

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

LG ELECTRONICS, INC.

Petitioner

v.

CONSTELLATION DESIGNS, LLC

Patent Owner

US Patent No. 11,019,509

Issue Date: May 25, 2021

Title: Receivers Incorporating Non-Uniform Constellations with
Overlapping Constellation Point Locations

Inter Partes Review No.: IPR2023-00320

DECLARATION OF DR. BERTRAND HOCHWALD

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I, Dr. Bertrand Hochwald, declare as follows:

I. INTRODUCTION

1. I have been retained by LG Electronics, Inc. (“Petitioner” or “LG”) to serve as an independent expert consultant in the *Inter Partes* review (IPR) proceedings regarding U.S. Patent No. 11,019,509 (“the ’509 Patent” or LGE1001). I have been asked to consider the validity of claims 3-7, 13-17, and 24-28 of the ’509 Patent (the “Challenged Claims”). My opinions are set forth below.

2. I am being compensated at my normal rate of \$675/hour for all services rendered. My compensation is not contingent upon the results of my study, the substance of my opinions, or the outcome of any proceeding involving the challenged claims. I have no financial interest in the outcome of this matter or on the pending litigation between Petitioner and Patent Owner.

3. My analysis of the materials produced in this proceeding is ongoing and I will continue to review any new material that is provided. This declaration is indicative of only those opinions that I have formed to date. I reserve the right to amend, revise, and/or supplement my opinions stated herein based on any new information that may become available to me or my continuing analysis of the materials already provided.

II. QUALIFICATIONS

4. My qualifications for forming the opinions in this report are summarized here and also noted in my Curriculum Vitae (“CV”), which is submitted as Appendix A.

5. In 1995, I received a Ph.D. in Electrical Engineering from Yale University. My Ph.D. work involved the analysis and processing of electromagnetic and audio signals for the estimation of the location of electromagnetic and audio sources. In 1993, I received an M.A. in Statistics from Yale University. My primary area of study was Signal Processing and Communications. I received an M.S. in Electrical Engineering from Duke University in 1986, and a B.S. in Engineering from Swarthmore College in 1984.

6. I have twenty-six years of combined industry and academic experience in the research and design of hardware, software, and systems for various technologies, including electronic devices, sensors, signal and image processing, networking and wireless communications. I have worked in various industry jobs, including at the Department of Defense, Bell Labs, and a start-up in California before joining the University of Notre Dame in 2011. As I explain below, much of my work has been in the general areas of audio/video signal processing and communications.

7. My most recent appointment, starting in 2011, is with the University of

Notre Dame, where I am currently a Freimann Chaired Professor of Electrical Engineering. I have taught both graduate and undergraduate classes in signal processing, information theory, communications, and in systems theory. I have also taught courses in electronics, analog and digital signal sensing, processing, computation, and electronic forms of wireline and wireless networking and communications. My primary areas of research include such systems, sensors, communication system design and signal processing. I advise graduate students who are attaining Ph.D. degrees through research and coursework. My research work now includes processing of high data rate signals (similar to those used to transmit and receive coded signals) in communication systems.

8. An example of my current work at the University includes a project that I lead called RadioHound distributed spectrum sensor system for remote monitoring using radio signals (<https://wireless.nd.edu/research/radiohound-distributed-spectrum-sensing/>), which is a multi-year effort involving several students, faculty, and technicians. The RadioHound system captures data from hundreds of sensors and displays it in a real-time setting for human interpretation and assessment. This project, which is funded by government and industrial sponsors, involves the design of hardware sensors, and software communications transceivers. The project has become an educational and research tool used by laboratories inside and outside the

University of Notre Dame.

9. Prior to Notre Dame, I worked from 2005-2010 at Beceem Communications, a 4G WiMax and LTE cellular communication chipset start-up company in Santa Clara, California, where I was Chief Scientist and Vice President of Systems Engineering. I was an integral part of the chipset development team. Beceem was bought by Broadcom Corporation in 2010 and no longer exists as a separate company. Several aspects of channel coding and wireless communications for our products were developed within this team.

10. From 1996-2005, I worked at Lucent Bell Laboratories in New Jersey, where I was a Distinguished Member of the Technical Staff doing research into various communication and networking systems. For example, my work in Bell Labs included wireless communications and multi-antenna signal processing and coding.

11. Before Bell Laboratories, I was a Visiting Assistant Professor at the University of Illinois in Urbana-Champaign during the 1995-1996 school year, where I worked on a broad range of research topics related to signal processing and wireless communications.

12. Prior to completing my Ph.D., during 1986-1989, I worked at the Department of Defense as a system engineer for signal processing and wireless

communication systems. In this role, I designed wireless communication equipment for audio and video signal monitoring and processing. Much of this work is classified for security reasons.

13. As a result of my research, I have obtained 48 patents, and I have published more than one-hundred articles in scholarly journals, many of them within the journals of the Institute of Electrical and Electronic Engineers (IEEE), one of the premier societies for electrical engineers. I have been an invited and plenary speaker at several international conferences throughout the world and have received awards and recognition for my research and publications. An example relevant publication includes A. Ashikhmin, A. van Wijngaarden, Z. Haibo, B. Hochwald, *et al*, “Design and development of a terrestrial digital video broadcast demodulation core: An international collaborative effort,” *Bell Labs Technical Journal*, vol. 12, pp. 97-118, 2007.

14. Since 2012, I have engaged in consulting work as an expert in various litigation matters including acoustic echo cancelling, multi-antenna technologies, cellular and wireless local-area-net standards and technologies, and touch-screen technologies. I have served as an expert on behalf of both plaintiffs and defendants in patent cases. I have served as a technology expert in various aspects of the litigation process, including trade secret disputes, trial testimony, *Markman* hearings,

and IPRs.

15. I have had experience drafting and successfully prosecuting my own patents, and have worked with other technology experts as a co-inventor and co-author. Some of my patents deal with coding for multi-antenna communications. An example is US Patent No. 6,363,121, which designs multidimensional constellations with a unitary structure for transmission across multiple antennas.

III. MATERIALS CONSIDERED

16. All of the opinions contained in this declaration are based on the documents I have reviewed and my professional judgment, as well as my education, experience, and professional knowledge. I am not an attorney and I am not offering any legal opinions in this declaration.

17. In forming my opinions expressed in this declaration, I relied on the '509 Patent (LGE1001), the prosecution history of the '509 Patent (LGE1002), the prior art references cited herein, and other exhibits I have cited in this declaration. Some of the additional prior art references I reviewed include:

Prior Art References
U.S. Patent No. 11,019,509 (LGE1001)

Prosecution History for U.S. Patent No. 11,019,509 (LGE1002)
U.S. Provisional application No. 60/933,319 (“’319 Provisional” or LGE1015)
Giuseppe Caire, Giorgio Taricco, and Ezio Biglieri, <i>Bit-Interleaved Coded Modulation</i> , IEEE Transactions of Information Theory, vol. 44, no. 3, May 1998 (“Caire” or LGE1018)
Complaint Exhibit, <i>Constellation Designs, LLC v. LG Electronics, Inc. et al</i> , Case No. 2:21-cv-00448 (E.D. Tex.) (LGE1023)
U.S. Patent No. 7,978,777 (the ’777 patent or “LGE1027”)
ATSC Recommended Practice: Guidelines for the Physical Layer Protocol, Document no. A/327:2018 (“ATSC327” or LGE1028)
ATSC 3.0 Standard: Physical Layer Protocol, Document no. A/322:2017 (“LGE1029”)
Nabil Sven Loghin, Jan Zöllner, Belkacem Mouhouche, Daniel Ansorregui, Jinwoo Kim, and Sung-Ik Park, <i>Non-Uniform Constellations for ATSC 3.0</i> , IEEE Transactions on

Broadcasting, vol. 62, no. 1, March 2016 (“Loghin” or LGE1030)
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18. Counsel (Fish & Richardson) has informed me that I should consider these materials through the lens of a person of ordinary skill in the art (POSITA) related to the '509 Patent, and I have done so during my review of these materials. *See also infra* Sections VIII-X. The '509 Patent was filed on December 27, 2019, and claims priority from U.S. Provisional application No. 60/933,319, which was filed on June 5, 2007. LGE1001, cover. For the purposes of this declaration only, Counsel has indicated that I should use June 5, 2007 as the date of my analysis below.

IV. OVERVIEW OF CONCLUSIONS FORMED

19. This declaration explains the conclusions that I have formed based on my analysis. Based on my review of the Challenged Claims and above-noted materials considered, it is my conclusion that:

- Claims 3-7, 13-17, and 24-28 are obvious over '777 patent in view of ATSC327.

20. In support of these conclusions, I provide an overview of the references and combinations in Section IX and more detailed comments regarding the obviousness of the Challenged Claims in Section X.

V. LEVEL OF ORDINARY SKILL IN THE ART

21. In rendering the opinions set forth in this declaration, I was asked to consider the Challenged Claims and the prior art through the eyes of a POSITA as of June 5, 2007. I understand that the factors considered in determining the ordinary level of skill in a field of art include the level of education and experience of persons working in the field; the types of problems encountered in the field; the teachings of the prior art, and the sophistication of the technology as of June 5, 2007. I understand that a POSITA is not a specific real individual, but rather is a hypothetical individual having the qualities reflected by the factors above. I understand that a POSITA would also have knowledge from the teachings of the prior art, including the art cited below.

22. Taking these factors into consideration, a POSITA would have had at least a Master's degree in an academic area emphasizing electrical engineering or a similar discipline, and at least two years of experience in the field working with, teaching, or researching communication systems including the use of constellations in transmitting signals between devices. Alternatively, the person could also hold a more advanced degree, e.g., a Masters or Doctor of Philosophy degree in these academic disciplines, with less than two years work experience in the same discipline.

23. By June 5, 2007, my level of skill in the art was at least that of a

POSITA. I am qualified to provide opinions concerning what a POSITA would have known and understood at that time, and my analysis and conclusions herein are from the perspective of a POSITA as of that date.

VI. LEGAL PRINCIPLES

24. I am not an attorney and I have not been asked to express any legal opinions. I have been informed by Counsel and understand that:

- documents and materials that qualify as prior art can render a patent claim unpatentable as being anticipated or obvious; and
- all prior art references are to be looked at from the viewpoint of a POSITA, and that this viewpoint prevents one from using his or her own insight or hindsight in deciding whether a claim is anticipated or rendered obvious.

25. In connection with the analysis presented in this declaration, I considered the following legal standards that counsel for Petitioner provided to me.

A. Anticipation

26. I understand that patents or printed publications that qualify as prior art can be used to invalidate a patent claim as anticipated or as obvious.

27. I understand that, once the claims of a patent have been properly construed, the second step in determining anticipation of a patent claim requires a comparison of the properly construed claim language to the prior art on a limitation-

by-limitation basis.

28. I understand that a prior art reference “anticipates” an asserted claim, and thus renders the claim invalid, if all limitations of the claim are disclosed in that prior art reference, either explicitly or inherently (*i.e.*, necessarily present).

B. Obviousness

29. I understand that even if a patent is not anticipated, it is still invalid if the differences between the claimed subject matter and the prior art are such that the subject matter as a whole would have been obvious to a POSITA as of the earliest priority date of a patent.

30. I have been informed by Counsel and understand that a claim is unpatentable for obviousness and that obviousness may be based upon a combination of prior art references. I am informed by Counsel and understand that the combination of familiar elements according to known methods is likely to be obvious when it does no more than yield predictable results. However, I am informed by Counsel and understand that a patent claim composed of several elements is not proved obvious merely by demonstrating that each of its elements was, independently, known in the prior art.

31. I am informed by Counsel and understand that when a patented invention is a combination of known elements, a court determines whether there was

an apparent reason to combine the known elements in the fashion claimed by the patent at issue by considering the teachings of prior art references, the effects of demands known to people working in the field or present in the marketplace, and the background knowledge possessed by a POSITA.

32. I am informed by Counsel and understand that a patent claim composed of several limitations is not proved obvious merely by demonstrating that each of its limitations was independently known in the prior art. I am informed by Counsel and understand that identifying a reason those elements would be combined can be important because inventions in many instances rely upon building blocks long since uncovered, and claimed discoveries almost of necessity will be combinations of what, in some sense, is already known. I am informed by Counsel and understand that it is improper to use hindsight in an obviousness analysis, and that a patent's claims should not be used as a "roadmap."

33. I am informed by Counsel and understand that an obviousness inquiry requires consideration of the following factors: (1) the scope and content of the prior art, (2) the differences between the prior art and the claims, (3) the level of ordinary skill in the art, and (4) any so called "secondary considerations" of non-obviousness, which include: (i) "long felt need" for the claimed invention, (ii) commercial success attributable to the claimed invention, (iii) unexpected results of the claimed

invention, and (iv) “copying” of the claimed invention by others.

34. I have been informed by Counsel and understand that an obviousness evaluation can be based on a single reference or a combination of multiple prior art references. I understand that the prior art references themselves may provide a suggestion, motivation, or reason to combine, but that the nexus linking two or more prior art references is sometimes simple common sense. I have been informed by Counsel and understand that obviousness analysis recognizes that market demand, rather than scientific literature, often drives innovation, and that a motivation to combine references may be supplied by the direction of the marketplace.

35. I have been informed by Counsel and understand that if a technique has been used to improve one device, and a POSITA at the time of invention would have recognized that it would improve similar devices in the same way, using the technique is obvious unless its actual application is beyond his or her skill.

36. I have been informed by Counsel and understand that practical and common sense considerations should guide a proper obviousness analysis, because familiar items may have obvious uses beyond their primary purposes. I have been informed by Counsel and understand that a POSITA looking to overcome a problem will often be able to fit together the teachings of multiple prior art references. I have been informed by Counsel and understand that obviousness analysis therefore takes

into account the inferences and creative steps that a POSITA would have employed at the time of invention.

37. I have been informed by Counsel and understand that a proper obviousness analysis focuses on what was known or obvious to a POSITA at the time of invention, not just the patentee. Accordingly, I understand that any need or problem known in the field of endeavor at the time of invention and addressed by the patent can provide a reason for combining the elements in the manner claimed.

38. I have been informed by Counsel and understand that a claim can be obvious in light of a single reference, without the need to combine references, if the elements of the claim that are not found explicitly or inherently in the reference can be supplied by the common sense of a POSITA.

39. I have been informed by Counsel and understand that there must be a relationship between any such secondary considerations and the invention, and that contemporaneous and independent invention by others is a secondary consideration supporting an obviousness determination.

40. In sum, my understanding is that prior art teachings are properly combined where a POSITA having the understanding and knowledge reflected in the prior art and motivated by the general problem facing the inventor, would have been led to make the combination of elements recited in the claims. Under this analysis,

the prior art references themselves, or any need or problem known in the field of endeavor at the time of the invention, can provide a reason for combining the elements of multiple prior art references in the claimed manner.

41. I have been informed by Counsel and understand that in an *inter partes* review (IPR), “the petitioner shall have the burden of proving a proposition of unpatentability,” including a proposition of obviousness, “by a preponderance of the evidence.”

VII. CLAIM CONSTRUCTION

42. I understand that when considering the meaning of claims subject to *inter partes* review, one must consider the claim language. I understand that claim terms are generally given their plain and ordinary meaning, as would be understood by a POSITA in the context of the specification, the prosecution history, and other claims. I have applied the above principles in forming my opinions provided in this declaration.

VIII. OVERVIEW OF U.S. PATENT NO. 11,019,509 (LGE1001)

A. Patent Family of the ’509 Patent

43. The ’509 Patent, titled “Methodology and Method and Apparatus for Signaling with Capacity Optimized Constellations” was filed on December 27, 2019, and issued on May 25, 2021. LGE1001, cover page. I understand that:

- the '509 Patent issued from US Patent Application No. 16/728,384, and claims to be a continuation of application No. 16/206,991, filed on November 30, 2018, now US Pat. No. 10,567,980;
- US Pat. No. 10,567,980 is a continuation of US Patent Application No. 15/682,475, filed on Aug. 21, 2017, now US Pat. No. 10,149,179;
- US Pat. No. 10,149,179 is a continuation of US Patent Application No. 15/200,800, filed on Jul. 1, 2016, now US Pat. No. 9,743,292;
- US Pat. No. 9,743,292 is a continuation of US Patent Application No. 14/491,731, filed on Sep. 19, 2014, now US Pat. No. 9,385,832;
- US Pat. No. 9,385,832 is a continuation of US Patent Application No. 13/618,630, filed on Sep. 14, 2012, now US Pat. No. 8,842,761;
- US Pat. No. 8,842,761 is a continuation of US Patent Application No. 13/118,921, filed on May 31, 2011, now US Pat. No. 8,270,511;
- US Pat. No. 8,270,511 is a continuation of US Patent Application No. 12/156,989, filed on Jun. 5, 2008, now US Pat. No. 7,978,777; and
- US Pat. No. 7,978,777 claims priority from U.S. Provisional application No. 60/933,319, filed on June 5, 2007. *Id.*

44. 3-7, 13-17, and 24-28 of the '509 Patent are not entitled to the priority to of June 5, 2008 or June 5, 2007 for the reason set forth in paragraphs 61-97.

B. Background of the '509 Patent

45. The '509 Patent is directed to communication systems that use “geometrically-shaped constellations” that have a capacity approaching the Shannon limit. LGE1001, 2:21-25, Abstract. In communication systems, the term “‘constellation’ is used to describe the possible symbols that can be transmitted by a typical digital communication system.” *Id.*, 1:42-44. When a transmitter transmits data symbols, a “receiver attempts to detect the symbols that were transmitted by mapping a received signal to the constellation.” *Id.*, 1:44-46. The '509 Patent explains that the “minimum distance (d_{min}) between constellation points is indicative of the capacity of a constellation at high signal-to-noise ratios (SNRs),” so “constellations used in many communication systems are designed to maximize d_{min} ” to bring the constellation capacity closer to the Shannon limit. *Id.*, 1:46-50.

46. According to the '509 Patent, many communication systems have been designed to increase the capacity of a communication channel, or come near to the theoretical capacity known as the Shannon limit. LGE1001, 1:55-60. “The Shannon limit can be thought of as being based upon a theoretical constellation known as a Gaussian distribution [constellation], which is an infinite constellation where symbols at the center of the constellation are transmitted more frequently than symbols at the edge of the constellation.” *Id.*, 1:62-67. Known methods to designs

systems reaching the Shannon capacity limit include using coding techniques such as turbo codes or LDPC codes. *Id.*, 1:55-2:6.

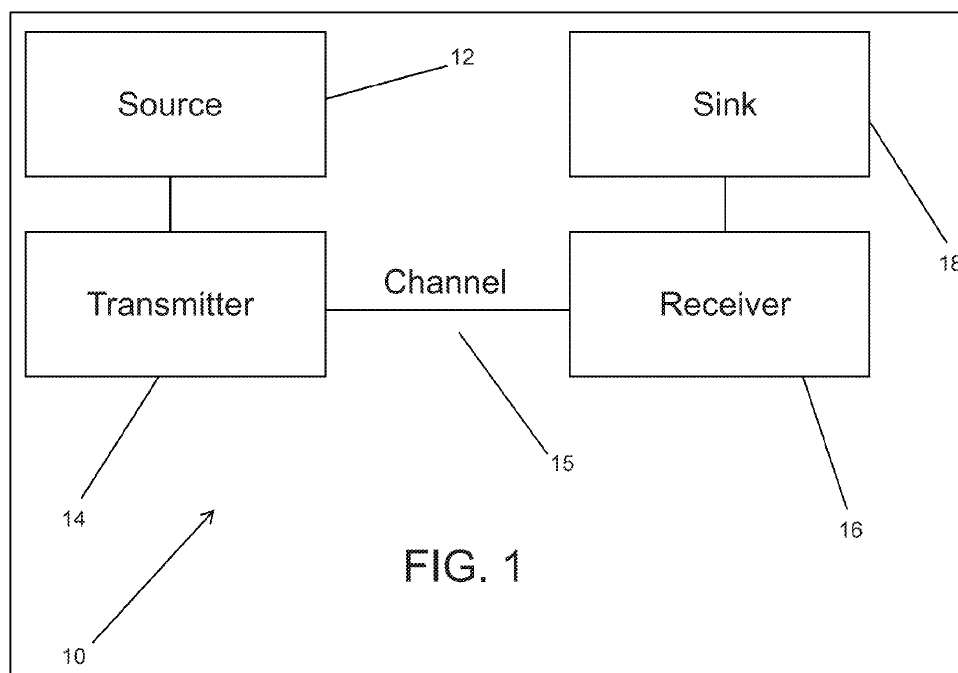
47. The '509 Patent acknowledges that using unequally spaced constellations to design systems approaching the Shannon capacity limit is not new. LGE1001, 1:55-2:17. One known system “uses unequally spaced constellations that are optimized to minimize the error rate of an uncoded system.” *Id.*, 2:6-9. “Another proposed system uses a constellation with equiprobable but unequally spaced symbols in an attempts[sic] to mimic a Gaussian distribution.” *Id.*, 2:10-12. Yet another known method “increases the dimensionality of a constellation or select a new symbol to be transmitted taking into consideration previously transmitted symbols.” *Id.*, 2:13-15. Although the '509 Patent contends that “constellation[s] were still designed based on a minimum distance criteria.” *Id.*, 2:15-17; known prior art systems that employed unequally spaced constellations without reliance on a minimum distance criteria also existed. *See infra* Sections IX, X.

C. Brief Description of the '509 Patent

48. The '509 Patent discloses “constructing a modulation such that the constrained capacity between a transmitter and a receiver approaches the Gaussian channel limit first described by Shannon.” LGE1001, 2:21-25. The '509 Patent discloses a method for locating points (in a one or multiple dimensional space) in

order to maximize capacity between the input and output of a bit or symbol mapper and demapper respectively.” *Id.*, 2:28-34.

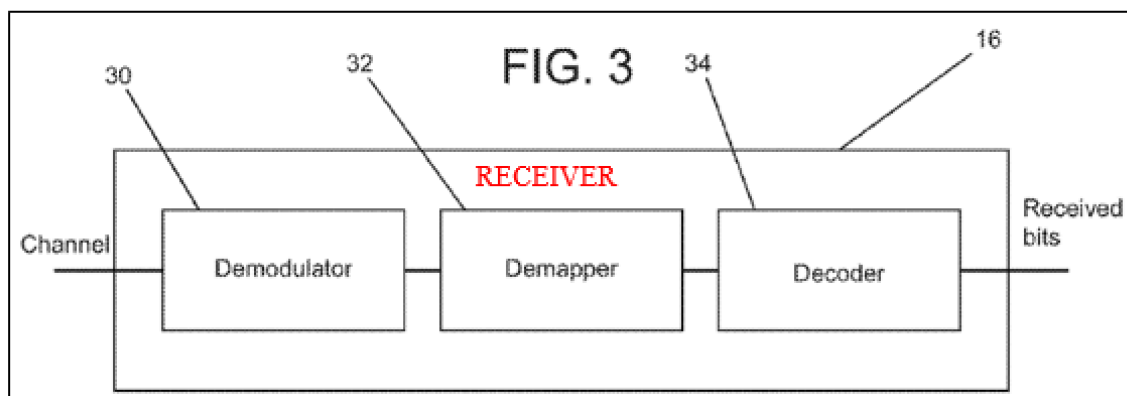
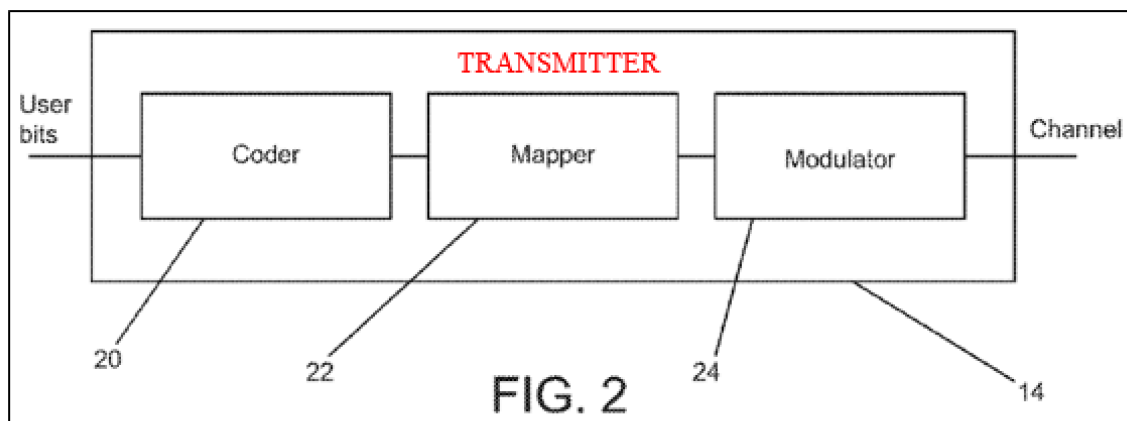
49. Figure 1 (reproduced below) shows a communication system 10 according to the '509 Patent, which includes “a source 12 that provides user bits to a transmitter 14,” which in turn “transmits symbols over a channel to a receiver 16 using a predetermined modulation scheme.” LGE1001, 5:30-35. Using knowledge of the modulation scheme, the receiver 16 decodes the signal and provides the decoded bits to a sink device 18 connected to the receiver 16. *Id.*, 5:35-38.



LGE1001, FIG. 1.

50. FIG. 2 (reproduced below) of the '509 Patent depicts the transmitter 14

and its components, which include a coder 20, a mapper 22, and a modulator 24. LGE1001, 3:45-46, 5:39-51. FIG. 3 (reproduced below) of the '509 Patent depicts the receiver 16 and its components, which include a demodulator 30, a demapper 32, and a decoder 34. LGE1001, 3:47-48, 5:52-60.



LGE1001, FIGS. 2-3.¹

51. The coder 20 of the transmitter 14 “receives user bits from a source and encodes the bits in accordance with a predetermined coding scheme,” such as a capacity approaching code (*e.g.*, turbo code, LDPC code) or other coding schemes that provide a coding gain. LGE1001, 5:39-45. A mapper 22 connected to the coder “maps the bits output by the coder to a symbol within a geometrically distributed signal constellation stored within the mapper” and “provides the symbols to a modulator 24, which modulates the symbols for transmission via the channel.” *Id.*, 5:46-51. The mapper of the transmitter encodes bits to symbols in a symbol constellation that “is a capacity optimized geometrically spaced symbol constellation that provides a given capacity at a reduced signal-to-noise ratio compared to a signal constellation that maximizes d_{min} .” *Id.*, 2:38-46, 2:51-55, 4:63-5:3. Signal-to-noise ratio (SNR) is “defined as the ratio of the average constellation energy per dimension to the average noise energy per dimension.” *Id.*, 7:53-54. The ’509 Patent explains that “capacity optimized constellation at low SNRs are geometrically shaped constellations that can achieve significantly higher performance gains (measured as

¹ Annotations to this and other figures in my declaration are indicated by colored text and/or marks.

reduction in minimum required SNR) than constellations that maximize d_{min} .” *Id.*, 8:24-29.

52. “Capacity measures that can be used in the selection of the location of constellation points include ... parallel decode (PD) capacity and joint capacity.” LGE1001, 5:6-8. The “PD capacity of a channel can be viewed in terms of the mutual information between the output bits of the encoder (such as an LDPC encoder) at the transmitter and the likelihoods computed by the demapper at the receiver,” and it is “influenced by both the placement of points within the constellation and by the labelling assignment.” *Id.*, 6:66-7:3. Joint capacity describes “the achievable capacity between the input of the mapper on the transmit side of the link and the output of the channel (including for example AWGN and Fading channels).” *Id.*, 7:17-21. This measure of “capacity” is again in reference to the distance to the “Shannon Gaussian capacity,” and the goal remains to be “reduce, and in some cases, nearly eliminate this gap.” *Id.*, 2:25-28. PD capacity and Joint capacity are both measured against the Shannon limit or Gaussian capacity as illustrated in FIG. 6a-b of the ’509 patent.

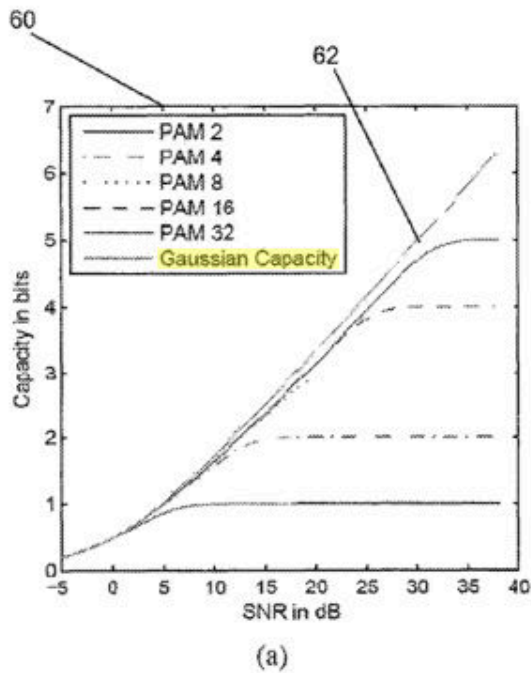


FIG. 6a

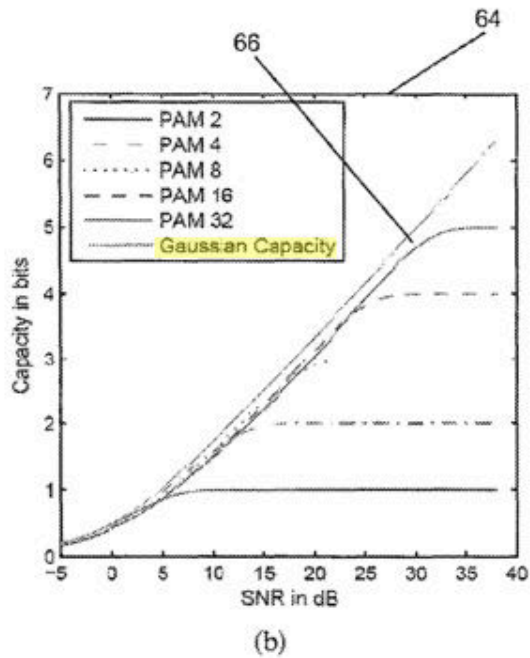


FIG. 6b

LGE1001, FIGs 6a-b.

53. Receiver 16 of FIG. 3 “includes a demodulator 30 that demodulates a signal received via the channel to obtain symbol or bit likelihoods” and a demapper 32 that “uses knowledge of the geometrically shaped symbol constellation used by the transmitter to determine these likelihoods.” LGE1001, 5:52-55. The demapper also “provides the likelihoods to a decoder 34 that decodes the encoded bit stream to provide a sequence of received bits to a sink.” *Id.*, 5:55-60.

54. The '509 Patent discloses that “[t]ransmitters and receivers ... utilize geometrically shaped symbol constellations” and that a geometrically shaped symbol

constellation can be “used that optimizes the capacity of the constellation.” LGE1001, 5:62-6:3. Various factors dictate the selection of a constellation, including whether the code rate is fixed and specific performance requirements (e.g., specified bit rate, a maximum transmit power). *Id.*, 6:5-8, 6:16-20. The ’509 Patent states that in “many embodiments, a geometrically shaped constellation is used to replace a conventional constellation (i.e. a constellation maximized for d_{min}) in the mapper of transmitters and the demapper of receivers within a communication system.” *Id.*, 6:8-12. Moreover, a conventional communication system can easily substitute a conventional constellation with a “geometrically shaped constellation that provides a capacity, which is greater than the capacity of a constellation maximized for d_{min} ,” by way of firmware or software upgrades of the transmitter/receiver. *Id.*, 6:24-33.

55. The ’509 Patent explains that PAM constellations can be paired with specific code rates to optimize capacity. LGE1001, 10:5-24. For example, FIG. 8a shows the lower SNR for optimized constellations relative to classic PAM constellations. *Id.* The ’509 Patent discloses certain conditions (e.g., bit rate, SNR) at which the PAM constellations can be optimized. For instance, FIGS. 11a-b provides a range of bit rates and SNRs at which PAM-4 constellations can be optimized for joint capacity or parallel decoding capacity. LGE1001, 11:4-11.

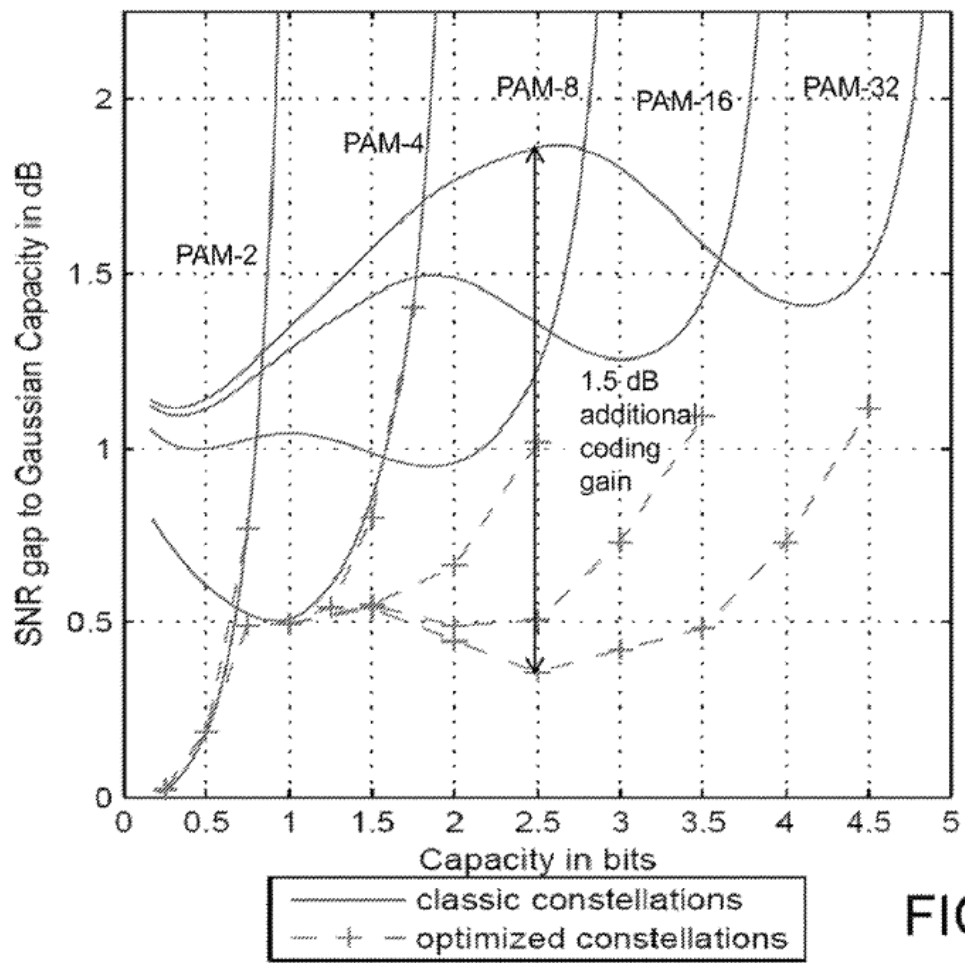


FIG. 8a

LGE1001, FIG. 8a.

