

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. 10,693,700

Issue Date: June 23, 2020

Title: Receivers Incorporating Non-Uniform Multidimensional Constellations
and Code Rate Pairs

Inter Partes Review No.: IPR2023-00319

DECLARATION OF DR. BERTRAND HOCHWALD

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I, Dr. Bertrand Hochwald, declare as follows:

I. INTRODUCTION

[0001] 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. 10,693,700 (the “’700 Patent” or LGE1001). I have been asked to consider the validity of claims 2-3, 5, 12-13, 15, 22-23, and 25 of the ’700 Patent (the “Challenged Claims”). My opinions are set forth below.

[0002] 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.

[0003] 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

[0004] 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.

[0005] 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.

[0006] 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.

[0007] 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.

[0008] 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.

[0009] 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.

[0010] 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.

[0011] 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.

[0012] 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.

[0013] 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.

[0014] 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.

[0015] 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

[0016] 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.

[0017] In forming my opinions expressed in this declaration, I relied on the '700 Patent (LGE1001), the prosecution history of the '700 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. 10,693,700 to Barsoum et al. (LGE1001 or “the ‘700 patent”)
Prosecution History for U.S. Patent No. 10,693,700 (LGE1002)
Ulrich Reimers et al., <i>DVB The Family of International Standards for Digital Video Broadcasting</i> , Second Edition, 2005 (“Ulrich”) (LGE1008 or “Ulrich”)
U.S. Provisional Application No. 60/933,319 (LGE1010 or “‘319 Provisional”)
De Gaudenzi et al., <i>Turbo-coded APSK modulations design for satellite broadband communications</i> , Int. J. Satell. Commun. Network. 2006; 24:261–281, Published online 19 May 2006 in Wiley InterScience (“LGE1014” or “DeGaudenzi”)
U.S. Patent No. 7,978,777 to Barsoum et al. (LGE1015 or “the ‘777 patent”)
ATSC Recommended Practice: Guidelines for the Physical

Layer Protocol, Document no. A/327:2018 (LGE1022 or “ATSC327”)
ATSC 3.0 Standard: Physical Layer Protocol, Document no. A/322:2018 (LGE1023 or “ATSC322”)
Loghin, et al., <i>Non-Uniform Constellations for ATSC 3.0</i> , IEEE Transactions on Broadcasting, Vol 62, No. 1, March 2016. (LGE1024 or “Loghin”)
G. Ungerboeck, Channel Coding with Multilevel/Phase Signals, IEEE Trans. Inform. Theory, Vol. IT-28, No. 1, Jan. 1982, pp. 55-67 (LGE1025 or “Ungerboeck”)

[0018] 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 ’700 Patent, and I have done so during my review of these materials. *See also infra* Sections VIII-X. The ’700 Patent was filed on December 23, 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, Counsel has indicated that I should use June 5, 2007 for the purposes of what a POSITA would have known or considered. I

have therefore used June 5, 2007 as the date for my analysis below.

IV. OVERVIEW OF CONCLUSIONS FORMED

[0019] 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:

- 1A: Claims 2-3, 12-13, and 22-23 are obvious over the '777 patent and ATSC322.
- 1B: Claims 5, 15, 25 are obvious over the '777 patent and ATSC 327

[0020] 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

[0021] 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.

[0022] 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.

[0023] 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

[0024] 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.

[0025] In connection with the analysis presented in this declaration, I considered the following legal standards that counsel for Petitioner provided to me.

A. Anticipation

[0026] 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.

[0027] 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.

[0028] 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

[0029] 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.

[0030] 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.

[0031] 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.

[0032] 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."

[0033] 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.

[0034] 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.

[0035] 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.

[0036] 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.

[0037] 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.

[0038] 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.

[0039] 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.

[0040] 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.

