mid-band and 600 MHz low-band – boosting speeds and increasing the footprint of T-Mobile's mid-band 5G. It's also a key step in expanding T-Mobile's nationwide standalone architecture 5G network by increasing SA 5G capacity and speeds. (October 2020) • A 2300 + 3500MHz 5G Non-Standalone Carrier Aggregation call made by Optus using Ericsson technology and Samsung's Galaxy S20 5G handset range. The call showed the benefit of using both spectrum frequencies simultaneously, namely, a significant increase in the average and peak 5G speeds that customers, with an eligible handset, will benefit from as the capability becomes available. (August 2020) • First to complete all three combinations of NR time division duplex (TDD) and frequency division duplex (FDD) carrier aggregation (CA) together with MediaTek. The companies carried out a 5G SA data call by aggregating 20MHz on FDD spectrum and 100MHz on TDD spectrum with MediaTek's Dimensity 1000+ chipset at the Ericsson Lab in Kista. (September 2020) • Completed pioneering interoperability tests for 5G SA carrier aggregation across both FDD/TDD and TDD/TDD bands together with Qualcomm Technologies. 5G CA allows service providers to use multiple sub-6 GHz spectrum channels simultaneously to transfer data between base stations and a 5G mobile device. (August 2020) Per Narvinger, Head of Product Area Networks, Ericsson says: "From technology development to wider area deployments, Ericsson continues to spearhead 5G innovation with customers and industry partners. To maximize the full potential of the mid-band spectrum, we've developed 5G NR carrier aggregation solutions that will help our customers deploy a better 5G with greater coverage, increased capacity and higher data speeds. These solutions will extend the coverage of the high capacity mid-band spectrum. By enabling peak speeds, coverage and capacity, 5G carrier aggregation will be a real game-changer." Ericsson's 5G NR carrier aggregation solution will be commercially available in the fourth quarter of 2020 with a global rollout expected during 2021. (https://www.ericsson.com/en/news/2020/10/5g-carrier-aggregation)

Ericsson ups the tempo on 5G Carrier Aggregation with world's first downlink 6CC data call

Available in English 日本語

Ericsson revs up the tempo on 5G Carrier Aggregation by combining six component carriers to set a record download speed of 5.7Gbps for the world's first 6CC (component carrier) data call.

NEWS

AUG 17, 2023

The data call was achieved using three FDD (frequency division duplex) bands combined with three TDD (time division duplex) bands in sub-6GHz, enabled by Ericsson RAN Compute hardware, state-of the-art carrier aggregation software, and innovative Advanced RAN Coordination functionality.

The 3FDD + 3TDD carrier aggregation testing was carried out in an Ericsson lab with a user equipment (UE) simulator. By combining FDD spectrum with TDD spectrum, more users can benefit from carrier aggregation gains.

In total, 400MHz of bandwidth was aggregated with FDD bandwidths ranging 20MHz to 50MHz to achieve the 5.7Gbps throughput. With six-component carrier capability, communications service providers can optimize use of network and spectrum assets to deliver higher data speeds and capacity that improve the experience of downlink-heavy applications. This can mean better audio and video quality for streaming users, faster file downloads, and a better working environment for digital nomads.

Sibel Tombaz, Head of Product Line 5G RAN at Ericsson Networks, says: "We are keeping the momentum on carrier aggregation by continuously stretching its potential to boost capacity and speed. Our successful 6CC data call shows how versatile our solution is and that we are poised to work with ecosystem partners to make this new band combination a reality. Our goal, as always, is to help customers meet end users' growing appetite for high-capacity, ultrahigh-speed 5G."

"Carrier Aggregation is crucial to getting the best possible 5G performance out of scattered spectrum assets," Tombaz adds. "And with 6CC, service providers will be able to maximize use of allocated spectrum and optimize the combined bandwidth for superior mobile experience."

(https://www.ericsson.com/en/news/2023/8/ericsson-ups-the-tempo-on-5g-carrier-aggregation-with-worlds-first-downlink-6cc-data-call)

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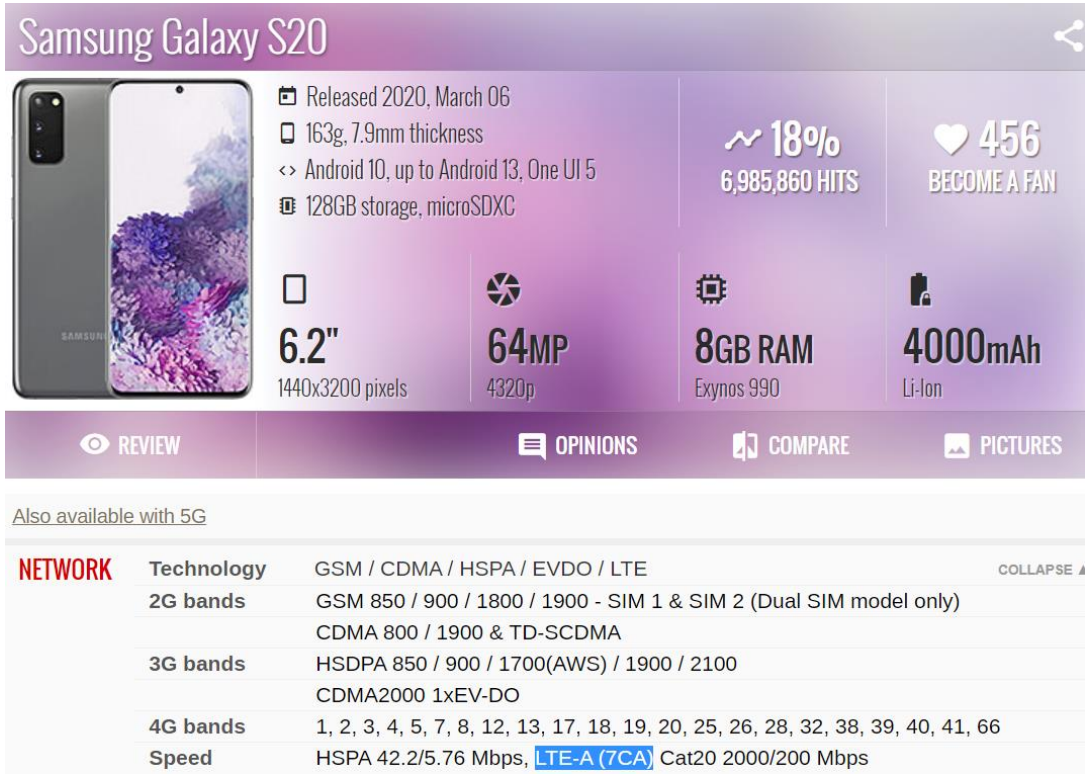
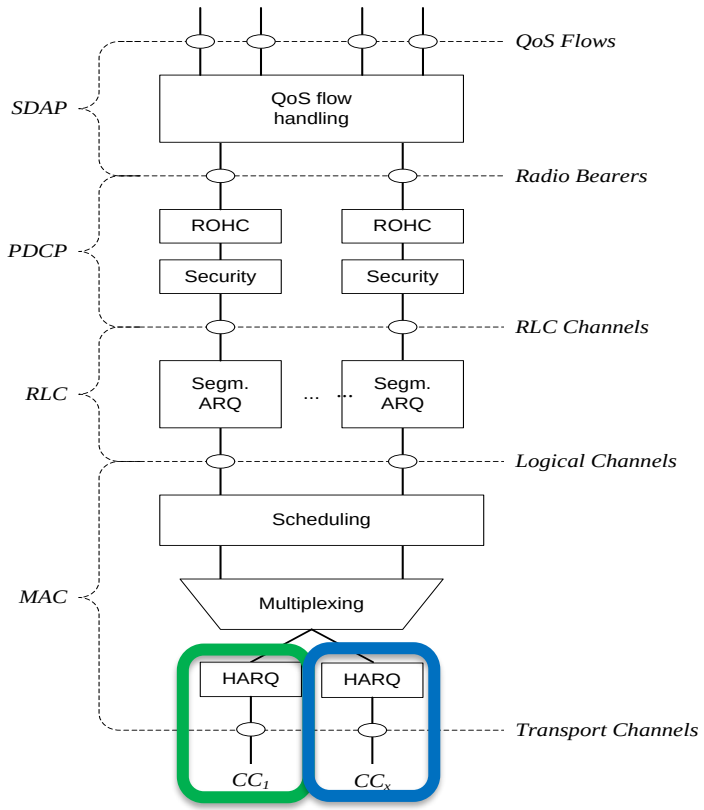
Claim 17	Public Documentation
	 Samsung Galaxy S20 Released 2020, March 06 163g, 7.9mm thickness Android 10, up to Android 13, One UI 5 128GB storage, microSDXC 18% 6,985,860 HITS 456 BECOME A FAN 6.2" 1440x3200 pixels 64MP 4320p 8GB RAM Exynos 990 4000mAh Li-Ion REVIEW OPINIONS COMPARE PICTURES Also available with 5G NETWORK COLLAPSE Technology: GSM / CDMA / HSPA / EVDO / LTE 2G bands: GSM 850 / 900 / 1800 / 1900 - SIM 1 & SIM 2 (Dual SIM model only) CDMA 800 / 1900 & TD-SCDMA 3G bands: HSDPA 850 / 900 / 1700(AWS) / 1900 / 2100 CDMA2000 1xEV-DO 4G bands: 1, 2, 3, 4, 5, 7, 8, 12, 13, 17, 18, 19, 20, 25, 26, 28, 32, 38, 39, 40, 41, 66 Speed: HSPA 42.2/5.76 Mbps, LTE-A (7CA) Cat20 2000/200 Mbps (https://www.gsmarena.com/samsung_galaxy_s20-10081.php)
[17a] a baseband digital system for providing a first digital signal comprising a first data to be transmitted and a second digital signal comprising a second data to be transmitted;	The Accused Instrumentalities include a baseband digital system for providing a first digital signal comprising a first data to be transmitted and a second digital signal comprising a second data to be transmitted. For example: **6.7 CARRIER AGGREGATION** In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below:

Claim 17	Public Documentation
	- In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell.  **Figure 6.7-2: Layer 2 Structure for UL with CA configured** (3GPP TS 38.300 V17.5.0)

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Ex.1028.0129

Claim 17	Public Documentation
[17b] a first digital-to-analog converter for receiving the first digital signal and converting the first digital signal into a first analog signal, the first analog signal carrying the first data across a first frequency range;	The Accused Instrumentalities include a first digital-to-analog converter for receiving the first digital signal and converting the first digital signal into a first analog signal, the first analog signal carrying the first data across a first frequency range. For example: **11.3.2.1 Transmitter architecture** Figure 11.3.2.1-1 illustrates various TX architectures options according to where the component carriers are combined, i.e., at digital baseband, or in analog waveforms before RF mixer, or after mixer but before the PA, or after the PA. Option A - In an adjacent *contiguous common carrier* aggregation scenario, the UE very likely has one PA. Connected to the PA can be a single RF chain (a zero-IF mixer, a wideband DAC, and a wideband IFFT) Option-B - Combines analog baseband waveforms from component Carrier first (e.g., via a mixer operating at an IF of roughly the bandwidth of the other component carrier in the example of 2-component carrier aggregation). Then the resulting wideband signal is up-converted to RF. Option-C - Does ZIF up-conversion of each component carrier before combining and feeding into a single PA. Option-D - Employs multiple RF chains and multiple PAs after which the high-power signals are combined and fed into a single antenna. PA coupling at the UE can be challenging for option-D. (3GPP TR 36.912 version 15.0.0 Release 15)

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Claim 17	Public Documentation

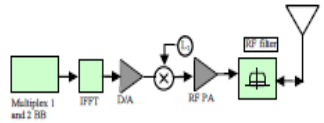
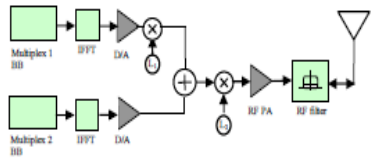
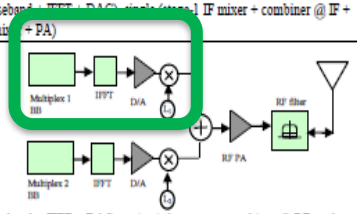
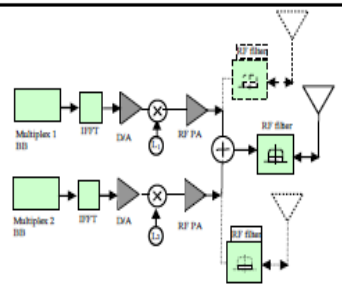
Tx Characteristics				
Option	Description (Tx architecture)	Intra Band aggregation		Inter Band aggregation
		Contiguous (CC)	Non contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes		
B	 Multiple (baseband + IFFT + DAC), single (stage-1) IF mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes	
C	 Multiple (baseband + IFFT + DAC + mixer), low-power combiner @ RF, and single PA	Yes	Yes	
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes	Yes + (depending on the specific EUTRA bands being aggregated),
X	*OTHERS*			

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios

(3GPP TR 36.912 version 15.0.0 Release 15)

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Claim 17	Public Documentation
[17c] a second digital-to-analog converter for receiving the second digital signal and converting the second digital signal into a second analog signal, the second analog signal carrying the second data across a second frequency range;	The Accused Instrumentalities include a second digital-to-analog converter for receiving the second digital signal and converting the second digital signal into a second analog signal, the second analog signal carrying the second data across a second frequency range. For example:

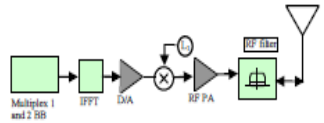
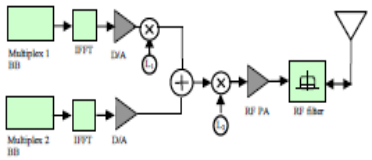
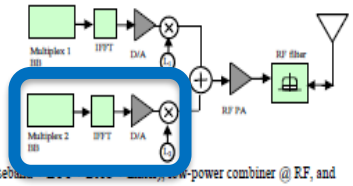
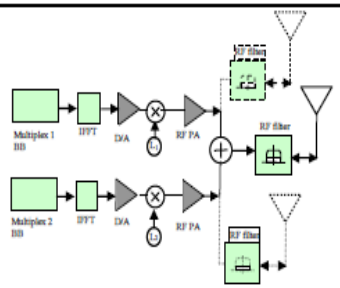
Tx Characteristics				
Option	Description (Tx architecture)	Intra Band aggregation		Inter Band aggregation
		Contiguous (CC)	Non contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes		
B	 Multiple (baseband + IFFT + DAC), single (stage-1 IF mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes	
C	 Multiple (baseb[illegible]-power combiner @ RF, and single PA	Yes	Yes	
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes	Yes + (depending on the specific EUTRA bands being aggregated),
X	*OTHERS*			