PAM-4 constellations optimized for joint capacity at different rates

(bps)	0.50	0.75	1.00	1.25	1.50
(SNR)	0.03	2.71	5.00	7.15	9.24
x_0	-1.41	-1.41	-1.40	-1.37	-1.36
x_1	0.00	0.00	-0.20	-0.33	-0.39
x_2	0.00	0.00	0.20	0.33	0.39
x_3	1.41	1.41	1.40	1.37	1.36

FIG. 11a

LGE1001, FIG. 11a.

PAM-4 constellations optimized for parallel decoding capacity at different

(bps)	0.50	0.75	1.00	1.25	1.50
(SNR)	0.19	3.11	5.26	7.22	9.25
x_0	-1.00	-1.30	-1.36	-1.37	-1.36
x_1	-1.00	-0.56	-0.39	-0.33	-0.39
x_2	1.00	1.30	1.36	0.33	1.36
x_3	1.00	0.56	0.39	1.37	0.39

FIG. 11b

LGE1001, FIG. 11b (the word “rates” appears to have been inadvertently omitted from the heading of the figure).

D. Summary of the Prosecution History of the '509 Patent

56. The '509 Patent issued from US application no. 16/728,384 (“**384 application**”) that was filed as a Track 1 application on December 27, 2019. LGE1001, 1; LGE1002, 1-103.

57. The independent claims (1, 11, and 22) of originally-filed patent application on December 27, 2019 included “a non-uniform symbol constellation that includes at least two constellation points having identical locations and different labels.” LGE1002, 31-40. During prosecution, the first Office action dated April 9, 2020, patent examiner rejected all claims (1-30) under 35 U.S.C. 112(a) or 35 U.S.C. 112 (pre-AIA), first paragraph, as failing to comply with the written description requirement. LGE1002, 1004-1005. In addition, claims 1, 10, 11, 20, 21 and 22 were rejected under pre-AIA 35 U.S.C. 102(e) as being anticipated by US patent publication no. 2008/0200114 to Eberlein et al. (Eberlein) and claims 9, 19 and 30 under pre-AIA 35 U.S.C. 103(a) as unpatentable over Eberlein in view of Walker et al. (US patent publication no. 2005/011581). LGE1002, 1005-1012.

58. In reply, Patent Owner (“PO”) (then applicant) filed a reply on July 9, 2020, arguing against the rejections without amending the claims. LGE1002, 1046-1074. On September 14, 2020, patent examiner responded with another office action (Final rejection). Among the rejections, the patent examiner withdrew the rejection

under 35 U.S.C. 112 while maintaining the 35 U.S.C. 102 and 103 rejections. LGE1002, 3073-3085.

59. The PO then scheduled a telephonic interview with the patent examiner on January 12, 2021 with respect to the '384 application. LGE1002, 3113-3114, 3139-3140. After the interview, PO filed a final office action response on March 5, 2021 in which the claims were amended by replacing some instances of “**non-uniform** symbol constellations” with “**unequally spaced** symbol constellations,” among additional amendments. LGE1002, 3119-3153. Subsequently, the Examiner issued a Notice of Allowance providing a generic reason for allowing the application, namely that the arts of record fail to teach or suggest the claimed language in the independent claims. *Id.*, 3169-3178.

IX. THE CHALLENGED CLAIMS ARE NOT ENTITLED TO A JUNE 5, 2007 PRIORITY DATE

A. Legal Standard for Priority

60. I have been informed by counsel that in order to rely on the filing date of an earlier application, 35 U.S.C. § 120 requires that the earlier application include a disclosure that complies with the written description requirement of 35 U.S.C. § 112.

61. I understand that to comply with the written description requirement,

the specification must describe the inventions sufficiently to convey to a person of skill in the art that the patentee had possession of the claimed invention at the time of the application, i.e., that the patentee invented what is claimed.

62. I understand that entitlement to a filing date extends only to the subject matter that is disclosed; not to that which is obvious. I understand this to mean the parent application must actually or inherently disclose the elements of the later-filed claims.

63. I understand that in evaluating whether a disclosure provides a sufficient written description for claimed subject matter, the written description must include some form of disclosure that directs a person skilled in the art to the claimed subject matter in the originally filed disclosure. I understand that Federal Courts have referred to such disclosure as a “blaze mark.”

64. I understand that the Challenged Claims were not “original claims” of any priority application, and the claimed subject matter was not included in the ’319 provisional application or the ’777 patent (collectively referred to herein as the “Barsoum Patents”). LGE1015; LGE1027. The text of the challenged claims were also not filed with the filing of the ’509 patent. LGE1002. Instead, the text of the challenged claims were derived during prosecution via amended. *Id.* Thus, the Challenged Claims were entered after the December 27, 2019 filing date of the ’509

patent which is more than 12 years after the earliest priority date of the Barsoum Patents.

1. The Barsoum Patents Do Not Contain Written Description Support For the Claimed Code Rate Ranges of Claims 3-5, 13-15, and 24-26

65. The Barsoum Patents lack written description support for the limitations of claims 3-5, 13-15, and 24-26 are directed towards respective constellation pairs having an LDPC code rate within a specific range of LDPC code rates.

66. Claims 3-4, 13-14, and 24-25 are directed towards unequally spaced constellation and LDPC code rate pairs, wherein:

- an unequally spaced constellation having an *LDPC code rate that is below 1/3*;
- an unequally spaced constellation having an *LDPC code rate that is below 5/8*; and
- an unequally spaced constellation having an *LDPC code rate below 7/10*.

67. Claims 5, 15, and 26 further claim multiple a plurality of predetermined LDPC code rate and unequally spaced symbol constellation pairs, wherein:

- *multiple* LDPC code rates and unequally spaced symbol constellation pairs that each include an LDPC code rate is *equal to or greater than*

3/8 and less than or equal to 6/8;

- *multiple* LDPC code rates and unequally spaced symbol constellation pairs that each include an LDPC code rate is *equal to or greater than 3/6 and less than or equal to 5/6;*
- *multiple* LDPC code rates and unequally spaced symbol constellation pairs that each include an LDPC code rate is *equal to or greater than 6/8 and less than or equal to 7/8;*
- *multiple* LDPC code rates and unequally spaced symbol constellation pairs that each include an LDPC code rate is *equal to or greater than 8/10 and less than or equal to 9/10;*
- an SNR of the communication channel is between 3.11dB and 9.25dB while using at least one of the multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is *equal to or greater than 3/8 and less than or equal to 6/8;*
- an SNR of the communication channel is between 9.00 dB and 15.93 dB while using at least one of the multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is *equal to or greater than 3/6 and less than or equal to 5/6;*

- an SNR of the communication channel is between 18.72 dB and 22.13 dB while using at least one of the multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is *equal to or greater than 6/8 and less than or equal to 7/8*;
- an SNR of the communication channel is between 24.79 dB and 28.20 dB while using at least one of the multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is *equal to or greater than 8/10 and less than or equal to 9/10*.

68. The Barsoum Patents do not contain written description support for these claim features sufficient to show that the Patent Owner had possession of the claimed subject matter as of the priority dates of the Barsoum Patents.

2. The Text of the Barsoum Patents Do Not Contain Any Blaze Marks Directing a POSITA to the Claimed Code Rate Ranges

69. There is nothing in the Barsoum Patents that demonstrates that the claimed *code rate ranges* and constellations were part of their invention. LGE1015, 1-6; LGE1027. To contrary, the '319 provisional application explains that there is “link margin to be gained by tailoring the design of a constellation *for a specific code rate*.” LGE1015, 2 (emphasis added).

70. To achieve the link margin gain, the '319 provisional application seeks to parameterize constellation design based on a **target code rate**. *Id.* Indeed, the '319 provisional applications explains that “optimal design of a constellation depends on the **target code rate** to be used with it.” LGE1015, 2. To this end, the '319 provisional application found that “[t]he number of user bits per dimension, η , is related to code rate, R , and the total number of real signaling dimensions, N_{dim} ,” using the following equation:

$$\eta = \frac{R(\log_2(M))}{N_{dim}},$$

wherein M is, as best understood by Petitioner, the number of constellation points. LGE1015, 2. Thus, though '319 provisional application suggests optimizing the design of a constellation based on a **target code rate**, there is nothing in the '319 provisional application that suggests, or otherwise identifies, the code rate ranges of the challenged claims.

71. Determination of a **code rate range** requires determination of one or more particular features of the **code rate range** depending upon the claimed range. For example, determination of the **code rate ranges** of claims 3 and 4 requires determination of a **maximum code rate** as an upper bound to the **code rate range** and determining whether the **maximum code rate** is included in the code rate range (or not). However, none of these aspects of the code rate ranges of 3-4 are found in

the '319 provisional application. LGE1015, 1-6

72. Petitioner further submits that mere disclosure of a single code rate (or an equation for calculating said single code rate) such as, e.g., $1/2$ on pg. 5 of the '319 application is not sufficient disclosure to claim a **code rate range** such as an “LDPC code rate below $5/8$ ” or “an LDPC code rate below $7/10$ ” in claims 3 and 4 that encompasses the single disclosed code rate. LGE1015, 1-6; LGE1002, 14:13-27 Instead, these **code rate ranges** of claims 3 and 4 are not supported by the '319 provisional application. LGE1015, 1-6

73. By way of another example, determination of the **code rate ranges** of claim 5 requires determination of a **minimum code rate** as a lower bound to the code rate range (e.g., $3/8$ in claim 5), determination of a **maximum code rate** as an upper bound to the code rate range (e.g., $6/8$ in claim 5), and determination, e.g., as to whether minimum code rate, maximum code rate, or both, are included in the code rate range (e.g., $3/8$ is included in the range of claim 5, as the language recites equal to or greater than). Moreover, multiple limitations of claim 5 also require a similarly unsupported determination of an SNR communication channel that is between a particular dB range that is paired with a **code rate range**. LGE1015, 1-6; LGE1002, 15:20-50 However, nothing in the '319 provisional application supports any of these claim features. LGE1015, 1-6.

74. The '777 patent does not remedy the deficiencies of the '319 provisional application regarding support for the claimed *code rate ranges*. The '777 patent describes “[p]rocesses for selecting capacity optimized constellations to achieve increased coding gains based upon a *specific coding rate*...” and that these processes are “for use in a communication system having a *fixed code rate* and modulation scheme.” LGE1027, 5:4-7, 9:3-8. In line with this design objective, the '777 patent provides design tables of constellations such as those shown in FIGs. 11a, 11b, 13a, 13b, 15a, 15b, 17a, 17b with each column of each design table corresponding to a constellation optimized with a *specific coding rate* that can be calculated using the equation from the '319 provisional application identified above. LGE1027, 3:61-4:21, 10:25-11:13, FIGS. 10a-17b.

75. For example, FIGs. 11a and 11b of the '777 patent show design tables of parallel decoding (PD) Capacity and joint capacity optimized PAM-4 constellations, with each column of the design table corresponding to a particular single dimensional PAM-4 constellation optimized for a *specific code rate*. (Explaining that each column in the table is a different constellation). The *specific code rate* for each single dimensional PAM-4 constellation of the design tables in FIGs. 11a and 11b and determined using the equation of '319 provisional application identified above is $R = 1/4$ for the first column / constellation, $R = 3/8$ for the second

column / constellation, $R=1/2$ for the third column / constellation, $R= 5/8$ for the fourth column / constellation, and $R= 3/4$ for the fifth column / constellation. LGE1027, 10:35-55, FIGs. 10a-11b. Thus, the constellation design tables of FIGS. 11a and 11b describe a plurality of single dimensional PAM-4 constellations that are each optimized to a *specific code rate* resulting in a set of discrete code rates of $R = \{1/4, 3/8, 1/2, 5/8, 3/4\}$ - i.e., *one specific code rate for each constellation of the design table respectively*. LGE1027, 10:35-55, FIGs. 10a-11b.

76. By way of another example, FIGs. 13a and 13b of the '777 patent show design tables of PD Capacity and joint capacity optimized single dimensional PAM-8 constellations, with each column of the design table corresponding to a particular single dimensional PAM-8 constellation optimized for a *specific code rate*. The *specific code rate* for each PAM-8 constellation of the design tables in FIGs. 13a and 13b and determined using the equation of '319 application identified above is $R= 1/6$ for the first column / constellation, $R=1/3$ for the second column / constellation, $R=1/2$ for the third column / constellation, $R= 2/3$ for the fourth column / constellation, and $R= 5/6$ for the fifth column / constellation. LGE1027, 10:56-11:7, FIGs. 12a-13b. Thus, the constellation design tables of FIGS. 13a and 13b describe a plurality of single dimensional PAM-8 constellations that are each optimized to a *specific code rate* resulting in a set of discrete code rates of $R = \{1/6,$

1/3, 1/2, 2/3, 5/6} - i.e., ***one specific code rate for each constellation of the design table respectively***. LGE1027, 10:56-11:7, FIGs. 12a-13b. The ***specific code rate*** of each single dimensional PAM-16 constellation of the single dimensional PAM-16 constellations design tables of FIGs. 15a-15b and ***specific code rate*** of each single dimensional PAM-32 constellation of the single dimensional PAM-32 constellation design tables of FIGs. 17a-17b do not explicitly list the respective code rate for each constellation of the design tables. LGE1027, 11:1-7. Nonetheless, the resulting analysis is the same. Via application of the equation from the '319 provisional application, a list of discrete code rates can be determined

77. In claiming benefit of priority of the Barsoum Patents, Patent Owner appears to contend that one can determine, in hindsight, certain ***code rate ranges*** for particular unequally spaced constellations, particular SNR communication channels, or both. To be clear, the Barsoum Patents do not provide a single statement explaining how these particular ***code rate ranges (or characteristics thereof)*** were determined for particular constellations, SNR communications channels, or both. As explained in *Purdue*, , the Barsoum Patents themselves must provide sufficient “blaze marks” directing POSITAs to teachings within the Barsoum Patents that support the claimed code rate ranges of the challenged patents. Here, no blaze marks exist. *Id.*

78. Therefore, for at least these reasons, claims 3-5, 13-15, and 24-26 are not entitled to the priority date of the Barsoum Patents.

3. The Written Description of the Barsoum Patents Do Not Contain Written Description Support for “Multiple” LDPC Code Rate and Unequally Spaced Constellation Pairs That Include a Code Rate Below 1/3

79. Claim 3 (and similarly claims 13 and 24) recites, among other features, “*multiple* LDPC code rate and unequally spaced symbol constellation *pairs that each include an LDPC code rate below 1/3* and a sixty-four-point unequally spaced symbol constellation of the first type.” LGE1001, 14:15-20 (emphasis added). The ’319 Provisional includes some discussion of code rates (see e.g., pg. 2, col. 2; pg. 5), but does not include any description of *multiple* LDPC code rate-constellation *pairs that include a code rate below 1/3*. Similarly, the provisional fails to provide any description of the other code rate-constellation pairs, code rates, and SNRs that are recited in claims 3-5, 13-15, and 24-26. Accordingly, these claims should not be accorded the benefit of and priority to the filing date of the ’319 Provisional.

80. The disclosure in the ’777 Patent does not remedy the deficiencies of the ’319 provisional. The ’777 Patent includes a few paragraphs related to QAM constellations. LGE1027, 3:15-19, 12:12-37. In these paragraphs, the ’777 patent discloses that “[q]uadrature amplitude modulation (QAM) constellations can be constructed by orthogonalizing PAM constellations into QAM inphase and

quadrature components.” LGE1027, 12:12-14, FIG. 21. Presumably, it is such disclosure combined with the description of PAM-4, PAM-8, PAM-16, and PAM-32 constellations (see e.g., FIGS. 6A-17B and corresponding descriptions) that Patent Owner relies upon to claim 64-, 256-, and 1024-point constellations in claims 2-6, 12-15, and 23-27 (note that there is no explicit disclosure of the claimed 256- and 1024-point constellations in the ’777 Patent). For example, the ’777 Patent discloses set of discrete code rates $R=\{1/6, 1/3, 1/2, 2/3, 5/6\}$ with respect to the PAM-8 constellation. LGE1027, 10:56-62 (“each of these slices correspond to systems with code rate $R=\eta \text{ bps}/\log_2(8)$, resulting in $R=\{1/6, 1/3, 1/2, 2/3, 5/6\}$ ”), FIGS. 13A, 13B; LGE1027, 10:58-62, FIG. 13A, 13B. But such disclosure does not support ***multiple*** LDPC code rate-constellation ***pairs that include a code rate below 1/3***, as claimed in claims 3, 13, and 24. Instead, at best, only one code rate below 1/3 is disclosed. LGE1027, 10:56-11:7.

81. Moreover, the ’777 Patent provides no disclosure that the claimed 256 and 1024 point unequally spaced constellations would have the *same characteristics* such as code rate or SNRs as purported corresponding PAM constellations would. For instance, the ’777 Patent does not teach that the claimed code rate range (below 7/10) for a 1024-point unequally spaced symbol constellation (as in claim 3) would be the same as the coding rate range or SNRs alluded to in the corresponding 32-

PAM constellation described in FIGS. 17A and 17B. Indeed, a POSITA would have understood that the capacities, coding rates, and SNRs for one-dimensional (PAM) and corresponding two-dimensional constellations are not the same.

4. The written description of the Barsoum patents do not demonstrate that the patent owner was “in possession” of the communication system claimed by claims 3-5, 13-15, and 24-26.

82. As explained in Section II(A)(1) above, the Barsoum Patents do not include sufficient written description that supports the *code rate ranges (and other claim features claimed in relation thereto)* of the Challenged Claims. Moreover, the Barsoum Patents fail to provide any “blaze marks” to a POSITA that would direct the POSITA to the code rate ranges of the challenged claims in the Barsoum Patents. Lack of such disclosure means that the Patent Owner did not possess a communication system that uses the claimed code rate ranges as of the priority dates of the Barsoum Patents.

83. Claims 3-5, 13-15, and 24-26 impart a *code rate range* limitation on particular constellations, SNR communications channels, or both, used by the receiver of the claimed communication system. However, the *code rate ranges* are not supported by the written description of the Barsoum Patents for the reasons set forth in Section II(A)(1). Accordingly, a POSITA would not be able to discern that the Patent Owner had possession of a communication system imparts particular *code*

rate ranges on particular constellations, SNR communications channels, or both, used by the receiver of the claimed communication system. For at least the reasons set forth in Section II(A)(1) and Section II(A)(2), the written description of the Barsoum Patents is not sufficient to show possession of the subject matter of claims 3-5 and 13-15. Therefore, the claims 3-5, 13-15, and 24-26 are not entitled to priority date of the Barsoum Patents.

5. The Written Description of the Barsoum Patents Do Not Demonstrate that the Patent Owner Was “In Possession” of the Communication System of claims 6, 16, and 26

84. Claim 6 recites:

“each of the plurality of unequally spaced symbol constellations is characterized by the assignment of labels and spacing of the constellation points such that each of the plurality of unequally spaced symbol constellations is capable of providing greater parallel decoding capacity when operated at a symbol constellation operating SNR than the other plurality of unequally spaced symbol constellations when operated at the same SNR.” LGE1001, 15:55-62.

85. These features do not find support in the written description of the Barsoum Patents

86. This limitation defines a very specific relative relationship between two groupings of unequally spaced constellations that is not supported by the ’777 Patent

specification. In particular, claim 6 recites an observation of a relative relationship between a first group of *unequally spaced symbol constellations*² to a second group of *unequally spaced space symbol constellations*³ when the two groups are *operated at the same SNR*. Nothing the '777 patent provides sufficient written description support for the comparison of these two groups of *unequally spaced symbol constellations*. To the contrary, the '777 patent, at best, only describes determining a relative relationship between a first *a* geometrically shaped (i.e., unequally spaced) constellation and a constellation optimized for $d_{\min}$. LGE1027, 6:14-20, 2:56-63 This disclosure of the '777 *does not* support the very specific groups or the relationship claimed between the groups. No other portions of the '777 Patent

² i.e., the first group of constellations in claim 6 is narrowly claimed as “*each of the plurality* of unequally spaced symbol constellations is characterized by the assignment of labels and spacing of the constellation points such that *each of the plurality* of unequally spaced symbol constellations *is capable of providing greater parallel decoding capacity when operated at a symbol constellation operating SNR*”

³ i.e., the second group of constellations in claim 6 is narrowly claimed as “other plurality of *unequally* spaced symbol constellations”

provide written description support that a POSITA would understand as indicating that Patent Owner has possession of the subject matter of claim 6 as of the priority date of the '777 Patent. The '319 provisional application similarly lacks written description support for the features of claim 6. Thus, subject matter of claim 6 is not entitled to the priority date of the '777 patent.

87. Claims 16 and 26 include features that correspond to claim 6. Thus, the subject matter of claims 15 and 26 are not entitled to the priority date of the '777 patent for at least the same reasons as claim 6.

6. The Written Description of the Barsoum Patents Do Not Demonstrate that the Patent Owner Was “In Possession” of the Communication System where “each of the plurality” of Multidimensional Symbol Constellations have a Greater Parallel Decoding Capacity than Other Symbol Constellations at the “same SNR” as recited by claims 6, 16, and 26

88. The '777 patent specifies that:

“Not all geometrically shaped constellations have a greater capacity than that of a constellation maximized for $d_{\min}$. One approach to selecting a geometrically shaped constellation having a greater capacity than that of a constellation maximized for $d_{\min}$ is to optimize the shape of the constellation with respect to a measure of capacity of the constellation for a given SNR. Capacity measures that can be used in the optimization process can include, but are not limited to, joint capacity or parallel

decoding capacity. LGE1027 6:13-22.

89. A POSITA would understand this passage of the '777 patent as specifying that *at least some* geometrically shaped (i.e., unequally spaced) constellations used by the communications system of the '777 patent *do not* have a greater capacity than other constellations used by the communication system of the '777 patent. LGE1027 6:13-22. In addition, a POSITA would have understood the '777 patent as explaining that operations can be performed on a unequally spaced constellation so that the unequally spaced constellation *can be optimized* for joint capacity optimization or parallel decoding optimization in order to have greater capacity. LGE1027 6:13-22. Thus, though some unequally spaced constellations do not have a greater capacity than other constellations maximized for $d_{\min}$, the written description of the '777 patent *explains how to optimize a geometrically shaped constellation so that it can be capable* of having a greater capacity such as a greater parallel decoding capacity. LGE1027 6:13-22.

90. Turning to claim 6, the Barsoum Patents fail to disclose that *each of the plurality* of different unequally spaced symbol constellations *have been optimized* to be *capable* of having greater parallel decoding capacity. Indeed, neither the language of claim 6 nor the language of parent claim 1 indicate that *each of the plurality* of different unequally spaced symbol constellations have been optimized for parallel decoding capacity. Moreover, nothing in the specification of the '777

patent or '509 patent provides any indication that ***each of the plurality of*** different unequally spaced symbol constellations of claim 6 have been optimized for parallel decoding capacity. To the contrary, a review of the specification of the '777 patent and the '509 patent reveals that “***[n]ot all geometrically shaped constellations have a greater capacity than that of a constellation maximized for d_{min} .***” LGE1001, 6:33-35; LGE1027, 6:13-15 (emphasis added).

91. Claim 6 is not supported by the written description of the '777 patent because “[n]ot all” ***of the plurality of*** different unequally spaced symbol constellations are ***capable of providing a greater parallel decoding capacity when operated at a symbol constellation operating SNR*** than the other plurality of unequally spaced symbol constellations when operated at the same SNR recited by claim 6. Thus, claim 6 is not entitled to the priority date of the '777 patent.

92. Finally, to the extent Patent Owner argues that even a constellation that is not optimized for parallel decoding capacity, as described by col. 6, 15-23 of the '777 patent, ***is capable*** of providing greater parallel decoding capacity when operated at a symbol constellation operating SNR than the other plurality of unequally spaced symbol constellations when operated at the same SNR. However, Petitioner’s arguments still stand. To the contrary, such an assertion further proves that the claim feature of “***plurality*** of unequally spaced symbol constellations is

characterized” includes unequally spaced constellations that are not optimized for parallel decoding capacity, of which, “[n]ot all” have a greater capacity than that of other plurality of unequally spaced symbol constellations when operated at the same SNR. In other words, a non-uniform constellation is only **capable** of providing greater parallel decoding capacity at a specific SNR than other symbol constellations in the plurality multidimensional symbol constellations at the same SNR **after** the non-uniform constellation has been optimized for parallel decoding capacity. LGE1027 6:13-22.

93. For such an argument to prevail, the Patent Owner would need to show that the **each of the plurality of** unequally spaced symbol constellations of claim 6 have been optimized for parallel decoding capacity. However, , nothing in the specification of the ’777 patent indicates in sufficient detail to a POSITA that Patent Owner had possession of the subject matter of claim 6 as of the priority date of the ’777 patent. Nothing else in the ’777 patent or the ’319 provisional application does anything to change the calculus of this analysis.

94. For at least these reasons, the Barsoum Patents fail to provide support for the features of claim 6 that recite “***each of the plurality of*** unequally spaced symbol constellations ***is capable of providing greater parallel decoding capacity when operated at a symbol constellation operating SNR*** than the other plurality of

unequally spaced symbol constellations when operated at the same SNR.” LGE1001, 14:65-15:3.

95. Claims 16 and 26 include claim features that correspond to the features of claim 6. Claims 16 and 26 lack support in the Barsoum Patents for the same reasons set forth above with respect to claim 6.

96. Therefore, the claims 6, 16, and 26 are not entitled to priority date of the Barsoum Patents.

X. APPLICATION OF THE PRIOR ART TO THE REFERENCES

97. As I explain in more detail below, the Challenged Claims are obvious in view of the grounds and mappings described below.

A. Ground 1: '777 in view of ATSC327 render claims 3-7, 13-17, and 24-28 obvious

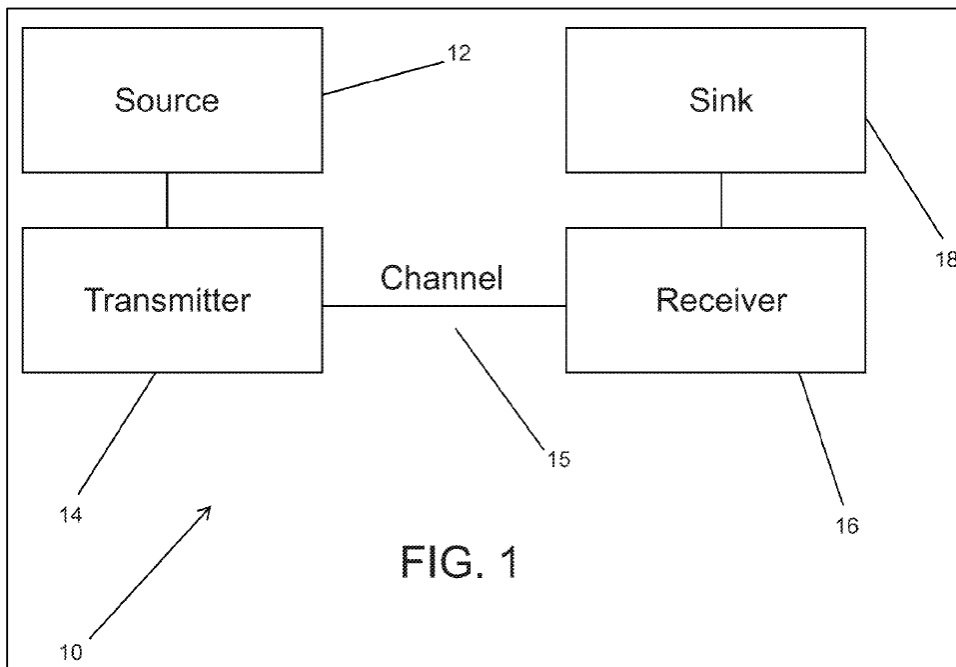
1. Overview of 777⁴

98. . The '777 Patent discloses “constructing a modulation such that the constrained capacity between a transmitter and a receiver approaches the Gaussian

⁴ General descriptions provided for this and other references and combinations thereof are incorporated into each subsection and mapping of the claims that includes citations to these references.

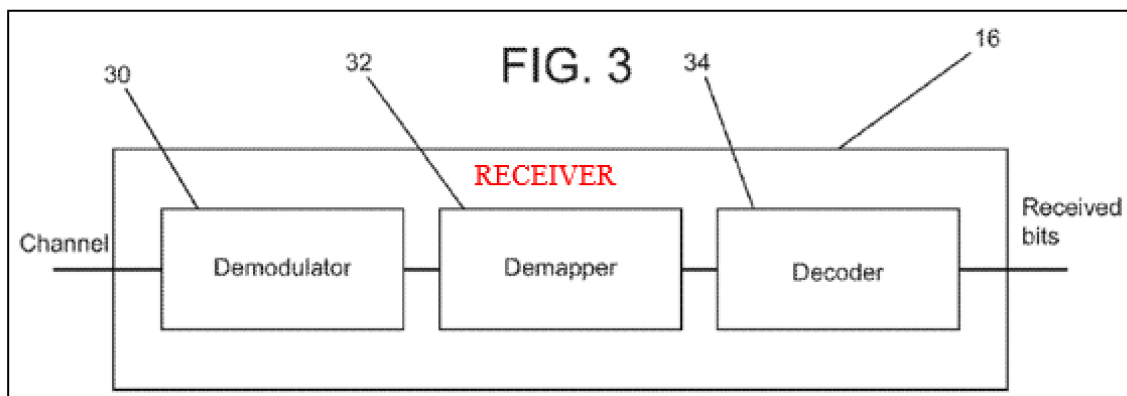
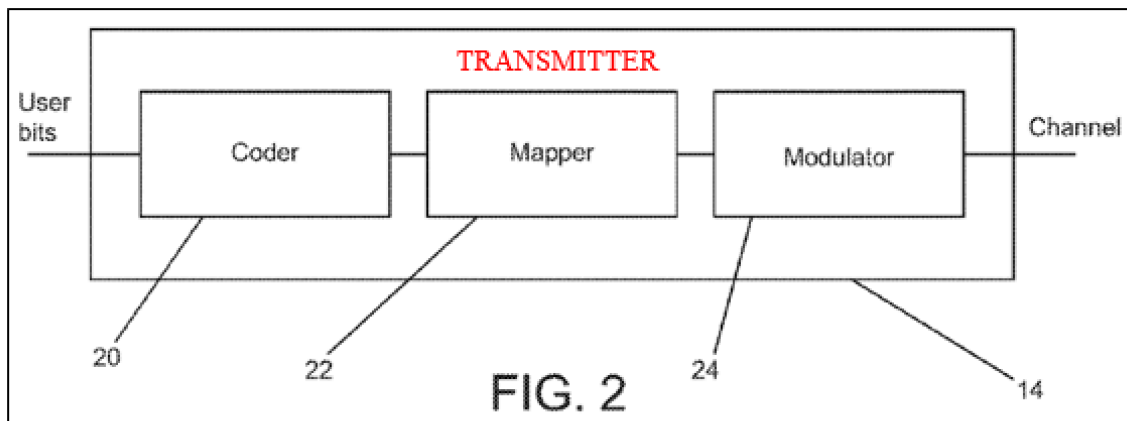
channel limit first described by Shannon.” LGE1027, 2:7-10. The ’777 Patent discloses “a method for locating points (in a one or multiple dimensional space) in order to maximize capacity between the input and output of a bit or symbol mapper and demapper respectively.” *Id.*, 2:17-20.

99. Figure 1 (reproduced below) shows a communication system 10 according to the ’777 Patent, which includes “a source 12 that provides user bits to a transmitter 14,” which in turn “transmits symbols over a channel to a receiver 16 using a predetermined modulation scheme.” LGE1027, 5:16-18. Using knowledge of the modulation scheme, the receiver 16 decodes the signal and provides the decoded bits to a sink device 18 connected to the receiver 16. *Id.*, 5:18-21.



LGE1027, FIG. 1.

100. FIG. 2 (reproduced below) of the '777 Patent depicts the transmitter 14 and its components, which include a coder 20, a mapper 22, and a modulator 24. LGE1027, 3:30-31, 5:22-34. FIG. 3 (reproduced below) of the '777 Patent depicts the receiver 16 and its components, which include a demodulator 30, a demapper 32, and a decoder 34. LGE1027, 3:32-33, 5:35-43.



LGE1027, FIGS. 2-3.⁵

101. The coder 20 of the transmitter 14 “receives user bits from a source and encodes the bits in accordance with a predetermined coding scheme,” such as a capacity approaching code (*e.g.*, turbo code, LDPC code) or other coding schemes that provide a coding gain. LGE1027, 5:23-27. A mapper 22 connected to the coder “maps the bits output by the coder to a symbol within a geometrically distributed signal constellation stored within the mapper” and “provides the symbols to a modulator 24, which modulates the symbols for transmission via the channel.” *Id.*, 5:29-34. The mapper of the transmitter encodes bits to symbols in a symbol constellation that “is a capacity optimized geometrically spaced symbol constellation that provides a given capacity at a reduced signal-to-noise ratio compared to a signal constellation that maximizes d_{min} .” *Id.*, 2:37-41, 2:45-48, 4:47-5:11. Signal-to-noise ratio (SNR) is “defined as the ratio of the average constellation energy per dimension to the average noise energy per dimension.” *Id.*, 7:30-33. The ’777 Patent explains that “capacity optimized constellation at low SNRs are geometrically shaped constellations that can achieve significantly

⁵ Annotations to this and other figures in this petition are indicated by colored text and/or marks.

higher performance gains (measured as reduction in minimum required SNR) than constellations that maximize d_{min} .” *Id.*, 8:2-7.

102. “Capacity measures that can be used in the selection of the location of constellation points include ... parallel decode (PD) capacity and joint capacity.” LGE1027, 5:56-59. The “PD capacity of a channel can be viewed in terms of the mutual information between the output bits of the encoder (such as an LDPC encoder) at the transmitter and the likelihoods computed by the demapper at the receiver,” and it is “influenced by both the placement of points within the constellation and by the labelling assignment.” *Id.*, 6:45-51. Joint capacity describes “the achievable capacity between the input of the mapper on the transmit side of the link and the output of the channel (including for example AWGN and Fading channels).” *Id.*, 6:65-7:1.