[0041] 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

[0042] 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 US PATENT NO. 10,693,700

A. Patent Family of the '700 Patent

[0043] The '700 Patent, titled "Receivers Incorporating Non-Uniform Multidimensional Constellations and Code Rate Pairs" was filed on December 23, 2019, and issued on June 23, 2020. LGE1001, cover page. I understand that:

- the '700 Patent issued from US Patent Application No. 16/726,037, and claims to be a continuation of application No. 16/206,991, filed on Nov. 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.*

[0044] Claims 2-3, 5, 12-13, 15, 22-23, and 25 of the '700 Patent are not entitled to the priority to June 5, 2007 for the reason set forth in paragraphs

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

A. Legal Standard for Priority

[0045] 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.

[0046] 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.

[0047] 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.

[0048] 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.”

[0049] 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”). LGE1010; LGE1015. Instead, the text of the challenged claims were filed on December 23, 2019 when US. App. No. 16/726,037, which eventually issued as the ’700 patent, was filed. LGE1002, 1,088-1,097. This December 23, 2019 filing 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 2-3, 12-13, and 22-23**

[0050] The Barsoum Patents lack written description support for the limitations of claims 2-3, 12-13, and 22-23 directed towards respective QAM

constellations having an LDPC code rate within a specific range of LDPC code rates. Claims 2, 12, and 22 are directed towards a QAM constellation having “*an LDPC code rate that is equal to or greater than 3/8 and less than or equal to 6/8.*” LGE1001, 14:6-55, 16:6-55, 18:1-50. Claims 3, 13, and 23, depend from claims 2, 12, and 22, respectively, and further comprises specific limitations of an additional plurality of different non-uniform multidimensional symbol constellations comprising claim multiple different sixty-four-point ***QAM*** constellations, multiple different ***QAM-256*** constellations, and multiple different ***QAM-1024*** constellations, wherein each of the additional plurality of different non-uniform multidimensional symbol constellations is only included in ***one*** of the plurality of predetermined LDPC code rate and multidimensional symbol constellation pairs, wherein:

- the LDPC code rate and multidimensional symbol constellation pairs that include one of the multiple different sixty-four-point symbol QAM constellations have an ***LDPC code rate that is equal to or greater than 2/6 and less than or equal to 5/6;***
- the LDPC code rate and multidimensional symbol constellation pairs that include one of the multiple different two-hundred-fifty-six-point symbol QAM constellations have an ***an LDPC code rate that is equal***

to or greater than 3/8 and less than or equal to 7/8; and

- the LDPC code rate and multidimensional symbol constellation pairs that include one of the multiple different one-thousand-twenty-four-point symbol QAM constellations have an *LDPC code rate that is equal to or greater than 4/10 and less than or equal to 9/10. Id.*

[0051] 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

[0052] There is nothing in the Barsoum Patents that demonstrates that the claimed *code rate ranges* and constellations were part of their invention. LGE1010, 1-6. 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.*” LGE1010, 2 (emphasis added).

[0053] 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 application explains that “optimal design of a constellation depends on the *target code rate* to be used with it.” LGE1010, 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:

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

wherein M is, as best understood by Petitioner, to be the number of constellation points. LGE1010, 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. Indeed, the examples illustrated in Fig. 6 of the ’319 provisional application focus on code rate = $\frac{1}{2}$.

[0054] Determination of a **code rate range** requires determination of a **minimum code rate** as a lower bound to the code rate range (e.g., $\frac{3}{8}$ in claim 2), determination of a **maximum code rate** as an upper bound to the code rate range (e.g., $\frac{6}{8}$ in claim 2), and determination of whether minimum code rate, maximum code rate, or both, are included in the code rate range (e.g., $\frac{3}{8}$ is included in the range of claim 2, as the language recites equal to or greater than). None of these aspects of the code rate ranges of the challenged claims are found in the ’319 provisional application.

[0055] 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*...” LGE1015, 5:4-7. 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. LGE1015, 3:61-4:21, 10:25-11:13, FIGS. 10a-17b.

[0056] 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 the '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. LGE1015, 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 (not QAM 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*. LGE1015, 10:35-55, FIGs. 10a-11b.