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios

(3GPP TR 36.912 version 15.0.0 Release 15)

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Ex.1028.0132

Claim 17	Public Documentation
[17d] a first up-converter circuit having a first input coupled to receive the first analog signal and a second input coupled to receive a first modulation signal having a first RF frequency, wherein the first up-converter outputs a first up-converted analog signal comprising a first up-converted frequency range from the first RF frequency minus one-half the first frequency range to the first RF frequency plus one-half the first frequency range;	The Accused Instrumentalities include a first up-converter circuit having a first input coupled to receive the first analog signal and a second input coupled to receive a first modulation signal having a first RF frequency, wherein the first up-converter outputs a first up-converted analog signal comprising a first up-converted frequency range from the first RF frequency minus one-half the first frequency range to the first RF frequency plus one-half the first frequency range. For example:

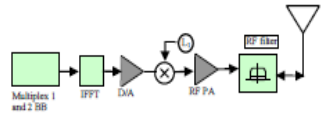
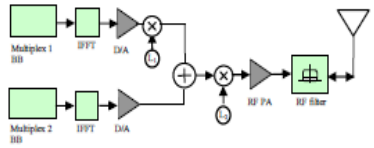
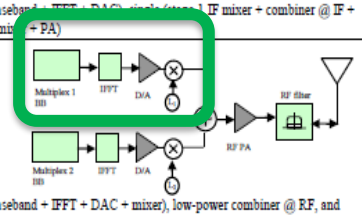
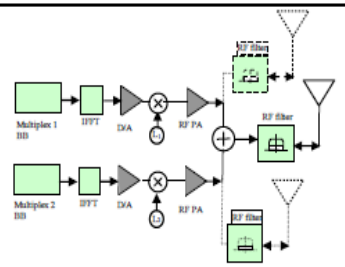
Tx Characteristics				
Option	Description (Tx architecture)	Intra Band aggregation		Inter Band aggregation
		Contiguous (CC)	Non contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes		
B	 Multiple (baseband + IFFT + DAC), single (stage-1 IF mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes	
C	 Multiple (baseband + IFFT + DAC + mixer), low-power combiner @ RF, and single PA	Yes	Yes	
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes	Yes + (depending on the specific EUTRA bands being aggregated),
X	*OTHERS*			

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios

(3GPP TR 36.912 version 15.0.0 Release 15)

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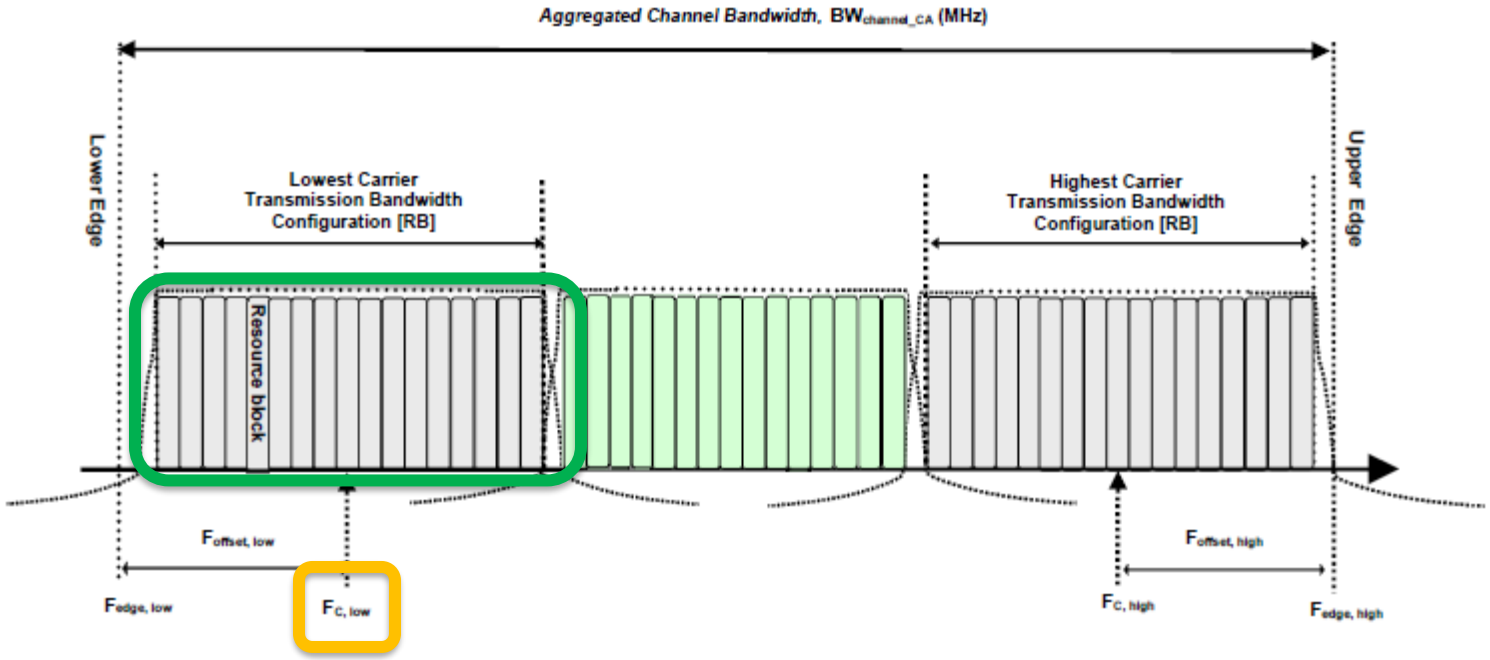
Claim 17	Public Documentation
	For carrier aggregation, the maximum transmission bandwidth configuration is defined per component carrier and the requirement is specified in clause 5.3.2. 5.3A.3 Minimum guardband and transmission bandwidth configuration for CA For intra-band contiguous carrier aggregation, *Aggregated Channel Bandwidth* and *Guard Bands* are defined as follows, see Figure 5.3A.3-1.  **Figure 5.3A.3-1: Definition of *Aggregated Channel Bandwidth* for intra-band carrier aggregation** $BWChannel_CA = Fedge,high - Fedge,low$ (MHz). The lower bandwidth edge $Fedge,_{low}$ and the upper bandwidth edge $Fedge,_{high}$ of the aggregated channel bandwidth are used as frequency reference points for transmitter and receiver requirements and are defined by

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Claim 17	Public Documentation
	$F_{edge,low} = F_{C,low} - F_{offset,low}$ $F_{edge,high} = F_{C,high} + F_{offset,high}$ The lower and upper frequency offsets depend on the transmission bandwidth configurations of the lowest and highest assigned edge component carrier and are defined as $F_{offset,low} = (N_{RB,low}*12 + 1)*SCS_{low}/2 + BW_{GB}$ (MHz) $F_{offset,high} = (N_{RB,high}*12 - 1)*SCS_{high}/2 + BW_{GB}$ (MHz) $BW_{GB} = \max(BW_{GB,Channel(k)})$ $N_{RB,low}$ and $N_{RB,high}$ are the transmission bandwidth configurations according to Table 5.3.2-1 for the lowest and highest assigned component carrier, SCS_{low} and SCS_{high} are the sub-carrier spacing for the lowest and highest assigned component carrier respectively. SCS_{low}, SCS_{high}, $N_{RB,low}$, $N_{RB,high}$, and $BW_{GB,Channel(k)}$ use the largest μ value among the subcarrier spacing configurations supported in the operating band for both of the channel bandwidths according to Table 5.3.5-1 and $BW_{GB,Channel(k)}$ is the minimum guard band for carrier k according to Table 5.3.3-1 for the said μ value. In case there is no common μ value for both of the channel bandwidths, μ=1 is used for SCS_{low}, SCS_{high}, $N_{RB,low}$, $N_{RB,high}$, and $BW_{GB,Channel(k)}$. (3GPP TS 38.101-1 V17.5.0)

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Petitioners' Ex. 1028
Ex.1028.0135

Claim 17	Public Documentation
[17e] a second up-converter circuit having a first input coupled to receive the second analog signal and a second input coupled to receive a second modulation signal having a second RF frequency, wherein the second up-converter outputs a second up-converted analog signal comprising a second up-converted frequency range from the second RF frequency minus one-half the second frequency range to the second RF frequency plus one-half the second frequency range, and wherein frequency difference between the first RF frequency and the second RF frequency is greater than the sum of one-half the first frequency range and one-half the second frequency range; and	The Accused Instrumentalities include a second up-converter circuit having a first input coupled to receive the second analog signal and a second input coupled to receive a second modulation signal having a second RF frequency, wherein the second up-converter outputs a second up-converted analog signal comprising a second up-converted frequency range from the second RF frequency minus one-half the second frequency range to the second RF frequency plus one-half the second frequency range, and wherein frequency difference between the first RF frequency and the second RF frequency is greater than the sum of one-half the first frequency range and one-half the second frequency range. For example:

Tx Characteristics

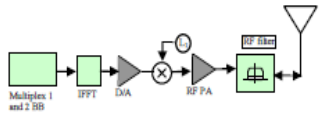
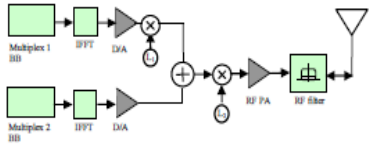
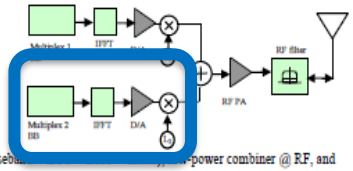
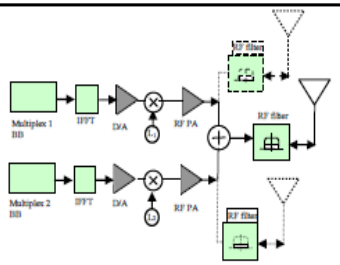
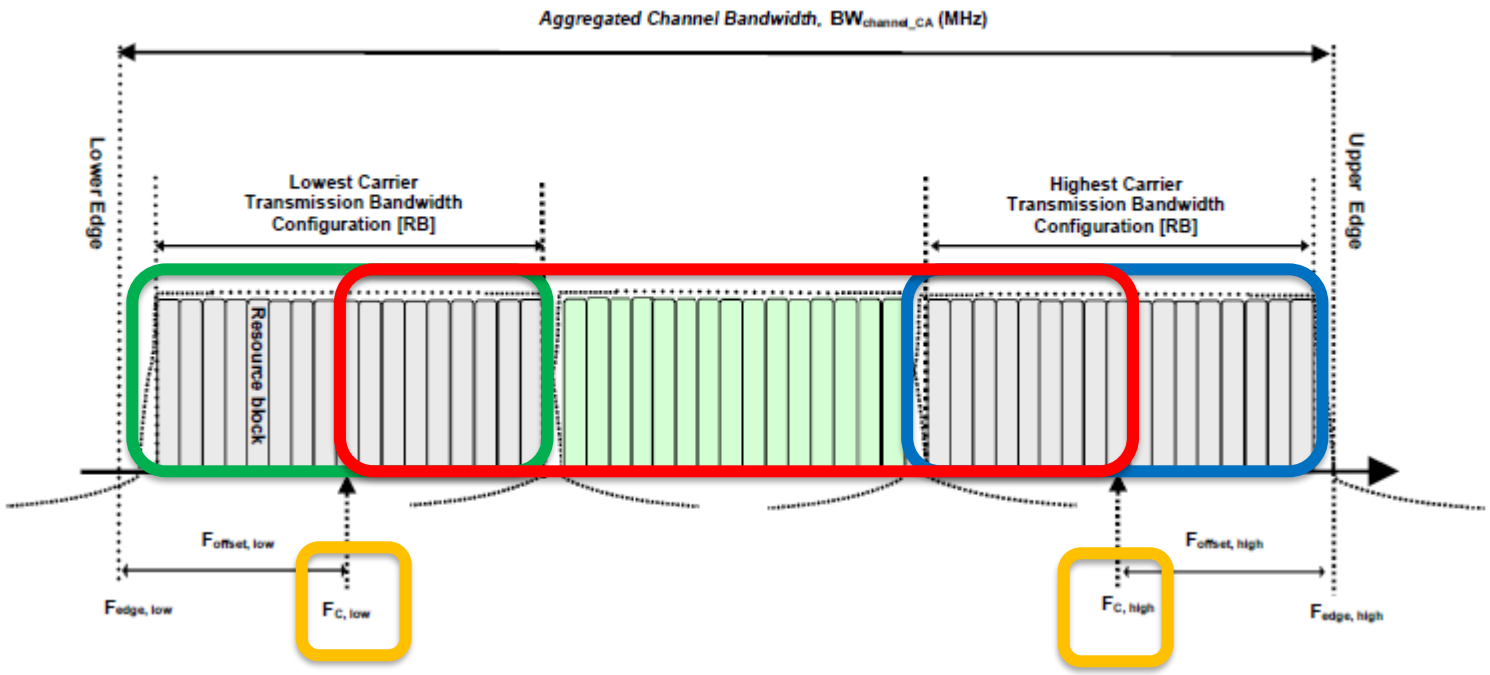
Option	Description (Tx architecture)	Intra Band aggregation		Inter Band aggregation
		Contiguous (CC)	Non contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes		
B	 Multiple (baseband + IFFT + DAC), single (stage-1 IF mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes	
C	 Multiple (baseb power combiner @ RF, and single PA	Yes	Yes	
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes	Yes + (depending on the specific EUTRA bands being aggregated),
X	*OTHERS*			

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios

(3GPP TR 36.912 version 15.0.0 Release 15)

Claim 17	Public Documentation
	For carrier aggregation, the maximum transmission bandwidth configuration is defined per component carrier and the requirement is specified in clause 5.3.2. 5.3A.3 Minimum guardband and transmission bandwidth configuration for CA For intra-band contiguous carrier aggregation, *Aggregated Channel Bandwidth* and *Guard Bands* are defined as follows, see Figure 5.3A.3-1.  **Figure 5.3A.3-1: Definition of *Aggregated Channel Bandwidth* for intra-band carrier aggregation** (3GPP TS 38.101-1 V17.5.0)

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Ex.1028.0137

Claim 17	Public Documentation
[17f] a power amplifier coupled to receive the first and second up-converted analog signals, wherein the bandwidth of the power amplifier is greater than the difference between a lowest frequency in the first up-converted frequency range and a highest frequency in the second up-converted frequency range.	The Accused Instrumentalities include a power amplifier coupled to receive the first and second up-converted analog signals, wherein the bandwidth of the power amplifier is greater than the difference between a lowest frequency in the first up-converted frequency range and a highest frequency in the second up-converted frequency range. For example:

Tx Characteristics

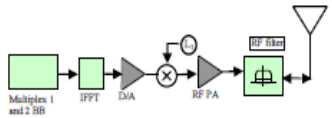
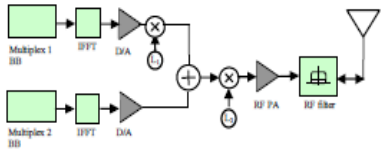
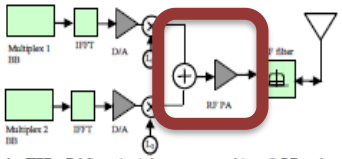
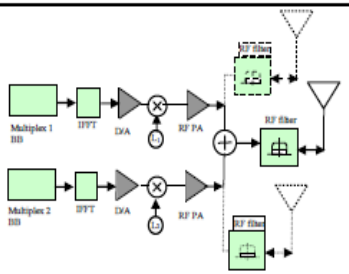
Option	Description (Tx architecture)	Intra Band aggregation		Inter Band aggregation
		Contiguous (CC)	Non contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes		
B	 Multiple (baseband + IFFT + DAC), single (stage-1 IF mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes	
C	 Multiple (baseband + IFFT + DAC + mixer), low-power combiner @ RF, and single PA	Yes	Yes	
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes	Yes + (depending on the specific EUTRA bands being aggregated),
X	*OTHERS*			

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios

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Claim 17	Public Documentation

	As a further example, in power amplifier designs believed to be representative of those used in the Accused Instrumentalities:
	https://www.broadcom.com/products/wireless/rf-front-end-modules/mobile-rf-fem
	
	Mobile RF FEM
	
	Broadcom provides custom RF frond end module (FEM) devices for mobile wireless applications. These devices incorporate multiband power amplifiers (PA), FBAR duplexers and multiplexers, SOI multi-mode LNAs and antenna switch, coupler and MIPI controller, designed to support various carrier aggregation (CA) for both FDD and TDD bands.
	Broadcom has shipped billions of RF FEM devices to the world's leading smartphone manufacturers.
	