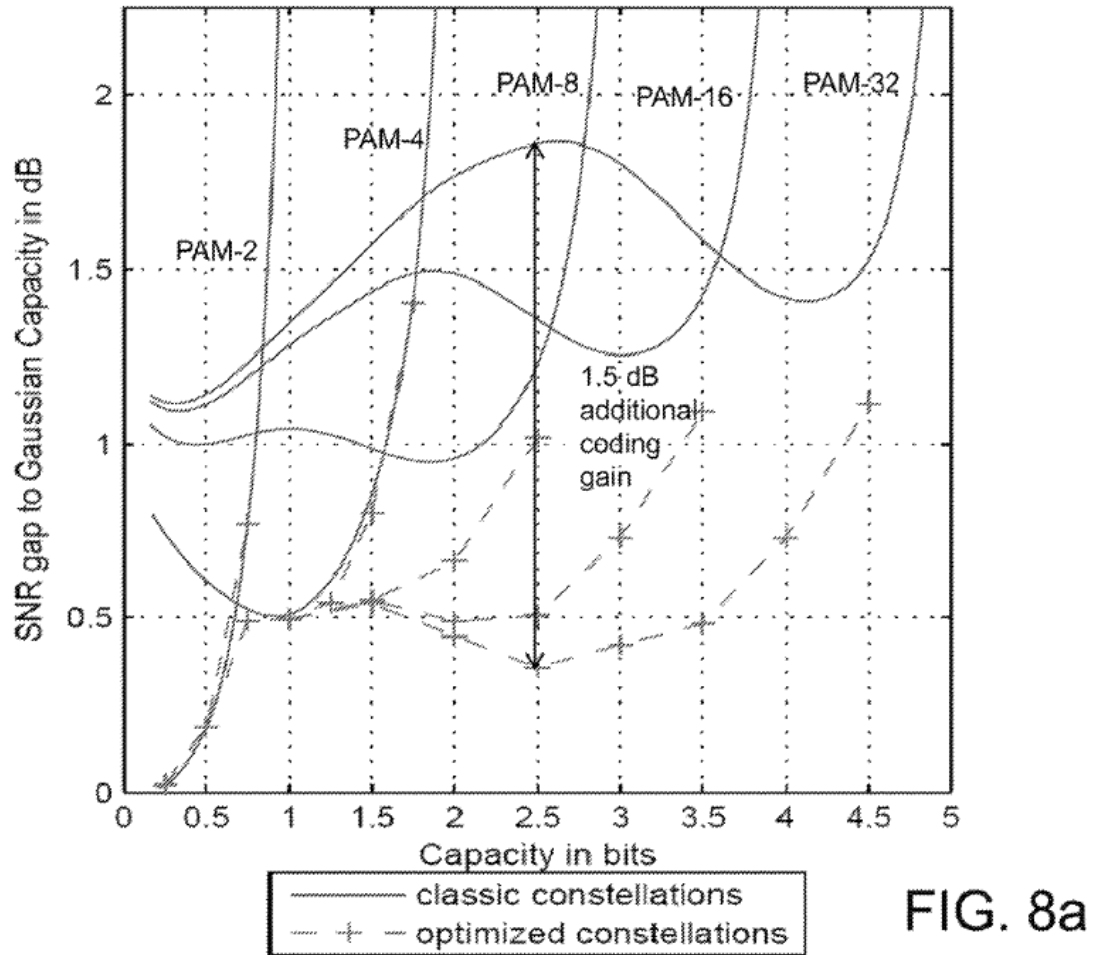
103. Receiver 16 of FIG. 3 “includes a demodulator 30 that demodulates a signal received via the channel to obtain symbol or bit likelihoods” and a demapper 32 that “uses knowledge of the geometrically shaped symbol constellation used by the transmitter to determine these likelihoods.” LGE1027, 5:35-40. The demapper also “provides the likelihoods to a decoder 34 that decodes the encoded bit stream to provide a sequence of received bits to a sink.” *Id.*, 5:41-43.

104. The ’777 Patent discloses that “[t]ransmitters and receivers ... utilize

geometrically shaped symbol constellations” and that a geometrically shaped symbol constellation can be “used that optimizes the capacity of the constellation.” LGE1027, 5:45-49. Various factors dictate the selection of a constellation, including whether the code rate is fixed and specific performance requirements (e.g., specified bit rate, a maximum transmit power). *Id.*, 5:54-6:4, 6:15-23. The ’777 Patent states that in “many embodiments, a geometrically shaped constellation is used to replace a conventional constellation (i.e. a constellation maximized for d_{min}) in the mapper of transmitters and the demapper of receivers within a communication system.” *Id.*, 5:57-61. Moreover, a conventional communication system can easily substitute a conventional constellation with a “geometrically shaped constellation that provides a capacity, which is greater than the capacity of a constellation maximized for d_{min} ,” by way of firmware or software upgrades of the transmitter/receiver. *Id.*, 6:5-13.

105. The ’777 Patent explains that PAM constellations can be paired with specific code rates to optimize capacity. LGE1027, 9:52-10:3. For example, FIG. 8a shows the lower SNR required for optimized constellations relative to classic PAM constellations. *Id.* The ’777 Patent discloses certain conditions (e.g., bit rate, SNR) at which the PAM constellations can be optimized. For instance, FIGS. 11a-b provides a range of bit rates and SNRs at which PAM-4 constellations can be

optimized for joint capacity or parallel decoding capacity. LGE1027, 10:47-55.



LGE1027, FIG. 8a.

106. Additionally, FIG. 11a and 11b disclose an example of a concept that the '509 patent will call types. LGE1001, claims 2b, 5b The first type (annotated in a red box below) “includes at least two constellation points having location that are the same and different labels.” LGE1001, claim 2b. That is, the constellation has at least two points that coincide (annotated in red circles). The second type (annotated

in a blue box below) contains “no two constellation points...share locations that are the same.” LGE1001, claim 5b. That is, no two constellation points in a second type coincide.

PAM-4 constellations optimized for joint capacity at different rates

(bps)	0.50	0.75	1.00	1.25	1.50
(SNR)	0.03	2.71	5.00	7.15	9.24
x_0	-1.41	-1.41	-1.40	-1.37	-1.36
x_1	0.00	0.00	-0.20	-0.33	-0.39
x_2	0.00	0.00	0.20	0.33	0.39
x_3	1.41	1.41	1.40	1.37	1.36

FIG. 11a

LGE1027, FIG. 11a.

PAM-4 constellations optimized for parallel decoding capacity at different

(bps)	0.50	0.75	1.00	1.25	1.50
(SNR)	0.19	3.11	5.26	7.22	9.25
x_0	-1.00	-1.30	-1.36	-1.37	-1.36
x_1	-1.00	-0.56	-0.39	-0.33	-0.39
x_2	1.00	1.30	1.36	0.33	1.36
x_3	1.00	0.56	0.39	1.37	0.39

FIG. 11b

LGE1027, FIG. 11b.

2. Overview of the ATSC327

107. ATSC327 is titled *Guidelines for the Physical Layer Protocol* and states that it is a supplement to the ATSC322 reference LGE1029.

108. “This document provides recommended practices for the ATSC 3.0 physical layer protocol standard specified by A/321 [2] and A/322 [3]. The intent of this document is to make recommendations for physical layer operating modes so that readers can make informed decisions about physical layer configurations. Also, this document provides some implementation guidelines to aid with flexible configurations of physical layer design resources in transmitter and receiver manufacturers’ equipment.” LGE1028, 1. ATSC327 seeks “to provide a toolbox of

technology that allows flexible operating modes for a variety of harsh channel conditions...” and “[i]t also contains detailed guidelines for transmitter and receiver design implementations based on engineering studies of the latest technologies in the ATSC 3.0 physical layer.” LGE1028, 1. Where ATSC322 “provides distinct features and description of the physical layer technologies,” the ATSC327 teaches the implementation of those technologies. LGE1028, 6.

109. As ATSC327 teaches that channel coding methods are used that include optimized constellations, Low Density Parity Check (LDPC) codes (2/15-13/15 code rates), and Non-Uniform Constellations (QAM) to “achieve near Shannon Limit performance of channel error mitigation across a wide range of SNR values.” LGE1028, 6.

110. ATSC327 uses a fixed number of these channel coding schemes by limiting the modulation and code rate (ModCod) combinations to 120. LGE1028, 18. Specifically, when implementing a ModCod scheme, ATSC327 teaches that “[t]here is one non-uniform constellation (NUC) defined for each ModCod combination” and that “for implementation, a look-up table with defined constellation mapping for each ModCod combination can be used.” LGE1028, 32

111. ATSC327 teaches these ModCod tables in two ways. First in Tables 4.7 and 4.8, the mandatory ModCod combinations are shown, which are the

minimum requirements for receiver and transmitter implementation in the ATSC

3.0 architecture. LGE1028, 19.

Table 4.7 Mandatory ModCod Combinations for Long Codes (64800 bits)

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	✓	✓	✓	✓	✓	✓	✓	✓		✓		
16QAM			✓	✓		✓	✓	✓		✓		
64QAM		✓	✓	✓	✓	✓	✓	✓	✓	✓		
256QAM			✓	✓		✓	✓	✓	✓	✓	✓	✓
1024QAM				✓		✓	✓	✓	✓	✓	✓	✓
4096QAM						✓		✓		✓	✓	✓

Table 4.8 Mandatory ModCod Combinations for Short Codes (16200 bits)

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	✓	✓	✓	✓	✓	✓	✓	✓				
16QAM				✓	✓	✓	✓			✓		
64QAM				✓	✓	✓	✓	✓	✓	✓		
256QAM				✓		✓	✓	✓	✓	✓	✓	✓

LGE1028, Table 4.7-4.8, 19

112. Tables 4.3 and 4.4 show “the required SNRs for AWGN and i.i.d. Rayleigh channels, respectively, in long code (64800 bits) cases. In these tables, capacity-equivalent ModCods are marked by the same color, and for each color, the ModCods that show the lowest required SNRs are marked in bold.” LGE1028, 18.

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-6.23	-4.32	-2.89	-1.70	-0.54	0.30	1.16	1.97	2.77	3.60	4.49	5.53
16QAM	-2.73	-0.25	1.46	2.82	4.21	5.21	6.30	7.32	8.36	9.50	10.57	11.83
64QAM	-0.26	2.27	4.15	5.96	7.66	8.92	10.31	11.55	12.88	14.28	15.57	17.03
256QAM	1.60	4.30	6.57	8.53	10.61	12.10	13.91	15.55	17.13	18.76	20.44	22.22
1024QAM	3.23	6.17	8.77	11.07	13.46	15.30	17.46	19.45	21.35	23.43	25.52	27.62
4096QAM	4.58	7.85	10.73	13.45	16.04	18.22	20.69	23.05	25.55	28.11	30.34	32.83

Table 4.4 Required SNRs (dB) for all ModCod Combinations, Long LDPC Codes (64800 bits) and i.i.d. Rayleigh Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-5.72	-3.62	-1.97	-0.55	0.86	1.95	3.16	4.35	5.62	7.05	8.76	10.97
16QAM	-1.84	0.81	2.69	4.32	5.98	7.21	8.63	9.94	11.40	12.78	14.60	16.85
64QAM	0.86	3.61	5.88	7.74	9.72	11.10	12.75	14.25	15.81	17.44	19.39	21.82
256QAM	2.89	5.97	8.46	10.59	12.92	14.58	16.54	18.23	20.06	21.94	24.01	26.62
1024QAM	4.65	8.04	10.85	13.25	15.91	17.84	20.13	22.34	24.47	26.61	28.82	31.59
4096QAM	6.23	9.83	12.95	15.75	18.79	21.03	23.67	26.37	28.64	31.18	33.82	36.54

LGE1028, Table 4.3-4.4, 18

3. The '777-ATSC327 Combination

113. The '777-ATSC327 combination includes a communication system comprising a receiver that is capable of demapping and decoding non-uniform multidimensional constellations that have been optimized to have a specific code rate at a specific SNR. LGE1027, 4:60-5:11, 5:35-43, FIG. 3; LGE1028, 18-19.

114. In the combination, the '777 Patent discloses a communication system comprising “[t]ransmitters and receivers ... [that] utilize geometrically shaped symbol constellations” and how the geometrically shaped symbol constellation can be “used that optimizes the capacity of the constellation.” LGE1027, 5:45-49. The

'777 Patent explains that PAM constellations can be paired with specific code rates to optimize capacity. LGE1027, 9:52-10:3.

115. Also in the combination, the '777 patent describes “[p]rocesses for selecting capacity optimized constellations to achieve increased coding gains based upon a specific coding rate.” LGE1027, 5:4-7. In addition, the '777 patent provides a number of one dimensional constellation design tables. LGE1027, 3:61-64, 4:5-8, 4:12-14, 4:19-21, 9-21FIGs. 11a, 11b, 13a, 13b, 15a, 15b, 17a, 17b. In the combination, the '777 patent teaches that a specific code rate can be calculated for each one dimensional constellation, with the one-dimensional constellations comprising a PAM-4 constellation, a PAM-8 constellation, a PAM-16 constellation, or a PAM-32 constellation. LGE1027, 5:4-7; 10:25-11:13. For PAM-4 constellation and the PAM-8 constellations, the '777 patent explicitly provides a discrete list of respective code rates, with each specific code rate in the list of code rates corresponding to a constellation of a constellation design table. LGE1027, 10:47-55, FIGs. 11a, 11b, 10:58-62, FIGs. 13a, 13b. The '777 Patent also explains to a POSITA that **QAM** constellations can be derived from **PAM** constellations. LGE1027, 3:9-19, 12:11-16.

116. Also in the combination, the system of the '777 patent is modified with the teachings of ATSC327 to pair multidimensional **QAM** constellations with

specific code rates and compare the SNR. LGE1028, 18-19. In the communication system of the combination, ATSC327 is used to enable the communication system to have “a look-up table with the defined constellation mapping for each ModCod combination can be used.” LGE1028, 32. In this table, “There is one non-uniform constellation (NUC) defined for each ModCod combination.” LGE1028, 32.

117. In the combination, the communication system of the '777 patent is configured to have a look-up table of non-uniform multidimensional constellations and code rate (ModCod) pairs that are capable of maximizing the channel capacity at a given SNR as seen in Tables 4.2 and 4.3 from ATSC327 (reproduced below):

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-6.23	-4.32	-2.89	-1.70	-0.54	0.30	1.16	1.97	2.77	3.60	4.49	5.53
16QAM	-2.73	-0.25	1.46	2.82	4.21	5.21	6.30	7.32	8.36	9.50	10.57	11.83
64QAM	-0.26	2.27	4.15	5.96	7.66	8.92	10.31	11.55	12.88	14.28	15.57	17.03
256QAM	1.60	4.30	6.57	8.53	10.61	12.10	13.91	15.55	17.13	18.76	20.44	22.22
1024QAM	3.23	6.17	8.77	11.07	13.46	15.30	17.46	19.45	21.35	23.43	25.52	27.62
4096QAM	4.58	7.85	10.73	13.45	16.04	18.22	20.69	23.05	25.55	28.11	30.34	32.83

Table 4.4 Required SNRs (dB) for all ModCod Combinations, Long LDPC Codes (64800 bits) and i.i.d. Rayleigh Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-5.72	-3.62	-1.97	-0.55	0.86	1.95	3.16	4.35	5.62	7.05	8.76	10.97
16QAM	-1.84	0.81	2.69	4.32	5.98	7.21	8.63	9.94	11.40	12.78	14.60	16.85
64QAM	0.86	3.61	5.88	7.74	9.72	11.10	12.75	14.25	15.81	17.44	19.39	21.82
256QAM	2.89	5.97	8.46	10.59	12.92	14.58	16.54	18.23	20.06	21.94	24.01	26.62
1024QAM	4.65	8.04	10.85	13.25	15.91	17.84	20.13	22.34	24.47	26.61	28.82	31.59
4096QAM	6.23	9.83	12.95	15.75	18.79	21.03	23.67	26.37	28.64	31.18	33.82	36.54

LGE1028, Table 4.3-4.4, 18

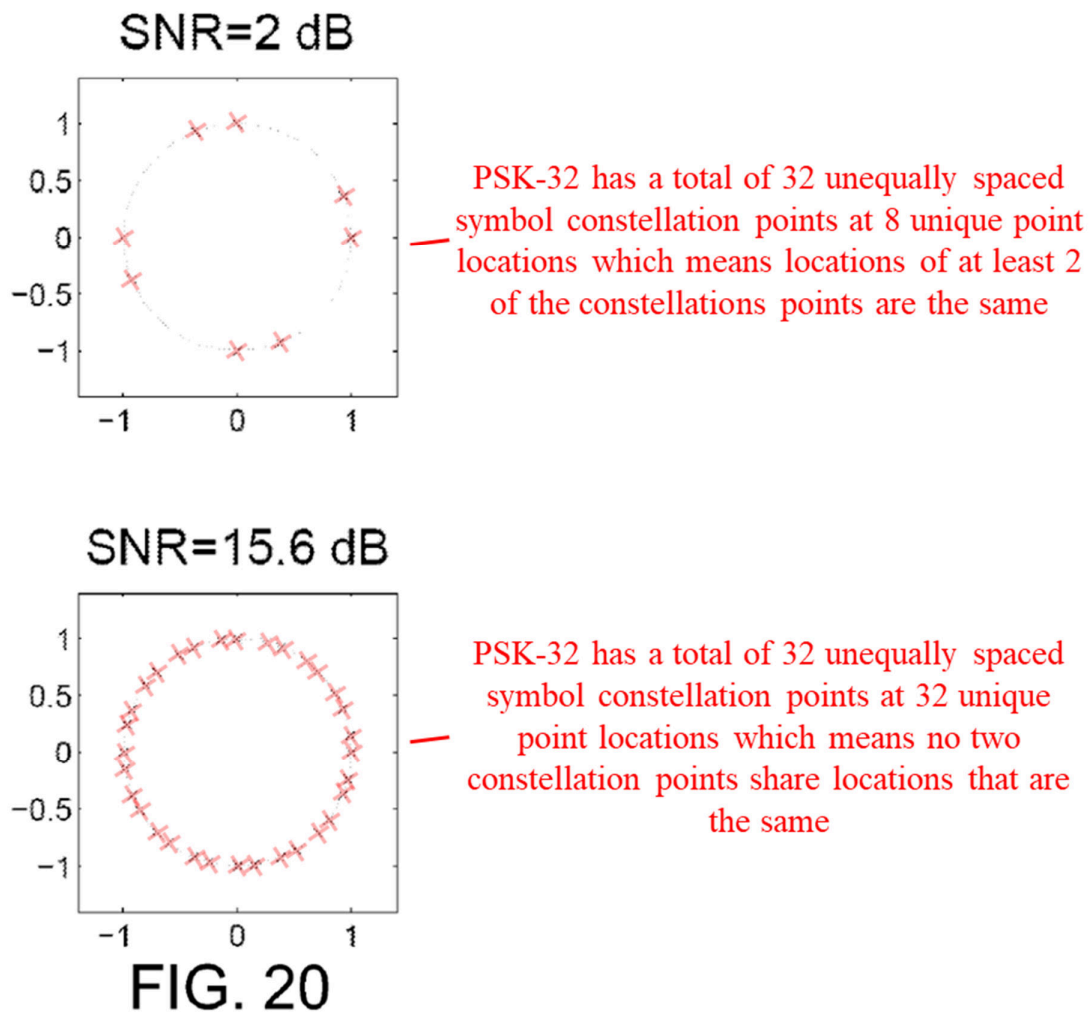
118. As the '777 patent clearly teaches “a geometrically shaped constellation is selected in conjunction with a code rate to meet specific performance requirements, which can for example include such factors as a specified bit rate, a maximum transmit power.” LGE1027; 5:64-6:1. The '777 patent suggests that “the receiver could implement a quality of performance based optimized constellation/code rate pair control mechanism. Such an approach would include some form of receiver quality measure. This could be the receiver's estimate of SNR or bit error rate.” LGE1027, 11:66-12:3. A POSITA armed with the teachings of ATSC327 would have found it obvious to implement a look-up table of ModCod combinations associated with given SNRs into both the transmitter and receiver. LGE1028, 19.

119. Further, based on the teachings in the '777-ATSC327, a POSITA would have been motivated to implement different types of unequally spaced symbol constellation in the ModCod combinations. As the '777 patent discloses two types of unequally spaced symbol constellation - first type includes at least two constellation points having locations that are the same and the second type includes no two constellation points within an unequally spaced symbol constellation share locations that are the same. For example, illustrates in FIG. 20 (reproduced below), illustrates different configurations of PSK-32 symbol constellation with

optimized locations of constellation points based on SNR values. LGE1027, FIG.

20. For example, at SNR=2dB, PSK-32 has 32 unequally spaced symbol constellation points at 8 unique point and at SNR=15.6dB, PSK-32 has 32 unequally spaced symbol constellation points at 32 unique points locations.

LGE1027, FIG. 20.



LGE1027, FIG. 20 (annotated and magnified view showing PSK-32 unequally

spaced symbol constellations at unique point locations, at SNR=2dB and 15.6dB).

4. Reasons to Combine the '777 patent with ATSC327

120. It would have been obvious for a person of ordinary skill in the art (POSITA) to modify the teachings of the '777 patent with the teachings of ATSC327 for a number of reasons. First, ATSC327 is a technical standards document that seeks to “to provide a toolbox of technology that allows flexible operating modes for a variety of harsh channel conditions...” and “[i]t also contains detailed guidelines for transmitter and receiver design implementations based on engineering studies of the latest technologies in the ATSC 3.0 physical layer.” LGE1028, 1. Thus, a POSITA working with a communication system such as the communication system of the '777 patent would have looked to ATSC327 to identify solutions to problems in the field.

121. Second, a POSITA would have looked to the teachings of the ATSC327 standard for “implementation guidelines to aid with flexible configurations of physical layer design resources in transmitter and receiver manufacturers’ equipment.” LGE1028, 1. For example, ATSC327 provides a finite list of multiple different non-uniform multidimensional QAM constellation-code rate pairs as listed in, for example, Tables 4.3 and 4.4. LGE1028, 18. A POSITA would have found it obvious to try each of the solutions in this finite list of

multiple different non-uniform multidimensional QAM constellation-code rate pairs and select the particular non-uniform multidimensional QAM constellation-code rate pair that best suites the needs of the system designed by the POSITA.

122. Third, a POSITA would have been motivated to design a system that uses the particular operating modes of ATSC327 to achieve the benefits that comes with being standard compliant. For example, having a system that is standards compliant would result in a system that is interoperable with communications systems in the industry and likely to achieve greater adoption in the market.

5. Ground 1 Prior Art Mappings

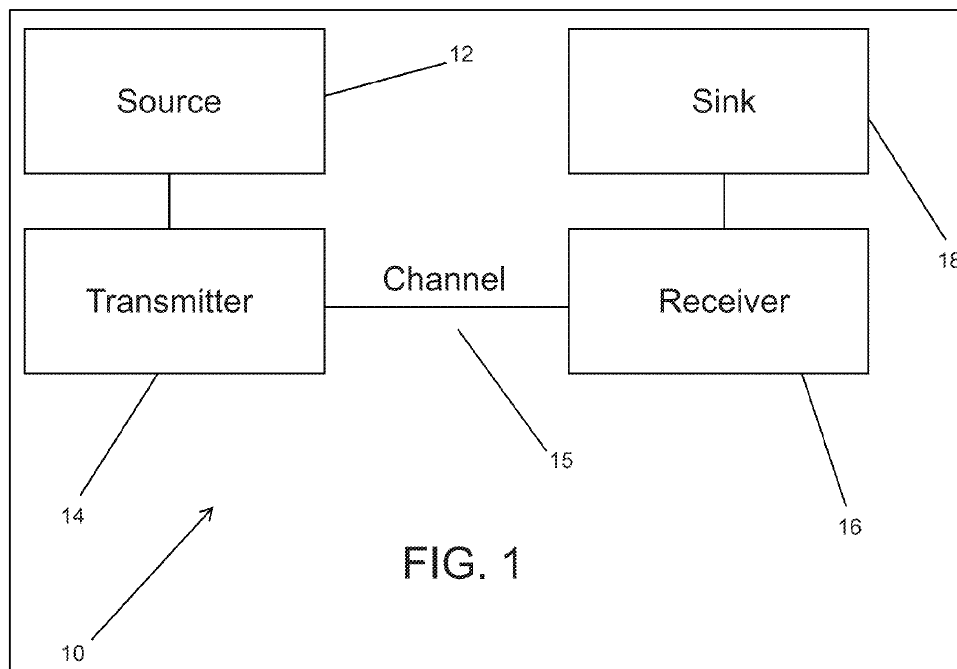
i. Claim 1

[1pre]⁶ A communication system, comprising:

123. . In the combination, the '777 patent discloses a communication system. *LGE1027, 5:16-21, abstract, FIGs. 1-3. For example, the '777 patent discloses “a digital communications system including a transmitter transmitting*

⁶ Because claim 3 depends from claim 1 and 2, I have been asked to also includes a mapping of the prior art references against claims 1 and 2 (and similarly other independent claims). [The Ground 1 is relying on the '777 patent as disclosing all the features of claim 1.](#)

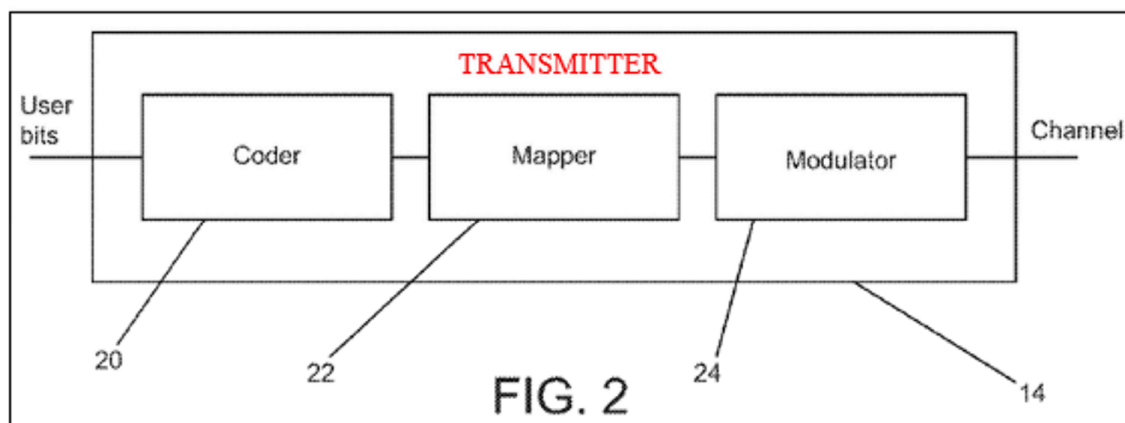
signal via a communications channel...” LGE1027, abstract. The digital communication system 10 of the '777 patent is depicted by FIG. 1 (reproduced below):



LGE1027, FIG. 1.

124. The communication system 10 (depicted above) includes “a source 12 that provides user bits to a transmitter 14,” which in turn “transmits symbols over a channel to a receiver 16 using a predetermined modulation scheme.” LGE1027, 5:16-18. Using knowledge of the modulation scheme, the receiver 16 decodes the signal and provides the decoded bits to a sink device 18 connected to the receiver 16. *Id.*, 5:18-21. The transmitter 14 of the patent communication system 10

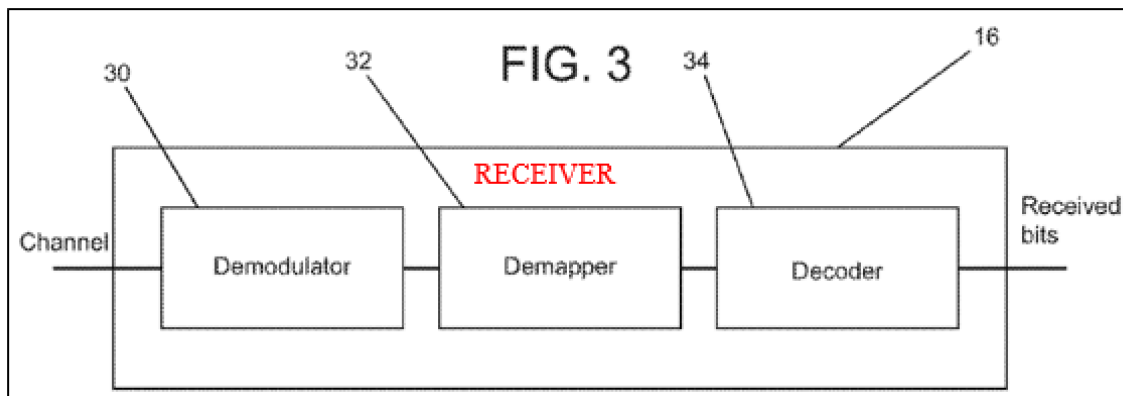
includes a coder 20, a mapper 22, and a modulator 24. LGE1027, 3:30-31, 5:22-34. The transmitter 14 is shown in FIG. 2 of the '777 patent (reproduced below):



LGE1027, FIG. 2.⁷

125. The receiver 16 of the communication system 10 includes a demodulator 30, a demapper 32, and a decoder 34. LGE1027, 3:32-33, 5:35-43. The receiver 16 of the communication system 10 is shown in FIG. 3 of the '777 patent (reproduced below):

⁷ Annotations to this and other figures in this petition are indicated by colored text and/or marks.



LGE1027, FIGS. 3.

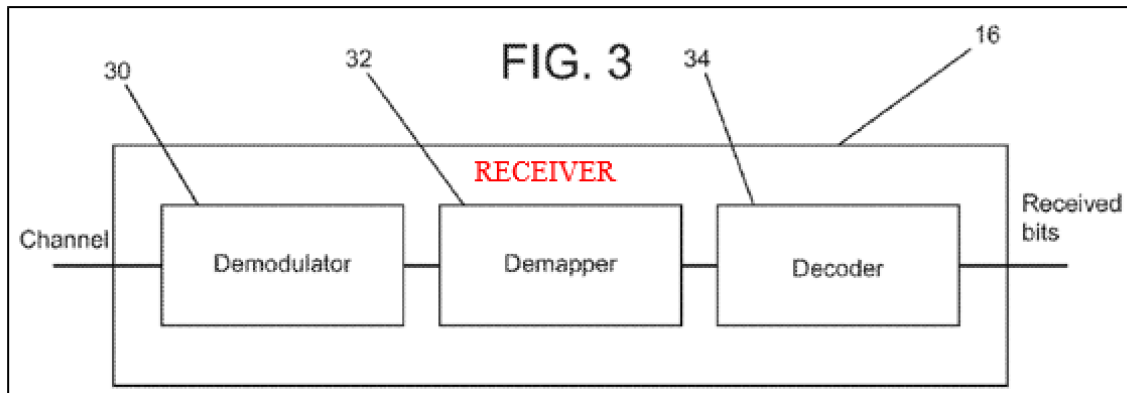
126. The “receiver 16 includes a demodulator 30 that demodulates a signal received via the channel to obtain symbol or bit likelihoods.” LGE1027, 5:35-43, FIG. 3. The “demapper uses knowledge of the geometrically shaped symbol constellation used by the transmitter to determine these likelihoods.” LGE1027, 5:38-40. The demapper also “provides the likelihoods to a decoder 34 that decodes the encoded bitstream to provide a sequence of received bits to a sink.” LGE1027, 5:41-43 Thus, the features of *[Ipre]* above would have been obvious to a POSITA in view of the ’777 patent.

[1a] a receiver capable of receiving signals via a communication channel having a channel signal-to-noise ratio (SNR), wherein the receiver comprises:

127. In the combination, the ’777 patent discloses ***a receiver 16 that is capable of receiving signals via a communication channel.*** LGE1027, 5:35-43; 13:37-38. For example, the “receiver 16 includes a demodulator 30 that

demodulates a signal received via the channel to obtain symbol or bit likelihoods.”

Id. The receiver 16 of the communication system 10 is shown in FIG. 3 of the '777 patent (reproduced below):

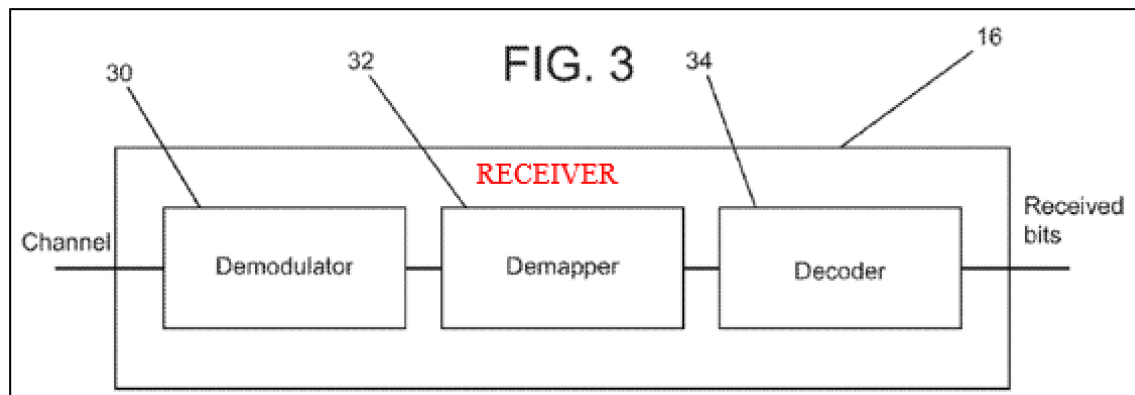


LGE1027, FIGS. 3.

128. It is known in the art that a communication channel has a channel signal-to noise ratio (SNR)The '777 patent alludes to this, for example, in explaining that the receiver 16 is configured to select a constellation “to provide increased capacity *at a predetermined range of channel signal-to-noise ratios (SNR).*” LGE1027:4:54-56; 7:26-33; 7:47-49; 13:34-38. Accordingly, it would have been obvious to a POSITA that the communication channels of the '777 patent have an SNR. Thus, the features of [1a] above would have been obvious to a POSITA in view of the '777 patent.

[1b] a demodulator capable of demodulating a received signal into a demodulated signal;

129. In the combination, the '777 patent discloses ***a demodulator capable of demodulating a received signal into a demodulated signal***. LGE1027, 5:35-43; 13:37-38. For example, the “receiver 16 includes a demodulator 30 that demodulates a signal received via the channel to obtain symbol or bit likelihoods.” *Id.* The receiver 16 then uses the demapper 32 to estimate likelihoods from the demodulated signal. LGE1027, 2:32-36, 2:52-543; 15:4-6; 16:14-15. The receiver 16 of the communication system 10 is shown in FIG. 3 of the '777 patent depicts a demodulator 30 (reproduced below).

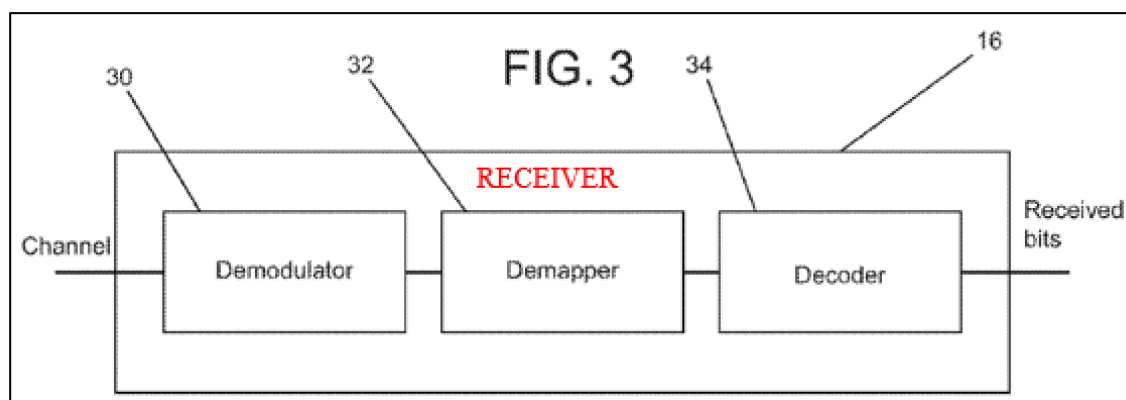


LGE1027, FIGS. 3.