[0057] 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 the '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. LGE1015, 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 (not QAM 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*. LGE1015, 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. LGE1015, 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.

[0058] 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 multidimensional **QAM** constellations from examples of specific code rates for single dimensional **PAM** constellations provided in the Barsoum Patents. LGE1010, 2-4, FIGs. 1-3; LGE1015, 10:34-11:13, FIG. 11b, 13b, 15b, 17b; LGE1001, 14:6-55. To be clear, the Barsoum Patents do not provide a single statement explaining that the code rate for one

dimensional PAM constellations would be the same as a code rate for a multidimensional QAM. As explained in *Purdue*, the '319 provisional application itself must provide sufficient “blaze marks” directing a Person of Ordinary Skill In The Art (POSITA) to teachings within the '319 provisional application that support the claimed LDPC code rate ranges of the challenged patents. See *Purdue*, 230 F.3d at 1326-1327. Here, no blaze marks exist. *Id.* Therefore, claims 2-3, 12-13, and 22-23 are not entitled to the priority date of the '319 Patent.

[0059] Moreover, the *specific code rate* described with respect to each respective constellation in the constellation design tables of FIG. 11a, 11b, 13a, 13b, 15a, 15b, 17a, 17b is directed towards a single dimensional **PAM** constellation, whereas the *code rate ranges* of the challenged claims are for multidimensional **QAM** constellations, thus making the code rate ranges of the challenged claims even *further* removed from anything found in the written description of the '777 patent described above. LGE1015, 3:61-4:21, 10:25-11:13, FIGS. 10a-17b; LGE1001, 14:6-55, 16:6-55, 18:1-49. Nothing in the Barsoum Patents provides any “blaze marks” that would direct a Person Of Ordinary Skill in the Art (POSITA) to find the *minimum code rate* of a code rate range for a multidimensional **QAM** constellation, the *maximum*

code rate of the claimed code rate range for a multidimensional *QAM* constellation, or whether minimum code rate, maximum code rate, or both, are included in or excluded from a code range of a multidimensional *QAM* constellation. see *Purdue*, 1326-1327. Thus, the Barsoum Patents fail to provide support for the *code rate ranges* of the challenged claims.

[0060] Finally, to the extent that it can be argued that Figures 10c, 12c, 14c, and 16c show constellation points optimized for parallel decoding capacity over a continuum of (or range of) capacities or code rates, nothing in these figures even prescribes the code rate ranges described in the claims. For example, the lowest code rate in Figure 14c appears to be somewhat larger than code rate = 3/8.

[0061] On this point of projecting features of a *PAM* constellation onto a *QAM* constellation, the '777 patent contends, without evidence, that “[d]ue to the orthogonality of the in-phase and quadrature components the capacity characteristics of the resulting QAM-64 constellation *are identical* to that of the PAM-8 constellation *on a per-dimension basis*.” LGE1001, 12:33-37; LGE1004, 12:36-37. At best, this statement merely indicates that a single dimension of a QAM-64 allegedly has identical capacity characteristics as a corresponding PAM-8. Neither this statement, nor the Barsoum Patents

considered in their entirety, disclose what the capacity characteristics of the QAM, considered as a whole, are. And a POSITA would not assume or have reason to believe that capacity characteristics of a single dimensional constellation would be the same as those of a multidimensional constellation.

[0062] For instance, the Barsoum Patents do not provide any written description explaining that specific code rates or SNRs for a *multi-dimensional QAM-16, QAM-64, QAM-256, QAM-1024 or constellation* (as in claims 2-3, 12-13, and 22-23) would be the same as the specific code rates or SNRs alluded to in the PAM-4, PAM-8, PAM-16, or PAM-32 constellations, respectively, described in FIGS. 10a-17b. Indeed, a POSITA would have understood that the capacities, coding rates, and SNRs for one-dimensional and corresponding two-dimensional constellations *are not the same*. For example, FIGS. 2(a) and 2(b) (reproduced below) of Ungerboeck, an *IEEE Transactions* paper from 1982, provides a comparison of the channel capacities of related 1-D and 2-D constellations (e.g., compare 4-AM or 8-AM in FIG. 2(a) with 16-QASK or 64-QASK in FIG. 2(b)). LGE1025, 57.