	The Broadcom ACFM-2S13 is a quadplexer device that combines Band 1 and Band 3 duplexers into a single, miniature package. Band 4 duplexer is co-banded. The device features a single antenna connection, eliminating the need for antenna switching. High Isolation between bands enables the use of carrier aggregation.
	
	The ACFM-2S13 is designed with Broadcom's innovative filter capability which makes possible ultra-small, high-Q filters at a fraction of their usual size. Low Tx Insertion Loss of the ACFM-2S13 reduces power amplifier current, extending battery life. The device enhances receiver sensitivity and dynamic range with low Rx Insertion Loss and high rejection of Tx signals at the Rx ports.
	Features
	• Single antenna
	• High cross band isolation
	  • Enables carrier aggregation
	• Band 4 co-banding
	• Miniature size
	  • 2.0 x 2.5 mm footprint
	  • 0.710 mm typ. height
	• High Power Rating
	• Environmental
	  • RoHS 6 Compliant
	  • Halogen Free
	  • TBBPA Free
	
	https://www.broadcom.com/products/wireless/demo-boards/acfm-2s13

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Claim 17	Public Documentation

SKYWORKS®

PRODUCT SUMMARY

SKY77786-11 High Band Multimode Multiband Power Amplifier Module Supporting LTE Advanced Applications

Applications

- Multiband 4G / LTE handsets
- FDD LTE Bands 7 and 30
- TDD LTE Band 38, 40, 41

Features

- Two T/R (RX) port and 3 outputs
- Industry-leading PAE for 4G
- Optimized for APT DCDC operation
- Fully programmable Mobile Industry Processor Interface (MIPI) control
- MIPI programmable bias modes optimize best 4G efficiency/linearity performance.
- Small, low profile package:
  - 3.0 x 3.0 x 0.71 mm
  - 20-pad configuration

Skyworks Green™ products are compliant with all applicable legislation and are halogen-free. For additional information, refer to Skyworks *Definition of Green*™, document number SQ04-0074.

Description

Skyworks SKY77786-11 SkyLiTE™ is a multimode multiband (MMMB) Power Amplifier Module (PAM) that supports 4G handsets and operates efficiently in LTE bands from 2.3 GHz to 2.7 GHz. The module is fully programmable through a Mobile Industry Processor Interface (MIPI®).

The PAM consists of a single high band LTE block, a Multi-Function Control (MFC) block, and a T/R switch block. RF input/output ports internally matched to 50 Ω to reduce the number of external components. A CMOS integrated circuit uses standard MIPI controls to provide the internal MFC interface and operation. Extremely low leakage current maximizes handset standby time.

The InGaP die and the silicon die and passive components are mounted on a multi-layer laminate substrate. The assembly is encapsulated in a 3.0 mm x 3.0 mm x 0.71 mm, 20-pad MCM, SMT package which is a more highly manufacturable, low cost solution.

4G: The SKY77786-11 supports 1.4, 3, 5, 10, 15, 20, 30, 35, 40 MHz channel bandwidths. Similar to 3G operation, output power is controlled by varying the input power and V_{CC} is adjusted using a DCDC converter to maximize efficiency for each power level.

4G Modulation scheme includes:

- FDD LTE
- TDD LTE
- Uplink Carrier Aggregation (CA) support for Bands 40/41 (up to 40 MHz)

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Claim 17	Public Documentation
	Elevating Performance with Industry-Leading Primary Path Architectures Skyworks is enabling technology evolutions industry-wide with its advanced cellular transmit solutions for mobile devices. Leveraging decades of systems and module expertise, we architect baseband agnostic solutions that utilize our advanced power amplifier, low noise amplifier, filter and switch technologies. Our portfolio covers 2G, 3G, 4G and 5G applications, addressing specific customer priorities for system efficiency, solution size and total cost. Skyworks' latest modules for 5G from our SKY5® portfolio feature the highest transmit efficiency — optimizing battery life and enhancing thermal benefits — and advanced BAW and TC-SAW technologies in an exceptionally compact form factor, while supporting the maximum combination of carrier aggregation (CA) bands. Our products uniquely provide the best performance at targeted frequency bands, supporting up to 100 MHz wide bandwidth, maximizing data throughput at ultra-fast speeds. https://www.skyworksinc.com/en/System-Solutions/Transmit

Claim 21

Claim 21	Public Documentation
[21] The communication system of claim 17 wherein the first data of the first digital signal is encoded using a first wireless protocol and the first data of the second digital signal is encoded using a second wireless protocol.	In the Accused Instrumentalities the first data of the first digital signal is encoded using a first wireless protocol and the first data of the second digital signal is encoded using a second wireless protocol. For example: For example: Cellular operators, for example AT&T, have deployed Dynamic Spectrum Sharing (DSS) and carrier aggregation technology that provides service using both LTE and 5G by sharing the same spectrum and using carrier aggregation, using two different protocols. Operators, for example AT&T, have also used carrier aggregation using a combination of FDD and TDD protocols, using two different protocols. AT&T Touts Standalone 5G Breakthrough Posted on April 18, 2023 6:25pm by Carl Weinschenk In a blog post today, AT&T touted its achievements involving 5G standalone technology, including the completion several weeks ago of what the company said was the first 5G standalone uplink two-carrier aggregation data call in the United States. Like most carriers, AT&T initially deployed 5G in non-standalone mode, which relies on previous-generation technology in the core network. As the blog post notes, standalone 5G uses a dedicated core, which can help support faster upload speeds, lower latency, and edge functions, as well as enhancing reliability. The 5G standalone uplink two-carrier aggregation data call was conducted at AT&T's Labs with Nokia's 5G AirScale portfolio and MediaTek's 5G M80 mobile test platform. AT&T aggregated low band n5 and mid-band n77 spectrum. When the n5 was aggregated with 40 MHz of the n77 mid-band, the test generated a 100% increase in uplink throughput compared to the n5 low-band alone. A 250% increase was seen when 100 MHz of n77 was aggregated with the n5 spectrum. "The bottom line? We achieved incredible upload speeds of over 70 Mbps on n5 with 40MHz of n77 and over 120 Mbps on n5 with 100MHz of n77," said Jason Sikes, AT&T's Associate Vice President of Device Architecture, in today's blog post.

Claim 21	Public Documentation
	AT&T also said that it completed a standalone 5G four component carrier downlink call several months ago. The call combined two frequency division duplex (FDD) and two time division duplex (TDD) carriers. AT&T was able to aggregate mid-band n77 in the C-band and 3.45 GHz spectrum ranges. The blog post also references AT&T's use of two-layer uplink multiple in multiple out (MIMO) on TDD in the n77 band. MIMO combines signals and data streams from multiple antennas to improve signal quality and data rates, the carrier said. "This feature ill not only improve uplink throughput but also enhance cell capacity and spectrum efficiency," Sikes said, although the post doesn't indicate the status of that development Looking ahead, AT&T plans to enable 5G new radio dual connectivity (NR-DC), which will involve the aggregation of low and mid-band spectrum with high-frequency mmWave spectrum on 5G SA. So far, AT&T's labs achieved 5G NR-DC downlink throughput speeds as high as 5.3 Gbps and uplink throughput speeds as fast as 670 Mbps. (https://www.telecompetitor.com/att-touts-standalone-5g-breakthrough/) # AT&T spectrum aggregation industry first ups 5G ante **Dan Meyer** | Executive Editor. April 19, 2023 1:00 PM AT&T tested spectrum aggregation models on the oft-overlooked uplink channel that the carrier claimed was an industry first and resulted in network speeds that could help meet growing 5G traffic demands. Jason Sikes, AVP for device architecture at AT&T, explained in a blog post that the carrier completed an uplink data call running on its 5G standalone (SA) network core that aggregated two different spectrum frequency bands. The test was in AT&T's labs using Nokia's 5G AirScale equipment running on MediaTek's mobile test platform. Sikes explained in an email to SDxCentral that the test used 10-megahertz of AT&T's low-band 850 MHz spectrum combined with varying amounts of the carrier's C-band spectrum. With 40-megahertz of C-band spectrum the carrier was able to increase uplink speeds by 100% to more than 70 Mb/s compared with just the base 850 MHz spectrum. It witnessed a 250% increase in speed to more than 120 Mb/s using 100-megahertz of C-band spectrum. "Think of this as adding more lanes in the network traffic highway," Sikes wrote in the blog. "No one in the U.S market has successfully aggregated two carriers in 5G SA uplink – until now." Sikes added that AT&T's mobile network has witnessed a 30% increase in uplink capacity demand per year.

Claim 21	Public Documentation
	"This new age of connectivity is not only about consuming more content but also generating more content than ever before," he noted of the increase. "Whether you are uploading large files, on a video call with family, live streaming, cloud gaming or using extended reality applications, the network is facing surging upstream traffic demands it never has before." The latest test followed one conducted by the carrier last fall that involved a four-channel downlink call that traversed its 5G SA network. That call aggregated a pair of frequency division duplex (FDD) carriers and a pair of time division duplex (TDD) carriers running in the C-band and the 3.45 GHz spectrum bands. FDD is where different bands of frequency are used by users; one for uplink and the other for downlink. TDD is where one frequency band will be used for uplink and downlink, switching between the two from moment to moment. Sikes also noted that AT&T was deploying a "two-layer uplink" multiple-input, multiple output (MINO) technology on TDD across its C-band spectrum. "This feature will not only improve uplink throughput but also enhance cell capacity and spectrum efficiency," he wrote, though he further added that the carrier did not use MIMO during the most recent uplink test. The carrier is planning to launch 5G New Radio Dual Connectivity (NR-DC) capabilities "in the coming months." This will allow for the aggregation of low- and mid-band spectrum with AT&T's millimeter-wave (mmWave) spectrum using the 5G SA core. Sikes noted this capability has resulted in lab test downlink speeds up to 5.3 Gb/s and uplink speeds up to 670 Mb/s. "This technology gives customers high-speed mobile broadband for both downlink and uplink in stadiums, airports and other high-density venues," Sikes wrote. In the follow-up email, Sikes added that "over time, private 5G and fixed wireless will benefit from these uplink and downlink enhancements." (https://www.sdxcentral.com/articles/analysis/att-spectrum-aggregation-industry-first-ups-5g-ante/2023/04/) # AT&T to deploy dynamic spectrum sharing in second half of 2020 By **Bevin Fletcher** . May 28, 2020 11:42am Verizon has probably been the carrier most vocal about benefits of dynamic spectrum sharing (DSS) technology, but rival AT&T is also a fan and SVP Igal Elbaz said Thursday that the carrier expects to deploy DSS later this year.