130. Thus, the features of *[1b]* above would have been obvious to a POSITA in view of the '777 patent.

[1c-1] a demapper, coupled to the demodulator, capable of determining likelihoods using the demodulated signal and a symbol constellation that includes constellation points at a plurality of unique point locations, where:

131. In the combination, the '777 patent discloses ***a demapper coupled to the demodulator***. LGE1027, 3:32-33, 5:35-43; FIG. 3. The '777 patents coupling of the demapper 32 to the demodulator is shown, for example, in FIG. 3 of the '777 patent (reproduced below):



LGE1027, FIGS. 3.

132. In the combination, the '777 patent discloses ***a demapper that is capable of determining likelihoods using the demodulated signal and a symbol constellation***. LGE1027, 2:52-55; 5:35-43, 6:24-51 FIG. 3. For example, the '777 patent discloses that “the demapper uses knowledge of the geometrically shaped symbol constellation used by the transmitter to determine likelihoods.” LGE1027, 5:35-43. In the combination, '777 patent discloses that the geometrically shaped

symbol constellation. LGE1027, 3:11-19; 4:29-31; 12:12-16; 12:38-49, FIGs. 20, 21.

133. In the combination, the '777 patent discloses ***a symbol constellation that includes constellation points at a plurality of unique point locations.***

LGE1027, 2:52-55; 3:20-25, 5:35-43, 6:24-51, 10:36-11:13, FIGs. 11b, 13b, 15b,

17b. For example, the '777 patent broadly suggests that “the communication systems can adapt location of points in a constellation in response to channel conditions, changes in code rate and/or to change the target user data rate.”

LGE1027, 5:7-11. In FIGs. 11b, 13b, 15b, and 17b, the '777 patent exemplifies PAM based symbol constellations that include constellation points at unique points locations. LGE1027, 3:65-67, 4: 5-7, 4:12-14, 4:19-21, 10:25-11:13, FIGs. 11b, 13b, 15b, and 17b. For PAM symbol constellation, “[l]ocus plots of PAM-4, 8, 16, and 32 constellations [are] optimized for PD capacity and joint capacity”.

LGE1027, 10:29-30. In one instance, optimization of locations of constellation points are performed based on SNR values, wherein, “[a]t low SNRs, the PD capacity optimized **PAM-4 constellations have only 2 unique points, while the Joint optimized constellations have 3.** As SNR is increased, **each optimization eventually provides 4 unique points.**” LGE1027, 10:45-47; FIGs. 10a-d, 11a-d.

PAM-4 constellations optimized for joint capacity at different rates

(bps)	0.50	0.75	1.00	1.25	1.50
(SNR)	0.03	2.71	5.00	7.15	9.24
x_0	-1.41	-1.41	-1.40	-1.37	-1.36
x_1	0.00	0.00	-0.20	-0.33	-0.39
x_2	0.00	0.00	0.20	0.33	0.39
x_3	1.41	1.41	1.40	1.37	1.36

3 unique point locations
4 unique point locations

FIG. 11a

LGE1027, 11a.

PAM-4 constellations optimized for parallel decoding capacity at different

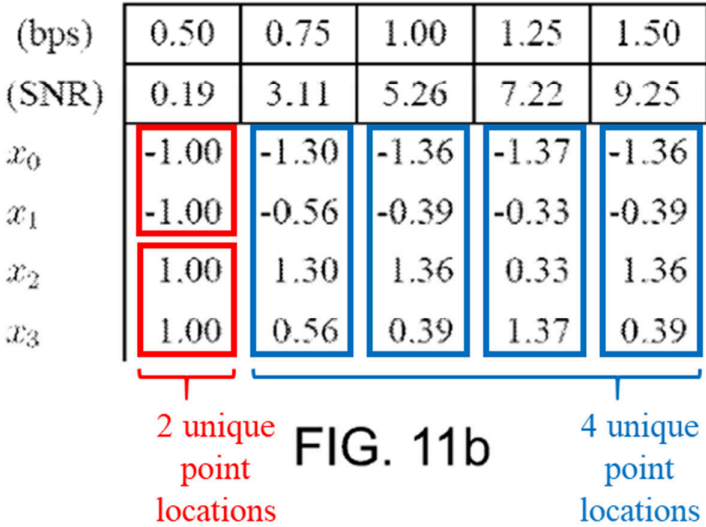


FIG. 11b

LGE1027, 11b.

PAM-8 constellations optimized for parallel decoding capacity at different

(bps)	0.5	1.0	1.5	2.0	2.5
(SNR)	0.19	5.27	9.00	12.42	15.93
x_0	-1.00	-1.36	-1.72	-1.64	-1.60
x_1	-1.00	-1.36	-0.81	-0.97	-1.03
x_2	-1.00	-0.39	1.72	1.64	-0.19
x_3	-1.00	-0.39	-0.62	-0.58	-0.58
x_4	1.00	1.36	0.62	0.58	1.60
x_5	1.00	1.36	0.02	0.15	1.03
x_6	1.00	0.39	0.81	0.97	0.19
x_7	1.00	0.39	-0.02	-0.15	0.58

FIG. 13b

2 unique
point
locations

4 unique
point
locations

8 unique
point
locations

LGE1027, 13b.

PAM-16 constellations optimized for parallel decoding capacity at different

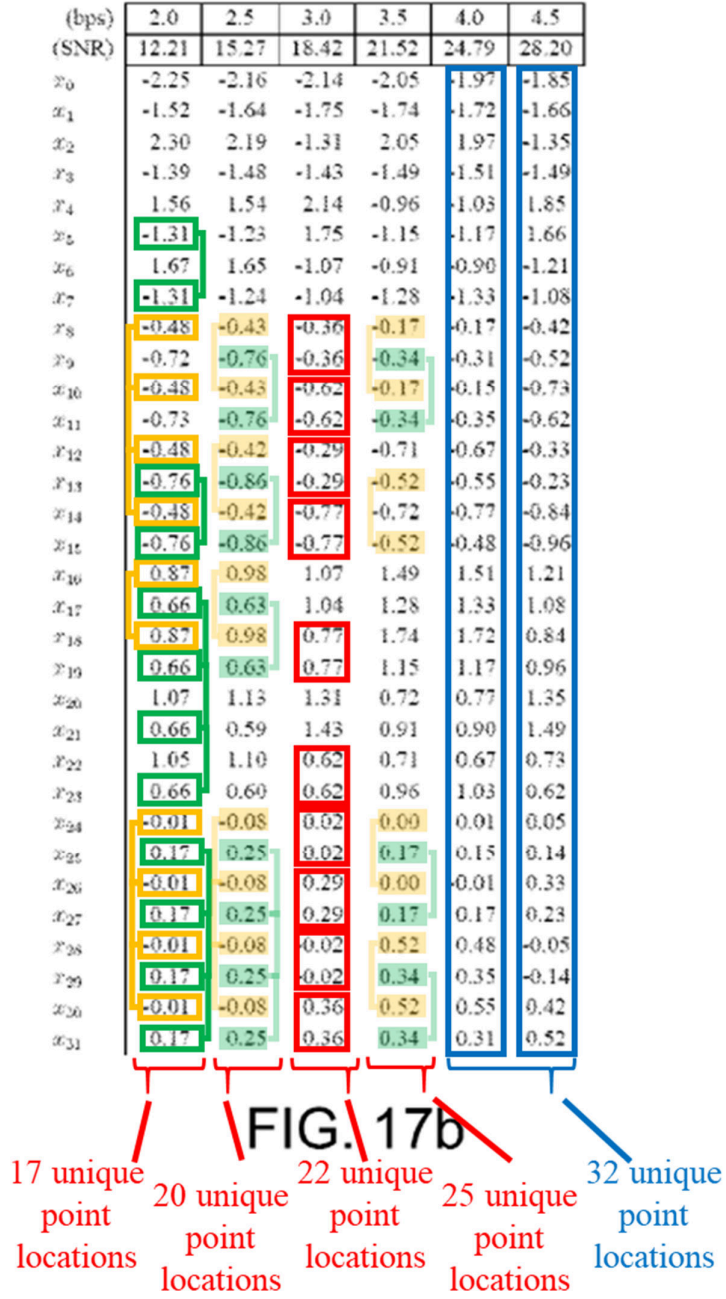
(bps)	1.5	2.0	2.5	3.0	3.5
(SNR)	9.00	12.25	15.42	18.72	22.13
x_0	-1.72	-1.98	-1.89	-1.84	-1.75
x_1	-1.72	-1.29	-1.36	-1.42	-1.42
x_2	-0.81	1.94	1.89	1.84	1.75
x_3	-0.81	-1.17	-1.14	-1.11	-1.15
x_4	1.72	-0.38	-0.35	-0.40	-0.47
x_5	1.72	-0.65	-0.70	-0.65	-0.68
x_6	-0.62	-0.38	-0.34	-0.29	-0.28
x_7	-0.62	-0.68	-0.76	-0.83	-0.90
x_8	0.62	1.09	1.13	1.11	1.15
x_9	0.62	0.76	0.76	0.84	0.90
x_{10}	0.02	1.26	1.35	1.42	1.42
x_{11}	0.02	0.76	0.70	0.65	0.68
x_{12}	0.81	0.06	0.00	0.05	0.09
x_{13}	0.81	0.29	0.34	0.29	0.28
x_{14}	-0.02	0.06	0.00	-0.05	-0.09
x_{15}	-0.02	0.29	0.35	0.40	0.47

FIG. 15b

8 unique point locations 12 unique point locations 15 unique point locations 16 unique point locations

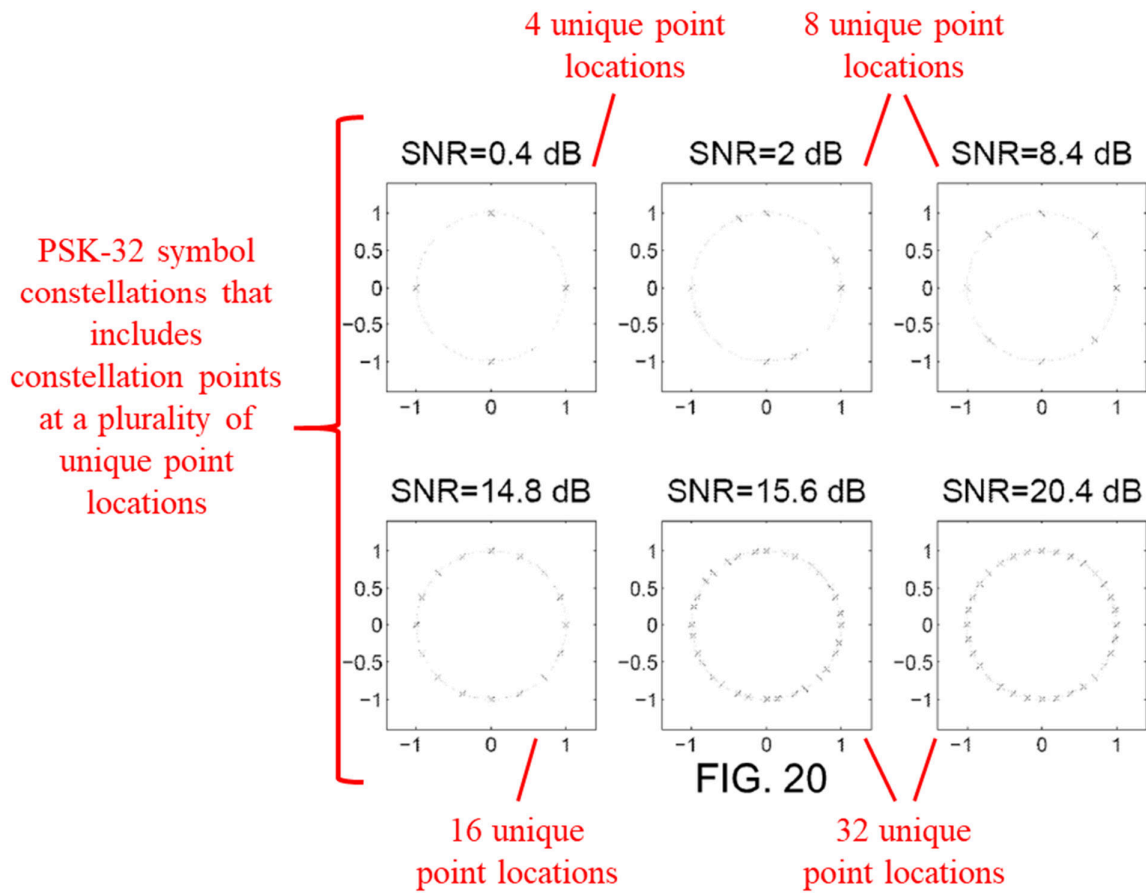
LGE1027, 15b.

PAM-32 constellations optimized for parallel decoding capacity at different



LGE1027, 17b.

134. Similarly, in FIG. 20, '777 patent illustrates, “a series of PSK-32 constellations optimized for PD capacity at different SNRs.” LGE1027, 4:26-28. In FIG. 20, different configurations of PSK-32 symbol constellation illustrates optimized locations of constellation points based on SNR values. LGE-1027, FIG. 20. For example, at SNR=0.4dB, PSK-32 has constellation points at 4 unique point locations, at SNR=2dB and 8.4dB, PSK-32 has constellation points at 8 unique point; at SNR=14.8dB, PSK-32 has constellation points at 16 point locations, and at SNR=15.6dB and 20.4dB, PSK-32 has constellation points at 32 unique points locations. LGE1027, FIG. 20.



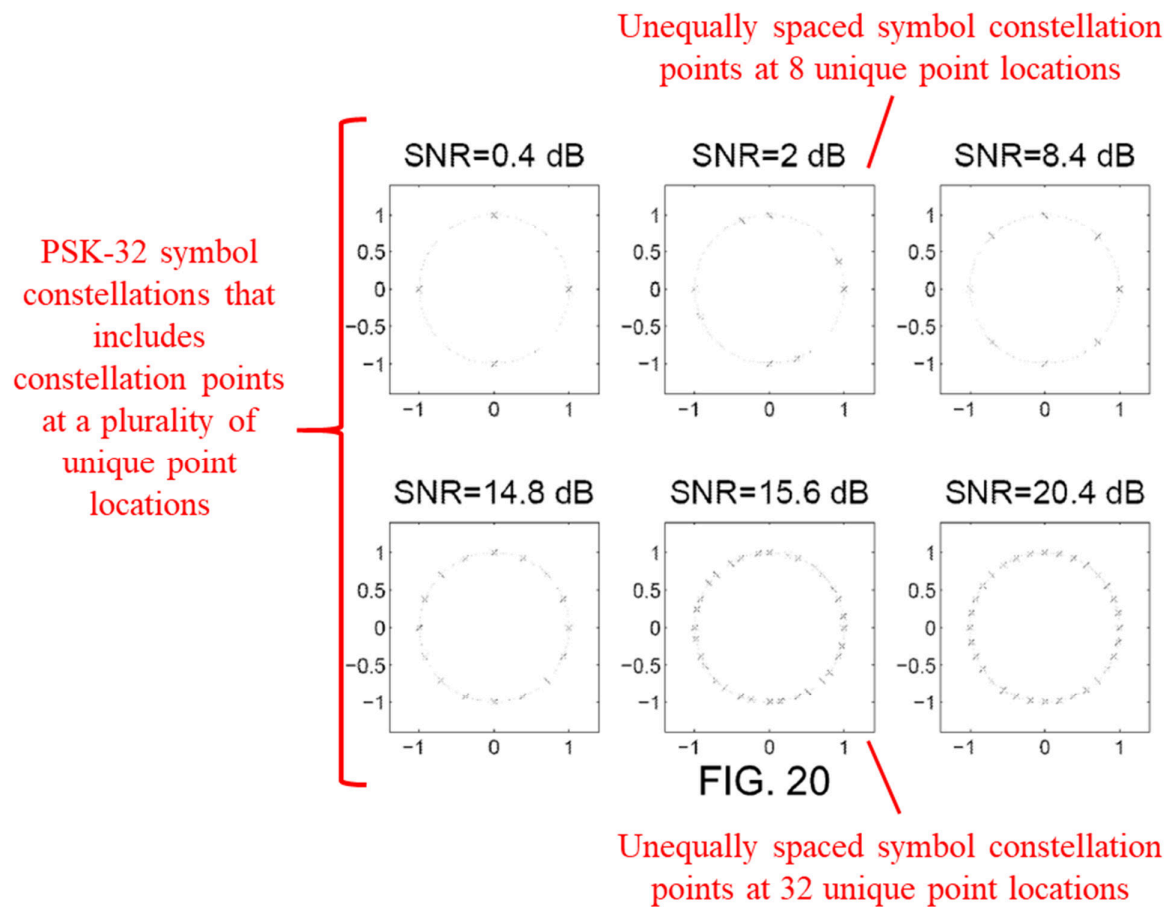
LGE1027, FIG. 20.

135. Thus, the features of *[1c-1]* above would have been obvious to a POSITA in view of the '777 patent.

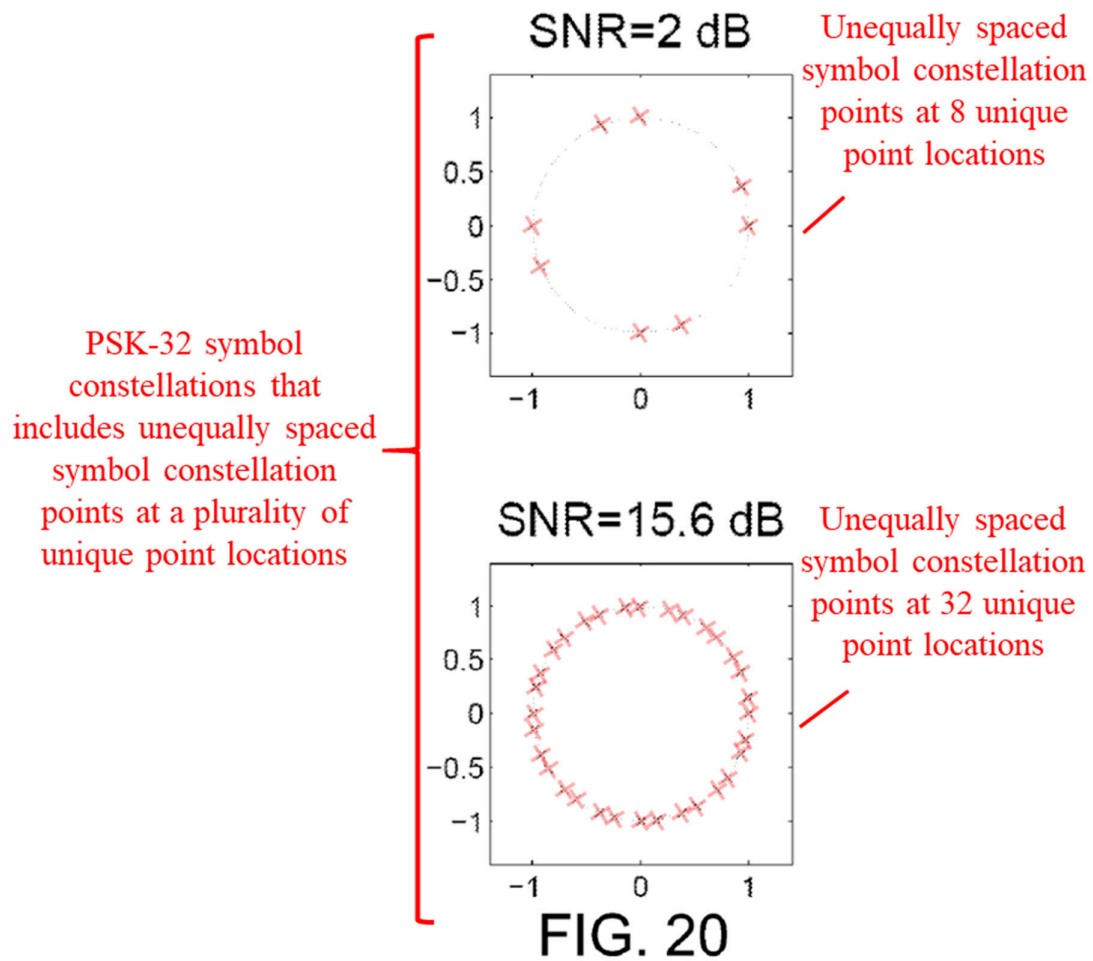
[1c-2] the plurality of unique point locations are unequally spaced;

136. *Supra* §V.A.4.[1c-1]. In the combination, the '777 patent discloses ***the plurality of unique point locations are unequally spaced.*** The '777 patent discloses that “[t]he present invention generally relates to bandwidth and/or power

efficient digital transmission systems and more specifically to *the use of unequally spaced constellations* having increased capacity.” LGE1027, 1:25-29. The ’777 patent further establishes that the “communication systems in accordance with embodiments of the invention are described that use *signal constellations, which have unequally spaced* (i.e. ‘geometrically’ shaped) *points*.” LGE1027, 4:47-59. As discussed above in [1c-1], ’777 discloses *a symbol constellation that includes constellation points at a plurality of unique point locations*. Supra §V.A.4.[1c-1]. In FIG. 20, the ’777 patent illustrates different configurations of PSK-32 symbol constellation with optimized locations of constellation points based on SNR values. LGE1027, FIG. 20. For example, at SNR=2dB, PSK-32 has unequally spaced symbol constellation points at 8 unique point and at SNR=15.6dB, PSK-32 has unequally spaced symbol constellation points at 32 unique points locations. LGE1027, FIG. 20.

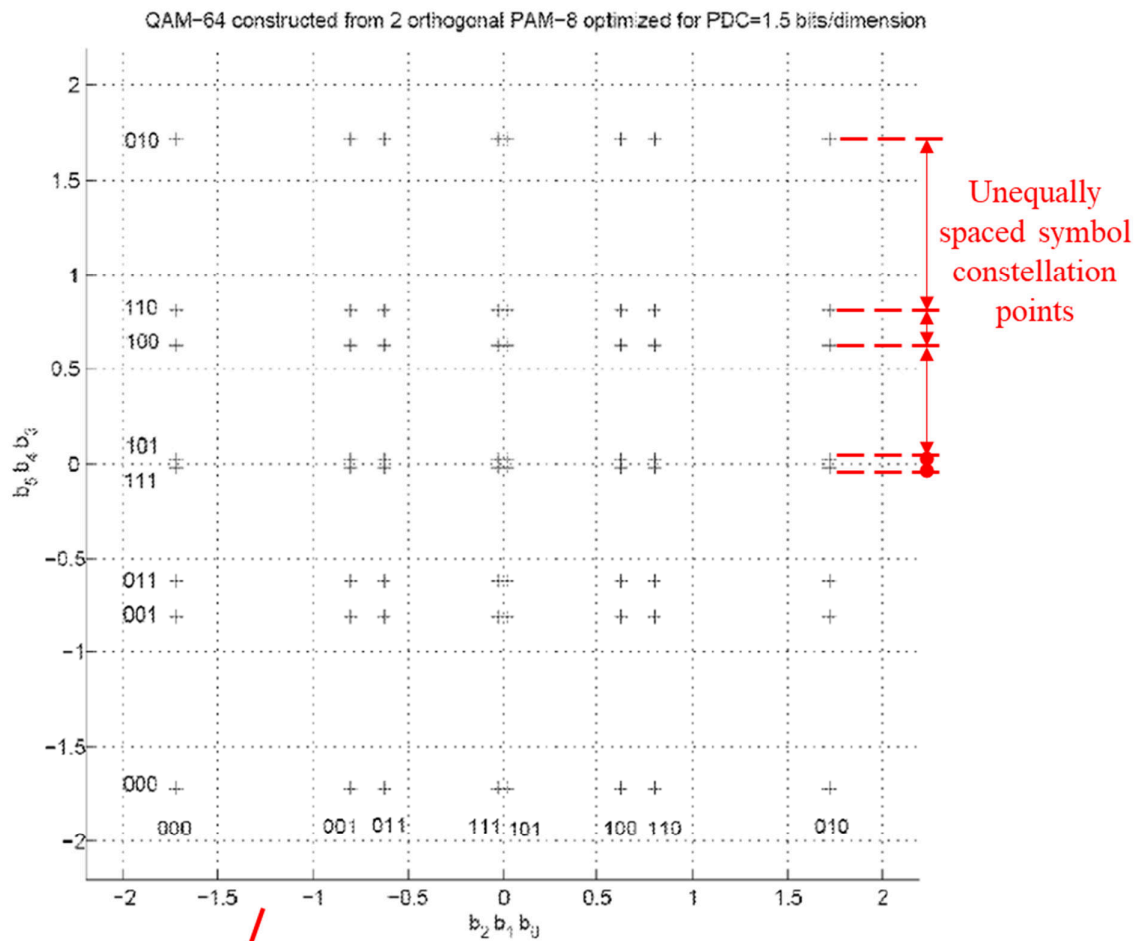


LGE1027, FIG. 20.



LGE1027, FIG. 20 (annotated and magnified view showing PSK-32 unequally spaced symbol constellations at unique point locations, at SNR=2dB and 15.6dB).

137. Further, in FIG. 21, the '777 patent also illustrates a QAM-64 unequally spaced symbol constellation points at 64 unique point locations. LGE1027, FIG. 21.

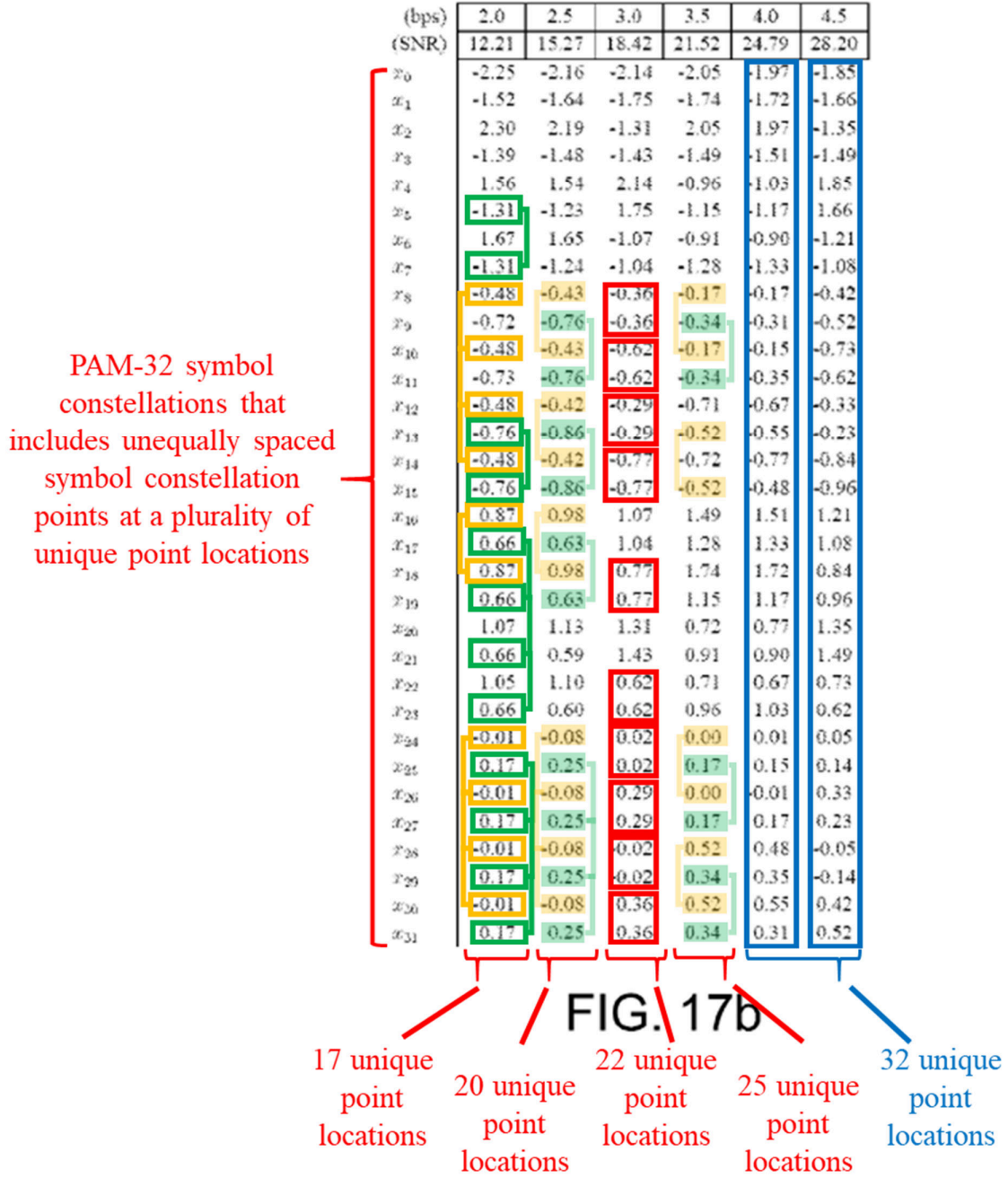


QAM-64 symbol constellation that includes
unequally spaced symbol constellation points
at 64 unique point locations

FIG. 21

LGE1027, FIG. 21.

PAM-32 constellations optimized for parallel decoding capacity at different

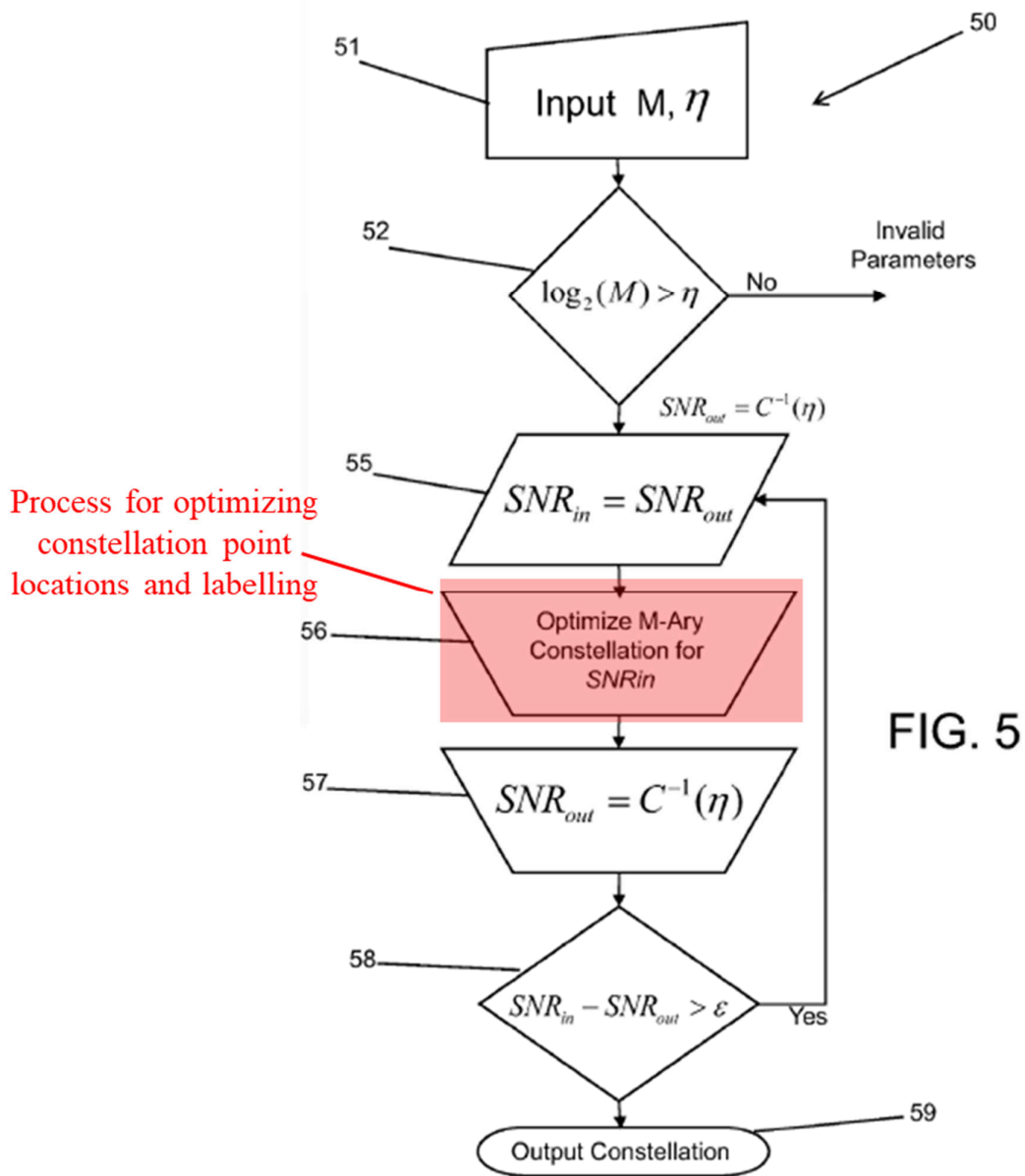


LGE1027, FIG. 17b.