[0063] FIGS. 2(a) and 2(b) of the '700 patent, reproduced below, graphically plot capacity versus signal to noise ratio (SNR) for uncoded modulation when $BER=10^{-5}$.

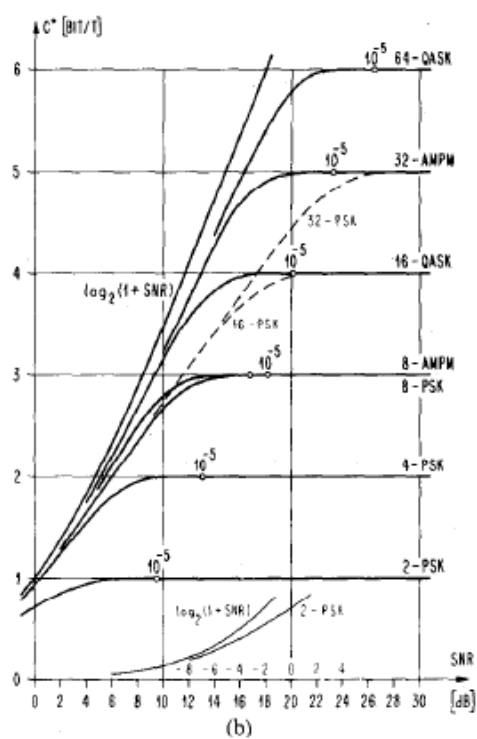
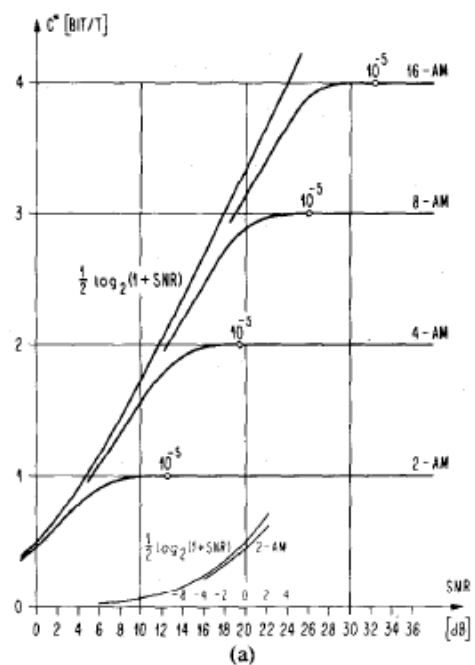


Fig. 2. Channel capacity C^* of bandlimited AWGN channels with discrete-valued input and continuous-valued output. a) One-dimensional modulation. b) Two-dimensional modulation.

LGE1015, 57.

[0064] In comparing the 4-AM (PAM) curve in FIG. 2(a) (reproduced above) to the 16-QASK (QAM) curve in FIG. 2(b) (reproduced above), it appears that the curve corresponding to 16-QASK (QAM) is approximately double the 4-AM (PAM) curve, but with differences to the 10^{-5} error SNR's. Extrapolating from this that the capacity curve for QAM is double the curve for PAM for a given SNR per dimension, the POSITA would also conclude that C_{PD} as described in the Barsoum patents is also double for QAM versus PAM. LGE1004, 6:55-60.

[0065] However, a POSITA seeking guidance from the Barsoum patents on the design of the constellation and code rates for QAM faces ambiguities. For example, a POSITA is instructed that, “[i]n most cases the capacity can be set to equal the target user bit rate per symbol per dimension.” LGE1004, 7:54-55. This suggests that the target user bit rate per symbol per dimension is double for QAM what it is for PAM. Hence, it becomes unclear how to extrapolate to QAM the tables, code rates, SNR's, and constellations that were designed for PAM.