Claim 21	Public Documentation
	"You should expect us to have DSS introduced in our network in the second half of 2020," said Elbaz, AT&T's senior vice president of Wireless Technology, speaking this morning to investment analysts at the virtual Cowen and Company Technology, Media & Telcom Conference. Elbaz called DSS a very important technology in terms of enabling both AT&T and other carriers to scale 5G rollouts. The timeline is similar to that of rival Verizon, which has pointed to dynamic spectrum sharing as key to its strategy for introducing broad nationwide 5G coverage this year using existing spectrum. Last month CEO Hans Vestberg indicated Verizon's plans to commercially deploy DSS in the second half of this year are still on track, with no COVID-19-related supply chain issues affecting the carrier's ability to do so. RELATED: AT&T 4G LTE connects IoT robots to kill germs, keep shelves stocked Dynamic spectrum sharing allows carriers to operate both 5G New Radio (NR) and LTE using the same spectrum channel by shifting or allocating resources between the two, based on the number of users or traffic needs. This is different from previous technology generation shifts, where carriers usually had to carve out or take away a portion of their existing spectrum and dedicate it to the new technology. Elbaz used the example of having four channels for LTE, and then needing to take away one channel, clean it, and use it only for 5G. That leaves an operator with only three channels instead of four for the vast majority of its users who are still on LTE. Meanwhile, there's a free channel for 5G, but it has very little usage because it takes time for new 5G users with capable devices to accumulate and generate traffic. "That's not an efficient way to manage your spectrum in the transition," Elbaz said. AT&T and T-Mobile have each already rolled out low-band 5G service that's not much speedier, or in some cases slower, than 4G LTE. Verizon, which is seen as lacking in low- and mid-band spectrum that it can dedicate to 5G, has stuck to 5G deployments using millimeter wave spectrum limited to small pockets of urban areas. Verizon is expected to participate for mid-band spectrum at the C-band auction set for December, but it will take time before that can be put to use. While DSS will let the carriers use existing spectrum to roll out 5G more quickly, it's been observed that the technology doesn't add extra capacity. RELATED: Charter talks with AT&T about wholesale MVNO agreement Analysts at LightShed Partners have said they expect Verizon will deliver broad 5G coverage enabled by a combination of DSS and carrier aggregation. As the firm explained, despite the confusing name, carrier aggregation enables operators to combine spectrum blocks, both blocks adjacent and non-adjacent, and from other bands to deliver faster speeds to end users. Although AT&T is pursuing a $6 billion cost-cutting initiative, Elbaz reiterated that AT&T will continue to invest in its core products, which include 5G, fiber and HBO Max (which just launched yesterday). That includes likely participation

Claim 21	Public Documentation
	for C-band spectrum. Still, Cowen analysts today suggested DSS could mean the carrier doesn't need to invest in as much new spectrum as it would otherwise. RELATED: AT&T 'not backing off' $6B cost cutting initiative While preparing for its 5G deployments, AT&T has bolstered its 4G LTE network, adding capacity with nearly 160 MHz of sub-6 GHz spectrum alongside its FirstNet public safety build. Network testing results tracked significant 4G LTE performance increases following enhancements that included additional spectrum and LTE-Advanced technologies such as carrier aggregation. AT&T stands out as the only carrier able to utilize 5-carrier aggregation on a wide scale for 4G LTE. According to RootMetrics, that helped boost AT&T's speed performance significantly in 51 out of 55 markets tested in the first half of 2020, compared to the end of 2019. Comparatively, for 4G LTE, Sprint and T-Mobile use 3-carrier aggregation, while Verizon uses 4-component carrier aggregation. Support for 5G carrier aggregation is expected in June with 3GPP Release 16. With DSS, AT&T can use existing channels for 5G, sharing instead of sacrificing 4G LTE spectrum resources. As more 5G devices come online, carriers can deploy DSS on additional, or eventually all, existing channels to serve both 4G LTE and 5G users. "[DSS] is a profound technology and really allows us to do that transition very efficiently," Elbaz said. RELATED: Ericsson defends dynamic spectrum sharing That said, there is at least one carrier that has cast some doubt on DSS. Last month T-Mobile President of Technology Neville Ray reiterated that one vendor was still trailing in a DSS product; T-Mobile doesn't depend DSS for its nationwide 5G network thanks to its 600 MHz portfolio. Ericsson led the charge on dynamic spectrum sharing technology, and its product is already being commercially used by global operators, including Swisscom, Telstra, and Play. Nokia, meanwhile, launched DSS in April, with volume shipments anticipated in July in line with availability of DSS-capable handsets. While Ray called DSS "still bumpy", he acknowledged T-Mobile will still deploy it. Verizon and AT&T executives have refuted problems with DSS, including Verizon's Vestberg, who last month said tests were going "very well." (https://www.fiercewireless.com/tech/at-t-to-deploy-dynamic-spectrum-sharing-second-half-2020)

Claim 23

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[23] The communication system of claim 17 wherein first and second data to be transmitted comprise a plurality of OFDM symbols, wherein a first symbol is transmitted during a first time slot across the first up-converted frequency range and a second symbol is transmitted during the first time slot across the second up-converted frequency range, and wherein a third symbol is transmitted during a second time slot across the first up-converted frequency range and a fourth symbol is transmitted during the second time slot across a second up-converted frequency range.	In the Accused Instrumentalities, first and second data to be transmitted comprise a plurality of OFDM symbols, wherein a first symbol is transmitted during a first time slot across the first up-converted frequency range and a second symbol is transmitted during the first time slot across the second up-converted frequency range, and wherein a third symbol is transmitted during a second time slot across the first up-converted frequency range and a fourth symbol is transmitted during the second time slot across a second up-converted frequency range. For example: 5G frame structure comprises frames of length 10 msec long, each frame comprises 10 sub-frames, each sub-frame comprises at least two time slots, and each frame comprises at least 20 time slots. Each time slot comprises a multitude of OFDM symbols. A transport block, data payload, in 5G is divided into a set of code blocks, each code block is transmitted on frequency resources of OFDM symbols that comprise a time slot. In a Carrier Aggregation (CA) method, a data stream is multiplexed onto multiple Component Carriers (CCs), e.g., onto a first and a second data stream. The first and second data ("information") streams are transmitted on a first and a second CC, respectively. The first data stream is transmitted on a first CC, on frequency resources of an OFDM symbol in a time slot of the first CC, and the second data stream is transmitted on a second CC, on frequency resources of an OFDM symbol in the time slot of the second CC. The code blocks of the transport block (payload, data stream) are multiplexed onto the CCs and transmitted in consecutive time slots. **6.7 CARRIER AGGREGATION** In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below: - In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell.

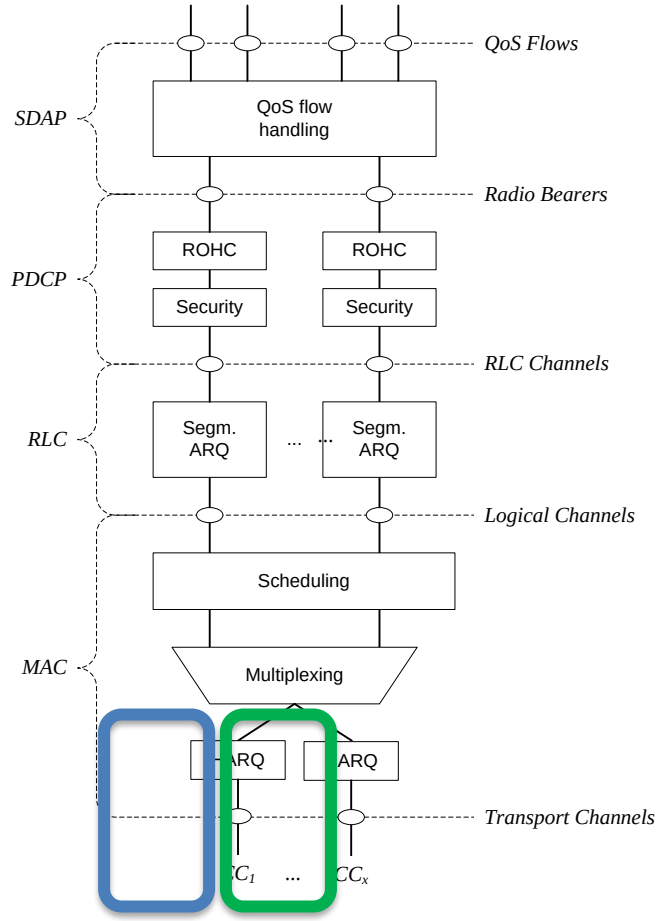

Figure 6.-2: Layer 2 Structure for UL with CA configured.

(3GPP TS 38.300 V17.4.0)

Frame structure and physical resources

4.1 GENERAL

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	Throughout this specification, unless otherwise noted, the size of various fields in the time domain is expressed in time units $T_c = 1/(\Delta f_{max} \cdot N_f)$ where $\Delta f_{max} = 480 \cdot 10^3$ Hz and $N_f = 4096$. The constant $\kappa = T_s/T_c = 64$ where $T_s = 1/(\Delta f_{ref} \cdot N_{f,ref})$, $\Delta f_{ref} = 15 \cdot 10^3$ Hz and $N_{f,ref} = 2048$. Throughout this specification, unless otherwise noted, statements using the term "UE" in clauses 4, 5, 6, or 7 are equally applicable to the IAB-MT part of an IAB node. **4.2 NUMEROLOGIES** Multiple OFDM numerologies are supported as given by Table 4.2-1 where μ and the cyclic prefix for a downlink or uplink bandwidth part are obtained from the higher-layer parameter *subcarrierSpacing* and *cyclicPrefix*, respectively. **Table 4.2-1: Supported transmission numerologies.** μ | $\Delta f = 2^{\mu} \cdot 15$ [kHz] | **Cyclic prefix** 0 | 15 | Normal 1 | 30 | Normal 2 | 60 | Normal, Extended 3 | 120 | Normal 4 | 240 | Normal **4.3 FRAME STRUCTURE** **4.3.1 FRAMES AND SUBFRAMES** Downlink, uplink, and sidelink transmissions are organized into frames with $T_f = (\Delta f_{max} N_f / 100) \cdot T_c = 10$ ms duration, each consisting of ten subframes of $T_{sf} = (\Delta f_{max} N_f / 1000) \cdot T_c = 1$ ms duration. The number of consecutive OFDM symbols per subframe is $N_{symb}^{subframe,\mu} = N_{symb}^{slot} N_{slot}^{subframe,\mu}$. Each frame is divided into two equally-sized half-frames of five subframes each with half-frame 0 consisting of subframes 0 – 4 and half-frame 1 consisting of subframes 5 – 9. There is one set of frames in the uplink and one set of frames in the downlink on a carrier.

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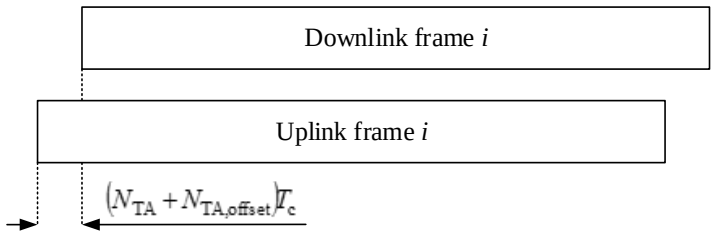
	Uplink frame number i for transmission from the UE shall start $T_{TA} = (N_{TA} + N_{TA,offset})T_c$ before the start of the corresponding downlink frame at the UE where $N_{TA,offset}$ is given by [5, TS 38.213], except for msgA transmission on PUSCH where $T_{TA} = 0$ shall be used.  **Figure 4.3.1-1: Uplink-downlink timing relation.** **4.3.2 SLOTS** For subcarrier spacing configuration μ, slots are numbered $n_s^{\mu} \in \{0, \ldots, N_{slot}^{subframe,\mu} - 1\}$ in increasing order within a subframe and $n_{s,f}^{\mu} \in \{0, \ldots, N_{slot}^{frame,\mu} - 1\}$ in increasing order within a frame. There are N_{symb}^{slot} consecutive OFDM symbols in a slot where N_{symb}^{slot} depends on the cyclic prefix as given by Tables 4.3.2-1 and 4.3.2-2. The start of slot n_s^{μ} in a subframe is aligned in time with the start of OFDM symbol $n_s^{\mu} N_{symb}^{slot}$ in the same subframe. OFDM symbols in a slot in a downlink or uplink frame can be classified as 'downlink', 'flexible', or 'uplink'. Signaling of slot formats is described in clause 11.1 of [5, TS 38.213]. (3GPP TS 38.211 V16.1.0) **5G NR Transport Block Size (TBS) Calculation** August 16, 2020Author3GPP Specification, 5G MAC Layer, 5G NR, 5G Physical Layer Frame structure and physical resources Transport Block in 5G NR, is nothing but the payload, which is passed between the MAC and Phy Layers, specifically for the shared data channel such as PDSCH and PUSCH. A Transport Block undergoes Phy layer

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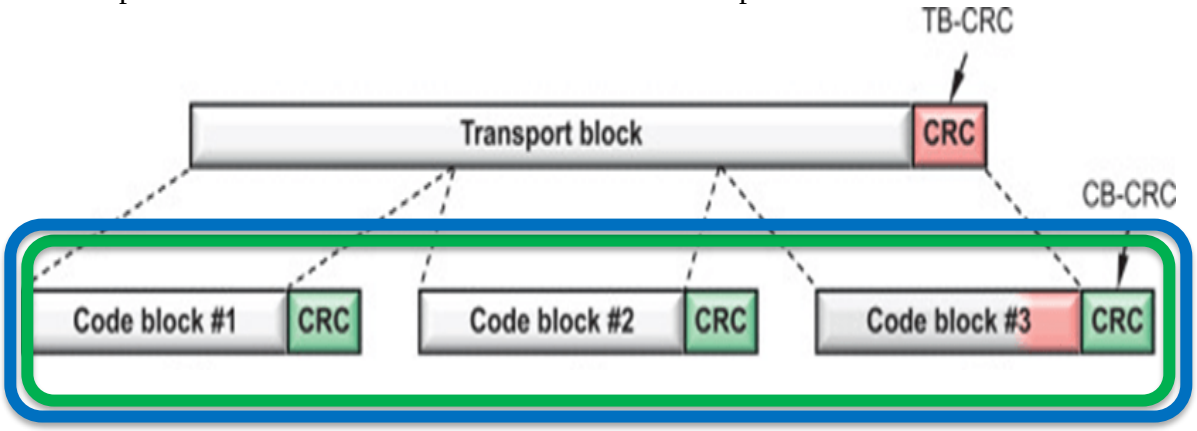
	processing at the transmitter before being mapped onto the PDSCH for transmission over the air interface. A Transport block is added with CRC and segmented into code blocks as shown as below. The transport block consists of up to million bits and the code block consists of up to 8448 bits.  (https://www.techplayon.com/5g-nr-transport-block-size-tbs-calculatin) **TIME-FREQUENCY RESOURCE** A ***resource element*** is the smallest time-frequency resource over one subcarrier of a single OFDM symbol. It is identified as $(k,l)_{p,\mu}$ where k is the index of the subcarrier in the frequency domain, l is the OFDM symbol position in time domain, p is the antenna port and μ is the subcarrier spacing configuration defined in Table 1 above. A ***resource block*** (a.k.a ***physical resource block*** – ***PRB***) is a block of $N^{RB}_{sc} = 12$ subcarriers over which the transmissions are scheduled. 5G NR physical layer uses time-frequency resource (***physical resource block***) for transmission.