138. Thus, the features of [1c-2] above would have been obvious to a POSITA in view of the '777 patent.

[1c-3] the constellation points each have a location and a different label; and

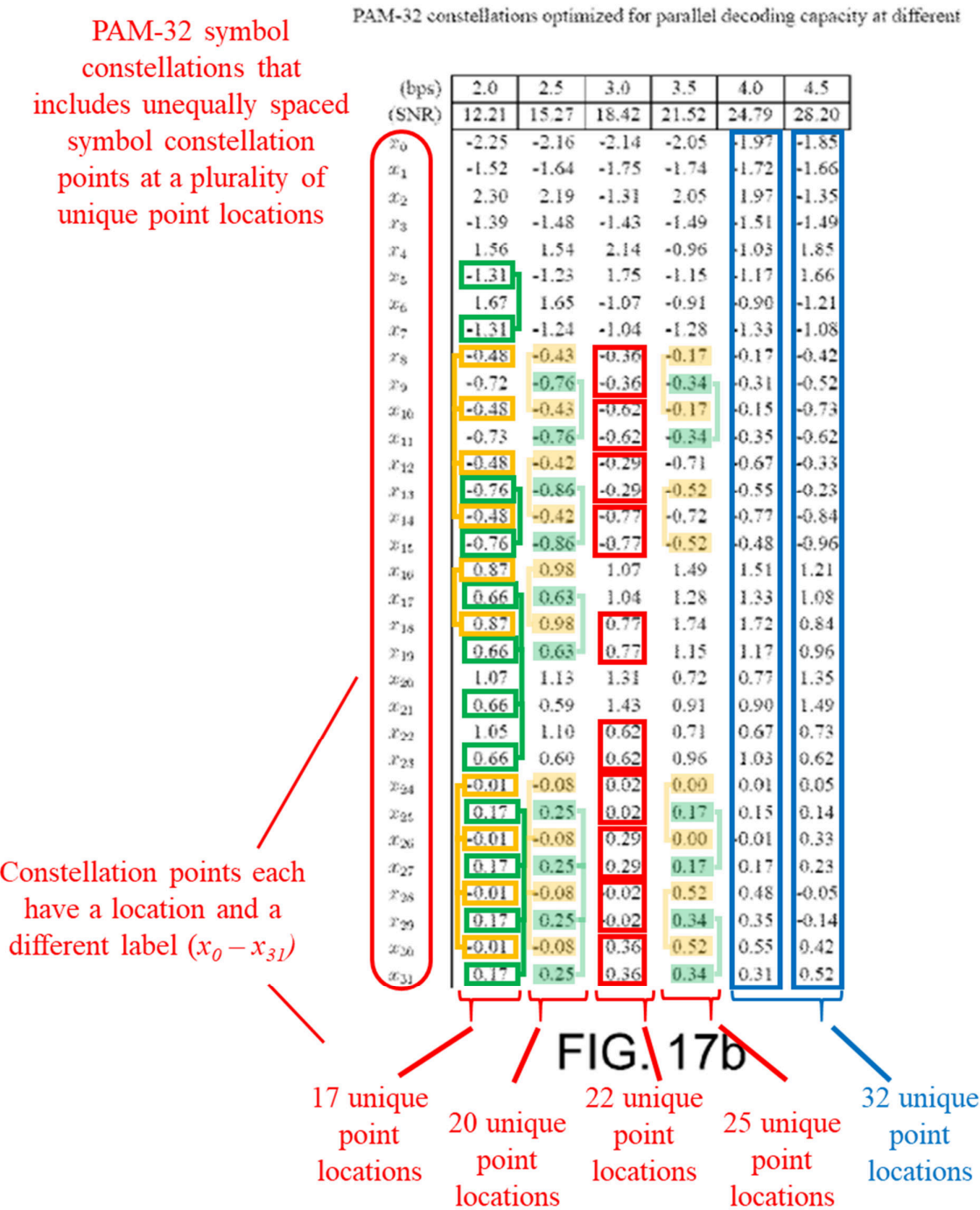
139. In the combination, the '777 patent discloses ***the constellation points each have a location and a different label***. For example, as discussed above, the symbol constellation points each have a location. *Supra* §§V.A.4.[1c-1], V.A.4.[1c-2], . Further, in FIG. 5, the '777 patent illustrates a flowchart about “[a] process for selecting the points [location], and potentially the labeling, of a geometrically shaped constellation for use in a communication system” and includes “[an] optimization process [that] gives the location of each constellation point identified by its symbol labeling.” LGE1027, 7:15-19; *Id.*, 8:41-42; *see also* 6:45-51, 8:30-46, 8:57-9:2, 10:25-35, FIG. 5;



LGE1027, FIG. 5.

140. In FIGs. 10a-17b, the '777 patent discloses, "locus plots and design tables show PAM-4,8,16,32 *constellation point locations and labelings* from low to high SNR corresponding to a range of low to high spectral efficiency."

LGE1027, 10:32-35; *see also id.*, FIGs. 10a-17b, FIG. 21.



LGE1027, FIG. 17b.

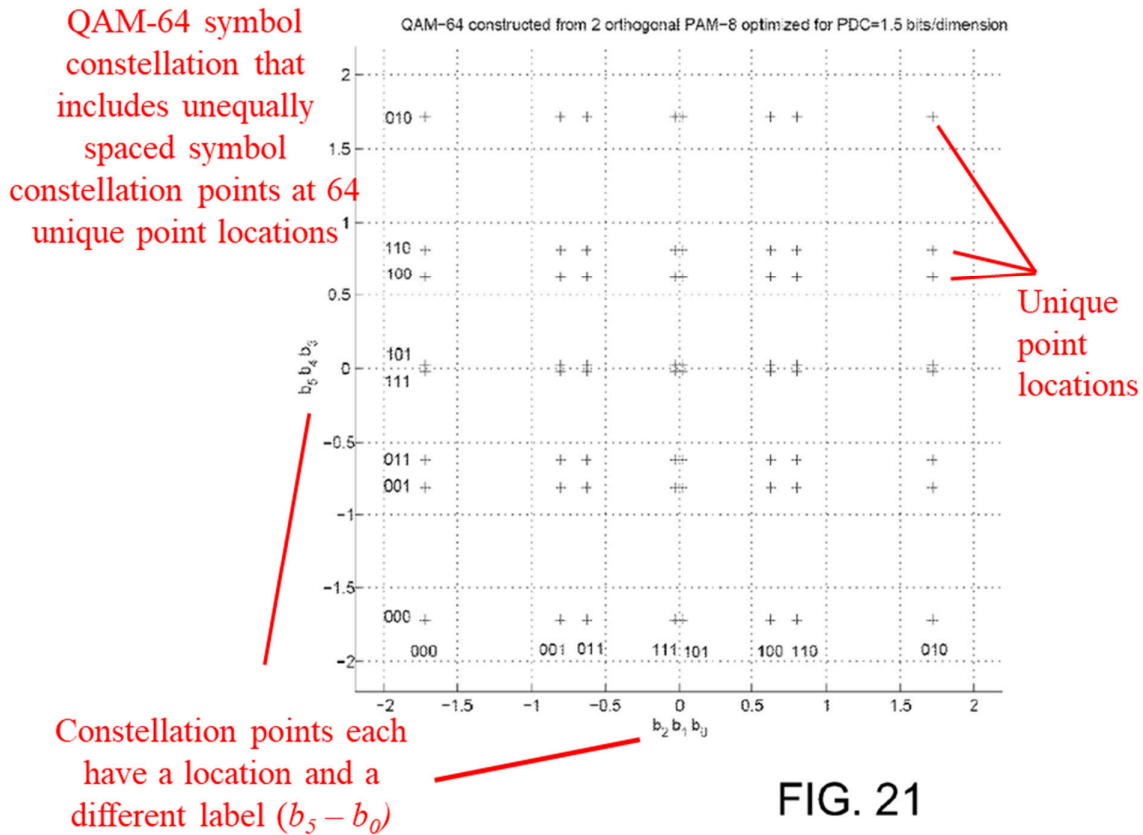


FIG. 21

LGE1027, FIG. 21.

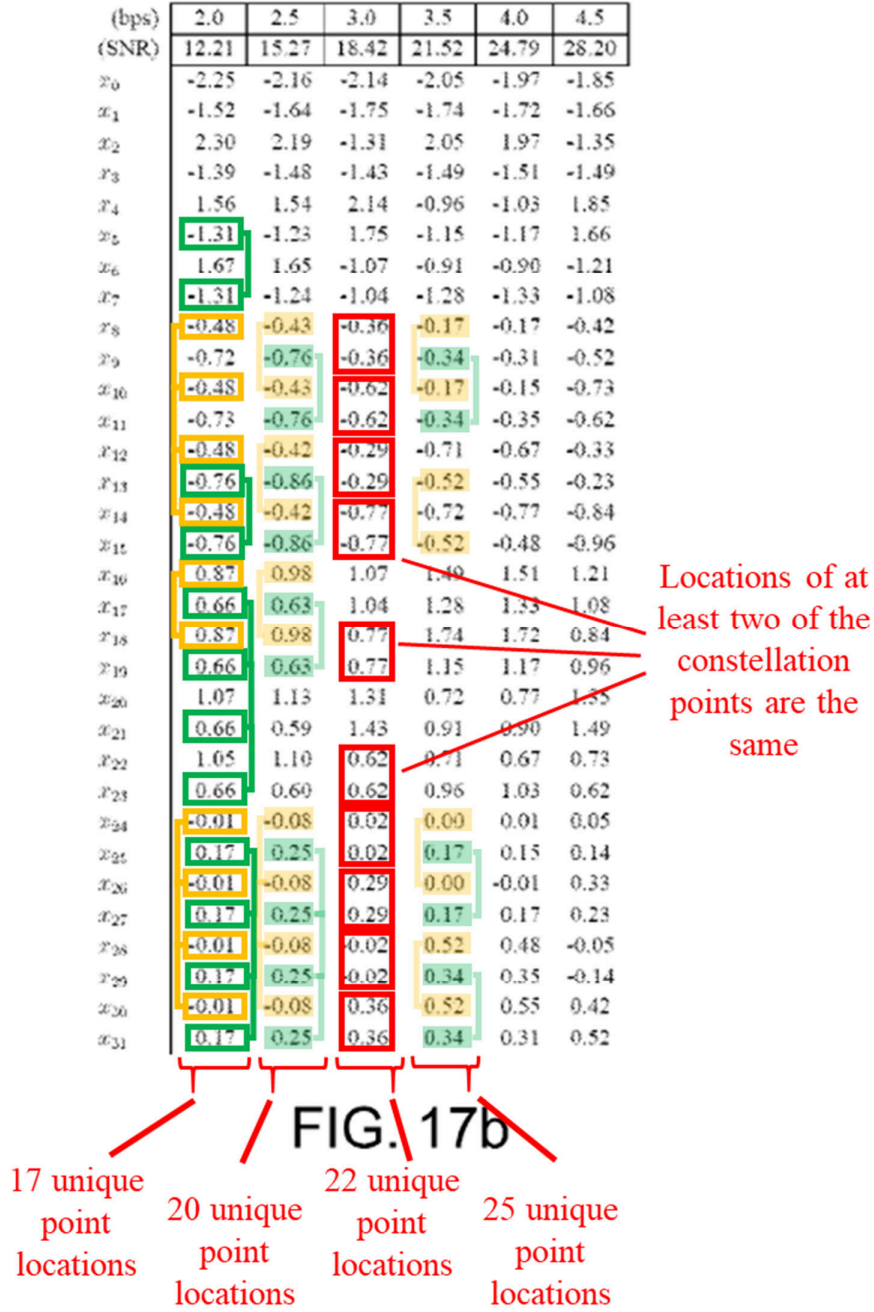
141. Thus, the features of [1c-3] above would have been obvious to a POSITA in view of the '777 patent.

[1c-4] the locations of at least two of the constellation points are the same; and

142. In the combination, the '777 patent discloses **the locations of at least two of the constellation points are the same**. For example, in 17b, the '777 patent illustrates PAM-32 constellation optimized for parallel decoding capacity at

different values of SNR. LGE1027, FIG. 17b. When SNR has values 2.0, 2.5, 3.0, and 3.5, the PAM-32 constellations having locations of at least two of the constellation points same. LGE1027, FIG. 17b.

PAM-32 constellations optimized for parallel decoding capacity at different



LGE1027, FIG. 17b.

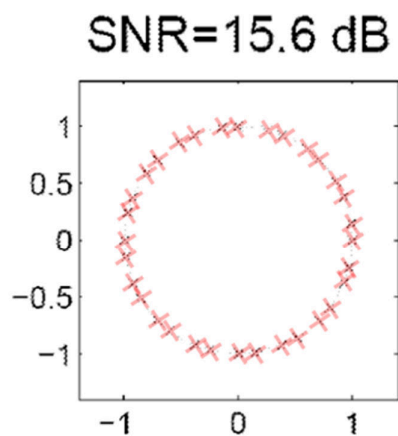
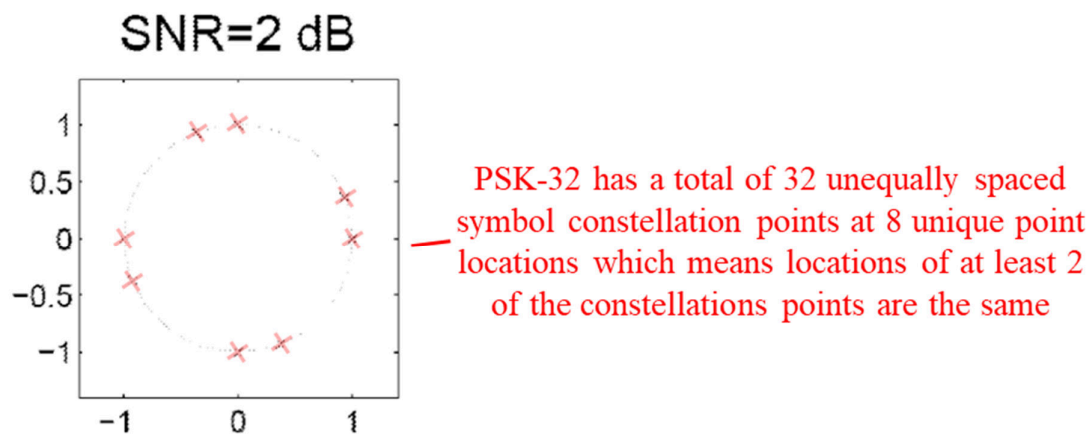


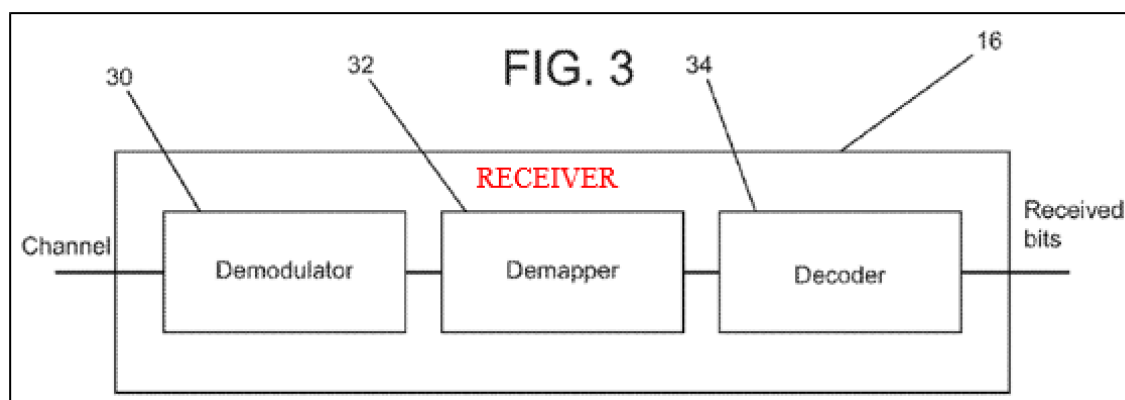
FIG. 20

LGE1027, FIG. 20 (annotated and magnified view showing PSK-32 unequally spaced symbol constellations at 8 unique point locations, at SNR=2dB)

143. Thus, the features of [1c-4] above would have been obvious to a POSITA in view of the '777 patent.

[1d] a decoder, coupled to the demapper, capable of using the likelihoods determined by the demapper to provide a sequence of received bits based upon a low density parity check (LDPC) code.

144. In the combination, the '777 patent discloses ***a decoder coupled to the demapper***. LGE1027, 5:40-43; Fig. 3. The '777 patent's coupling of the decoder 34 to the demapper 32 is shown, for example, in FIG. 3 of the '777 patent (reproduced below):



LGE1027, FIGS. 3.

145. In the combination, the '777 patent discloses a ***decoder capable of using the likelihoods determined by the demapper to provide a sequence of received bits based upon a low density parity check (LDPC) code***. LGE1027, 5:41-43; 13:31-33; 13:50-51; *see also supra* §V.A.4.[1b]. The decoder of the '777 patent “provides the likelihoods to a decoder 34 that decodes the encoded bitstream to provide a sequence of received bits to a sink.” LGE1027, 5:41-43. The encoded

bitstream that the decoder decodes is encoded using an “encoder (such as an LDPC encoder) at the transmitter.” LGE1027, 6:45-49; 5:25-27. Given that LDPC encoding is used to encode the bitstream, a POSITA would understand that the decoder is configured to decode LDPC encoding.” Accordingly, using the decoder of the ’777 patent to decode a sequence of received bits that were previously encoded using LDPC based upon a low density parity check (LDPC) code would have been obvious to a POSITA. *Id.* Thus, the bolded claim limitation above would have been obvious to a POSITA in view of the ’777 patent.

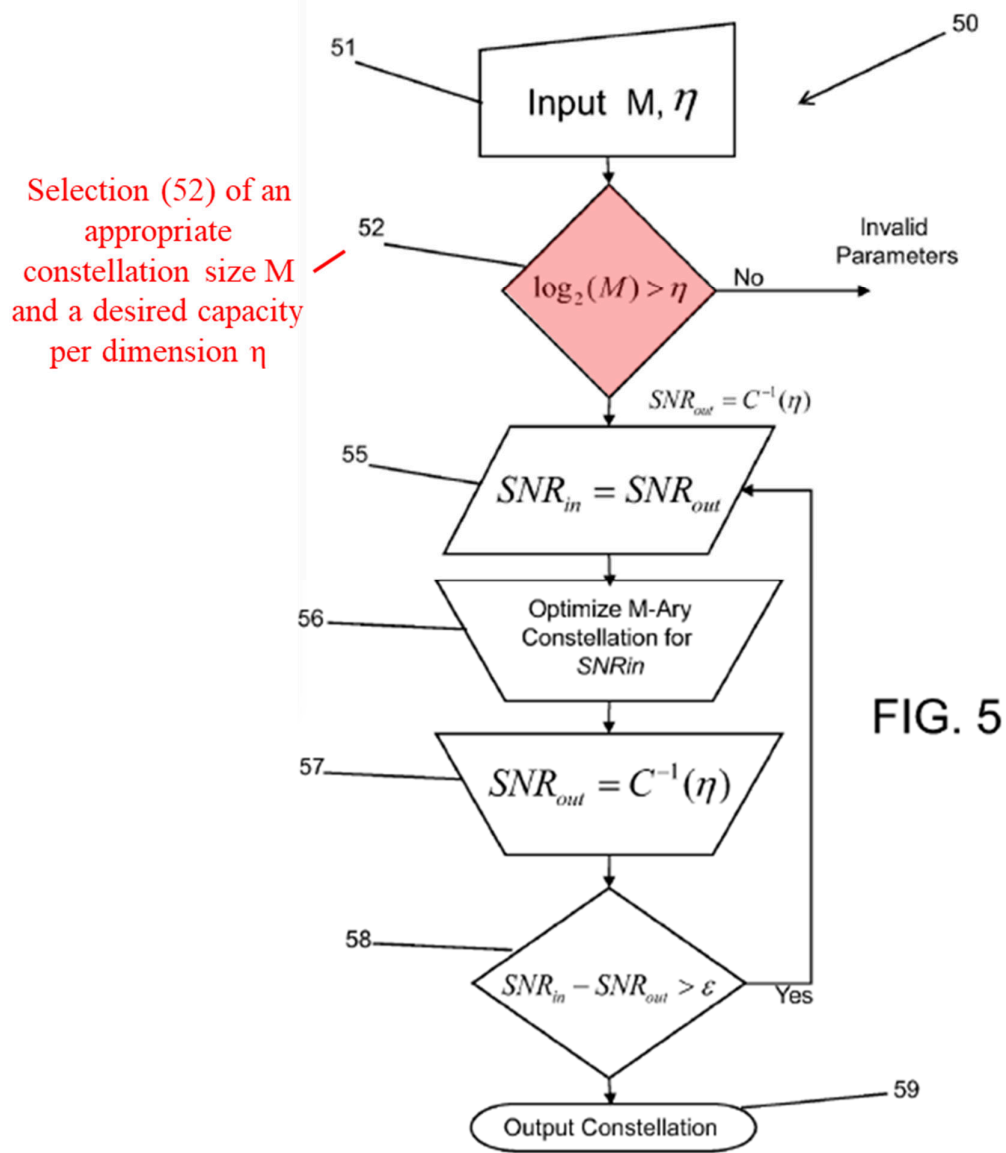
ii. Claim 2

[2a]⁸ The communication system of claim 1, wherein: the symbol constellation is selected from a plurality of unequally spaced symbol constellations;

146. In the combination, the ’777 patent discloses ***the symbol constellation is selected from a plurality of unequally spaced symbol constellations.*** For example, the ’777 patent discloses a section dedicated on “[s]electing a

⁸ Because claim 3 depends from claim 1 and 2, I have been asked to also includes a mapping of the prior art references includes a mapping of the prior art references against claims 1 and 2 (and similarly other independent claims). [In Ground 1, this petition is relying on the ’777 patent as disclosing all the features of claim 2.](#)

[c]onstellation [h]aving an [o]ptimal [c]apacity” and illustrates the process involved in FIG. 5, “a flow chart showing a process for obtaining a constellation optimized for capacity for use in a communication system having a fixed code rate and modulation scheme.” LGE1027, 7:11-8:29; *id.*, 3:39-42, FIG. 5; *see also id.*, 5:4-7. In FIG. 5 illustrates that “process 50 commences with the selection (52) of an appropriate constellation size M and a desired capacity per dimension η ”; in addition, “the process involves a check (52) to ensure that the constellation size can support the desired capacity.” LGE1027, 7:19-21; *id.*, 7:21-23. The selection takes of the symbol constellation takes place from among multiple “[g]eometrically shaped constellations.” LGE1027, 7:10-11. The ’777 patent further establishes that the “communication systems in accordance with embodiments of the invention are described that use *signal constellations, which have unequally spaced* (i.e. ‘geometrically’ shaped) *points*.” LGE1027, 4:47-59. Thus, ’777 patent discloses *the symbol constellation is selected from a plurality of unequally spaced symbol constellations*.



LGE1027, FIG. 5.

147. Thus, the features of [1d] above would have been obvious to a POSITA in view of the '777 patent.

[2b] the plurality of unequally spaced symbol constellations includes a plurality of unequally spaced symbol constellations of a first type that comprise multiple different sixty-four-point symbol constellations, multiple different two-hundred-fifty-six-point symbol constellations, and multiple different one-thousand-twenty-four-point symbol constellations, where unequally spaced symbol constellations of the first type include at least two constellation points having locations that are the same and different labels;

148. In the combination, the '777 patent discloses *the plurality of unequally spaced symbol constellations includes a plurality of unequally spaced symbol constellations of a first type that comprise multiple different sixty-four-point symbol constellations, multiple different two-hundred-fifty-six-point symbol constellations, and multiple different one-thousand-twenty-four-point symbol constellations*. For example, the '777 patent discloses geometric (i.e., non-uniform) one dimensional PAM-8 constellations of FIG. 13b. LGE1027, 10:56-62, FIG. 13b. However, the '777 patent explains that one dimensional geometric PAM constellations can be orthogonalized into multidimensional QAM constellations. LGE1027, 3:11-19; 4:29-31; 12:12-16; 12:26-33; 12:38-49. A POSITA would have understood in view of the teachings of the '777 patent that orthogonalizing the geometric (i.e., non-uniform) one dimensional PAM-8 constellations of FIG. 13b into respective multidimensional QAM constellations would yield multiple different geometric (i.e., non-uniform) multidimensional QAM-64 constellations (FIG. 21 being one example). LGE1027 12:26-33, FIG. 21A. POSITA would have

understood from the teachings of the '777 patent that the plurality of multidimensional symbol constellations would be capable of including the geometric (i.e., non-uniform) multidimensional QAM-64 constellations. LGE1027, 3:11-19; 4:29-31; 5:56-6:4; 12:12-16; 12:38-49. Thus, these features of [3a] would have been obvious to a POSITA.

149. For the reasons stated above, a POSITA would have found it obvious to continue the orthogonalization process described above to take a PAM-8 and create an QAM-64, to then repeat the process for orthogonalizing a PAM-16 into a QAM-256 and a PAM-32 into a QAM-1024. LGE1027 12:26-33, FIG. 21.

150. As discussed above in [1c-3] and [1c-4], the '777 patent also discloses *unequally spaced symbol constellations of the first type include at least two constellation points having locations that are the same and different labels*. *Supra* §§V.A.4.[1c-3], V.A.4.[1c-4]. A POSITA would have been motivated to implement QAM-64, QAM-256, and QAM-1024 *unequally spaced symbol constellations of the first type* including *at least two constellation points having locations that are the same and different labels*. In another instance, a POSITA would have also considered other modulations schemes such as PSK, PAM, and/or the like.

151. Thus, the features of [2b] above would have been obvious to a

POSITA in view of the '777 patent.

[2c] the receiver is capable of selecting an LDPC code rate and the unequally spaced symbol constellation as a pair from a plurality of predetermined LDPC code rate and unequally spaced symbol constellation pairs; and

152. The '777 patent discloses *wherein the receiver is capable of selecting an LDPC code rate and unequally spaced symbol constellation pair from a plurality of predetermined LDPC code rate and unequally spaced symbol constellation pairs* for at least the reasons set forth above with respect to limitation [1c-1] above. Supra §V.A.4.[1c-1].

153. For example, the '777 patent discloses a plurality of geometric (i.e., unequally spaced or non-uniform), one-dimensional constellations that each have the number of constellation points (i.e., 4) in FIG. 11b (annotated and reproduced below):

PAM-4 constellations optimized for parallel decoding capacity at different

(bps)	0.50	0.75	1.00	1.25	1.50
(SNR)	0.19	3.11	5.26	7.22	9.25
x_0	-1.00	-1.30	-1.36	-1.37	-1.36
x_1	-1.00	-0.56	-0.39	-0.33	-0.39
x_2	1.00	1.30	1.36	0.33	1.36
x_3	1.00	0.56	0.39	1.37	0.39
Code rate	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$

FIG. 11b

LGE1027, FIG. 11b

154. As described in [1c-1]-[1c-4] above, the '777 patent explains that each of the four constellations in the constellation design table of FIG. 11b can be optimized into a plurality of corresponding geometric unequally spaced symbol constellations. *See above* [1c-1]-[1c-4].

155. Also implicit in the constellation design tables such as FIG. 11b is a corresponding specific code rate that effectively creates a constellation-code rate pair combination for each column. For example, the LDPC code rate (shown in green text in annotated FIG. 11b above) is determined the constellation optimization equation set forth in the '319 application provisional, which is incorporated by reference into the '777 patent. In particular, the LDPC code rate for each constellation in FIG. 11b is determined based on “[t]he number of user bits per dimension, η , is related to code rate (e.g., LDPC code rate), R , and the total number of real signaling dimensions, N_{dim} ,” using the following equation:

$$\eta = \frac{R(\log_2(M))}{N_{dim}},$$

wherein M is, as best understood by Petitioner, the number of constellation points.

LGE1015, 2. Here, η is the capacity in bps provided in FIG. 11b, N_{dim} is the number of dimensions (e.g., 1 for PAM-4 (shown in FIG. 11b) or 2 for QAM constellation), and M is number of points (e.g., 4 for PAM-4 (shown in FIG. 11b) or 16 for the optimized unequally spaced QAM constellation). LGE1027, FIG.

11b; LGE1015, 2. Thus, a POSITA would have understood that each column of FIG. 11b comprises unequally spaced symbol constellation and LDPC code rate pairs.

156. Thus, a POSITA would have understood that '777 patent discloses *the receiver is capable of selecting an LDPC code rate and unequally spaced symbol constellation pair from a plurality of predetermined LDPC code rate and unequally spaced symbol constellation pairs.*

[2d] each of the plurality of unequally spaced symbol constellations is only included in one of the plurality of predetermined LDPC code rate and unequally spaced symbol constellation pairs.

157. In the combination, the '777 patent discloses *each of the plurality of unequally spaced symbol constellations is only included in one of the plurality of predetermined LDPC code rate and unequally spaced symbol constellation pairs* for at least the reasons set forth above with respect to limitation [2a] and the analysis of other features of [2c] above. Supra §§V.A.4.[2a] and [2c]. As explained above in [1c-1]-[1c-4] and [2a], the constellation design tables such as FIG. 11b is a corresponding specific code rated that effectively creates a constellation-code rate pair combination for each column. Thus, the bolded claim limitation above would have been obvious to a POSITA in view of the '777 patent.

iii. Claim 3

[3a] The communication system of claim 2, wherein the plurality of predetermined LDPC code rate and unequally spaced symbol constellation pairs includes:

multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate below 1/3 and a sixty-four-point unequally spaced symbol constellation of the first type;

158. In the combination, the '777 patent discloses ***wherein the plurality of predetermined LDPC code rate and unequally spaced symbol constellation pairs includes: multiple LDPC code rate and unequally spaced symbol constellation pairs*** for at least the reasons set forth above in [2a], [2b], [2c], and [2d].

159. For the limitation of particular ranges, the '777-ATSC327 combination uses the look-up tables of A327 which disclose that when optimizing the non-uniform constellations and LDPC code rate pairs, "[t]here is one non-uniform constellation (NUC) defined for each ModCod combination," and "a look-up table with the defined constellation mapping for each ModCod combination can be used." LGE1028, 32. The annotated look-up table (below) shows the claimed ranges. Additionally, a POSITA would have found it obvious to select a 64QAM constellations having a code rate that falls within the claimed range. For example, referring to Table 4.3 (reproduced below), a POSITA would have implemented multiple 64QAM having a respective code rates falling within the code rates as 2/15, 3/15, and 4/15 at the required SNR values of -0.26, 2.27, and 4.15, respectively. LGE1028, Table 4.3.

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-6.23	-4.32	-2.89	-1.70	-0.54	0.30	1.16	1.97	2.77	3.60	4.49	5.53
16QAM	-2.73	-0.25	1.46	2.82	4.21	5.21	6.30	7.32	8.36	9.50	10.57	11.83
64QAM	-0.26	2.27	4.15	5.96	7.66	8.92	10.31	11.55	12.88	14.28	15.57	17.03
256QAM	1.60	4.30	6.57	8.53	10.61	12.10	13.91	15.55	17.13	18.76	20.44	22.22
1024QAM	3.23	6.17	8.77	11.07	13.46	15.30	17.46	19.45	21.35	23.43	25.52	27.62
4096QAM	4.58	7.85	10.73	13.45	16.04	18.22	20.69	23.05	25.55	28.11	30.34	32.83

Table 4.4 Required SNRs (dB) for all ModCod Combinations, Long LDPC Codes (64800 bits) and i.i.d. Rayleigh Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-5.72	-3.62	-1.97	-0.55	0.86	1.95	3.16	4.35	5.62	7.05	8.76	10.97
16QAM	-1.84	0.81	2.69	4.32	5.98	7.21	8.63	9.94	11.40	12.78	14.60	16.85
64QAM	0.86	3.61	5.88	7.74	9.72	11.10	12.75	14.25	15.81	17.44	19.39	21.82
256QAM	2.89	5.97	8.46	10.59	12.92	14.58	16.54	18.23	20.06	21.94	24.01	26.62
1024QAM	4.65	8.04	10.85	13.25	15.91	17.84	20.13	22.34	24.47	26.61	28.82	31.59
4096QAM	6.23	9.83	12.95	15.75	18.79	21.03	23.67	26.37	28.64	31.18	33.82	36.54

LGE1028, Table 4.3-4.4, 18

[3b] multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate below 5/8 and a two-hundred-and-fifty-six-point unequally spaced symbol constellation of the first type; and

160. The annotated look-up table (below) shows the claimed ranges.

Additionally, a POSITA would have found it obvious to select a 256QAM constellations having a code rate that falls within the claimed range. For example, referring to Table 4.3 (reproduced below), a POSITA would have implemented multiple 256QAM having a respective code rates falling within the code rate ranges of 2/15-9/15 with their respective required SNR values. LGE1028, Table 4.3.

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-6.23	-4.32	-2.89	-1.70	-0.54	0.30	1.16	1.97	2.77	3.60	4.49	5.53
16QAM	-2.73	-0.25	1.46	2.82	4.21	5.21	6.30	7.32	8.36	9.50	10.57	11.83
64QAM	-0.26	2.27	4.15	5.96	7.66	8.92	10.31	11.55	12.88	14.28	15.57	17.03
256QAM	1.60	4.30	6.57	8.53	10.61	12.10	13.91	15.55	17.13	18.76	20.44	22.22
1024QAM	3.23	6.17	8.77	11.07	13.46	15.30	17.46	19.45	21.35	23.43	25.52	27.62
4096QAM	4.58	7.85	10.73	13.45	16.04	18.22	20.69	23.05	25.55	28.11	30.34	32.83

Table 4.4 Required SNRs (dB) for all ModCod Combinations, Long LDPC Codes (64800 bits) and i.i.d. Rayleigh Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-5.72	-3.62	-1.97	-0.55	0.86	1.95	3.16	4.35	5.62	7.05	8.76	10.97
16QAM	-1.84	0.81	2.69	4.32	5.98	7.21	8.63	9.94	11.40	12.78	14.60	16.85
64QAM	0.86	3.61	5.88	7.74	9.72	11.10	12.75	14.25	15.81	17.44	19.39	21.82
256QAM	2.89	5.97	8.46	10.59	12.92	14.58	16.54	18.23	20.06	21.94	24.01	26.62
1024QAM	4.65	8.04	10.85	13.25	15.91	17.84	20.13	22.34	24.47	26.61	28.82	31.59
4096QAM	6.23	9.83	12.95	15.75	18.79	21.03	23.67	26.37	28.64	31.18	33.82	36.54

LGE1028, Table 4.3-4.4, 18

[3c] multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate below 7/10 and a one-thousand-twenty-four-point unequally spaced symbol constellation of the first type.

161. The annotated look-up table (below) shows the claimed ranges.

Additionally, a POSITA would have found it obvious to select a 1024QAM constellations having a code rate that falls within the claimed range. For example, referring to Table 4.3 (reproduced below), a POSITA would have implemented multiple 1024QAM having a respective code rates falling within the code rate ranges of 2/15-10/15 with their respective required SNR values. LGE1028, Table 4.3.

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate												7/10
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15	
QPSK	-6.23	-4.32	-2.89	-1.70	-0.54	0.30	1.16	1.97	2.77	3.60	4.49	5.53	
16QAM	-2.73	-0.25	1.46	2.82	4.21	5.21	6.30	7.32	8.36	9.50	10.57	11.83	
64QAM	-0.26	2.27	4.15	5.96	7.66	8.92	10.31	11.55	12.88	14.28	15.57	17.03	
256QAM	1.60	4.30	6.57	8.53	10.61	12.10	13.91	15.55	17.13	18.76	20.44	22.22	
1024QAM	3.23	6.17	8.77	11.07	13.46	15.30	17.46	19.45	21.35	23.43	25.52	27.62	
4096QAM	4.58	7.85	10.73	13.45	16.04	18.22	20.69	23.05	25.55	28.11	30.34	32.83	

Table 4.4 Required SNRs (dB) for all ModCod Combinations, Long LDPC Codes (64800 bits) and i.i.d. Rayleigh Channel

Constellation	Code Rate												7/10
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15	
QPSK	-5.72	-3.62	-1.97	-0.55	0.86	1.95	3.16	4.35	5.62	7.05	8.76	10.97	
16QAM	-1.84	0.81	2.69	4.32	5.98	7.21	8.63	9.94	11.40	12.78	14.60	16.85	
64QAM	0.86	3.61	5.88	7.74	9.72	11.10	12.75	14.25	15.81	17.44	19.39	21.82	
256QAM	2.89	5.97	8.46	10.59	12.92	14.58	16.54	18.23	20.06	21.94	24.01	26.62	
1024QAM	4.65	8.04	10.85	13.25	15.91	17.84	20.13	22.34	24.47	26.61	28.82	31.59	
4096QAM	6.23	9.83	12.95	15.75	18.79	21.03	23.67	26.37	28.64	31.18	33.82	36.54	

LGE1028, Table 4.3-4.4, 18

iv. Claim 4

[4a] The communication system of claim 3, wherein the receiver is capable of decoding the signals received over the communication channel when the SNR of the communication channel is:

162. In the combination, the '777 patent discloses *wherein the receiver is capable of decoding the signals received over the communication channel when the SNR of the communication channel is:* for at least the reasons set forth above in [1pre], [1a], and [1b].