[0066] There are further statements such as “[a] user bit rate per dimension of 2.5 bits for a system transmitting 5 bits per symbol constitutes a code rate of $\frac{1}{2}$.” *Id.* 10:32-35. However, a two-dimensional QAM constellation with 32

symbols, which has 5 bits per symbol, and therefore 2.5 bits per dimension, requires a code rate of 1 to achieve a “user bit rate per dimension of 2.5 bits.” Hence a POSITA is unclear as to which statements in the specification regarding code rates apply to QAM or any constellation besides PAM.

[0067] A POSITA would have understood that capacity configurations for one dimensional and two dimensional constellations are not the same. Indeed, because a two dimensional constellation (e.g., 16-QAM) has a squared number of points compared to a corresponding one-dimensional constellation (e.g., PAM-4), the specific code rate determined for each one dimensional constellation, such as a PAM-4 constellation, described by the Barsoum Patents cannot be relied upon to support a specific code rate for a QAM constellation as recited in claims 2-3, 12-13, and 22-23. And even if a specific QAM constellation code rate could somehow be supported, a range of code rates for different QAM constellations is not disclosed by the Barsoum Patents.

[0068] Therefore, the claims 2-3, 12-13, and 22-23 are not entitled to priority date of the Barsoum Patents.

3. The Written Description of the Barsoum Patents Do Not Demonstrate that the Patent Owner Was “In Possession” of the Communication System Claimed by claims 2-3, 12-13, and 22-23

[0069] As explained in Section II(B)(1) above, the Barsoum Patents do not include sufficient written description that supports the *code rate ranges* of the Challenged Claims. 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.

[0070] Claims 2-3, 12-13, and 22-23, which incorporate the features of the independent claims by virtue of their dependency, impart a *code rate range* limitation on the different non-uniform multidimensional constellation that is included in one of the “plurality of predetermined LDPC code rate and multidimensional symbol constellation pairs” from which an LDPC code rate and multidimensional symbol constellation pair is selected by the receiver of the claimed communication system. LGE1001, 13:43-14:30. However, the *code rate ranges* are not supported by the written description of the Barsoum Patents for the reasons set forth in Section II(B)(1). Accordingly, a POSITA would not be able to discern that the Patent Owner had possession of a communication system “that selects an LDPC code rate and multidimensional symbol constellation pair from a “plurality of predetermined LDPC code rate and multidimensional symbol constellation pairs” that is limited to multidimensional symbol constellation pairs having code rates specified by

the *code rate ranges* of the challenged claims.

[0071] For at least the reasons set forth in Section II(B)(1) and Section II(B)(2), the written description of the Barsoum Patents is not sufficient to show possession of the subject matter of claims 2-3, 12-13, and 22-23. Therefore, claims 2-3, 12-13, and 22-23 are not entitled to priority date of the Barsoum Patents.

4. The Written Description of the Barsoum Patents Do Not Demonstrate that the Patent Owner Was “In Possession” of a Communication System recited by claims 5, 15, and 25

Claim 5 recites:

“each of the plurality of different non-uniform multidimensional symbol constellations is capable of providing a greater parallel decoding capacity at a specific SNR than the other symbol constellations in the plurality of multidimensional symbol constellations at the same SNR.” LGE1001, 14:65-15:3.

[0072] These features do not find support in the written description of the Barousm Patents.

[0073] This limitation defines a very specific relative relationship between two groupings of non-uniform spaced constellations that is not supported by the '777 Patent specification. LGE-1003, [zz]. In particular, claim 5 recites an observation of a relative relationship between a first group of *non-uniform*

*multidimensional symbol constellations*¹ to a second group of other symbol constellations² when the two groups are *operated at the same SNR*. Nothing in the '777 patent provides sufficient written description support for the comparison of these two groups of *constellations*. To the contrary, the '777 patent, at best, only describes determining a relative relationship between *a* geometrically shaped (i.e., unequally spaced) constellation and a constellation optimized for $d_{\min}$. LGE1015, 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 provide written description support that a POSITA would understand as indicating that Patent Owner has possession of the subject matter of claim 5 as of the priority date of the '777 Patent. The '319 provisional application similarly lacks written description support for the features of claim 5. Thus, subject matter of claim 5 is not entitled to the priority date of the '777 patent.