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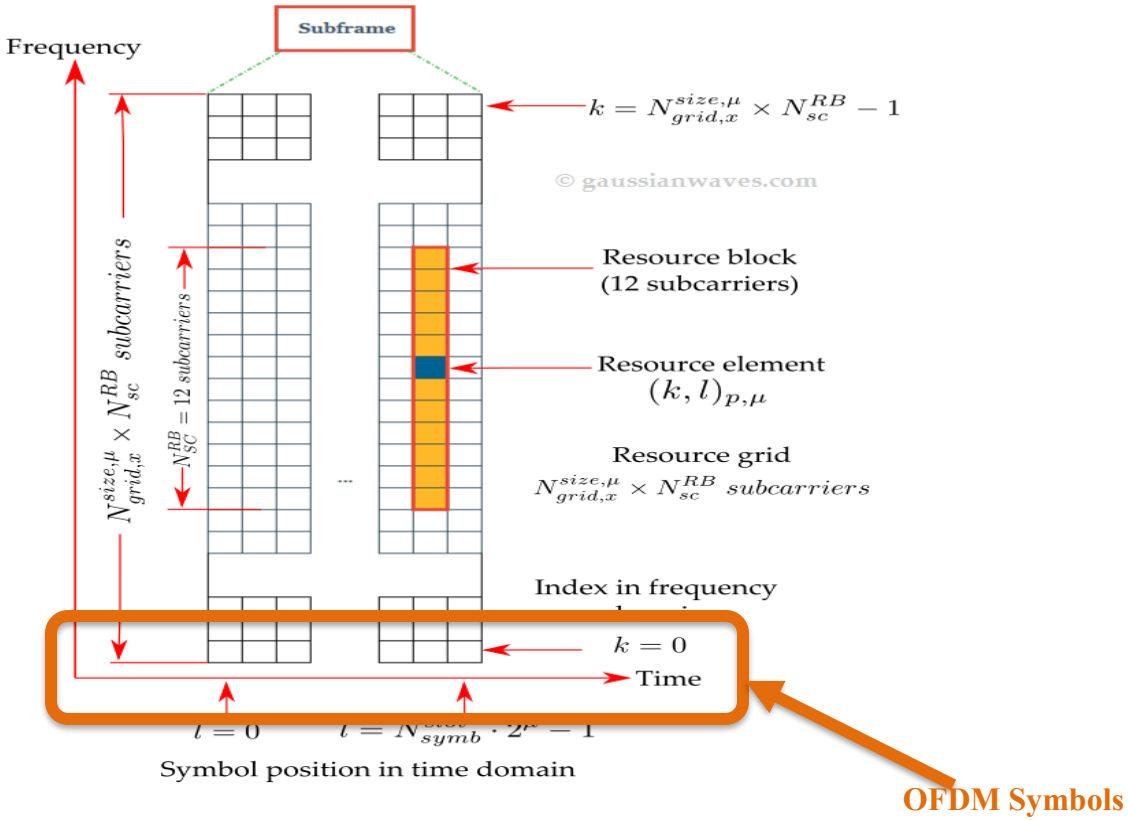
	A resource grid consists of $N^{size,\mu}_{grid,x}$ subcarriers and $N^{subframe,\mu}_{symb}$ number of OFDM symbols (***Table 2 and 3***).  ***Figure 3: Resource element, Resource block, Resource grid in 5G NR*** (https://www.gaussianwaves.com/2022/02/5g-nr-resource-block)

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Claim 24

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[24pre] An electronic circuit comprising:	To the extent the preamble is found to be limiting, the Accused Instrumentalities perform a method of transmitting information in a wireless communication channel. For example, Defendant deploys and uses 4G and 5G RAN Solutions by vendors Ericsson and Nokia. These 4G and 5G RAN Solutions are 4G and 5G NR cellular radio access network systems supporting carrier aggregation, and the accused systems include all the installed components for the 4G and 5G NR RAN solution systems deployed by Defendant. *See, e.g.*: 5.4 Carrier aggregation 5.4.1 Carrier aggregation In Carrier Aggregation (CA), two or more Component Carriers (CCs) are aggregated. A UE may simultaneously receive or transmit on one or multiple CCs depending on its capabilities: - A UE with single timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells sharing the same timing advance (multiple serving cells grouped in one TAG); - A UE with multiple timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells with different timing advances (multiple serving cells grouped in multiple TAGs). NG-RAN ensures that each TAG contains at least one serving cell; - A non-CA capable UE can receive on a single CC and transmit on a single CC corresponding to one serving cell only (one serving cell in one TAG). CA is supported for both contiguous and non-contiguous CCs. When CA is deployed frame timing and SFN are aligned across cells that can be aggregated, or an offset in multiples of slots between the PCell/PSCell and an SCell is configured to the UE. The maximum number of configured CCs for a UE is 16 for DL and 16 for UL. (3GPP TS 38.300 V17.4.0) 6.7 Carrier Aggregation In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below:

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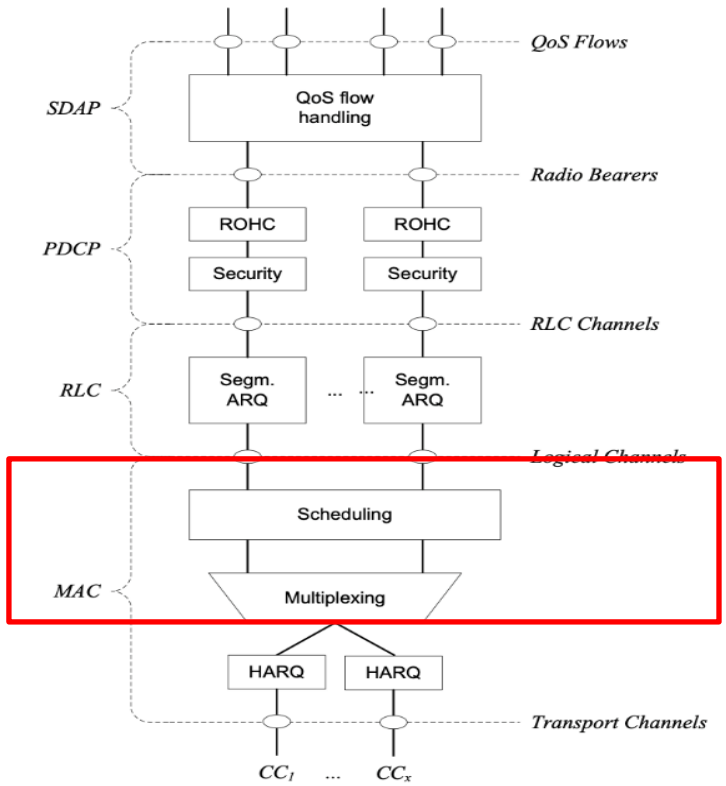
	- In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell. (3GPP TS 38.300 V17.4.0)  **Figure 6.7-2: Layer 2 Structure for UL with CA configured** (3GPP TS 38.300 V17.4.0)

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Claim 24	Public Documentation
	5G Carrier Aggregation is set to deliver a significant performance boost to mobile users but what is it and how does it work? The ongoing rollout of commercial 5G networks has significantly improved the experience for mobile subscribers around the world. As the ecosystem matures, a growing number of more advanced 5G Standalone (5G SA) networks will be central to delivering the speed and ultra-low latency to support cutting-edge applications. 5G Carrier Aggregation will play a vital role in underpinning the significant performance boost promised by 5G SA, representing an important milestone in the evolution of wireless infrastructure. Carrier Aggregation is a software functionality in Radio Access Networks and user devices which allows Mobile Network Operators (MNOs) to combine the capabilities of radio cells at distinct frequency allocations to enhance the end user experience. A key technology already in the LTE-Advanced networks, Carrier Aggregation enabled the evolution to Gigabit-LTE, achieving user data rates of more than 1 Gbps. However, in 5G networks, Carrier Aggregation will enable the evolution to multi-Gigabit-5G, reaching user data rates of about 4 Gbps and above. 5G Carrier Aggregation is also capable of improving the geographic availability, more commonly referred to as coverage, of high data rates. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/)

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	Carrier Aggregation in 5G Networks To accelerate rollout, the initial commercial 5G networks relied on the LTE infrastructure in radio access and the core network, referred to as 5G non-Standalone (5G NSA). 5G NSA allows MNOs to increase the bandwidth available to end users by bundling 4G and 5G carriers through 4G-5G Dual Connectivity. This allowed 5G users to benefit from existing LTE Carrier Aggregation capabilities with up to two 5G carriers aggregated alongside LTE carriers. To unlock the full capability of 5G, including ultra-low latency, reliability, and efficiency, MNOs are introducing 5G Standalone (5G SA) with a dedicated 5G Core and highly efficient 5G air interface, without dependency on existing LTE networks. The number of specified 5G SA Carrier Aggregation band combinations is increasing with each quarterly revision of the 3GPP specifications, enabling further options to achieve multi-Gigabit 5G data rates. These specifications are important to ensure interoperability between user equipment, such as smartphones, and networks. Between 2021 to 2022, the focus of the specifications for Carrier Aggregation in 5G SA in FR1 shifted from two component carriers to three and four component carriers. As the number of 5G frequency bands exceeds that of LTE-A, the possible Carrier Aggregation band combinations are greatly expanded, offering increased deployment options and flexibility for MNOs in different markets. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/)

Claim 24	Public Documentation
	Key benefits of 5G Carrier Aggregation Improved data speeds and throughput 5G Carrier Aggregation will boost the network performance to meet the requirements of data-hungry applications, such as augmented and virtual reality services, for both industrial and consumer use cases. Greater cell coverage As operators are looking to maximize the use of their available spectrum assets in different FDD and TDD bands, Carrier Aggregation is the key to reaching extended coverage range. This helps reduce the need to deploy new cell sites, bringing cost savings to operators. It also improves mobile user experience with consistent level of service across the network. Enhanced energy efficiency In 2019, the mobile industry made a milestone commitment to transform the sector and reach net zero carbon emissions by 2050. Carrier Aggregation has been demonstrated to reduce overall power consumption levels while increasing throughput and maintaining high service levels. This indicates that the technology could contribute to reducing overall energy usage and the mobile industry's carbon footprint. Improved coverage can also contribute to longer battery life for individual devices, requiring less frequent charging. Greater ROI According to data from GSA, the total amount raised in 2021 from spectrum auctions and assignments reached at least $140.1Bn. Radio spectrum is a finite and extremely valuable resource, representing a considerable financial burden for most MNOs. Therefore, with ever increasing demands for bandwidth, utilising this spectrum in the most efficient way becomes a top operational priority. 5G CA represents one of the most effective methods for MNOs to get the most from their outlay by maximising spectral efficiency. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/) Samsung Galaxy users in the United States will now enjoy faster 5G speeds, all thanks to T-Mobile's carrier aggregation technology. At the Mobile World Congress 2023 event in Barcelona, T-Mobile announced the successful deployment of 5G carrier aggregation on its standalone 5G network.

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	Ericsson, Nokia, Qualcomm Technologies, Inc., and Samsung teamed up with T-Mobile in the completion of the 5G Carrier Aggregation tech. The phone used for the project was a Samsung Galaxy S23 series model. Consequently, T-Mobile customers with a Galaxy S23, Galaxy S23+, or Galaxy S23 Ultra will be the first to benefit from four-carrier aggregations later this year. (https://www.sammobile.com/news/t-mobile-carrier-aggregation-5g-samsung-galaxy-s23/) # AT&T Quietly Lights Up Carrier Aggregation in Chicago ***Mar 6, 2014, 12:10 PM by Eric M. Zeman*** ***updated Mar 7, 2014, 7:32 AM*** AT&T has improved its LTE network in Chicago and several other markets by using an LTE-Advanced technique called Carrier Aggregation. GigaOm confirmed the soft launch with AT&T SVP of Network Technologies Kris Rinne. With Carrier Aggregation, AT&T has combined the channels of its existing spectrum to double the capacity. AT&T is running LTE in both the 700MHz and AWS bands in Chicago. By aggregating the channels together, AT&T can deliver theoretical peak download speeds of 110Mbps to devices with the proper radio support. At the moment, AT&T is selling only one device with Carrier Aggregation, the Unite mobile hotspot. The Samsung Galaxy S5 is expected to be the first smartphone to support Carrier Aggregation in the U.S. AT&T did not name the other two markets that have access to Carrier Aggregation, but said that more markets on are on the way. Sprint, T-Mobile, and Verizon Wireless are all in various stages of deploying Carrier Aggregation in their own LTE networks. (https://www.phonescoop.com/articles/article.php?a=13751) # AT&T: We are deploying 3-channel carrier aggregation on LTE network By **Mike Dano** . Sep 14, 2016 3:37pm

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	AT&T confirmed to *FierceWireless* that it too is deploying three-channel carrier aggregation on its LTE network. The news indicates AT&T is joining the rest of the nation's Tier 1 carriers in deploying the technology. "We're currently in the process of deploying 3-way carrier aggregation on our network," said AT&T spokesman Steven Schwadron. "AT&T started strategically deploying LTE-A in early 2014 and now we cover with LTE-A the vast majority of our customers in our LTE coverage area. We're also adding also additional spectrum and equipment on an ongoing basis to further boost our network performance." Schwadron added that AT&T currently sells 26 devices that are "LTE-A capable," and that the carrier lists them on its website. Schwadron added that, while LTE-Advanced peak speeds can be significantly higher than LTE speeds, "performance will depend on many factors including location and network traffic." Importantly, though, Schwadron declined to provide any further details, including what spectrum bands AT&T is combining through carrier aggregation and where the service is available. He said only that AT&T is deploying the technology into "high-density, high-traffic areas." AT&T's acknowledgement that it is deploying carrier aggregation isn't much of a surprise. AT&T's John Donovan said in 2014 that the operator would deploy carrier aggregation technology where it can, depending on how much spectrum it has available to meld together. Further, in 2015, AT&T's Tom Keathley told *FierceWireless* that AT&T had expanded its use of carrier aggregation to include major markets such as New York, San Francisco and Dallas. However, AT&T's admission that it is deploying three-channel carrier aggregation is noteworthy since much of the industry's discussion on the topic has so far focused on two-channel carrier aggregation. Carrier aggregation technology allows wireless network operators to essentially glue together transmissions across different spectrum bands in order to provide faster download speeds. For example, AT&T could use the technology to meld transmissions across its 700 MHz and AWS spectrum bands via two-channel carrier aggregation. Three-channel aggregation would add another chuck of spectrum, such as transmissions over PCS spectrum, to the transmission. Of course, AT&T isn't alone in deploying three-channel carrier aggregation: Verizon, Sprint and T-Mobile have all said they too are either deploying it or will soon. Sprint last week confirmed to *FierceWireless* that it launched three-channel carrier aggregation in Chicago and Kansas City, merging transmissions across three different channels of its 2.5 GHz spectrum and providing speeds up to 200 Mbps. And T-Mobile has said it too is already offering three-channel carrier aggregation, though it did not say where. For its part, Verizon has said it is currently offering two-channel carrier aggregation in the 461 cities, and Verizon's Mike Haberman said the operator will also offer three-channel carrier aggregation in locations where it has sufficient spectrum. To be clear, though, three-channel carrier aggregation must be enabled both in the network and on the users' device.

(https://fiercewireless.com/wireless/at-t-we-are-deploying-3-channel-carrier-aggregation-lte-network)

AT&T Pushing Toward Four Carrier Aggregation, LAA in Second Half of This Year

By Diana Goovaerts | March 2, 2017

BARCELONA – U.S. wireless carrier AT&T is pushing toward the launch of four carrier aggregation in the second half of this year, including some configurations that utilize unlicensed spectrum via License Assisted Access (LAA).