[4b] equal to or less than 5.27 dB while using an LDPC code rate and unequally spaced symbol constellation pair that includes an LDPC code rate that is below 1/3 and a sixty-four-point unequally spaced symbol constellation of the first type;

163. In the combination, the ATSC327 discloses ***equal to or less than 5.27 dB while using an LDPC code rate and unequally spaced symbol constellation pair that includes an LDPC code rate that is below 1/3 and a sixty-four-point unequally spaced symbol constellation of the first type.***

164. Recall that “[t]here is one non-uniform constellation (NUC) defined for each ModCod combination,” in Table 4.3 and that LDPC code rates are used. LGE1028, 32. For example, referring to Table 4.3 (reproduced below), a POSITA would have been motivated to implement ModCod combinations in the ’777 patent’s communication system. LGE1027, 5:12-43; LGE1028, Table 4.3. As discussed in above in [2b], a POSITA would have selected a first type of unequally spaced symbol constellation having 64 constellations points paired with a predetermined LDPC code rate to form ModCod combinations. LGE1027, 5:34-6:1. For example, referring to Table 4.3 (reproduced below), a POSITA would have implemented multiple 64QAM having a respective code rates falling within the code rates as 2/15, 3/15, and 4/15 at the required SNR values of -0.26, 2.27, and 4.15, respectively. LGE1028, Table 4.3. Similarly, referring to Table 4.4 (reproduced below), a POSITA would have implemented multiple 64QAM having

a respective code rates falling within the code rates as 2/15 and 3/15 at the required SNR values of 0.86 and 3.61, respectively. LGE1028, Table 4.4.

165. The annotated look-up table (below) shows the claimed ranges and values.

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-6.23	-4.32	-2.89	-1.70	-0.54	0.30	1.16	1.97	2.77	3.60	4.49	5.53
16QAM	-2.73	-0.25	1.46	2.82	4.21	5.21	6.30	7.32	8.36	9.50	10.57	11.83
64QAM	-0.26	2.27	4.15	5.96	7.66	8.92	10.31	11.55	12.88	14.28	15.57	17.03
256QAM	1.60	4.30	6.57	8.53	10.61	12.10	13.91	15.55	17.13	18.76	20.44	22.22
1024QAM	3.23	6.17	8.77	11.07	13.46	15.30	17.46	19.45	21.35	23.43	25.52	27.62
4096QAM	4.58	7.85	10.73	13.45	16.04	18.22	20.69	23.05	25.55	28.11	30.34	32.83

Table 4.4 Required SNRs (dB) for all ModCod Combinations, Long LDPC Codes (64800 bits) and i.i.d. Rayleigh Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-5.72	-3.62	-1.97	-0.55	0.86	1.95	3.16	4.35	5.62	7.05	8.76	10.97
16QAM	-1.84	0.81	2.69	4.32	5.98	7.21	8.63	9.94	11.40	12.78	14.60	16.85
64QAM	0.86	3.61	5.88	7.74	9.72	11.10	12.75	14.25	15.81	17.44	19.39	21.82
256QAM	2.89	5.97	8.46	10.59	12.92	14.58	16.54	18.23	20.06	21.94	24.01	26.62
1024QAM	4.65	8.04	10.85	13.25	15.91	17.84	20.13	22.34	24.47	26.61	28.82	31.59
4096QAM	6.23	9.83	12.95	15.75	18.79	21.03	23.67	26.37	28.64	31.18	33.82	36.54

LGE1028, Table 4.3-4.4, 18

[4c] equal to or less than 15.42 dB while using an LDPC code rate and unequally spaced symbol constellation pair that includes an LDPC code rate below 5/8 and a two-hundred-fifty-six-point unequally spaced symbol constellation of the first type; and

166. In the combination, the ATSC327 discloses *equal to or less than 15.42 dB while using an LDPC code rate and unequally spaced symbol constellation pair that includes an LDPC code rate below 5/8 and a two-hundred-*

fifty-six-point unequally spaced symbol constellation of the first type. As discussed in above in [2b], a POSITA would have selected a first type of unequally spaced symbol constellation having 256 constellations points paired with a predetermined LDPC code rate to form ModCod combinations. LGE1027, 5:34-6:1. For example, referring to Table 4.3 (reproduced below), a POSITA would have implemented multiple 256QAM having a respective code rates falling within the code rates 2/15, 3/15, 4/15, 5/15, 6/15, 7/15, and 8/15 at the required SNR values of 1.6, 4.3, 6.57, 8.53, 10.61, 12.1, and 13.91, respectively. Similarly, referring to Table 4.4 (reproduced below), a POSITA would have implemented multiple 256QAM having a respective code rates falling within the code rates as ranges 2/15-7/15 with their respective required SNR values. LGE1028, Table 4.4.

167. The annotated look-up table (below) shows the claimed ranges and values. LGE1028, 18

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-6.23	-4.32	-2.89	-1.70	-0.54	0.30	1.16	1.97	2.77	3.60	4.49	5.53
16QAM	-2.73	-0.25	1.46	2.82	4.21	5.21	6.30	7.32	8.36	9.50	10.57	11.83
64QAM	-0.26	2.27	4.15	5.96	7.66	8.92	10.31	11.55	12.88	14.28	15.57	17.03
256QAM	1.60	4.30	6.57	8.53	10.61	12.10	13.91	15.55	17.13	18.76	20.44	22.22
1024QAM	3.23	6.17	8.77	11.07	13.46	15.30	17.46	19.45	21.35	23.43	25.52	27.62
4096QAM	4.58	7.85	10.73	13.45	16.04	18.22	20.69	23.05	25.55	28.11	30.34	32.83

Table 4.4 Required SNRs (dB) for all ModCod Combinations, Long LDPC Codes (64800 bits) and i.i.d. Rayleigh Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-5.72	-3.62	-1.97	-0.55	0.86	1.95	3.16	4.35	5.62	7.05	8.76	10.97
16QAM	-1.84	0.81	2.69	4.32	5.98	7.21	8.63	9.94	11.40	12.78	14.60	16.85
64QAM	0.86	3.61	5.88	7.74	9.72	11.10	12.75	14.25	15.81	17.44	19.39	21.82
256QAM	2.89	5.97	8.46	10.59	12.92	14.58	16.54	18.23	20.06	21.94	24.01	26.62
1024QAM	4.65	8.04	10.85	13.25	15.91	17.84	20.13	22.34	24.47	26.61	28.82	31.59
4096QAM	6.23	9.83	12.95	15.75	18.79	21.03	23.67	26.37	28.64	31.18	33.82	36.54

LGE1028, Table 4.3-4.4, 18

[4d] equal to or less than 21.52 dB while using an LDPC code rate and unequally spaced symbol constellation pair that includes an LDPC code rate below 7/10 and a one-thousand-twenty-four-point unequally spaced symbol constellations of the first type.

168. In the combination, the ATSC327 discloses *equal to or less than 21.52 dB while using an LDPC code rate and unequally spaced symbol constellation pair that includes an LDPC code rate below 7/10 and a one-thousand-twenty-four-point unequally spaced symbol constellations of the first type*. As discussed in above in [2b], a POSITA would have selected a first type of unequally spaced symbol constellation having 1024 constellations points paired with a predetermined LDPC code rate to form ModCod combinations. LGE1027,

5:34-6:1. For example, referring to Table 4.3 (reproduced below), a POSITA would have implemented multiple 1024QAM constellations that each have a respective code rates falling within the code rate that falls within the code rate range of 2/15-10/15 at their respective required SNR values. Similarly, referring to Table 4.4 (reproduced below), a POSITA would have implemented multiple 1024QAM constellation that each have a respective code rates falling within the code rate that falls within the code rate ranges of 2/15-8/15 with their respective required SNR values. LGE1028, Table 4.4.

169. The annotated look-up table (below) shows the claimed ranges and values. LGE1028, 18

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-6.23	-4.32	-2.89	-1.70	-0.54	0.30	1.16	1.97	2.77	3.60	4.49	5.53
16QAM	-2.73	-0.25	1.46	2.82	4.21	5.21	6.30	7.32	8.36	9.50	10.57	11.83
64QAM	-0.26	2.27	4.15	5.96	7.66	8.92	10.31	11.55	12.88	14.28	15.57	17.03
256QAM	1.60	4.30	6.57	8.53	10.61	12.10	13.91	15.55	17.13	18.76	20.44	22.22
1024QAM	3.23	6.17	8.77	11.07	13.46	15.30	17.46	19.45	21.35	23.43	25.52	27.62
4096QAM	4.58	7.85	10.73	13.45	16.04	18.22	20.69	23.05	25.55	28.11	30.34	32.83

Table 4.4 Required SNRs (dB) for all ModCod Combinations, Long LDPC Codes (64800 bits) and i.i.d. Rayleigh Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-5.72	-3.62	-1.97	-0.55	0.86	1.95	3.16	4.35	5.62	7.05	8.76	10.97
16QAM	-1.84	0.81	2.69	4.32	5.98	7.21	8.63	9.94	11.40	12.78	14.60	16.85
64QAM	0.86	3.61	5.88	7.74	9.72	11.10	12.75	14.25	15.81	17.44	19.39	21.82
256QAM	2.89	5.97	8.46	10.59	12.92	14.58	16.54	18.23	20.06	21.94	24.01	26.62
1024QAM	4.65	8.04	10.85	13.25	15.91	17.84	20.13	22.34	24.47	26.61	28.82	31.59
4096QAM	6.23	9.83	12.95	15.75	18.79	21.03	23.67	26.37	28.64	31.18	33.82	36.54

v. Claim 5

***[5a] The communication system of claim 4, wherein:
the plurality of unequally spaced symbol constellations include a plurality of
unequally spaced symbol constellations of a second type that comprises multiple
different sixteen-point symbol constellations, multiple different sixty-four-point
symbol constellations, multiple different two-hundred-fifty-six-point symbol
constellations, and multiple different one-thousand-twenty-four-point symbol
constellations;***

170. In the combination, the '777 patent discloses *the plurality of
unequally spaced symbol constellations include a plurality of unequally spaced
symbol constellations of a second type that comprises multiple different sixteen-
point symbol constellations, multiple different sixty-four-point symbol
constellations, multiple different two-hundred-fifty-six-point symbol
constellations, and multiple different one-thousand-twenty-four-point symbol
constellations*: for at least the reasons set forth above in [2a], [2b], and [2c].

***[5b] no two constellation points within an unequally spaced symbol constellation
of the second type share locations that are the same;***

171. Within the ModCod combination look-up tables, “[t]here is one non-
uniform constellation (NUC) defined for each ModCod combination.” LGE1028,

[5c] the demapper is also capable of determining likelihoods using the demodulated signal and an unequally spaced symbol constellation of the second type; and

172. See *Supra* [1c-1]. The '777-ATSC327 combination provides the ability of the demapper to demodulate multidimensional signals. LGE1027, 12:44-47

[5d] the plurality of predetermined LDPC code rate and unequally spaced symbol constellation pairs include: multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 3/8 and less than or equal to 6/8 and a sixteen-point unequally spaced symbol constellation of the second type;

173. The annotated look-up table (below) shows the claimed ranges and values. LGE1028, 18 In the '777-ATSC327 combination, A327 discloses through Table 4.3 a ***plurality of predetermined LDPC code rate and unequally spaced symbol constellation pairs include:*** For example, recall that the ModCod pairs all have non-uniform constellations *see* [5b] and that the '777 Combination can utilize LDPC codes *see* [1d]. LGE1027, 5:41-43; 13:31-33; 13:50-51; LGE1028, 32. Table 4.3 also discloses ***multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 3/8 and less than or equal to 6/8 and a sixteen-point unequally spaced symbol constellation.*** For example, a 8/15 LDPC code rate can be selected with a 16QAM constellation for the table. As discussed above in §V.A.3, the 777-

ATSC327 may include a second type of unequally spaced symbol constellation that includes no two constellation points within an unequally spaced symbol constellation share locations that are the same. *See supra* §V.A.3; LGE1027, FIG. 20.

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-6.23	-4.32	-2.89	-1.70	-0.54	0.30	1.16	1.97	2.77	3.60	4.49	5.53
16QAM	-2.73	-0.25	1.46	2.82	4.21	5.21	6.30	7.32	8.36	9.50	10.57	11.83
64QAM	-0.26	2.27	4.15	5.96	7.66	8.92	10.31	11.55	12.88	14.28	15.57	17.03
256QAM	1.60	4.30	6.57	8.53	10.61	12.10	13.91	15.55	17.13	18.76	20.44	22.22
1024QAM	3.23	6.17	8.77	11.07	13.46	15.30	17.46	19.45	21.35	23.43	25.52	27.62
4096QAM	4.58	7.85	10.73	13.45	16.04	18.22	20.69	23.05	25.55	28.11	30.34	32.83

Table 4.4 Required SNRs (dB) for all ModCod Combinations, Long LDPC Codes (64800 bits) and i.i.d. Rayleigh Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-5.72	-3.62	-1.97	-0.55	0.86	1.95	3.16	4.35	5.62	7.05	8.76	10.97
16QAM	-1.84	0.81	2.69	4.32	5.98	7.21	8.63	9.94	11.40	12.78	14.60	16.85
64QAM	0.86	3.61	5.88	7.74	9.72	11.10	12.75	14.25	15.81	17.44	19.39	21.82
256QAM	2.89	5.97	8.46	10.59	12.92	14.58	16.54	18.23	20.06	21.94	24.01	26.62
1024QAM	4.65	8.04	10.85	13.25	15.91	17.84	20.13	22.34	24.47	26.61	28.82	31.59
4096QAM	6.23	9.83	12.95	15.75	18.79	21.03	23.67	26.37	28.64	31.18	33.82	36.54

LGE1028, Table 4.3-4.4, 18

[5e] multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 3/6 and less than or equal to 5/6 and a sixty-four-point unequally spaced symbol constellation of the second type;

174. The annotated look-up table (below) shows the claimed ranges and values. LGE1028, 18 In the '777-ATSC327 combination, A327 discloses through Table 4.3 *multiple LDPC code rate and unequally spaced symbol constellation*

pairs that each include an LDPC code rate that is equal to or greater than 3/6 and less than or equal to 5/6 and a sixty-four-point unequally spaced symbol constellation. For example, a 10/15 LDPC code rate can be selected with a 64QAM constellation for the table. As discussed above in §V.A.3, the 777-ATSC327 may include a second type of unequally spaced symbol constellation that includes no two constellation points within an unequally spaced symbol constellation share locations that are the same. *See supra* §V.A.3; LGE1027, FIG. 20.

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-6.23	-4.32	-2.89	-1.70	-0.54	0.30	1.16	1.97	2.77	3.60	4.49	5.53
16QAM	-2.73	-0.25	1.46	2.82	4.21	5.21	6.30	7.32	8.36	9.50	10.57	11.83
64QAM	-0.26	2.27	4.15	5.96	7.66	8.92	10.31	11.55	12.88	14.28	15.57	17.03
256QAM	1.60	4.30	6.57	8.53	10.61	12.10	13.91	15.55	17.13	18.76	20.44	22.22
1024QAM	3.23	6.17	8.77	11.07	13.46	15.30	17.46	19.45	21.35	23.43	25.52	27.62
4096QAM	4.58	7.85	10.73	13.45	16.04	18.22	20.69	23.05	25.55	28.11	30.34	32.83

Table 4.4 Required SNRs (dB) for all ModCod Combinations, Long LDPC Codes (64800 bits) and i.i.d. Rayleigh Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-5.72	-3.62	-1.97	-0.55	0.86	1.95	3.16	4.35	5.62	7.05	8.76	10.97
16QAM	-1.84	0.81	2.69	4.32	5.98	7.21	8.63	9.94	11.40	12.78	14.60	16.85
64QAM	0.86	3.61	5.88	7.74	9.72	11.10	12.75	14.25	15.81	17.44	19.39	21.82
256QAM	2.89	5.97	8.46	10.59	12.92	14.58	16.54	18.23	20.06	21.94	24.01	26.62
1024QAM	4.65	8.04	10.85	13.25	15.91	17.84	20.13	22.34	24.47	26.61	28.82	31.59
4096QAM	6.23	9.83	12.95	15.75	18.79	21.03	23.67	26.37	28.64	31.18	33.82	36.54

LGE1028, Table 4.3-4.4, 18

[5f] multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 6/8 and less than or equal to 7/8 and a two-hundred-and-fifty-six-point unequally spaced symbol constellation of the second type; and

175. The annotated look-up table (below) shows the claimed ranges and values. LGE1028, 18 In the '777-ATSC327 combination, A327 discloses through Table 4.3 ***multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 6/8 and less than or equal to 7/8 and a two-hundred-and-fifty-six-point unequally spaced symbol constellation.*** For example, a 12/15 LDPC code rate can be selected with a 256QAM constellation for the table. As discussed above in §V.A.3, the 777-ATSC327 may include a second type of unequally spaced symbol constellation that includes no two constellation points within an unequally spaced symbol constellation share locations that are the same. *See supra* §V.A.3; LGE1027, FIG. 20.

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate										6/8	7/8
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-6.23	-4.32	-2.89	-1.70	-0.54	0.30	1.16	1.97	2.77	3.60	4.49	5.53
16QAM	-2.73	-0.25	1.46	2.82	4.21	5.21	6.30	7.32	8.36	9.50	10.57	11.83
64QAM	-0.26	2.27	4.15	5.96	7.66	8.92	10.31	11.55	12.88	14.28	15.57	17.03
256QAM	1.60	4.30	6.57	8.53	10.61	12.10	13.91	15.55	17.13	18.76	20.44	22.22
1024QAM	3.23	6.17	8.77	11.07	13.46	15.30	17.46	19.45	21.35	23.43	25.52	27.62
4096QAM	4.58	7.85	10.73	13.45	16.04	18.22	20.69	23.05	25.55	28.11	30.34	32.83

Table 4.4 Required SNRs (dB) for all ModCod Combinations, Long LDPC Codes (64800 bits) and i.i.d. Rayleigh Channel

Constellation	Code Rate										6/8	7/8
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-5.72	-3.62	-1.97	-0.55	0.86	1.95	3.16	4.35	5.62	7.05	8.76	10.97
16QAM	-1.84	0.81	2.69	4.32	5.98	7.21	8.63	9.94	11.40	12.78	14.60	16.85
64QAM	0.86	3.61	5.88	7.74	9.72	11.10	12.75	14.25	15.81	17.44	19.39	21.82
256QAM	2.89	5.97	8.46	10.59	12.92	14.58	16.54	18.23	20.06	21.94	24.01	26.62
1024QAM	4.65	8.04	10.85	13.25	15.91	17.84	20.13	22.34	24.47	26.61	28.82	31.59
4096QAM	6.23	9.83	12.95	15.75	18.79	21.03	23.67	26.37	28.64	31.18	33.82	36.54

LGE1028, Table 4.3-4.4, 18.

[5g] multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 8/10 and less than or equal to 9/10 and a one-thousand-twenty-four-point unequally spaced symbol constellation of the second type;

176. The annotated look-up table (below) shows the claimed ranges and values. LGE1028, 18 In the ‘777-ATSC327 combination, A327 discloses through Table 4.3 *multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 8/10 and less than or equal to 9/10 and a one- thousand-twenty-four-point unequally spaced symbol constellation*. For example, a 12/15 LDPC code rate can be selected with a 1024QAM constellation for the table. As discussed above in §V.A.3, the

777-ATSC327 may include a second type of unequally spaced symbol constellation that includes no two constellation points within an unequally spaced symbol constellation share locations that are the same. *See supra* §V.A.3; LGE1027, FIG. 20.

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate											8/10	9/10
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15	
QPSK	-6.23	-4.32	-2.89	-1.70	-0.54	0.30	1.16	1.97	2.77	3.60	4.49	5.53	
16QAM	-2.73	-0.25	1.46	2.82	4.21	5.21	6.30	7.32	8.36	9.50	10.57	11.83	
64QAM	-0.26	2.27	4.15	5.96	7.66	8.92	10.31	11.55	12.88	14.28	15.57	17.03	
256QAM	1.60	4.30	6.57	8.53	10.61	12.10	13.91	15.55	17.13	18.76	20.44	22.22	
1024QAM	3.23	6.17	8.77	11.07	13.46	15.30	17.46	19.45	21.35	23.43	25.52	27.62	
4096QAM	4.58	7.85	10.73	13.45	16.04	18.22	20.69	23.05	25.55	28.11	30.34	32.83	

Table 4.4 Required SNRs (dB) for all ModCod Combinations, Long LDPC Codes (64800 bits) and i.i.d. Rayleigh Channel

Constellation	Code Rate											8/10	9/10
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15	
QPSK	-5.72	-3.62	-1.97	-0.55	0.86	1.95	3.16	4.35	5.62	7.05	8.76	10.97	
16QAM	-1.84	0.81	2.69	4.32	5.98	7.21	8.63	9.94	11.40	12.78	14.60	16.85	
64QAM	0.86	3.61	5.88	7.74	9.72	11.10	12.75	14.25	15.81	17.44	19.39	21.82	
256QAM	2.89	5.97	8.46	10.59	12.92	14.58	16.54	18.23	20.06	21.94	24.01	26.62	
1024QAM	4.65	8.04	10.85	13.25	15.91	17.84	20.13	22.34	24.47	26.61	28.82	31.59	
4096QAM	6.23	9.83	12.95	15.75	18.79	21.03	23.67	26.37	28.64	31.18	33.82	36.54	

LGE1028, Table 4.3-4.4, 18.

[5h] the receiver is capable of decoding the signals received over the communication channel when the SNR of the communication channel is: between 3.11 dB and 9.25 dB while using at least one of the multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 3/8 and less than or equal to 6/8 and a sixteen-point unequally spaced symbol constellation of the second type;

177. The '777-ATSC327 combination teaches *the receiver is capable of decoding the signals received over the communication channel when the SNR of*

the communication channel, see [1a], [1b], and [1d].

178. Further the A327 teaches to “[n]ote that these mandatory ModCod combinations may be useful when broadcasters have a desired physical layer throughput and need to choose the best-performing ModCod combination among all the possible ModCod combinations that have the same throughput. For maximum broadcaster flexibility, and possible future extensibility of ATSC 3.0, *it is strongly recommended that all the ModCod combinations* (i.e., 72 choices for long codes and 48 choices for short codes) *be implemented* in ATSC 3.0 *transmitters as well as* in ATSC 3.0 *receivers.*” LGE1028, 19.

179. The annotated look-up table (below) shows the claimed ranges and values. LGE1028, 18 In the ’777-ATSC327 combination, A327 discloses through Table 4.3 an SNR of *between 3.11 dB and 9.25 dB while using at least one of the multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 3/8 and less than or equal to 6/8 and a sixteen-point unequally spaced symbol constellation.* For example, a 8/15 LDPC code rate can be selected with a 16QAM constellation for the table having a SNR value of 6.30dB. As discussed above in §V.A.3, the 777-ATSC327 may include a second type of unequally spaced symbol constellation that includes no two constellation points within an unequally spaced symbol

constellation share locations that are the same. *See supra* §V.A.3; LGE1027, FIG.

20.

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-6.23	-4.32	-2.89	-1.70	-0.54	0.30	1.16	1.97	2.77	3.60	4.49	5.53
16QAM	-2.73	-0.25	1.46	2.82	4.21	5.21	6.30	7.32	8.36	9.50	10.57	11.83
64QAM	-0.26	2.27	4.15	5.96	7.66	8.92	10.31	11.55	12.88	14.28	15.57	17.03
256QAM	1.60	4.30	6.57	8.53	10.61	12.10	13.91	15.55	17.13	18.76	20.44	22.22
1024QAM	3.23	6.17	8.77	11.07	13.46	15.30	17.46	19.45	21.35	23.43	25.52	27.62
4096QAM	4.58	7.85	10.73	13.45	16.04	18.22	20.69	23.05	25.55	28.11	30.34	32.83

Table 4.4 Required SNRs (dB) for all ModCod Combinations, Long LDPC Codes (64800 bits) and i.i.d. Rayleigh Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-5.72	-3.62	-1.97	-0.55	0.86	1.95	3.16	4.35	5.62	7.05	8.76	10.97
16QAM	-1.84	0.81	2.69	4.32	5.98	7.21	8.63	9.94	11.40	12.78	14.60	16.85
64QAM	0.86	3.61	5.88	7.74	9.72	11.10	12.75	14.25	15.81	17.44	19.39	21.82
256QAM	2.89	5.97	8.46	10.59	12.92	14.58	16.54	18.23	20.06	21.94	24.01	26.62
1024QAM	4.65	8.04	10.85	13.25	15.91	17.84	20.13	22.34	24.47	26.61	28.82	31.59
4096QAM	6.23	9.83	12.95	15.75	18.79	21.03	23.67	26.37	28.64	31.18	33.82	36.54

LGE1028, Table 4.3-4.4, 18

[5i] between 9.00 dB and 15.93 dB while using at least one of the multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 3/6 and less than or equal to 5/6 and a sixty-four-point unequally spaced symbol constellation of the second type;

180. The annotated look-up table (below) shows the claimed ranges and values. LGE1028, 18 In the '777-ATSC327 combination, A327 discloses through Table 4.3 an SNR of *between 9.00 dB and 15.93 dB while using at least one of the multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 3/6 and less than*

or equal to 5/6 and a sixty-four-point unequally spaced symbol constellation. For example, a 10/15 LDPC code rate can be selected with a 64QAM constellation for the table having a SNR value of 12.88dB. As discussed above in §V.A.3, the 777-ATSC327 may include a second type of unequally spaced symbol constellation that includes no two constellation points within an unequally spaced symbol constellation share locations that are the same. See *supra* §V.A.3; LGE1027, FIG. 20.

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Co 3/6												5/6	
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15		
QPSK	-6.23	-4.32	-2.89	-1.70	-0.54	0.30	1.16	1.97	2.77	3.60	4.49	5.53		
16QAM	-2.73	-0.25	1.46	2.82	4.21	5.21	6.30	7.32	8.36	9.50	10.57	11.83		
64QAM	-0.26	2.27	4.15	5.96	7.66	8.92	10.31	11.55	12.88	14.28	15.57	17.03		
256QAM	1.60	4.30	6.57	8.53	10.61	12.10	13.91	15.55	17.13	18.76	20.44	22.22		
1024QAM	3.23	6.17	8.77	11.07	13.46	15.30	17.46	19.45	21.35	23.43	25.52	27.62		
4096QAM	4.58	7.85	10.73	13.45	16.04	18.22	20.69	23.05	25.55	28.11	30.34	32.83		

Table 4.4 Required SNRs (dB) for all ModCod Combinations, Long LDPC Codes (64800 bits) and i.i.d. Rayleigh Channel

Constellation	Co 3/6												5/6	
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15		
QPSK	-5.72	-3.62	-1.97	-0.55	0.86	1.95	3.16	4.35	5.62	7.05	8.76	10.97		
16QAM	-1.84	0.81	2.69	4.32	5.98	7.21	8.63	9.94	11.40	12.78	14.60	16.85		
64QAM	0.86	3.61	5.88	7.74	9.72	11.10	12.75	14.25	15.81	17.44	19.39	21.82		
256QAM	2.89	5.97	8.46	10.59	12.92	14.58	16.54	18.23	20.06	21.94	24.01	26.62		
1024QAM	4.65	8.04	10.85	13.25	15.91	17.84	20.13	22.34	24.47	26.61	28.82	31.59		
4096QAM	6.23	9.83	12.95	15.75	18.79	21.03	23.67	26.37	28.64	31.18	33.82	36.54		

LGE1028, Table 4.3-4.4, 18

[5j] between 18.72 dB and 22.13 dB while using at least one of the multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 6/8 and less than or equal to 7/8 and a two-hundred-and-fifty-six-point unequally spaced symbol constellation of the second type; and

181. The annotated look-up table (below) shows the claimed ranges and values. LGE1028, 18 In the '777-ATSC327 combination, A327 discloses through Table 4.3 an SNR of ***between 18.72 dB and 22.13 dB while using at least one of the multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 6/8 and less than or equal to 7/8 and a two-hundred-and-fifty-six-point unequally spaced symbol constellation.*** For example, a 12/15 LDPC code rate can be selected with a 256QAM constellation for the table having a SNR value of 20.44dB. As discussed above in §V.A.3, the 777-ATSC327 may include a second type of unequally spaced symbol constellation that includes no two constellation points within an unequally spaced symbol constellation share locations that are the same. *See supra* §V.A.3; LGE1027, FIG. 20.

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate										6/8	7/8
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-6.23	-4.32	-2.89	-1.70	-0.54	0.30	1.16	1.97	2.77	3.60	4.49	5.53
16QAM	-2.73	-0.25	1.46	2.82	4.21	5.21	6.30	7.32	8.36	9.50	10.57	11.83
64QAM	-0.26	2.27	4.15	5.96	7.66	8.92	10.31	11.55	12.88	14.28	15.57	17.03
256QAM	1.60	4.30	6.57	8.53	10.61	12.10	13.91	15.55	17.13	18.76	20.44	22.22
1024QAM	3.23	6.17	8.77	11.07	13.46	15.30	17.46	19.45	21.35	23.43	25.52	27.62
4096QAM	4.58	7.85	10.73	13.45	16.04	18.22	20.69	23.05	25.55	28.11	30.34	32.83

LGE1028, Table 4.3, 18

[5k] between 24.79 dB and 28.20 dB while using at least one of the multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 8/10 and less than or equal to 9/10 and a one-thousand-twenty-four-point unequally spaced symbol constellation of the second type.

182. The annotated look-up table (below) shows the claimed ranges and values. LGE1028, 18 In the '777-ATSC327 combination, A327 discloses through Table 4.3 an SNR of *between 24.79 dB and 28.20 dB while using at least one of the multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 8/10 and less than or equal to 9/10 and a one-thousand-twenty-four-point unequally spaced symbol constellation*. For example, a 12/15 LDPC code rate can be selected with a 1024QAM constellation for the table having a SNR value of 5.52dB. As discussed above in §V.A.3, the 777-ATSC327 may include a second type of unequally spaced symbol constellation that includes no two constellation points

within an unequally spaced symbol constellation share locations that are the same.

See *supra* §V.A.3; LGE1027, FIG. 20.

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate												8/10	9/10
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15		
QPSK	-6.23	-4.32	-2.89	-1.70	-0.54	0.30	1.16	1.97	2.77	3.60	4.49	5.53		
16QAM	-2.73	-0.25	1.46	2.82	4.21	5.21	6.30	7.32	8.36	9.50	10.57	11.83		
64QAM	-0.26	2.27	4.15	5.96	7.66	8.92	10.31	11.55	12.88	14.28	15.57	17.03		
256QAM	1.60	4.30	6.57	8.53	10.61	12.10	13.91	15.55	17.13	18.76	20.44	22.22		
1024QAM	3.23	6.17	8.77	11.07	13.46	15.30	17.46	19.45	21.35	23.43	25.52	27.62		
4096QAM	4.58	7.85	10.73	13.45	16.04	18.22	20.69	23.05	25.55	28.11	30.34	32.83		

LGE1028, Table 4.3, 18

vi. Claim 6

**[6a] The communication system of claim 1, wherein:
the non uniform symbol constellation is selected from a plurality of unequally spaced symbol constellations; and**

183. The '777 patent discloses all the features of [6a] for the reasons set forth above. See [1a] and [2a].

[6b] each of the plurality of unequally spaced symbol constellations is characterized by the assignment of labels and spacing of the constellation points such that each of the plurality of unequally spaced symbol constellations is capable of providing greater parallel decoding capacity when operated at a symbol constellation operating SNR than the other plurality of unequally spaced symbol constellations when operated at the same SNR.

184. In the '777-ATSC327 combination, '777 teaches that *each of the plurality of unequally spaced symbol constellations is characterized by the assignment of labels* (see *supra* [2d]) and ATSC327 discloses the other limitations

of [6b]. LGE1028, 18, Table 4.3, 4.4. In the '777-ATSC327 combination, ATSC327 is used to enable the communication system to have “a look-up table with the defined constellation mapping for each ModCod combination can be used.” LGE1028, 32. In this table (e.g., Tables 4.3), “[t]here is one non-uniform constellation (NUC) defined for each ModCod combination.” LGE1028, 32.

185. A POSITA would have understood how to implement Table 4.3 (reproduced below) was look-up table that includes a *plurality of unequally spaced symbol constellations* that are optimized for capacity *at a symbol constellation operating SNR*. LGE1028, 18, Table 4.3, 4.4; LGE100, [zz]. Further, a POSITA would have found it obvious that when comparing ModCod combinations from the implemented Table 4.3, that *each* of the constellation code rate pairs has a required SNR in order to achieve a desired capacity and that to compare two constellations from this table *at the same SNR* would result in one of the two constellations (the constellation optimized to perform at a symbol constellation operating SNR) *providing a greater capacity than the other symbol constellation*. LGE1028, 18, Table 4.3, 4.4

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-6.23	-4.32	-2.89	-1.70	-0.54	0.30	1.16	1.97	2.77	3.60	4.49	5.53
16QAM	-2.73	-0.25	1.46	2.82	4.21	5.21	6.30	7.32	8.36	9.50	10.57	11.83
64QAM	-0.26	2.27	4.15	5.96	7.66	8.92	10.31	11.55	12.88	14.28	15.57	17.03
256QAM	1.60	4.30	6.57	8.53	10.61	12.10	13.91	15.55	17.13	18.76	20.44	22.22
1024QAM	3.23	6.17	8.77	11.07	13.46	15.30	17.46	19.45	21.35	23.43	25.52	27.62
4096QAM	4.58	7.85	10.73	13.45	16.04	18.22	20.69	23.05	25.55	28.11	30.34	32.83

LGE1028, Table 4.3-4.4, 18

186. For example, Table 4.3 (annotated above) shows a first plurality of non-uniform multidimensional QAM-16 constellations (annotated in the red box) with code rates 4/15-5/15 and another plurality multidimensional QAM-16 constellations (annotated in the blue box) with code rates 7/15-9/15. When comparing the capacity of each of the multidimensional constellations in the first plurality (red box) relative to the multidimensional constellations of the second plurality (blue box) at the same SNR of 2.82dB, each of the plurality of constellations in the first plurality of non-uniform multidimensional QAM constellations (red box) will have a greater capacity at a specific SNR than the other constellations in the second plurality (blue box) operating at the same SNR. For example, the 16QAM constellation that is paired with the 4/15 rate code will have greater capacity at SNR = 1.46 dB than any constellation in the blue box at specific SNR = 1.46 dB (same SNR). Furthermore, the 16QAM constellation that is paired with the 5/15 rate code will have greater capacity at specific SNR = 2.82

dB than any constellation in the blue box at SNR = 2.82 dB (same SNR).