AT&T Vice President of RAN and Device Design Gordon Mansfield on Thursday told Wireless Week the carrier is eyeing deployment of four carrier aggregation in the early second part of the year. The advancement will be made via a software upgrade to the carrier's network, he said, and is part of the carrier's push toward gigabit speeds.

"With the spectrum positions that the operators have in the U.S., you've got to bring together some unlicensed spectrum as well (to hit gigabit speeds)," Mansfield said. "You can get close, you can get up to several hundred with just the macro network and the licensed spectrum, but the way you get to a gigabit is you use licensed spectrum with 4×4 MIMO and 256-QAM and you bring in LAA with unlicensed carriers. And in that case it will actually be 4CA."

According to Mansfield, four carrier aggregation will be used in conjunction with technologies like 256-QAM and 4×4 MIMO to help reach 1 Gbps or more on the network.

In areas where the carrier has a densely built network with small cells, Mansfield said four carrier aggregation with LAA will be used. But in the macro network, he said, four carrier aggregation will be on licensed bands.

While devices today currently only support one of the three aforementioned technologies at a time, Mansfield indicated devices are headed down the pipe as soon as in the second quarter that will have baseband modems capable of supporting all simultaneously. Mansfield declined to name the vendors who are planning such releases.

Mansfield specified, though, that some capabilities will be available on the device right out of the box. Others, like LAA, will be added via an over the air software update pushed out over the network later in the year, he said. (https://www.5gtechnologyworld.com/att-pushing-toward-four-carrier-aggregation-laa-in-second-half-of-this-year/)

Claim 24	Public Documentation
	# AT&T in early 2020: results show excellent speeds on both 5G and LTE Dave Andersen, Apr 23, 2020 **AT&T delivered faster speeds in 51 out of 55 markets tested to date in the first half of 2020.** With our testing efforts currently on hold due to the COVID-19 pandemic, we thought now would be a perfect time to take a look at how the carriers have performed across the 55 markets we've tested so far in the first half of 2020. We'll soon publish carrier-specific reports with overviews of performance for both 5G and 4G LTE in 1H 2020, and to kick things off, we'll start with AT&T. AT&T has deployed its 5G using 850 MHz low-band spectrum in several cities across the US, and the carrier has shown particularly impressive gains since our last round of testing in the second half of 2019. While AT&T's median download speeds on 4G LTE were already fast in most metros across the country in 2019, the carrier stepped up even more in the first half of 2020. We found excellent and improved download speeds on the carrier's 4G LTE network in the 55 markets we completed testing before we paused our scouting efforts, and AT&T's low-band 5G is also providing generally fast speeds (though not as fast as Verizon's mmWave 5G). This strong showing by AT&T can't entirely be chalked up to its 5G service, however. AT&T has been investing heavily over the past 18 months to bolster its already robust 4G LTE network. AT&T erected new cell sites in cities across the country, added more spectrum layers, and utilized 5-carrier aggregation (5CA) on a wide scale paired with 4x4 MIMO technology to maximize its vast spectrum holdings and provide faster speeds. AT&T also reallocated some of the spectrum reserved for its FirstNet Public Safety network and began using it for general customers while still satisfying its commitments to first responders. In short, AT&T has taken numerous steps to upgrade its network as 5G deployments continue, and AT&T subscribers are reaping the rewards in the form of faster connectivity that should only get better as the carrier's 5G continues to expand and mature. **AT&T's advantage: widespread 5-carrier aggregation and 4x4 MIMO technology** A primary reason for AT&T's improved speed results in 2020 is the carrier's widespread usage of 5-carrier aggregation (5CA) technology. In short, 5CA allows AT&T to combine five separate channels to increase bandwidth and provide faster speeds. On top of its capacity gains from 5CA, the efficiency of each of those five channels is maximized by

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	AT&T's utilization of 4x4 MIMO (Multiple Input Multiple Output) technology. MIMO refers to using multiple radio antennas at both the tower and the device, which helps improve capacity, coverage, and speed. In a 4x4 system, there are four antennas on both the tower and device, whereas with 2x2 MIMO, there are two antennas on the tower and device. If you think of each channel with 4x4 MIMO as utilizing four independent data streams, 5CA allows 20 independent streams to be combined, which results in greater bandwidth and, in turn, faster speeds. However, in order for a carrier to utilize 5CA, it's imperative to hold spectrum in five channels, and AT&T is in a unique position as the only carrier with the spectrum necessary for wide scale use of 5CA. In addition, AT&T also utilizes 256QAM, a spectrum modulation method that provides the highest possible level of spectral efficiency, and the carrier has expanded the reach of its Band 2 spectrum (the biggest of the five channels in 5CA) by adding new cell towers in cities across the US. AT&T has an advantage over the competition as the only carrier that can utilize 5-carrier aggregation on a wide scale in the US. Sprint and T-Mobile use 3-carrier aggregation, while Verizon uses 4-carrier aggregation technology. **The results: broad use of 5CA and 4x4 MIMO lead to much faster speeds** AT&T's speeds took a significant step forward during our first-half 2020 testing. Among the 55 cities we tested, AT&T's speeds improved in a whopping 51 of those markets, which was more than any other carrier (Sprint was the closest, with improvements in 47 markets). Even more impressive is that AT&T's median download speeds jumped by at least 15 Mbps in 22 of those markets, with increases of at least 10 Mbps in 37 out of 55 cities. Considering that 15 Mbps is generally fast by itself, an increase of 15 Mbps from a speed that was already fast can profoundly change the end-user experience. (https://rootmetrics.com/en-US/content/att-early-2020-performance-review) # 5-carrier aggregation gives AT&T network edge – RootMetrics By **Bevin Fletcher** . Apr 24, 2020 4:45pm AT&T delivered speed gains across 51 markets in the early part of 2020, with its wide-scale use of 5-component carrier aggregation and 4x4 MIMO giving it an edge over competition, according to RootMetrics. RootMetrics temporarily suspended its network testing but in the meantime is publishing carrier-specific reports on 4G LTE and 5G performance in the first half of 2020.

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	AT&T's speeds improved significantly in 51 out of 55 markets in RootMetrics' testing, outpacing every other carrier. Speed performance on AT&T's network jumped more than 30 Mbps in four cities at the start of 2020, compared to the end of 2019. RELATED: Verizon grabs RootMetrics awards in Los Angeles The biggest increase was seen in Ogden, Utah, where median download speeds spiked 37 Mbps from 38.2 Mbps in 2019 to 75.2 Mbps in early 2020. Markets rounding out the top five for AT&T's most improved speeds include Minneapolis, Cincinnati, Charleston, South Carolina, and Allentown, Pennsylvania. In 37 of the 55 markets tested, speeds jumped at least 10 Mbps compared to 2019, and at least 15 Mbps in 22 markets. "Considering that 15 Mbps is generally fast by itself, an increase of 15 Mbps from a speed that was already fast can profoundly change the end-user experience," the report noted. RootMetrics' tests done last year only connected to AT&T's 4G LTE, while the 2020 results connected to the carrier's low-band 5G where available. In the latest test period, AT&T's network recorded median download speeds above 50 Mbps in 23 markets, compared to just three markets in the second half of 2019. At the start of this year, only two cities registered speeds under 20 Mbps. AT&T is moving forward with its low-band 5G rollouts, just this week expanding to 90 additional cities, but RootMetrics called out the carrier's heavy investment over the last 18 months to enhance its already strong 4G LTE network. RELATED: 5G a 'mixed bag' as Verizon gets high speeds, T-Mobile offers better coverage – RootMetrics "AT&T erected new cell sites in cities across the country, added more spectrum layers, and utilized 5-carrier aggregation (5CA) on a wide scale paired with 4x4 MIMO technology to maximize its vast spectrum holdings and provide faster speeds," RootMetrics reported. "AT&T also reallocated some of the spectrum reserved for its FirstNet Public Safety network and began using it for general customers while still satisfying its commitments to first responders." AT&T is in a unique position to use five-component carrier aggregation (5CA), according to the testing company, a technology which requires and enables it to combine five separate channels for increased capacity. "AT&T has an advantage over the competition as the only carrier that can utilize 5-carrier aggregation on a wide scale in the U.S.," according the report. That compares to Sprint and T-Mobile's use of 3-carrier aggregation, while Verizon uses 4-component carrier aggregation. While 5-carrier aggregation is helping enhance AT&T's speeds over low-band spectrum, 8-component carrier aggregation (8CC) has been cited in work to hit record 5G speeds using millimeter wave spectrum.

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	In lab tests in February, Ericsson alongside Qualcomm, used 8CC to aggregate 800 MHz of millimeter wave spectrum and achieve a record 5G speed of 4.3 Gbps. RELATED: Verizon works with Samsung, Qualcomm to achieve 4.2 Gbps on its 5G network Verizon, meanwhile, worked with Samsung and Qualcomm earlier this year, using the technology to aggregate 800 MHz of 28 GHz mmWave spectrum and hit speeds of 4.2 Gbps on its live 5G network in Texas. Verizon SVP of Technology Planning Adam Koeppe said at the time that 8-channel carrier aggregation using mmWave would be widely available on the carrier's network this year. In terms of RootMetrics' latest report, the company didn't test AT&T's 5G+ network, which was just recently opened up to consumers and leans on high-band millimeter wave instead of low-band spectrum. Out of the 55 markets, AT&T's low-band flavor of 5G still delivered strong results. That includes Philadelphia, which ranked the fastest with median 5G download speeds of 94.5 Mbps – though limited availability of just 1.6%. "AT&T's network investments have clearly paid dividends for its subscribers on both 5G and 4G LTE," RootMetrics concluded. "As more and more 5G devices become available, consumers will find even faster speeds thanks not only to 5G, but also because some 5G-ready smartphones can take advantage of AT&T's pairing of wide-scale 5CA with 4x4 MIMO." (https://www.fiercewireless.com/operators/widespread-5-carrier-givesat-t-network-edge-rootmetric) **April 18, 2023** Taking 5G to the Next Level with Standalone 5G By Jason Sikes, AVP Device Architecture *AT&T Labs makes industry-first 5G SA Uplink 2-CA data connection in the U.S. to improve upload speeds, with additional speed and other upgrades in the works* AT&T is architecting tomorrow's wireless network to ***connect people to greater possibility***. As engineers, we design, build, test, refine and repeat so that you can get more out of your 5G connection and developers can build and deploy the next generation of apps and services. A key part of this evolution is the critical transition phase we are entering in scaling from 5G non-standalone (NSA) to 5G standalone (SA).

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	How does Standalone take 5G to the next level? Unlike 5G NSA that still relies on a 4G LTE core, 5G SA uses a dedicated 5G core that can unlock capabilities like faster upload speeds, ultra-low latency, ultra-high reliability and edge functions. This technology will be key to business opportunities like the next generation of connected cars. We have said that we plan to deploy Standalone 5G when the ecosystem is ready, and AT&T is charging forward to advance SA ecosystem readiness. Businesses and developers will be some of the first to take advantage of the new technologies standalone 5G enables as we continue to move from research & development to their deployment. **Uplink: where challenge meets opportunity** This new age of connectivity is not only about consuming more content but also generating more content than ever before. Demand for uplink capacity and speed continues to increase, about 30% a year in AT&T's mobility network. Whether you are uploading large files, on a video call with family, live streaming, cloud gaming or using extended reality applications, the network is facing surging upstream traffic demands it never has before. Our latest network innovations are complex but are all about helping meet this new demand. Just a few weeks ago, we completed the **first 5G SA Uplink 2-carrier aggregation data call in the U.S.** Carrier aggregation (CA) means we are combining or "aggregating" different frequency bands to give you more bandwidth and capacity. For you, this means faster uplink transmission speeds. *Think of this as adding more lanes in the network traffic highway*. No one in the U.S market has successfully aggregated two carriers in 5G SA uplink – until now. This is part of our ongoing effort to provide greater reliability for our customers. The test was conducted in our labs with Nokia's 5G AirScale portfolio and MediaTek's 5G M80 mobile test platform. We aggregated our low-band n5 and our mid-band n77 spectrum. Compared to our low-band n5 alone, we saw a 100% increase in uplink throughput by aggregating our low-band n5 with 40MHz of our mid-band n77. Taking it a step further, we achieved a 250% increase aggregating 100MHz of n77. The bottom line? We achieved incredible upload speeds of over 70 Mbps on n5 with 40MHz of n77 and over 120 Mbps on n5 with 100MHz of n77. While carrier aggregation is like adding more traffic lanes in the highway, adding another vehicle to carry traffic is another way we are managing surging uplink demand. We are doing this via a **two-layer uplink MIMO** on time division duplex (TDD) in our mid-band n77. MIMO combines signals and data streams from multiple antennas ("vehicles") to improve signal quality and data rates. This feature will not only improve uplink throughput but also enhance cell capacity and spectrum efficiency. **Network design and device readiness go hand in hand**

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	Although we continue to make progress in enhancing uplink coverage, we haven't forgotten about the downlink. Enhanced downlink and uplink carrier aggregation capabilities work together to bring the 5G SA performance today's technologies need. Last fall, we completed a **5G SA four component carrier downlink** call by combining two FDD carriers and two TDD carriers. These capabilities allow AT&T devices to aggregate our mid-band n77 in the C-Band and 3.45GHz spectrum ranges. Compared with low band and mmWave spectrum, mid-band n77 provides a good balance between coverage and speed. This follows the **5G SA three component carrier downlink feature** that we introduced last year to 2022 AT&T Flagship devices which combines one frequency division duplex (FDD) carrier and two TDD carriers. In the coming months, AT&T will also enable **5G New Radio Dual Connectivity (NR-DC)**, aggregating our low and mid-band spectrum with our high-band mmWave spectrum on 5G SA. Our labs have achieved 5G NR-DC downlink throughput speeds of up to 5.3Gbps and uplink throughput speeds of up to 670Mbps. This technology will help provide high-speed mobile broadband for both downlink and uplink in stadiums, airports, and other high-density venues. The 5G SA ecosystem is rapidly evolving, with new technologies and capabilities being introduced to provide differentiated experiences. Here are some features that are on the horizon for 5G SA: • Specialized Network Services – think network slicing, precision location, private routing, etc. – for tailored network solutions to meet specific user requirements; • Non-terrestrial network solutions to supplement coverage in remote locations ; and • Reduced capability 5G (RedCap) for a new generation of 5G capable wearables, industrial IoT or wireless sensors and other small form factor consumer devices. AT&T is dedicated to being the best connectivity provider. The 5G SA ecosystem is rapidly evolving, with new technologies and capabilities being introduced to set the foundation for next generation applications and services. (https://about.att.com/blogs/2023/standalone-5g-innovations.html) # AT&T spectrum aggregation industry first ups 5G ante **Dan Meyer** | Executive Editor. April 19, 2023 1:00 PM AT&T tested spectrum aggregation models on the oft-overlooked uplink channel that the carrier claimed was an industry first and resulted in network speeds that could help meet growing 5G traffic demands.

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	Jason Sikes, AVP for device architecture at AT&T, explained in a blog post that the carrier completed an uplink data call running on its 5G standalone (SA) network core that aggregated two different spectrum frequency bands. The test was in AT&T's labs using Nokia's 5G AirScale equipment running on MediaTek's mobile test platform. Sikes explained in an email to SDxCentral that the test used 10-megahertz of AT&T's low-band 850 MHz spectrum combined with varying amounts of the carrier's C-band spectrum. With 40-megahertz of C-band spectrum the carrier was able to increase uplink speeds by 100% to more than 70 Mb/s compared with just the base 850 MHz spectrum. It witnessed a 250% increase in speed to more than 120 Mb/s using 100-megahertz of C-band spectrum. "Think of this as adding more lanes in the network traffic highway," Sikes wrote in the blog. "No one in the U.S market has successfully aggregated two carriers in 5G SA uplink – until now." Sikes added that AT&T's mobile network has witnessed a 30% increase in uplink capacity demand per year. "This new age of connectivity is not only about consuming more content but also generating more content than ever before," he noted of the increase. "Whether you are uploading large files, on a video call with family, live streaming, cloud gaming or using extended reality applications, the network is facing surging upstream traffic demands it never has before." The latest test followed one conducted by the carrier last fall that involved a four-channel downlink call that traversed its 5G SA network. That call aggregated a pair of frequency division duplex (FDD) carriers and a pair of time division duplex (TDD) carriers running in the C-band and the 3.45 GHz spectrum bands. FDD is where different bands of frequency are used by users; one for uplink and the other for downlink. TDD is where one frequency band will be used for uplink and downlink, switching between the two from moment to moment. Sikes also noted that AT&T was deploying a "two-layer uplink" multiple-input, multiple output (MINO) technology on TDD across its C-band spectrum. "This feature will not only improve uplink throughput but also enhance cell capacity and spectrum efficiency," he wrote, though he further added that the carrier did not use MIMO during the most recent uplink test. The carrier is planning to launch 5G New Radio Dual Connectivity (NR-DC) capabilities "in the coming months." This will allow for the aggregation of low- and mid-band spectrum with AT&T's millimeter-wave (mmWave) spectrum using the 5G SA core. Sikes noted this capability has resulted in lab test downlink speeds up to 5.3 Gb/s and uplink speeds up to 670 Mb/s. "This technology gives customers high-speed mobile broadband for both downlink and uplink in stadiums, airports and other high-density venues," Sikes wrote. In the follow-up email, Sikes added that "over time, private 5G and fixed wireless will benefit from these uplink and downlink enhancements."

Claim 24	Public Documentation
	(https://www.sdxcentral.com/articles/analysis/att-spectrum-aggregation-industry-first-ups-5g-ante/2023/04/) WHY CHOOSE NOKIA 5G CARRIER AGGREGATION? Together with the leading mobile network operators across the world and the user equipment ecosystem, we have commercially introduced two component, three component and four component 5G Carrier Aggregation to enable Multi-Gigabit 5G on sub-6 GHz frequency allocations. We also have Carrier Aggregation commercially available for high-band. On millimeter wave spectrum, Carrier Aggregation with eight component carriers in downlink and four component carriers in uplink enables reaching even higher data rates. Nokia 5G Carrier Aggregation: • Works in 5G Non-Standalone and 5G Standalone in the same cells for smooth migration from NSA to SA • Boosts 5G performance • By aggregating low-band carriers for coverage and mid-band carriers for capacity, helps deliver Multi-Gigabit user data speeds already today. 5G Carrier Aggregation is software running on the baseband unit, easy to activate in Nokia 5G networks. The supported Carrier Aggregation band combinations are following the quarterly 3GPP specification updates. Our quarterly software updates ensure the best possible band combination support, and bring more flexibility for mobile operators to optimize their network coverage and capacity. Nokia 5G Carrier Aggregation works with massive MIMO and dynamic spectrum sharing, enabling a further capacity boost on mid-band and more flexibility for low-band aggregation. Nokia AirScale ensures uncompromised RF bandwidth for efficient multi-carrier sub-6 GHz Carrier Aggregation. Additionally, our AirScale baseband is optimized for providing the processing capacity and scalability for multi-carrier, large bandwidth Carrier Aggregation.

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	(https://www.nokia.com/networks/mobile-networks/carrier-aggregation/) # Ericsson spearheads 5G carrier aggregation milestones with key partners Ericsson has achieved groundbreaking milestones for carrier aggregation in 5G New Radio (NR) technology together with key customers and ecosystem partners. Ericsson has recently pushed 5G carrier aggregation (5G CA) technology to new levels after a series of successful interoperability tests with customers including T-Mobile and Optus, and ecosystem partners such as Qualcomm and MediaTek. The interoperability tests use carrier aggregation to extend the coverage of 5G, boost network capacity, and increase data speeds. Ericsson's collaboration with partners has so far resulted in several 5G firsts: • World's first 5G standalone (SA) data session with 5G CA on a commercial smartphone completed with T-Mobile, LG and MediaTek. With 5G CA, T-Mobile can combine its different 5G spectrum bands – starting with 2.5 GHz mid-band and 600 MHz low-band – boosting speeds and increasing the footprint of T-Mobile's mid-band 5G. It's also a key step in expanding T-Mobile's nationwide standalone architecture 5G network by increasing SA 5G capacity and speeds. (October 2020) • A 2300 + 3500MHz 5G Non-Standalone Carrier Aggregation call made by Optus using Ericsson technology and Samsung's Galaxy S20 5G handset range. The call showed the benefit of using both spectrum frequencies simultaneously, namely, a significant increase in the average and peak 5G speeds that customers, with an eligible handset, will benefit from as the capability becomes available. (August 2020) • First to complete all three combinations of NR time division duplex (TDD) and frequency division duplex (FDD) carrier aggregation (CA) together with MediaTek. The companies carried out a 5G SA data call by aggregating 20MHz on FDD spectrum and 100MHz on TDD spectrum with MediaTek's Dimensity 1000+ chipset at the Ericsson Lab in Kista. (September 2020) • Completed pioneering interoperability tests for 5G SA carrier aggregation across both FDD/TDD and TDD/TDD bands together with Qualcomm Technologies. 5G CA allows service providers to use multiple sub-6 GHz spectrum channels simultaneously to transfer data between base stations and a 5G mobile device. (August 2020)

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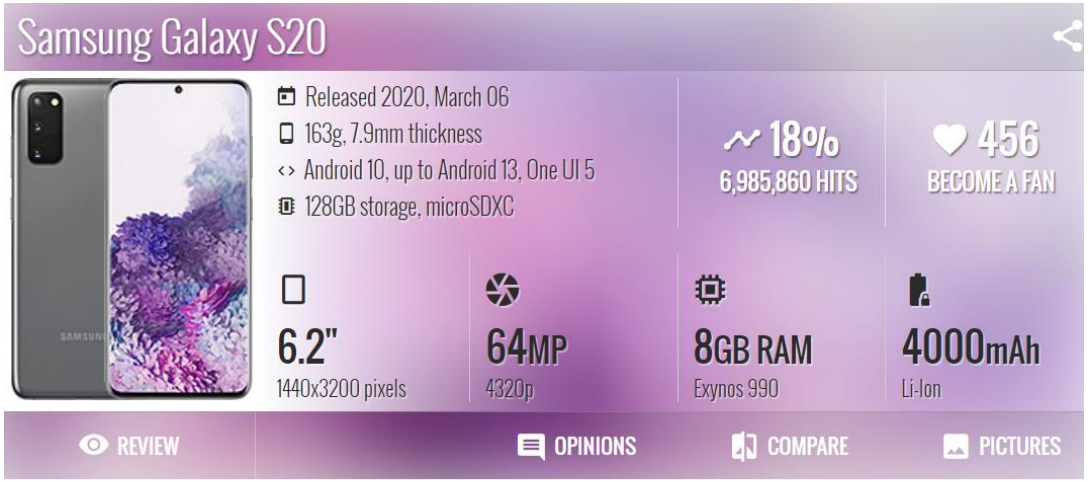
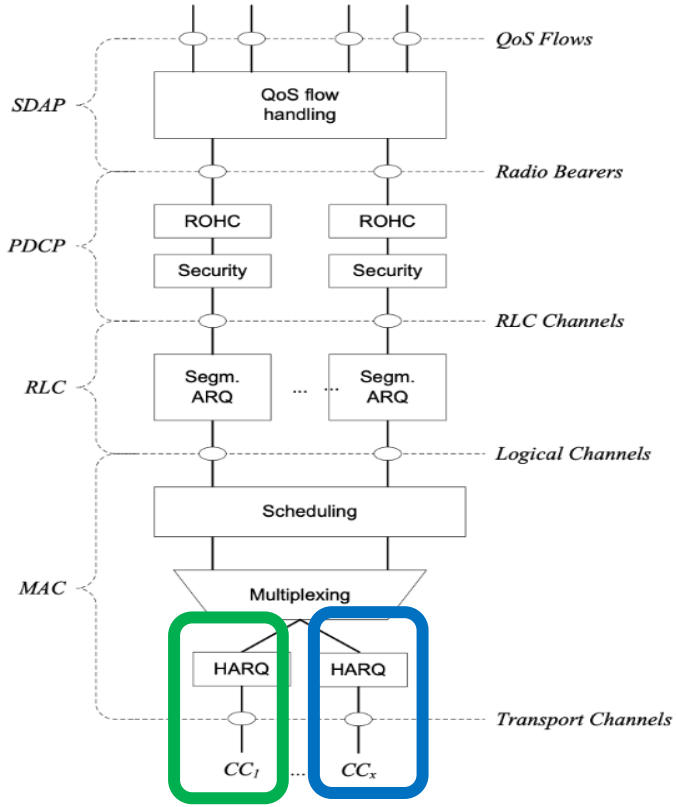
	Per Narvinger, Head of Product Area Networks, Ericsson says: "From technology development to wider area deployments, Ericsson continues to spearhead 5G innovation with customers and industry partners. To maximize the full potential of the mid-band spectrum, we've developed 5G NR carrier aggregation solutions that will help our customers deploy a better 5G with greater coverage, increased capacity and higher data speeds. These solutions will extend the coverage of the high capacity mid-band spectrum. By enabling peak speeds, coverage and capacity, 5G carrier aggregation will be a real game-changer." Ericsson's 5G NR carrier aggregation solution will be commercially available in the fourth quarter of 2020 with a global rollout expected during 2021. (https://www.ericsson.com/en/news/2020/10/5g-carrier-aggregation)

Claim 24	Public Documentation
	 Also available with 5G NETWORK — Technology: GSM / CDMA / HSPA / EVDO / LTE (COLLAPSE) 2G bands: GSM 850 / 900 / 1800 / 1900 - SIM 1 & SIM 2 (Dual SIM model only) CDMA 800 / 1900 & TD-SCDMA 3G bands: HSDPA 850 / 900 / 1700(AWS) / 1900 / 2100 CDMA2000 1xEV-DO 4G bands: 1, 2, 3, 4, 5, 7, 8, 12, 13, 17, 18, 19, 20, 25, 26, 28, 32, 38, 39, 40, 41, 66 Speed: HSPA 42.2/5.76 Mbps, LTE-A (7CA) Cat20 2000/200 Mbps (https://www.gsmarena.com/samsung_galaxy_s20-10081.php)
[24a] a first down-converter circuit having a first input coupled to receive a first up-converted signal, a second input coupled to receive a first demodulation signal having a first RF frequency, and an output, wherein the first down-converter circuit outputs a first down-converted signal on the first down-converter output;	The Accused Instrumentalities include a first down-converter circuit having a first input coupled to receive a first up-converted signal, a second input coupled to receive a first demodulation signal having a first RF frequency, and an output, wherein the first down-converter circuit outputs a first down-converted signal on the first down-converter output. For example: **6.7 CARRIER AGGREGATION** In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below: - In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell.

Claim 24	Public Documentation
	 **Figure 6.7-2: Layer 2 Structure for UL with CA configured** ısed in the Accused Instrumentalities: (3GPP TS 38.300 V17.5.0)