187. In addition, ATSC327 teaches “mandatory ModCod combinations for long codes (shown in table 4.7),” which explicitly discloses the two pluralities (annotated in Table 4.7 below). LGE1028, 19 A POSITA would have found it obvious that the constellations optimized for performance at given SNRs when compared at the same SNR, which is either the same or closer to the minimum required SNR of a plurality of optimized constellations, that the constellations more closely optimized to the SNR at which the constellations are being compared (same SNR), will have more capacity than those constellations that are optimized for SNRs farther separated from the compared (same SNR).

Table 4.7 Mandatory ModCod Combinations for Long Codes (64800 bits)

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	✓	✓	✓	✓	✓	✓	✓	✓		✓		
16QAM			✓	✓		✓	✓	✓		✓		
64QAM		✓	✓	✓	✓	✓	✓	✓	✓	✓		
256QAM			✓	✓		✓	✓	✓	✓	✓	✓	✓
1024QAM				✓		✓	✓	✓	✓	✓	✓	✓
4096QAM						✓		✓		✓	✓	✓

LGE1028, 19

188. It would have been obvious to a POSITA that when choosing to assign each NUC constellation to a code rate in Table 4.3, the pairing would be based off of maximum efficiency and therefore would maximize the capacity for each constellation code rate pair at a given SNR. LGE1024, 199. Further, the empirical

evidence for this is available in appendixes B and C of ATSC327, where the threshold C/N values are calculated then the Simulation, Lab, and Field values for SNR are compared. LGE1028, 98-118. With the aid of the empirical data, a POSITA would organize Table 4.3 in such a way to maximize capacity of each constellation at the given SNRs.

189. With Table 4.3 organized for capacity, it would have been obvious to a POSITA that an optimized constellation and code rate pair for a given SNR, would no longer be optimized when one of the parameters (SNR) changes. LGE1028, Table 4.3-4.4, 18. A POSITA would understand that when moving a constellation and code rate from the optimized parameters and comparing it to any other constellation and code rate pair, that each of the still optimized constellation code rate pairs would have a greater capacity than the “no longer optimized” constellation code rate pair when compared at the same SNR. LGE1028, Table 4.3-4.4, 18 A POSITA’s understanding of the constellation/rate pairs in Table 4.3 would be that every constellation in that table has been optimized to work well with the paired code rate, and the corresponding SNR listed in that table. So moving across a row in that table, even though the constellations are all "16-QAM", they are all unique differently-spaced constellations. Annex C of the ATSC322 document lists the point-locations of all the constellations, indexed by code rate. For QPSK, the constellations are all

the same, independently of code rate. For 16-QAM, the constellations differ for each code rate. 64-QAM all differ, and so on. LGE1028, Table 4.3-4.4, 18

190. For example, a POSITA would understand that to take a 16-QAM constellation from the right side of the table (that was optimized for the rate 10/15 code), and try to use it on the left (with, say, rate = 5/15 code), then one is pairing a constellation on the right with a code rate on the left. This mismatched-pair would presumably do worse than the constellation matched with the rate 5/15 code for the SNR listed on the table (2.82 dB). Similarly, pairing a 16-QAM constellation optimized for rate 5/15 with a code of rate = 10/15 would do worse than the 16-QAM constellation that was optimized for rate 10/15 code at SNR listed on table 4.3 (8.36). LGE1028, Table 4.3-4.4, 18

191. A POSITA would have found it obvious that when two pluralities of constellations that have each been optimized for capacity in particular ranges of SNRs, are then compared at the same SNR, and if the (same) SNR at which they are being compared is within the range of one of the pluralities, that the plurality operating (during the comparison) closer to its own required SNR will have a higher capacity than the plurality operating further from its required SNR..

192. Therefore, the limitations of [5] would have been obvious to a POSITA in view of the '777-ATSC327 combination.

vii. Claim 7

[7] The communication system of claim 6, wherein the symbol constellation operating SNR is a channel SNR where the receiver is capable of using the respective unequally spaced symbol constellation to receive data at a frame error rate (FER) of 10^{-2} or lower.

193. The ‘777-ATSC327 combination teaches *wherein the symbol constellation operating SNR is a channel SNR where the receiver is capable of using the respective unequally spaced symbol constellation to receive data at a frame error rate (FER) of 10^{-2} or lower.*

194. ATSC327 discloses through figure 6.12, receiver performance against the theoretical channel capacity limit or Shannon Limit. LGE1028, 82. “Given the four different LDPC decoding algorithms (i.e., SPA, MSA, OMSA, and NMSA), the simulation performance of ATSC 3.0 LDPC codes in an AWGN channel was analyzed.” LGE1028, 79. A POSITA would have known that an Additive White Gaussian Noise (AWGN) channel contributes to a baseline estimated channel SNR. Figure 6.12 (annotated below) shows that when using a channel SNR, the receiver is capable of receiving data at a frame error rate (FER) of 10^{-2} or lower.

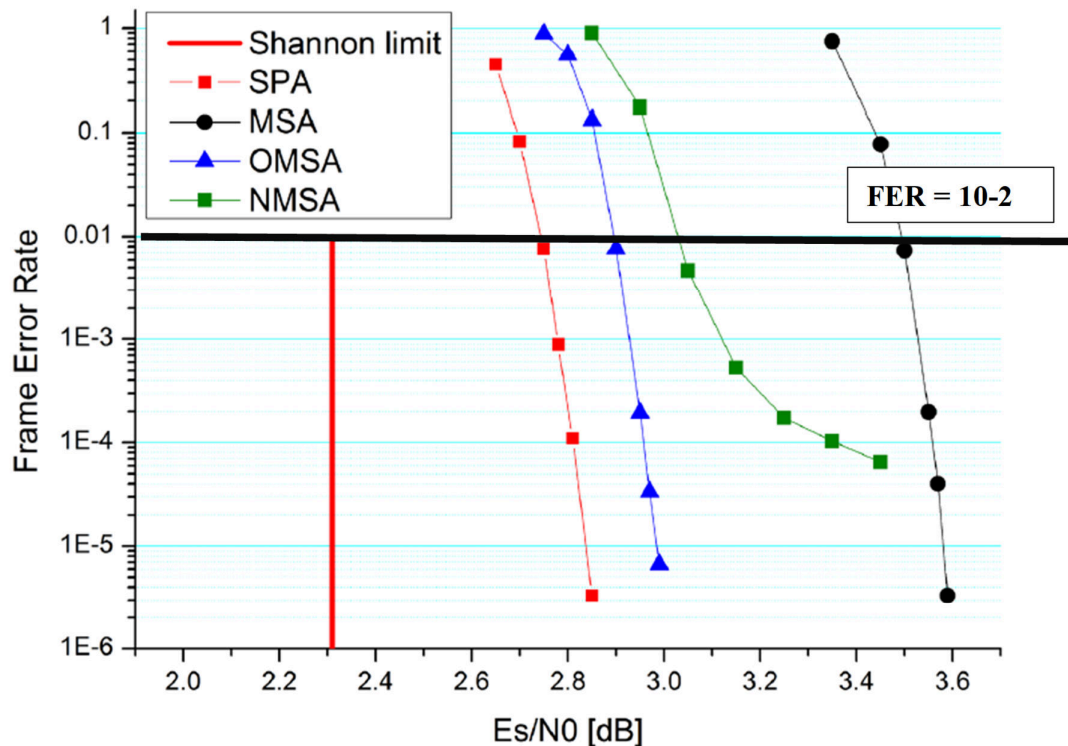


Figure 6.12 LDPC code performance based on various decoding algorithms (Code rate = 10/15, Code length = 64800, AWGN channel).

LGE1028, 82

viii. Claim 11

[11pre] *A communication system, comprising:*

195. I have been told to assume that the preamble is limiting, 777-

ATSC327 renders [11pre] obvious. *See supra* [1pre].

[11a] *a receiver that receives signals via a communication channel having a channel signal-to-noise ratio (SNR), wherein the receiver comprises:*

196. *See supra* [1a].

[11b] a demodulator that demodulates a received signal into a demodulated signal;

197. See *supra* [1b].

[11c-1] a demapper that determines likelihoods using the demodulated signal and a symbol constellation that includes constellation points at a plurality of unique point locations, where:

198. See *supra* [1c-1].

[11c-2] the plurality of unique point locations are unequally spaced;

199. See *supra* [1c-2].

[11c-3] the constellation points each have a location and a different label; and

200. See *supra* [1c-3].

[11c-4] the locations of at least two of the constellation points are the same; and

201. See *supra* [1c-4].

[11d] a decoder that uses the likelihoods determined by the demapper to provide a sequence of received bits based upon a low density parity check (LDPC) code;

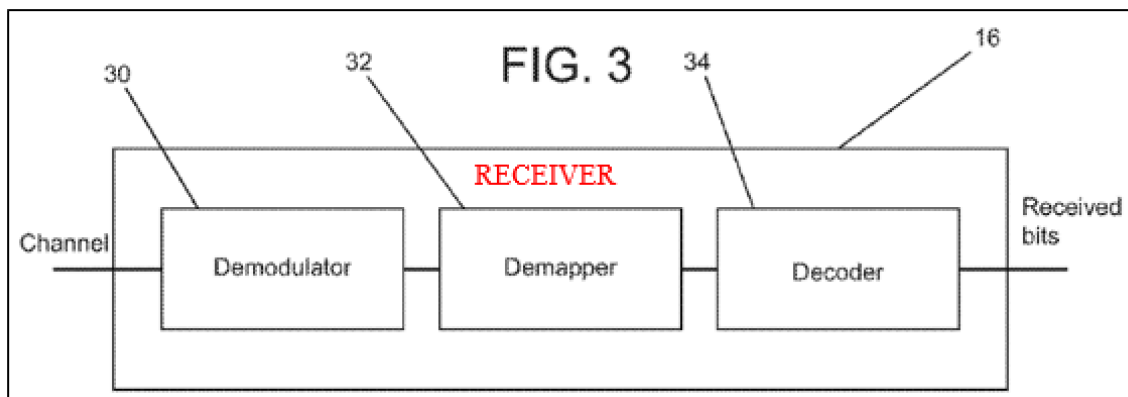
202. See *supra* [1d].

[11e] wherein the demapper is interposed between the demodulator and the decoder and the demapper receives information from the demodulator and provides information to the decoder.

203. See *supra* [1c-1] and [1d], see also *supra* [11pre], [11c], and [11d]. In

this combination, the '777 patent discloses a ***demapper is interposed between the demodulator and the decoder and the demapper receives information from the***

demodulator and provides information to the decoder. For example, the “receiver 16 includes a demodulator 30 that demodulates a signal received via the channel to obtain symbol or bit likelihoods.” LGE1027, 5:35-43; 13:37-38. The receiver 16 of the communication system 10 is shown in FIG. 3 of the ’777 patent (reproduced below) illustrates a demapper 32 interposed between a demodulator 30 and a decoder 34. LGE1027, FIG. 3. The decoder 34 receives information from the demodulator 30 and provides information to the decoder 34. LGE1027, 5:35-43, FIG. 3.



LGE1027, FIGS. 3.

204. Thus, the bolded claim limitation above would have been obvious to a POSITA in view of the ’777 patent.

ix. Claims 12, 23

[12a], [23a] The communication system of claim 11/21, wherein: the symbol constellation is selected from a plurality of unequally spaced symbol constellations;

205. See supra [2a].

[12b] the plurality of unequally spaced symbol constellations includes a plurality of unequally spaced symbol constellations of a first type that comprise multiple different sixty-four-point symbol constellations, multiple different two-hundred-fifty-six-point symbol constellations, and multiple different one-thousand-twenty-four-point symbol constellations, where unequally spaced symbol constellations of the first type include at least two constellation points having locations that are the same and different labels;

[23b] the plurality of unequally spaced symbol constellations includes a plurality of unequally spaced symbol constellations of a first type that comprise multiple different sixty-four-point symbol constellations, multiple different two-hundred-fifty-six-point symbol constellations, and multiple different one-thousand-twenty-four-point symbol constellations, where unequally spaced symbol constellations of the first type include at least two constellation points having identical locations and different labels;

206. See supra [2b].

[12c], [23c] the receiver selects an LDPC code rate and the unequally spaced symbol constellation as a pair from a plurality of predetermined LDPC code rate and unequally spaced symbol constellation pairs; and

207. See supra [2c].

[12d], [23d] each of the plurality of unequally spaced symbol constellations is only included in one of the plurality of predetermined LDPC code rate and unequally spaced symbol constellation pairs.

208. See supra [2d].

x. Claims 13, 14

[13a], [24a] The communication system of claim 12, wherein the plurality of predetermined LDPC code rate and unequally spaced symbol constellation pairs includes:

multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate below 1/3 and a sixty-four-point unequally spaced symbol constellation of the first type;

209. See *supra* [3a].

[13b], [24b multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate below 5/8 and a two-hundred-and-fifty-six-point unequally spaced symbol constellation of the first type; and]

210. See *supra* [3b].

[13c], [24c] multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate below 7/10 and a one-thousand-twenty-four-point unequally spaced symbol constellation of the first type.

211. See *supra* [3c].

xi. Claims 14, 25

[14a], [25a] The communication system of claim 13, wherein the receiver is capable of decoding the signals received over the communication channel when the SNR of the communication channel is:
equal to or less than 5.27 dB while using an LDPC code rate and unequally spaced symbol constellation pair that includes an LDPC code rate that is below 1/3 and a sixty-four-point unequally spaced symbol constellation of the first type;

212. See *supra* [4a].

[14b], [25b] equal to or less than 15.42 dB while using an LDPC code rate and unequally spaced symbol constellation pair that includes an LDPC code rate below 5/8 and a two-hundred-fifty-six-point unequally spaced symbol constellation of the first type; and

213. See *supra* [4b].

[14c], [25c] equal to or less than 21.52 dB while using an LDPC code rate and unequally spaced symbol constellation pair that includes an LDPC code rate below 7/10 and a one-thousand-twenty-four-point unequally spaced symbol constellations of the first type.

214. See *supra* [4c].

xii. Claims 15, 26

[15a], [26a] The communication system of claim 14, wherein: the plurality of unequally spaced symbol constellations includes a plurality of unequally spaced symbol constellations of a second type that comprises multiple different sixteen-point symbol constellations, multiple different sixty-four-point symbol constellations, multiple different two-hundred-fifty-six-point symbol constellations, and multiple different one-thousand-twenty-four-point symbol constellations;

215. See *supra* [5a].

[15b], [26b] no two constellation points within an unequally spaced symbol constellation of the second type have locations that are the same;

216. See *supra* [5b].

[15c] the demapper also determines likelihoods using the demodulated signal and an unequally spaced symbol constellation of the second type; and

217. See *supra* [5c].

[26c]

218. See *supra* [21b]. As discussed above in [21b], in the combination, the '777 patent discloses that the receiver also transforms received signals into received bits using an unequally spaced symbol constellation of the second type. Regarding the second type, the '777 patent discloses multiple examples in 11b,

13b, 15b, and 17b, of PAM-4, PAM-8, PAM-16, and PAM-32, respectively wherein no two constellation points have locations that are the same. See supra [2b] and [26b].

219. Thus, the bolded claim limitation above would have been obvious to a POSITA in view of the '777 patent.

***[15d], [26d] the plurality of predetermined LDPC code rate and unequally spaced symbol constellation pairs includes:
multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than $3/8$ and less than or equal to $6/8$ and a sixteen-point unequally spaced symbol constellation of the second type;***

220. See supra [5d].

[15e], [26e] multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than $3/6$ and less than or equal to $5/6$ and a sixty-four-point unequally spaced symbol constellation of the second type;

221. See supra [5e].

[15f], [26f] multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than $6/8$ and less than or equal to $7/8$ and a two-hundred-and-fifty-six-point unequally spaced symbol constellation of the second type; and

222. See supra [5f].

[15g], [26g] multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than $8/10$ and less than or equal to $9/10$ and a one-thousand-and-twenty-four-point unequally spaced symbol constellation of the second type;

223. See *supra* [5g].

[15h], [26h] the receiver is capable of decoding the signals received over the communication channel when the SNR of the communication channel is: between 3.11 dB and 9.25 dB while using at least one of the multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than $3/8$ and less than or equal to $6/8$ and a sixteen-point unequally spaced symbol constellation of the second type;

224. See *supra* [5h].

[15i], [26i] between 9.00 dB and 15.93 dB while using at least one of the multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than $3/6$ and less than or equal to $5/6$ and a sixty-four-point unequally spaced symbol constellation of the second type;

225. See *supra* [5i].

[15j], [26j] between 18.72 dB and 22.13 dB while using at least one of the multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than $6/8$ and less than or equal to $7/8$ and a two-hundred-and-fifty-six-point unequally spaced symbol constellation of the second type; and

226. See *supra* [5j].

[15k], [26k] between 24.79 dB and 28.20 dB while using at least one of the multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 8/10 and less than or equal to 9/10 and a one-thousand-twenty-four-point unequally spaced symbol constellation of the second type.

227. *See supra* [5k].

xiii. Claims 16, 27

[16a], [27a] The communication system of claim 11, wherein: the symbol constellation is selected from a plurality of unequally spaced symbol constellations; and

228. *See supra* [6a].

[16b], [27b] each of the plurality of unequally spaced symbol constellations is characterized by the assignment of labels and spacing of the constellation points such that each of the plurality of unequally spaced symbol constellations provides greater parallel decoding capacity when operated at a symbol constellation operating SNR than the other plurality of unequally spaced symbol constellations when operated at the same SNR.

229. *See supra* [6b].

xiv. Claims 17, 28

[17], [28] The communication system of claim 16, wherein the symbol constellation operating SNR is a channel SNR where the receiver uses the respective unequally spaced symbol constellation to receive data at a frame error rate (FER) of 10^{-2} or lower.

230. *See supra* [7].

xv. Claims 21

[21pre] A communication system, comprising

231. I have been told to assume that the preamble is limiting, EBC renders

[21pre] obvious. *See supra* [1pre].

[21a] a receiver that receives signals via a communication channel having a channel signal-to-noise ratio (SNR),

232. *See supra* [1a].

[21b] wherein the receiver uses a symbol constellation to transform the received signals into received bits, and the symbol constellation includes constellation points at a plurality of unique point locations, where:

233. As explained above in [1a]-[1c-1]. *See supra* [21pre], [21a], and [1c-3]. In this combination, the '777 patent discloses ***the receiver uses a symbol constellation to transform the received signals into received bits, and the symbol constellation includes constellation points at a plurality of unique point locations***. For example, “the receiver includes a demodulator configured to demodulate the received signal via the communication channel, a demapper configured to estimate likelihoods from the demodulated signal, a decoder that is configured to estimate decoded bits from the likelihoods generated by the demapper.” LGE1027, Abstract, 5:35-43; 13:37-38. As discussed above in [1c-1], in the combination, the '777 patent discloses ***symbol constellation includes constellation points at a plurality of unique point locations***.

234. . Thus, the bolded claim limitation above would have been obvious to a POSITA in view of the '777 patent.

[21c-1] the plurality of unique point locations are unequally spaced;

235. *See supra* [1c-2].

[21c-2] the constellation points each have a location and a different label; and

236. *See supra* [1c-3].

[21c-3] the locations of at least two of the constellation points are the same.

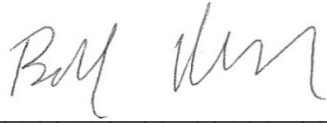
237. *See supra* [1c-4].

XI. CONCLUSION

238. All the Challenged Claims are obvious in view of the above-noted grounds and references.

239. I declare that all statements made herein of my knowledge are true, and that all statements made on information and belief are believed to be true. I further declare that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment or both, under Section 1001 of Title 18 of the United States Code.

Date: December 9, 2022

BY: 

Bertrand Hochwald

APPENDIX A

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Degrees:

BS (Engineering) 1984, Swarthmore College
MS (Electrical Engineering) 1986, Duke University
MA (Statistics) 1993, Yale University
PhD (Electrical Engineering) 1995, Yale University

Experience:

Department of Defense, Fort Meade, Maryland. *Electrical Engineer*, 1986–1989.
Yale University, New Haven, Connecticut. *Teaching assistant*, 1990–1994.
University of Illinois, Urbana-Champaign
Postdoctoral Research Associate in data compression, 1995.
Visiting Faculty in Department of Electrical Engineering, 1996.
Bell Laboratories, Lucent Technologies, Murray Hill, New Jersey
Member of Technical Staff, 1996–2002.
Distinguished Member of Technical Staff, 2002–2005.
Columbia University, New York
Visiting Faculty in Department of Electrical Engineering, 2005.
Beceem Communications, Santa Clara, California
Chief Scientist, 2005–2009,
Vice-President Systems Engineering, 2009–2010.
Stanford University, Palo Alto, California
Consulting Professor of Electrical Engineering, 2006–2010.
University of Notre Dame, Notre Dame, Indiana
Frank M. Freimann Professor of Electrical Engineering, 2011–present.
University of Notre Dame, Notre Dame, Indiana
Co-Director of The Wireless Institute, 2016–present.

Honors:

New York State: *Regents Scholarship*, 1980.
Pennsylvania ACM computer programming competition: *Winner*, 1983.
Duke University: *Eta Kappa Nu engineering honor society*, 1985.
Department of Defense: *Special Achievement Awards*, 1988, 1989.
Yale University: *Prize Teaching Fellowship teaching award*, 1993.
Bell Laboratories: *President's Gold Award*, 2002.
Thomson Essential Science Indicators
Top one-tenth of one percent referenced papers, 2002 and 2003.
IEEE Transactions on Communications
Stephen O. Rice Best Paper Award, 2006.
IEEE
Fellow, 2008.
Thomson Reuters
World's Most Influential Scientific Minds, multiple years.

Honors (cont'd):

IEEE Transactions on Circuits and Systems
Young Author Best Paper Award, 2016 (my PhD student).
IEEE Transactions on Antennas and Propagation
H. A. Wheeler Prize Paper Award, 2018.
The Marconi Society
Paul Baran Young Scholar Award, 2018 (my PhD student).
National Academy of Inventors
Fellow, 2019.

Research Gifts, Grants and Contracts:

Principal Investigator, “NSF EAGER: Multiple Transmitter Chains to Minimize Exposure to Electromagnetic Radiation in Portable Devices,” National Science Foundation CCF-1141868, August 1, 2011–July 31, 2013, \$200,000.
Co-Principal Investigator, “Planning Grant: I/UCRC in Broadband Wireless Technologies and Applications,” National Science Foundation IIP-1266124, April 1, 2013–March 31, 2014, \$14,544.
Co-Principal Investigator, “I/UCRC Phase I: BWAC@NDWI: Broadband Wireless Access and Applications at the Notre Dame Wireless Institute,” National Science Foundation, IIP-1439682, August 1, 2014–July 31, 2019, \$325,000.
Principal Investigator, “Modeling, Analysis, and Code Design for Portable Wireless Transmitters Subject to an Electromagnetic Exposure Constraint,” National Science Foundation, CCF-1403458, September 1, 2014–August 31, 2018, \$1,200,000.
Principal Investigator, “Notre Dame Millimeter-Band Capability,” Equipment Restoration and Renewal Grant, May 31, 2015–May 31, 2016, \$183,000.
Principal Investigator, “Channel Estimation Technologies based on AoA/AoD in High-Frequency Wireless Communication Systems,” Huawei Technologies, June 22, 2015–October 31, 2016, \$181,217.
Principal Investigator, “*Radiohound*: A Low-Cost Spectrum Beacon/Sensor with Millimeter Wave Capability,” Alcatel-Lucent and Interdigital Corporations, June 1, 2015–May 31, 2018, \$240,000.
Principal Investigator, “Low-Complexity High-Bandwidth Multiport Matching Networks for Coupled Loads,” National Science Foundation, ECCS-1509188, August 1, 2015–July 31, 2018, \$400,000.
Principal Investigator, “Notre Dame Coherent RadioHound: A Distributed Spectrum Sensor Network,” Laboratory for Telecommunications Sciences, May 6, 2016–May 5, 2017, \$187,124.
Co-Principal Investigator, “Wideband Time-Domain Millimeter-Wave Device and Channel Characterization Testbed,” Department of the Navy, July 15, 2016–July 14, 2017, \$326,573.
Principal Investigator, “SpecEES: Wideband Wireless Communications with Low-Power Transceiver-Cell Circuits,” National Science Foundation, ECCS-1731056, August 15, 2017–August 14, 2020, \$650,000.
Principal Investigator, “Data Gathering Plan for Radio-Frequency Machine-Learning Systems,” Defense Advanced Research Projects Agency, October 1, 2017–June 1, 2018, \$149,332.
Principal Investigator, “REU Site: AWARE Advanced Wireless Research Experiences at the University of Notre Dame,” National Science Foundation CNS-1757804, January 15, 2018–December 31, 2020, \$359,789.
Co-Principal Investigator, “Physical Layer Signature Discrimination of Transmitters,” The George J Kostas Research Institute for Homeland Security at Northeastern University (KRI), March 30, 2018–October 29, 2020, \$100,000.

Research Gifts, Grants and Contracts (cont'd):

- Co-Principal Investigator, "An Infrastructure-less and Heterogeneous Distributed Sensor for Electromagnetic Spectrum Sensing and Emitter Geolocation," Department of the Army, June 15, 2018–June 14, 2019, \$370,234.
- Co-Principal Investigator, "Improving STEM Retention Through Hands-On Implementation and Red-Teaming," Office of Naval Research, August 15, 2018–August 14, 2021, \$735,830.
- Principal Investigator, "Ultra Low Cost/Power Massive MIMO Architecture and Algorithm," Futurewei Technologies, Inc, Gift, September 13, 2018, \$200,000.
- Principal Investigator, "Ultra Low-Cost Low-Power Millimeter-Wave Transceiver," AT&T Innovation Lab, September 15, 2018–September 14, 2020, \$220,000.
- Principal Investigator, "MLWiNS: Quality Versus Quantity in Spectrum Sensing with Distributed Sensors," National Science Foundation jointly with Intel Corporation, July 1, 2020–June 30, 2023, \$665,000.
- Principal Investigator, "Low-Cost Low-Power Millimeter-Wave Transceiver," AT&T Innovation Lab, January 1, 2021–December 31, 2021, \$110,000.
- Co-Principal Investigator, "Stationary and Aerial-Based RF/Radar Detection of Drones, Concealed Threats and Anomalous Communications," Department of Homeland Security, October 1, 2021–September 30, 2031, \$1,000,000.
- Senior Personnel, "SpectrumX - An NSF Spectrum Innovation Center," National Science Foundation, September 15, 2021–September 14, 2026, \$25,000,000.
- Co-Principal Investigator, "Self-Powered Wireless Sensor System for Health Monitoring of Liquid-Sodium Cooled Fast Reactors," Department of Energy, October 1, 2021–September 30, 2024, \$640,000.

Patents:

- "Multiple Antenna Communication System and Method Thereof," #6058105, May 2, 2000.
- "Wireless Transmission Method for Antenna Arrays, Having Improved Resistance to Fading," #6327310, December 4, 2001.
- "Antenna Array Having Reduced Sensitivity to Frequency-Shift Effects," #6349219, February 19, 2002.
- "Wireless Transmission Method for Antenna Arrays Using Unitary Space-Time Signals," #6363121, March 26, 2002.
- "Space-Time Spreading Method of CDMA Wireless Communication," #6452916, September 17, 2002.
- "Method of Wireless Communication Using Structured Unitary Space-Time Signal Constellations," #6693976, February 17, 2004.
- "Method for Wireless Differential Communication Using Multiple Transmitter Antennas," #6724842, April 20, 2004.
- "Method for Wireless Communication using Unitary Space-Time Signal Constellations," #6801579, October 5, 2004.
- "Method of Multiple-Antenna Wireless Communication Using Space-Time Codes," #6944236, September 13, 2005.
- "Cayley-Encoding of Unitary Matrices for Differential Communication," #7170954, January 30, 2007.
- "Method and Apparatus for Detection and Decoding of Signals Received from a Linear Propagation Channel," #7236536, June 26, 2007.
- "Method of Signal Transmission to Multiple Users From a Multi-Element Array," #7317764, January 08, 2008.
- "Downlink Coordinated Transmission in OFDMA Systems," #7706335, April 27, 2010.
- "Downlink Coordinated Transmission in OFDMA Systems, Including WiMax Systems," #7764658, July 27, 2010.

Patents (cont'd):

- “Spherical Decoder for Wireless Communications,” #7822150, October 26, 2010.
- “Method for Estimating Frequency Offset at a Subscriber Station Receiver in a Multi-Carrier System,” #7916800, March 29, 2011.
- “Estimating Frequency Offset at a Subscriber Station Receiver,” #7929595, April 19, 2011.
- “Method of a Receiver Estimating a Plurality of Channels,” #8194774, June 5, 2012.
- “Method of Aiding Uplink Beamforming Transmission,” #8259672, September 4, 2012.
- “Multi-Stream Priority-Based Space-Time Coding,” #8284693, October 9, 2012.
- “Estimating a Subscriber Location,” #8290508, October 16, 2012.
- “Selecting a Transmission Mode Between a Subscriber and a Base Station,” #8311003, November 13, 2012.
- “Noninvasive Characterization of Electrical Power Distribution Systems,” #8427169, April 23, 2013.
- “Method and System of Beamforming a Broadband Signal Through a Multiport Network,” #8432997, April 30, 2013.
- “Estimating a Subscriber Location,” #8611925, December 17, 2013.
- “Characterization of Electrical Power Distribution Systems,” #8633705, January 21, 2014.
- “Allocating Antennas for Cyclic Delay Diversity,” #8675761, March 18, 2014.
- “Wireless Transceivers with Filter Arrangement for WiFi and WiMax coexistence,” #8681748, March 25, 2014.
- “Multiple Antenna Signal Transmission,” #8737529, May 27, 2014.
- “Selecting a Transmission Mode Between a Subscriber and a Base Station,” #8750236, June 10, 2014.
- “Multiple Antenna Transceiver,” #8761694, June 24, 2014.
- “Characterization of Electrical Power Distribution Systems Using Characterization Matrices,” #8810253, August 19, 2014.
- “Method and System of Beamforming a Broadband Signal Through a Multiport Network,” #8811530, August 19, 2014.
- “Distribution of Transmit Signal to Multiple Transmit Antennas for Reduction of Measured Specific Absorption Rate,” #8811918, August 19, 2014.
- “Method of Transmission from Multiple Transmit Chains Based on a Cost Function for Electromagnetic Radiation,” #8818294, August 26, 2014.
- “Method and System for Uplink Coordinated Reception in Orthogonal Frequency Division Multiple Access Systems,” #8855046, October 7, 2014.
- “Method of Coding Using Multiple Transmit Chains for Reduced Exposure to Electromagnetic Radiation,” #8929828, January 6, 2015.
- “Method and Apparatus for Link Adaptation in a Wireless Communication Network,” #8942184, January 27, 2015.
- “Method and Apparatus for Managing Uplink Communication in Wireless Network,” #9026123, May 5, 2015.
- “Method of Updating Transmission of Channel Information Based on Eaves-Dropping of Beamformed Signals,” #9178597, December 8, 2015.
- “Adaptive Transmit Beamforming,” #9209876, December 8, 2015.
- “Method and Apparatus for Managing Uplink Communication in a Wireless Communication Network,” #9210716, December 8, 2015.
- “Wireless Transceivers with Filter Arrangement for WiFi and LTE coexistence,” #9232564, January 5, 2016.
- “Mobile Subscriber Information Transmission Over Multiple Uplink Frames,” #9236975, January 12, 2016.
- “Method of Aiding Uplink Beamforming Transmission,” #9344178, May 17, 2016.

Patents (cont'd):

“Adaptive Transmit Beamforming for Frequency Division Duplexing Systems,”

#9537684, January 3, 2017.

“Mitigating Beam Squint in Millimeter Wave Wireless Communication Systems,”

#10819405, October 27, 2020.

“Low-Resolution, Low-Power, Radio-Frequency Receiver,” #11121896, September 14, 2021.

Professional Feature Videos, Projects, Web-pages, and Plenary Talks

“Multiple Antennas: How a Point-to-Point Advantage Becomes a Multi-user Advantage.” Plenary Speaker at the *22nd Biennial Symposium on Communications*, Queens University, Kingston, Ontario, June 2004.

“A Random-Channel Graph-Theoretic Perspective of Wireless Networks.” Plenary Speaker at the *2006 Seventh Annual IEEE Workshop on Signal Processing Advances in Wireless Communication*, Cannes, France, July 2006.

“The Role of MIMO in Fourth-Generation Mobile Wireless Systems and Beyond.” Plenary Speaker at the *2009 IEEE Communication Theory Workshop*, Napa, California, May 2009.

“What Have We Learned So Far About MIMO in Mobile Wireless Systems?” Plenary Speaker at the *2009 Tenth Annual IEEE Workshop on Signal Processing Advances in Wireless Communication*, Perugia, Italy, June 2009.

“Bandwidth of Large-Scale Multiport Radio-Frequency Systems.” Plenary Speaker at the *20th International ITG Workshop on Smart Antennas*, Munich, Germany, March 2016.

“Building a Better Phone,” University of Notre Dame web page feature story, 2016: <https://www.nd.edu/stories/building-a-better-phone/>

“Notre Dame Researchers Target Cell Phone Radiation,” WSBT television feature story, 2016: <https://wsbt.com/news/local/notre-dame-researchers-target-cell-phone-radiation>.
<https://engineering.nd.edu/news-publications/engineering-in-the-news/notre-dame-researchers-target-cell-phone-radiation>

Principle Investigator for the *RadioHound Spectrum Sensing System*, 2015–present: <https://wireless.nd.edu/research/radiohound-distributed-spectrum-sensing>

Editorial, Panelist, and Professional Service Activities

Owner and Editor of <http://mars.bell-labs.com>, the *Multiple-Antenna Research and Solutions* web-site dedicated to promoting research into space-time techniques, 1998–2005. (800 subscribers)

Guest Associate Editor, *IEEE Transactions on Signal Processing Special Issue on Signal Processing for Communications*, with N. Al-Dhahir, G. Giannakis, B. Hughes and T. Marzetta, vol. 50, October 2002.

Guest Editor, *IEEE Transactions on Information Theory Special Issue on Space-Time Transmission, Reception, Coding and Signal Design*, with G. Caire, B. Hassibi and T. Marzetta, vol. 49, October 2003.

Associate Editor for MIMO Techniques, *IEEE Transactions on Communications*, November 2003–2005.

Associate Editor for *IEEE Transactions on Information Theory*, 2011–2012.

IEEE Fellows Committee for the Information Theory Society, 2016–2017.

Panelist, National Science Foundation Signal Processing Systems Faculty Early Career Development Program (CAREER), November 2002; Computer and Information Science Communications/Signal-Processing Research Program, April 2004; Theoretical Foundations of Communications and Signal-Processing Research Program, May 2007; Computing and Communication Foundations (CCF): Core Programs, February 2010; Communications and Information Foundations (CIF), December 2011; Communications and Signal Processing, April 2014; Computer and Network Systems Research Experience for Undergraduates (CNS-REU), November 2018.

Technical Program Chair, *2018 IEEE Communication Theory Workshop*, Miramar Beach, Florida, May 2018.

University Service Activities

Graduate Admissions Committee, 2012–present.