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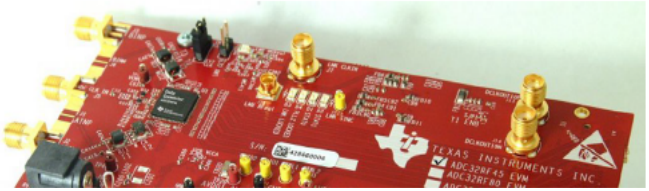
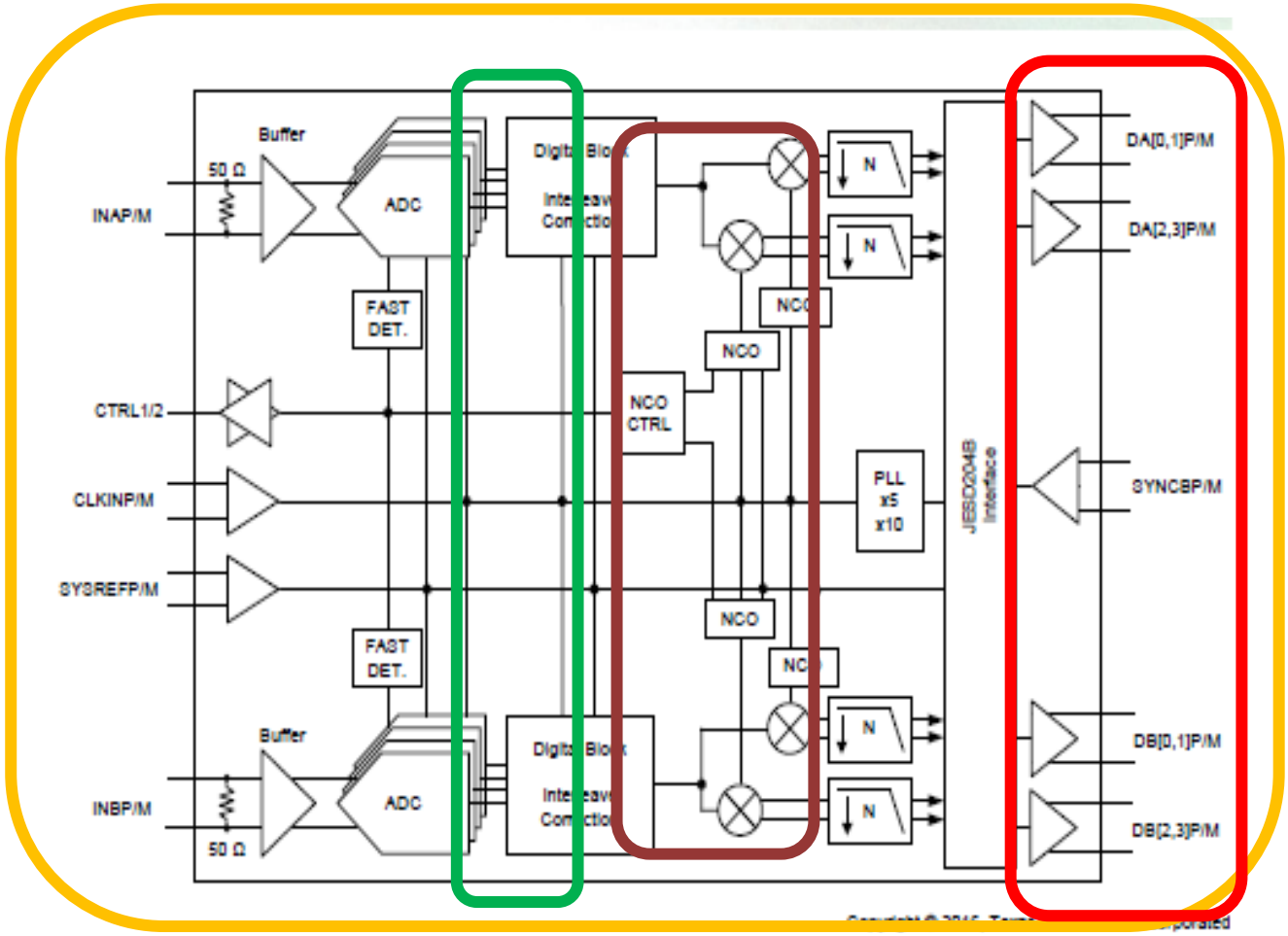
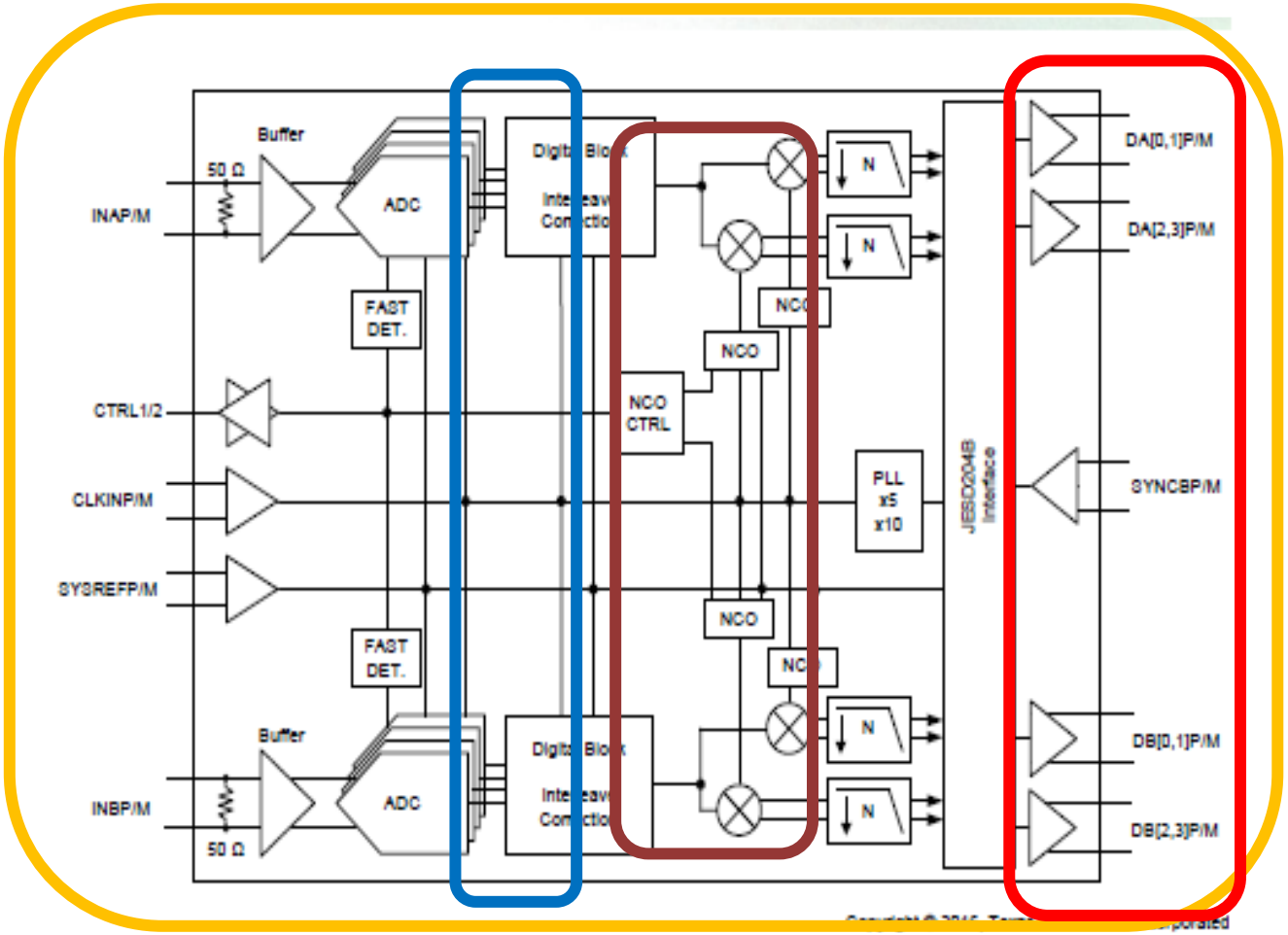
Petitioners' Ex. 1028
Ex.1028.0172

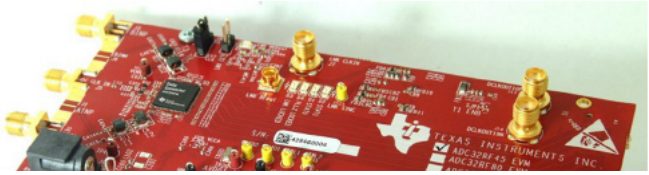
Claim 24	Public Documentation
	TI Designs ***Multi-Band RF Sampling Receiver Solution*** **TI Designs** The RF sampling receiver captures signals directly in the radio frequency (RF) band. In a multi-band application, the desired signals do not have a very wide band, but they are spaced far apart within the spectrum. The ADC32RF80 is a dual-channel, 14-bit, 3-GSPS RF sampling telecom receiver. The 3-dB input bandwidth is 3 GHz, and it captures signals up to 4 GHz. The device includes two digital down converters (DDC) per channel. The DDC offers decimation values from 8 to 32 and includes a 16-bit numerically controlled oscillator to move the captured signal down to digital baseband. With the high sampling rate of the ADC32RF80, the device captures a large swatch of the RF spectrum, which contains signals in multiple bands and potentially undesired interferers. The DDC independently mixes the desired bands to digital baseband. Decimation reduces the output data rate to a lower level and provides digital filtering around the desired band to eliminate interference and to improve signal-to-noise ratio (SNR) performance. This feature is critical for high-end telecommunication receivers that require high dynamic range. (https://www.ti.com/lit/ug/tidubq3/tidubq3.pdf) **Design Features** • 3-GSPS RF Sampling Receiver Solution • Low Noise, High Dynamic Range RF Sampling Receiver Solution • Programmable Decimation from 8 to 32 • Dual Digital Down-Converter With Independent Numerically Controlled Oscillators **Featured Applications** • Wireless Base Station Multi-Band or Multi-Mode Receiver • Multi-carrier GSM Receiver • Digital Pre-Distortion Feedback Receiver • Telecommunications Receiver • Carrier Aggregation Receiver 

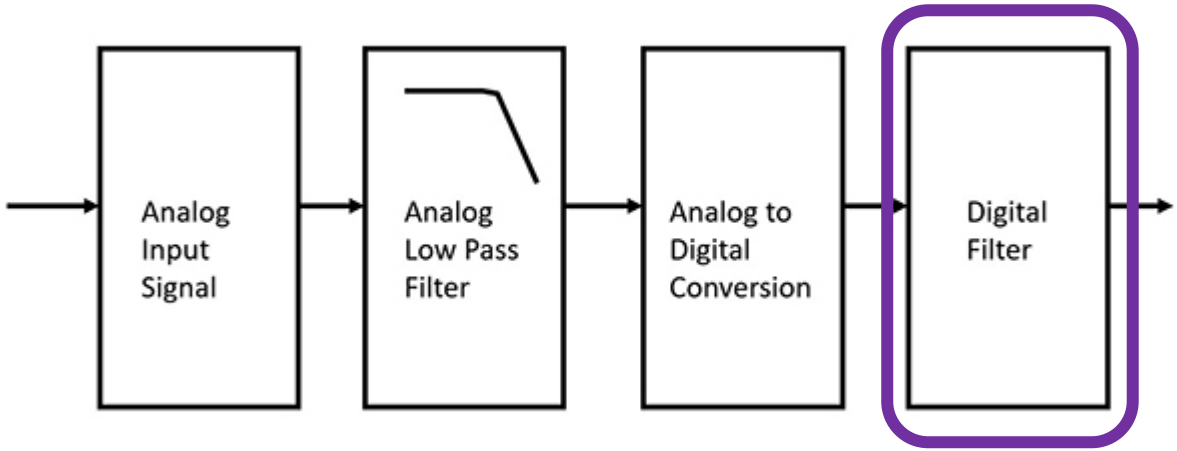
Claim 24	Public Documentation
	 (https://www.ti.com/lit/ug/tidubq3/tidubq3.pdf)

Claim 24	Public Documentation

	The Broadcom ACFM-2S13 is a quadplexer device that combines Band 1 and Band 3 duplexers into a single, miniature package. Band 4 duplexer is co-banded. The device features a single antenna connection, eliminating the need for antenna switching. High Isolation between bands enables the use of carrier aggregation.
	
	The ACFM-2S13 is designed with Broadcom's innovative filter capability which makes possible ultra-small, high-Q filters at a fraction of their usual size. Low Tx Insertion Loss of the ACFM-2S13 reduces power amplifier current, extending battery life. The device enhances receiver sensitivity and dynamic range with low Rx Insertion Loss and high rejection of Tx signals at the Rx ports.
	Features
	• Single antenna
	• High cross band isolation
	  • Enables carrier aggregation
	• Band 4 co-banding
	• Miniature size
	  • 2.0 x 2.5 mm footprint
	  • 0.710 mm typ. height
	• High Power Rating
	• Environmental
	  • RoHS 6 Compliant
	  • Halogen Free
	  • TBBPA Free
	
	(https://www.broadcom.com/products/wireless/demo-boards/acfm-2s13)

Claim 24	Public Documentation
[24b] a second down-converter circuit having a first input coupled to receive the first up-converted signal, a second input coupled to receive a second demodulation signal having a second RF frequency different than the first RF frequency, and an output, wherein the second down-converter outputs a second down-converted signal on the second down-converter output, wherein the first up-con verted signal comprises a first signal modulated at the first RF frequency and a second signal modulated at the second RF frequency; and	The Accused Instrumentalities include a second down-converter circuit having a first input coupled to receive the first up-converted signal, a second input coupled to receive a second demodulation signal having a second RF frequency different than the first RF frequency, and an output, wherein the second down-converter outputs a second down-converted signal on the second down-converter output, wherein the first up-con verted signal comprises a first signal modulated at the first RF frequency and a second signal modulated at the second RF frequency. For example, in receiver designs believed to be representative of those used in the Accused Instrumentalities:  (https://www.ti.com/lit/ug/tidubq3/tidubq3.pdf)

Claim 24	Public Documentation
[24c] a filter having an input coupled to the output of the first down-converter and the output of the second down-converter, and in accordance therewith, the filter receives the first and second down-converted signals.	The Accused Instrumentalities include a filter having an input coupled to the output of the first down-converter and the output of the second down-converter, and in accordance therewith, the filter receives the first and second down-converted signals. For example, in receiver designs believed to be representative of those used in the Accused Instrumentalities: ***TI Designs*** ***Multi-Band RF Sampling Receiver Solution*** TEXAS INSTRUMENTS **TI Designs** The RF sampling receiver captures signals directly in the radio frequency (RF) band. In a multi-band application, the desired signals do not have a very wide band, but they are spaced far apart within the spectrum. The ADC32RF80 is a dual-channel, 14-bit, 3-GSPS RF sampling telecom receiver. The 3-dB input bandwidth is 3 GHz, and it captures signals up to 4 GHz. The device includes two digital down converters (DDC) per channel. The DDC offers decimation values from 8 to 32 and includes a 16-bit numerically controlled oscillator to move the captured signal down to digital baseband. With the high sampling rate of the ADC32RF80, the device captures a large swatch of the RF spectrum, which contains signals in multiple bands and potentially undesired interferers. The DDC independently mixes the desired bands to digital baseband. Decimation reduces the output data rate to a lower level and provides digital filtering around the desired band to eliminate interference and to improve signal-to-noise ratio (SNR) performance. This feature is critical for high-end telecommunication receivers that require high dynamic range. **Design Features** • 3-GSPS RF Sampling Receiver Solution • Low Noise, High Dynamic Range RF Sampling Receiver Solution • Programmable Decimation from 8 to 32 • Dual Digital Down-Converter With Independent Numerically Controlled Oscillators **Featured Applications** • Wireless Base Station Multi-Band or Multi-Mode Receiver • Multi-carrier GSM Receiver • Digital Pre-Distortion Feedback Receiver • Telecommunications Receiver • Carrier Aggregation Receiver  (https://www.ti.com/lit/ug/tidubq3/tidubq3.pdf)

Claim 24	Public Documentation
	Analog versus digital filters If an analog engineer and digital engineer discuss filters, the digital engineer may dismiss analog. This would be a mistake. The filtering standard with any analog-to-digital (A/D) conversion is to have the analog LPF before the digital filter (Figure 1).  *Figure 1: A block diagram of an analog-to-digital signal chain with the analog filter before the digital filter. (Image source: DigiKey)* After the analog LPF attenuates higher frequencies above the bandwidth of interest, the ADC converts the signal into a digital word. Following this accomplishment, the digital filter can operate on the signal within the bandwidth of interest. (https://www.digikey.com/en/articles/why-and-how-to-use-digital-filters-for-analog-to-digital-conversions)