Graduate Committee, 2012–2013, 2016–2018.

College Council, 2014–2017.

Committee for Appointments and Promotions, 2016–2017.

CRADA (Cooperative Research and Development Agreement) between University of Notre Dame and Crane Naval Base, Crane, Indiana, 2016–present.

Co-Director, University of Notre Dame Wireless Institute, 2016–present. In 2017–2018, approximately \$4M/yr in expenditures was routed through the Institute in various projects, including *RadioHound*.

Principal Investigator of an ongoing (2018–) National Science Foundation-funded Research Experience for Undergraduates (REU), sponsoring ten undergraduates from around the United States that visit the University of Notre Dame Wireless Institute for a ten-week research program every summer.

Past Co-Advised PhD Students:

Ibrahim Abou-Faycal (Massachusetts Institute of Technology), 1998
Sriram Vishwanath (Stanford University), 2002
Christian Peel (Brigham-Young University), 2003
Radhika Gowaikar (Caltech), 2005
Heunchul Lee and Kyoung Jae Lee (Korea University), 2007

MS and PhD Students at University of Notre Dame:

Luyu Zhao, MS 2013
Ding Nie, PhD 2015
Kang Gao, PhD
Abbas Termos, PhD
Arash EbadiShahrivar, PhD
Lihua Wan, PhD
Xiangbo Meng, PhD
Miaomiao Hu, PhD

Courses, Book Chapters, Tutorials

- “Probabilistic Methods in Signal and System Analysis.” Senior-level undergraduate course, University of Illinois, Urbana-Champaign, January–May 1996.
- “Multi-Antenna Wireless Communications—from Theory to Algorithms,” with B. Hassibi and T. Marzetta. Tutorial at *IEEE Conference on Acoustics, Speech and Signal Processing*, Orlando, FL, May 2002.
- “Communication Theory.” Senior-level undergraduate course, Columbia University, September–December 2005.
- “Linear and Dirty-Paper Techniques for the Multiuser MIMO Downlink,” with Christian B. Peel, Quentin H. Spencer, A. Lee Swindlehurst and Martin Haardt. Book chapter in *Space-Time Processing for MIMO Communications*, A. B. Gershman and N. D. Sidiropoulos (editors), Chichester: John Wiley & Sons, 2005.

Theses and Journal Papers

- “Aspects of Vector-Sensor Processing.” PhD thesis, Yale University, 1995.
- B. Hochwald and A. Nehorai, “Concentrated Cramér-Rao bound expressions,” *IEEE Transactions on Information Theory*, vol. 40, pp. 363–371, March 1994.
- B. Hochwald and A. Nehorai, “Minimum bias priors for estimating additive terms in state-space models,” *IEEE Transactions on Automatic Control*, vol. 40, pp. 684–693, April 1995.
- B. Hochwald and A. Nehorai, “Polarimetric modeling and parameter estimation with applications to remote sensing,” *IEEE Transactions on Signal Processing*, vol. 43, pp. 1923–1935, August 1995.
- B. Hochwald and A. Nehorai, “Identifiability in array processing models with vector-sensor applications,” *IEEE Transactions on Signal Processing*, vol. 44, pp. 83–95, January 1996.
- B. Hochwald and A. Nehorai, “On identifiability and information-regularity in parameterized normal distributions,” *Circuits, Systems, and Signal Processing*, vol. 16, pp. 83–89, January 1997.
- B. Hochwald and A. Nehorai, “Magnetoencephalography with diversely-oriented and multi-component sensors,” *IEEE Transactions on Biomedical Engineering*, vol. 44, pp. 40–50, January 1997.
- B. Hochwald and K. Zeger, “Tradeoff between source and channel coding,” *IEEE Transactions on Information Theory*, vol. 43, pp. 1412–1424, September 1997.
- B. Hochwald, “Tradeoff between source and channel coding on a Gaussian channel,” *IEEE Transactions on Information Theory*, vol. 44, pp. 3044–3055, November 1998.
- B. Hochwald and P. Jelenković, “State Learning and Mixing in Entropy of Hidden Markov Processes and the Gilbert-Elliott Channel,” *IEEE Transactions on Information Theory*, vol. 45, pp. 128–138, January 1999.
- T. Marzetta and B. Hochwald, “Capacity of a mobile multiple-antenna communication link in Rayleigh flat fading,” *IEEE Transactions on Information Theory*, vol. 45, pp. 139–157, January 1999.
- B. Hochwald and T. Marzetta, “Unitary space-time modulation for multiple-antenna communications in Rayleigh flat fading,” *IEEE Transactions on Information Theory*, vol. 46, pp. 543–564, March 2000.
- B. Hochwald, T. Marzetta, T. Richardson, W. Sweldens, and R. Urbanke, “Systematic design of unitary space-time constellations,” *IEEE Transactions on Information Theory*, vol. 46, pp. 1962–1973, September 2000.
- B. Hochwald and W. Sweldens, “Differential unitary space-time modulation,” *IEEE Transactions on Communications*, vol. 48, pp. 2041–2052, December 2000.
- B. Hochwald and T. Marzetta, “Adapting a downlink array from uplink measurements,” *IEEE Transactions on Signal Processing*, vol. 49, pp. 642–653, March 2001.
- B. Hochwald, T. Marzetta, and C. Papadias, “A transmitter diversity scheme for wideband CDMA systems based on space-time spreading,” *IEEE Journal on Selected Areas of Communication: Special Issue on Wideband CDMA*, vol. 19, pp. 48–60, March 2001.
- A. Shokrollahi, B. Hassibi, B. Hochwald, and W. Sweldens, “Representation theory for high-rate multiple-antenna code design,” *IEEE Transactions on Information Theory*, vol. 47, pp. 2335–2367, September 2001.

Journal Papers (cont'd)

- B. Hochwald, T. Marzetta, and B. Hassibi, "Space-time autocoding," *IEEE Transactions on Information Theory*, vol. 47, pp. 2761–2781, November 2001.
- T. Marzetta, B. Hassibi, and B. Hochwald, "Structured unitary space-time autocoding constellations," *IEEE Transactions on Information Theory*, vol. 48, pp. 942–950, April 2002.
- B. Hassibi and B. Hochwald, "Cayley differential unitary space-time codes," *IEEE Transactions on Information Theory*, vol. 48, pp. 1485–1503, June 2002.
- B. Hassibi and B. Hochwald, "High-rate codes that are linear in space and time," *IEEE Transactions on Information Theory*, vol. 48, pp. 1804–1824, July 2002.
- N. Al-Dhahir, G. Giannakis, B. Hochwald, B. Hughes, and T. Marzetta, "Guest editorial," *IEEE Transactions on Signal Processing*, vol. 50, pp. 2381–2384, October 2002.
- B. Hochwald and S. ten Brink, "Achieving near-capacity on a multiple-antenna channel," *IEEE Transactions on Communications*, vol. 53, pp. 389–399, March 2003.
- B. Hassibi and B. Hochwald, "How much training is needed in multiple-antenna wireless links?" *IEEE Transactions on Information Theory*, vol. 49, pp. 951–963, April 2003.
- B. Hochwald, G. Caire, B. Hassibi, and T. Marzetta, "The academic and industrial embrace of space-time methods," *IEEE Transactions on Information Theory: Special Issue on Space-Time Transmission, Reception, Coding and Signal Processing*, vol. 49, pp. 2329–2331, October 2003.
- B. Hochwald, T. Marzetta, and V. Tarokh, "Multiple-antenna channel hardening and its implications for rate-feedback and scheduling," *IEEE Transactions on Information Theory*, vol. 50, pp. 1893–1909, September 2004.
- H. Vikalo, B. Hassibi, B. Hochwald, and T. Kailath, "On the capacity of frequency-selective channels in training-based transmission schemes," *IEEE Transactions on Signal Processing*, vol. 52, pp. 2572–2583, September 2004.
- D. Garrett, L. Davis, S. ten Brink, B. Hochwald, and G. Knagge, "Silicon complexity for maximum-likelihood MIMO detection using spherical decoding," *IEEE Journal of Solid State Circuits*, vol. 39, pp. 1544–1552, September 2004.
- A. Alexiou, D. Avidor, P. Bosch, S. Das, P. Gupta, B. Hochwald, T. Klein, J. Ling, A. Lozano, T. Marzetta, S. Mukherjee, C. Papadias, R. Valenzuela, and H. Viswanathan, "Duplexing, resource allocation, and inter-cell coordination: design recommendations for next-generation wireless systems," *Wireless Communications and Mobile Computing*, vol. 5, pp. 77–93, May 2005.
- T. Marzetta and B. Hochwald, "Fast transfer of channel state information in wireless systems," *IEEE Transactions on Signal Processing*, vol. 54, pp. 1268–1278, April 2006.
- R. Gowaikar, B. Hochwald, and B. Hassibi, "Communication over a wireless network with random connections," *IEEE Transactions on Information Theory*, vol. 52, pp. 2857–2871, July 2006.
- C. Peel, B. Hochwald and A. L. Swindlehurst, "A vector-perturbation technique for near-capacity multi-antenna multi-user communication—Part I: Channel inversion and regularization," *IEEE Transactions on Communications*, vol. 53, pp. 195–202, January 2005. **Winner of the 2006 IEEE Transactions on Communications Stephen O. Rice Best Paper Award.**

Journal Papers (cont'd)

- B. Hochwald, C. Peel, and A. L. Swindlehurst, "A vector-perturbation technique for near-capacity multi-antenna multi-user communication—Part II: Perturbation," *IEEE Transactions on Communications*, vol. 53, pp. 537–544, March 2005. **Winner of the 2006 IEEE Transactions on Communications Stephen O. Rice Best Paper Award.**
- A. Ashikhmin, A. van Wijngaarden, Z. Haibo, B. Hochwald, T. Marzetta, V. Purohit, C. Qinghong, P. Wilford, S-R. Zhou, M. Zuniga, E. Zuranski, "Design and development of a terrestrial digital video broadcast demodulation core: An international collaborative effort," *Bell Labs Technical Journal*, vol. 12, pp. 97–118, 2007.
- B. Hochwald and H. Artés, "Orthogonalizing beams to train unscheduled terminals," *IEEE Transactions on Signal Processing*, vol. 57, pp. 3063–3074, August 2009.
- E. Stauffer and B. Hochwald, "Low-complexity multi-stream space-time codes—Part I: Direct-sum codes and design criteria," *IEEE Transactions on Communications*, vol. 60, pp. 81–88, January 2012.
- B. Hochwald and E. Stauffer, "Low-complexity multi-stream space-time codes—Part II: Unitary-transform codes," *IEEE Transactions on Communications*, vol. 60, pp. 375–383, February 2012.
- D. Nie, B. Hochwald, and E. Stauffer, "Systematic design of large-scale multiport decoupling networks," *IEEE Transactions on Circuits and Systems I: Regular Papers*, vol. 61, pp. 2172–2181, July 2014.
- B. Hochwald, D. Love, S. Yan, P. Fay, J-M. Jin, "Incorporating specific absorption rate constraints into wireless signal design," *IEEE Communications Magazine*, vol. 52, pp. 126–133, September, 2014.
- D. Nie and B. Hochwald, "Broadband matching bounds for coupled loads," *IEEE Transactions of Circuits and Systems I: Regular Papers*, vol. 62, pp. 995–1004, April 2015. **Winner of the 2016 IEEE Transactions on Circuits and Systems Best Paper Award by a Young Author.**
- D. Ying, D. Love, and B. Hochwald, "Closed-loop precoding and capacity analysis for multiple antenna wireless systems with user radiation exposure constraints," *IEEE Transactions on Wireless Communications*, vol. 14, pp. 5859–5870, October 2015.
- D. Nie and B. Hochwald, "Bandwidth analysis of multiport radio-frequency systems—Part I," *IEEE Transactions on Antennas and Propagation*, vol. 65, pp. 1081–1092, March 2017. **Winner of the 2018 IEEE Transactions on Antennas and Propagation H. A. Wheeler Prize Paper Award.**
- D. Nie and B. Hochwald, "Bandwidth analysis of multiport radio-frequency systems—Part II," *IEEE Transactions on Antennas and Propagation*, vol. 65, pp. 1093–1107, March 2017.
- D. Ying, D. Love, and B. Hochwald, "Sum-rate analysis for multi-user MIMO systems with user exposure constraints," *IEEE Transactions on Wireless Communications*, vol. 16, pp. 7376–7388, November 2017.
- D. Nie and B. Hochwald, "Improved broadband matching bound," *IEEE Transactions on Antennas and Propagation*, vol. 65, pp. 5878–5885, November 2017.
- J. Li, S. Yan, Y. Liu, B. Hochwald, and J-M. Jin, "A high-order model for fast estimation of electromagnetic absorption induced by multiple transmitters in portable devices," *IEEE Transactions on Antennas and Propagation*, vol. 65, pp. 6768–6778, December 2017.
- A. Ebadi-Shahrivar, P. Fay, D.J. Love, and B. Hochwald, "Determining electromagnetic exposure compliance of multi-antenna devices in linear time," *IEEE Transactions on Antennas and Propagation*, vol. 67, pp. 7585–7596, December 2019.

Journal Papers (cont'd)

- M. Castellanos, Y. Liu, D. Love, B. Peleato, J.-M. Jin, and B. Hochwald, "Signal-level models of pointwise electromagnetic exposure for millimeter-wave communication," *IEEE Transactions on Antennas and Propagation*, pp. 3963–3977, May 2020.
- A. Molev-Shteiman, X-F. Qi, L. Mailander, N. Prasad, and B. Hochwald, "New equivalent model of a quantizer with noisy input and its applications for MIMO system analysis and design," *IEEE Access*, September 2020.
- M. Castellanos, D. Ying, D. Love, B. Peleato, and B. Hochwald, "Dynamic electromagnetic exposure allocation for Raleigh fading MIMO channels," *IEEE Transactions on Wireless Communications*, pp. 728–740, February 2021.
- N. Estes, K. Gao, B. Hochwald, J. N. Laneman, and J. Chisum, "Efficient modeling of low-resolution millimeter-wave transceivers for massive MIMO wireless communications systems," *Microwave and Optical Technology Letters*, pp. 1134–1140, April 2021.
- N. Kleber, M. Haenggi, J. Chisum, B. Hochwald, J. N. Laneman, "Directivity in RF Sensor Networks for Widespread Spectrum Monitoring," to appear in *IEEE Transactions on Cognitive Communications and Networking*.
- N. Kleber, J. Chisum, B. Hochwald, J. N. Laneman, "Three-Dimensional RF Sensor Networks for Widespread Spectrum Monitoring," to appear in *IEEE Transactions on Cognitive Communications and Networking*.

Conference Papers

- B. Hochwald and A. Nehorai, "Minimum bias priors for estimating additive terms in state-space models," *Proceedings of the Twenty-Sixth Asilomar Conference on Signals, Systems, and Computers*, pp. 836–840, Pacific Grove, CA, October 1992 (Invited).
- B. Hochwald and A. Nehorai, "Electromagnetic vector sensors and active target localization and identification," *IEEE International Conference on Acoustics, Speech, and Signal Processing*, pp. IV 25–28, Minneapolis, MN, April 1993.
- B. Hochwald and A. Nehorai, "Identifiability in array processing models with vector-sensor applications," *Proceedings of the IEEE Seventh Signal Processing Workshop on Statistical Signal and Array Processing*, pp. 121–124, Québec City, Canada, June 1994.
- B. Hochwald and A. Nehorai, "Polarimetric modeling and parameter estimation with electromagnetic vector sensors," *Proceedings of the 1994 IEEE International Geoscience and Remote Sensing Symposium*, pp. 1129–1132, Caltech, Pasadena, CA, August 1994 (Invited).
- B. Hochwald and A. Nehorai, "Optimizing an array of sensors for magnetoencephalography," *Proceedings of the 17th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, pp. 861–862, Montréal, Canada, September 1995.
- B. Hochwald and K. Zeger, "Bounds on the tradeoff between source and channel coding with a delay constraint," *Proceedings of 1996 International Symposium on Information Theory and its Applications*, pp. 755–758, Victoria, Canada, September 1996.
- B. Hochwald and K. Zeger, "Tradeoff between source and channel coding," *Proceedings of 1997 International Symposium on Information Theory*, pg. 335, Ulm, Germany, June 1997.
- B. Hochwald and T. Marzetta, "Multiple-antenna communications when nobody knows the Rayleigh fading coefficients," *Proceedings of Thirty-Fifth Annual Allerton Conference on Communication, Control and Computing*, pp. 1033–1042, Monticello, IL, September 1997.
- B. Hochwald and P. Jelenković, "The role of memory in entropy approximation for hidden Markov models," *Proceedings of Thirty-Fifth Annual Allerton Conference on Communication, Control and Computing*, pp. 1013–1022, Monticello, IL, September 1997.
- T. Marzetta and B. Hochwald, "Fundamental limitations on multiple-antenna wireless links in Rayleigh fading," *Proceedings of 1998 International Symposium on Information Theory*, pg. 310, Boston, MA, August 1998.
- B. Hochwald, "Source and channel coding tradeoff on a Gaussian channel," *Proceedings of 1998 International Symposium on Information Theory*, pg. 248, Boston, MA, August 1998.
- B. Hochwald and T. Marzetta, "Space-time modulation scheme for unknown Rayleigh fading environments," *Proceedings of Thirty-Sixth Annual Allerton Conference on Communication, Control and Computing*, pp. 431–440, Monticello, IL, September 1998.
- B. Hochwald and T. Marzetta, "Space-time modulation for unknown fading," *Proceedings of SPIE, Digital Wireless Communication*, pp. 10–19, Orlando, FL, April 1999.
- B. Hochwald, C. Papadias, T. Marzetta, M. Buehrer and R. Soni, "Space-time spreading for CDMA systems," *Sixth workshop on Smart Antennas in Wireless Mobile Communications*, Stanford University, Stanford, CA, July 1999.

Conference Papers (cont'd)

- B. Hochwald and W. Sweldens, "Multiple-antenna differential modulation," *Proceedings of Thirty-Seventh Annual Allerton Conference on Communication, Control, and Computing*, pp. 1266–1273, Monticello, IL, September 1999.
- B. Hochwald, T. Marzetta, and C. Papadias, "A novel space-time spreading scheme for wireless CDMA systems," *Proceedings of Thirty-Seventh Annual Allerton Conference on Communication, Control, and Computing*, pp. 1284–1293, Monticello, IL, September 1999.
- T. Marzetta, B. Hochwald, and B. Hassibi, "A new approach to single-user multiple-antenna wireless communication," *Proceedings of the 2000 Conference on Information Sciences and Systems*, pp. WA4-16–WA4-21, Princeton, NJ, March 2000.
- T. Marzetta, B. Hochwald, and B. Hassibi, "Space-time autocoding: arbitrarily reliable communication in a single fading interval," *Proceedings of the 2000 International Symposium on Information Theory*, pg. 313, Sorrento, Italy, June 2000.
- B. Hassibi, B. Hochwald, A. Shokrollahi, and W. Sweldens, "Multiple antennas and representation theory," *Proceedings of the 2000 International Symposium on Information Theory*, pg. 337, Sorrento, Italy, June 2000.
- B. Hochwald and W. Sweldens, "A method of differential transmission with multiple antennas," *Proceedings of the IEEE Sixth International Symposium on Spread-Spectrum Techniques and Applications*, pg. 122, Parsippany, NJ, September 2000.
- B. Hassibi, B. Hochwald, A. Shokrollahi, and W. Sweldens, "Codes for differential signaling with many antennas," *Wireless Communications and Networking Conference*, pp. 23–24, vol. 1, 2000.
- B. Hassibi and B. Hochwald, "Optimal training in space-time systems," *Conference Record of the Thirty-Fourth Asilomar Conference on Signals, Systems and Computers*, pp. 743–747, vol. 1, Asilomar, CA, October 2000.
- B. Hassibi and B. Hochwald, "High-rate linear space-time codes," *Proceedings of the Thirty-Eighth Annual Allerton Conference on Communication, Control and Computing*, pp. 1047–1056, Monticello, IL, October 2000.
- H. Vikalo, B. Hassibi, B. Hochwald, and T. Kailath, "Optimal training for frequency-selective fading channels," *Proceedings of the 2001 IEEE International Conference on Acoustics, Speech and Signal Processing*, pp. 2105–2108, vol. 4, Salt Lake City, UT, May 2001.
- B. Hassibi and B. Hochwald, "High-rate linear space-time codes," *Proceedings of the 2001 IEEE International Conference on Acoustics, Speech and Signal Processing*, pp. 2461–2464, vol. 4, Salt Lake City, UT, May 2001.
- B. Hassibi and B. Hochwald, "Linear dispersion codes," *Proceedings of the IEEE International Symposium on Information Theory*, pg. 325, Washington, D.C., June 2001.
- T. Marzetta, B. Hassibi, and B. Hochwald, "Space-time autocoding constellations with pairwise-independent signals," *Proceedings of the IEEE International Symposium on Information Theory*, pg. 326, Washington, D.C., June 2001.
- B. Hochwald and S. ten Brink, "Iterative list sphere decoding to attain capacity on a multi-antenna link," *Proceedings of the Thirty-Ninth Annual Allerton Conference on Communication, Control and Computing*, pp. 815–824, Monticello, IL, October 2001.

Conference Papers (cont'd)

- B. Hochwald and B. Hassibi, "Cayley codes for multi-antenna differential modulation," *Conference Record of the Thirty-Fifth Asilomar Conference on Signals, Systems and Computers*, pp. 232–235, vol. 1, Asilomar, CA, October 2001.
- V. Tarokh and B. Hochwald, "Existence and construction of block interleavers," *IEEE International Conference on Communications*, pp. 1855–1857, vol. 3, New York, NY, April 2002.
- S. ten Brink and B. Hochwald, "Detection thresholds of iterative MIMO processing," *Proceedings of the 2002 International Symposium on Information Theory*, pg. 22, Lausanne, Switzerland, June 2002.
- B. Hochwald and S. Vishwanath, "Space-Time Multiple Access: Linear growth in the sum-rate," *Proceedings of the Fortieth Annual Allerton Conference on Communication, Control and Computing*, Monticello, IL, October 2002.
- B. Hochwald, T. Marzetta, and V. Tarokh, "Multi-antenna channel hardening and its implications for rate feedback and scheduling," *DIMACS Workshop on Signal Processing for Wireless Transmission*, Piscataway, NJ, October 2002.
- D. Garrett, L. Davis, B. Hochwald, and S. ten Brink, "APP processing for high-performance MIMO systems," *Proceedings of the Twenty-Fifth IEEE Custom Integrated Circuits Conference*, San Jose, CA, September 2003.
- B. Hochwald, C. Peel, and L. Swindlehurst, "Achieving near-capacity in multi-antenna multi-user systems," *Proceedings of the Forty-First Annual Allerton Conference on Communication, Control and Computing*, Monticello, IL, October 2003.
- T. Marzetta and B. Hochwald, "Learning the channel at the transmitter," *Proceedings of the Forty-Second Annual Allerton Conference on Communication, Control and Computing*, Monticello, IL, October 2004.
- R. Gowaikar, B. Hochwald and B. Hassibi, "An Achievability result for random networks," *Proceedings of the 2005 International Symposium on Information Theory*, Adelaide, Australia, September 2005.
- C. Yuen and B. Hochwald, "Dropping users in a multi-antenna broadcast channel," *Proceedings of the Information Theory and Applications Workshop*, San Diego, CA, February 2006.
- R. Gowaikar, B. Hochwald and B. Hassibi, "Throughput scaling in random wireless networks," *Proceedings of the Information Theory and Applications Workshop*, San Diego, CA, February 2006.
- C. Yuen and B. Hochwald, "How to gain 1.5 dB in vector precoding" *Proceedings of the 2006 IEEE Global Telecommunications Conference*, San Francisco, CA, November 2006.
- D. Love, B. Hochwald and K. Krishnamurthy, "Exchanging third-party information in a network," *Proceedings of the Information Theory and Applications Workshop*, San Diego, CA, February 2007.
- B. Hochwald and H. Artés, "Orthogonalizing a random set of beams," *Proceedings of the Information Theory and Applications Workshop*, San Diego, CA, February 2008.
- E. Stauffer and B. Hochwald, "Low-complexity space-time codes for high and low-priority streams," *Proceedings of the Information Theory and Applications Workshop*, San Diego, CA, February 2009.
- A. Jalali, D. Love, S. Sanghavi, and B. Hochwald, "Conferencing on trees," *Proceedings of Conference on Information Sciences and Systems*, Baltimore, MD, pp. 763-768, March 18-20, 2009.

Conference Papers (cont'd)

- L. Jalloul, N. Czink, B. Hochwald, and A. Paulraj, "Why downlink cyclic delay diversity helps uplink transmit diversity," *Proceedings of the 69th IEEE Vehicular Technology Conference*, Barcelona, Spain, April 2009.
- B. Hochwald and L. Jalloul, "Statistical distributions that arise in constrained beamforming with incomplete channel information," *Proceedings of the Information Theory and Applications Workshop*, San Diego, CA, February 2010.
- B. Hochwald and D. Love, "Minimizing exposure to electromagnetic radiation in portable devices," *Proceedings of the Information Theory and Applications Workshop*, San Diego, CA, February 2012.
- B. Hochwald, D. Love, S. Yan and J-M. Jin, "SAR codes," *Proceedings of the Information Theory and Applications Workshop*, San Diego, CA, February 2013.
- D. Ying, D. Love and B. Hochwald, "Beamformer optimization with a constraint on user electromagnetic exposure," *Proceedings of 2013 47th Annual Conference on Information Sciences and Systems*, March 2013, pp. 1–6.
- D. Ying, D. Love and B. Hochwald, "Transmit covariance optimization with a constraint on user electromagnetic radiation exposure," *Proceedings 2013 Globecom Wireless Communications Symposium*, December 2013, pp. 4104–4109.
- D. Nie, B. Hochwald, and E. Stauffer, "Electromagnetic decoupling and complexity," *Proceedings of the Information Theory and Applications Workshop*, San Diego, CA, February 2014 (Invited).
- D. Nie, B. Hochwald, and E. Stauffer, "Minimum complexity decoupling networks for arbitrary coupled loads," *Proceedings of the 2014 International Symposium on Antennas and Propagation*, Memphis, TN, July 2014, pp. 460–461.
- D. Nie and B. Hochwald, "Bandwidth analysis of low-complexity decoupling networks for multiple coupled antennas," *Proceedings of the Forty-Eighth Asilomar Conference on Signals, Systems, and Computers*, Pacific Grove, CA, November 2014 (Invited), pp. 1076–1082.
- D. Nie and B. Hochwald, "Bandwidth bounds for matching coupled loads," *Proceedings of the 2015 IEEE International Symposium on Circuits and Systems*, Lisbon, Portugal, May 2015, pp. 137–140.
- D. Nie and B. Hochwald, "Bandwidth upper bounds for matching coupled loads," *Proceedings of the 2015 IEEE International Symposium on Antennas and Propagation*, Vancouver, BC, July 2015, pp. 1394–1395.
- A. Termos and B. Hochwald, "Capacity benefits of antenna coupling," *Proceedings of the Information Theory and Applications Workshop*, San Diego, CA, February 2016 (Invited).
- D. Nie and B. Hochwald, "Bandwidth as a function of number of sources and loads in multiport radio-frequency systems," *Proceedings of the 2016 IEEE International Symposium on Antennas and Propagation*, Fajardo, Puerto Rico, June 2016.
- D. Nie and B. Hochwald, "Improved Bode-Fano broadband matching bound," *Proceedings of the 2016 IEEE International Symposium on Antennas and Propagation*, Fajardo, Puerto Rico, June 2016. **Winner of the 2016 International Symposium on Antennas and Propagation Student Paper Competition.**
- B. Hochwald and D. Nie, "Bandwidth-multiplexing tradeoff in multi-antenna systems," *Proceedings of the 2016 Antenna Applications Symposium*, Monticello, IL, September 2016, pp. 295–308.

Conference Papers (cont'd)

- M. Castellanos, D. Love and B. Hochwald, “Hybrid precoding for millimeter wave systems with a constraint on user electromagnetic radiation exposure,” *Proceedings of IEEE Asilomar Conference on Signals, Systems, and Computers*, Pacific Grove, CA, Nov. 6–9, 2016 (Invited).
- M. Cai, K. Gao, D. Nie, B. Hochwald and J. N. Laneman, “Effect of wideband beam squint on codebook design in phased-array wireless systems,” *Proceedings of 2016 IEEE Global Communications Conference (GLOBECOM)*, Washington D.C., December 2016.
- K. Gao, M. Cai, D. Nie, B. Hochwald and J. N. Laneman, “Beampattern-based tracking for millimeter wave communication systems,” *Proceedings of 2016 IEEE Global Communications Conference (GLOBECOM)*, Washington D.C., December 2016.
- K. Gao, N. Estes, B. Hochwald, J. Chisum and J. N. Laneman, “Power-performance analysis of a simple one-bit transceiver,” *Proceedings of the 2017 Information Theory and Applications Workshop*, San Diego, CA, February 2017.
- N. Kleber, A. Termos, G. Martinez, J. Merritt, B. Hochwald, J. Chisum, A. Striegel and J. N. Laneman, “RadioHound: A pervasive sensing network for sub-6 GHz dynamic spectrum monitoring,” *IEEE International Symposium on Dynamic Spectrum Access Networks*, Baltimore, MD, March 2017.
- A. Ebadi-Shahrivar, J. Ren, B. Hochwald and P. Fay, “Mixed quadratic model for peak spatial average SAR of coherent multiple antennas devices,” *Proceedings of the IEEE AP-S Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting*, San Diego, July 9–14, 2017.
- J. Li, S. Yan, Y. Liu, B. Hochwald and J-M. Jin, “A high-order model for fast estimation of specific absorption rate induced by multiple transmitters in portable devices,” *Proceedings of the IEEE AP-S Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting*, San Diego, July 9–14, 2017.
- M. Cai, J. N. Laneman, B. Hochwald, “Carrier aggregation for phased-array analog beamforming with beam squint,” *Proceedings of 2017 IEEE Global Communications Conference (GLOBECOM)*, Singapore, December 2017.
- K. Gao, J. N. Laneman and B. Hochwald, “Beamforming with multiple one-bit wireless transceivers,” *Proceedings of the 2018 Information Theory and Applications Workshop*, San Diego, CA, February 2018.
- K. Gao, J. N. Laneman, and B. Hochwald “Capacity of multiple one-bit transceivers in a Rayleigh environment,” *Proceedings of the 2018 IEEE Wireless Communications and Networking conference*, Barcelona, April 2018.
- A. Ebadi-Shahrivar, P. Fay, D. J. Love, and B. Hochwald, “Multi-antenna SAR estimation in linear time,” *Proceedings of the 2018 IEEE International Symposium on Antennas and Propagation*, Boston, July 2018.
- K. Gao, J. N. Laneman, N. Estes, J. Chisum, and B. Hochwald, “Training for channel estimation in nonlinear multi-antenna transceivers,” *Proceedings of the 2019 Information Theory and Applications Workshop*, San Diego, CA, February 2019.
- A. Ebadi-Shahrivar, P. Fay, D.J. Love, and B. Hochwald, “Codebook requirements for estimating multi-antenna SAR in linear time,” *Proceedings of the 2019 IEEE International Symposium on Antennas and Propagation*, Atlanta, GA, July 2019.

Conference Papers (cont'd)

- K. Gao, J. N. Laneman, N. Estes, J. Chisum, and B. Hochwald, "Channel estimation with one-bit transceivers in a Rayleigh environment," *Proceedings of 2019 IEEE Global Communications Conference (GLOBECOM)*, Waikoloa, Hawaii, December 2019.
- A. Termos and B. Hochwald, "Robust Neural Network-Based Spectrum Occupancy Mapping," *IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks*, December 2021.

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Expert Activities

Clients: **Netgear** – Harris Corp. v. Netgear Inc., 6:11-cv-1866 (M.D. Fla.)

Faegre Baker Daniels LLP
Phased arrays of antennas and cellular patents
No report (Feb.–Mar., 2012)

Netgear – Ruckus Wireless Inc. v. Netgear Inc., 4:08-cv-02310 (N.D. Cal.)

Boyle Fredrickson SC
Antenna selection and wireless local area network patents
Expert report (Mar.–May 2012)

Airvana – Airvana Network Solutions Inc. v. Ericsson Inc., 650360/2012 (NY Sup.)

Wilmer Cutler Pickering Hale & Dorr LLP
3GPP CDMA wireless technology business agreement
Expert report, deposition and trial testimony (Mar. 2012–Apr. 2013)

Apple – Adaptix Inc. v. Apple Inc. et al., 6:12-cv-00124 & -00125 (E.D. Tex.)

Wilmer Cutler Pickering Hale & Dorr LLP
WiMax and LTE OFDMA subcarrier allocation patents
No report (Dec. 2012–Dec. 2013)

Apple – Ericsson Inc. v. Apple Inc., 2:15-cv-00287 et al., (E.D. Tex.)

Wilmer Cutler Pickering Hale & Dorr LLP
Multiple-antenna transmission methods and HARQ in wireless systems patents
No report (May–Jul. 2015)

Wave Electronics – Andrea Elect. Corp. v. Lenovo Group et al., 2:14-cv-04489, (E.D. New York)

Alston & Bird LLP, Denko Coburn Lauff LLP, Akin Gump Strauss Hauer & Feld LLP
Adaptive echo canceller patents
Expert reports, testimony at Markman hearing (Oct. 2015–Jan. 2016)

Apple – Andrea Electronics v. Apple Inc., 2:16-cv-05220 (E.D. New York)

Sidley Austin LLP
Adaptive echo canceller patents
Expert reports, deposition, (Nov. 2016–Mar. 2018)

Apple – Cellular Communications Equipment LLC v. Apple Inc., 2:15-cv-00576 (E.D. Tex.)

DLA Piper LLP
Carrier aggregation in cellular systems patents
Expert report (Feb.–May 2017)

Huawei – Huawei Technologies Co. v. Samsung Electronics Co., IPR2017-01973 & -01974

Sidley Austin LLP
Random access channels and discontinuous transmissions in LTE systems
Expert report (Jul. 2017–Jun. 2018)

Apple – WiLAN USA, Inc. v. Apple Inc., 3:14-cv-02838 (N.D. Cal.)

DLA Piper LLP
Packing and fragmenting in LTE systems
Expert report, deposition (Nov. 2017–Aug. 2018)

Neodron – Neodron, Ltd. v. Amazon, Dell, HP, Lenovo, Motorola, Microsoft, and Samsung,
ITC Inv. 337-TA-1162, filed May 23, 2019

Russ, August & Kabat

Capacitive touch-screen technologies

Expert report, deposition (Aug. 2019–Feb. 2020)

Collision – Collision Communications, Inc v. Nokia and Ericsson, 2:21-cv-308, 2:21-cv-327

Ropes & Gray LLP

Multiuser detection in wireless systems

Expert report (Oct. 2021–)

Vivint – SB IP Holdings v. Vivint, Inc., IPR2022-00810

Foley & Lardner LLP

Image and audio processing for security systems

Expert report (Mar. 2022–)