1 i.e., - “*each of the plurality* of different non-uniform multidimensional symbol constellations having the same number of constellation points”

2 i.e., - “the other symbol constellations in the plurality of multidimensional symbol constellations”

[0074] Claims 15 and 25 include features that correspond to claim 5. Thus, the subject matter of claims 15 and 25 are not entitled to the priority date of the '777 patent for at least the same reasons as claim 5.

5. The Written Description of the Barsoum Patents Does Not Demonstrate that the Patent Owner Was “In Possession” of a 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 5, 15, and 25

[0075] Claim 5 recites:

“each of the plurality of different non-uniform multidimensional symbol constellations is capable of providing a greater parallel decoding capacity at a specific SNR than the other symbol constellations in the plurality of multidimensional symbol constellations at the same SNR.” LGE1001, 14:65-15:3.

[0076] These features do not find support in the written description of the Barsoum Patents. 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. LGE1015, 6:13-22.

[0077] A POSITA would understand this passage of the '777 patent as specifying that *at least some* geometrically shaped (i.e., non-uniform) 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. LGE1015, 6:13-22. In addition, a POSITA would have understood the '777 patent as explaining that operations can be performed on a non-uniform constellation so that the non-uniform constellation **can be optimized** for joint capacity optimization or parallel decoding optimization in order to have greater capacity. LGE1015 6:13-22. Thus, though some non-uniform 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 non-uniform constellation so that it can be capable* of having a greater capacity such as a greater parallel decoding capacity. LGE1015, 6:13-22.

[0078] Turning to claim 5, the Barsoum Patents fail to disclose that *each of the plurality* of different non-uniform multidimensional symbol constellations *have been optimized* to be *capable* of having greater parallel decoding capacity. Indeed, neither the language of claim 5 nor the language of parent claim 1 indicate that *each of the plurality* of different non-uniform multidimensional symbol constellations have been optimized for parallel decoding capacity. Moreover, nothing in the specification of the '777 patent or '700 patent provides any indication that *each of the plurality of* different non-uniform multidimensional symbol constellations of claim 5 have been optimized for parallel decoding capacity. To the contrary, a review of the specification of the '777 patent and the '700 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; LGE1015, 6:13-15 (emphasis added).

[0079] Claim 5 is not supported by the written description of the '777 patent because "[n]ot all" *of the plurality of* different non-uniform multidimensional

symbol constellations are *capable of providing a greater parallel decoding capacity at a specific SNR* than the *other symbol constellations in the plurality of multidimensional symbol constellations* recited by claim 5.

Thus, claim 5 is not entitled to the priority date of the '777 patent.

[0080] 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 a greater parallel decoding capacity at a specific SNR than other symbol constellations in the plurality of multidimensional symbol constellations at the same SNR, such an assertion further proves that the claim feature of “the plurality of different non-uniform multidimensional symbol constellations” includes non-uniform constellations that are not optimized for parallel decoding capacity, of which, “[n]ot all” have a greater capacity than that of other symbol constellations in the plurality of multidimensional symbol constellations. 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 of multidimensional symbol constellations at the same SNR *after* the non-uniform constellation has been optimized for parallel decoding capacity. LGE1015, 6:13-22.

[0081] For such an argument to prevail, Patent Owner would need to show that the ***each of the plurality of*** different non-uniform multidimensional symbol constellations of claim 5 have been optimized for parallel decoding capacity . However, nothing in the claims or specification of the '777 patent indicates that ***each of the plurality of*** different non-uniform multidimensional symbol constellations of claim 5 have been optimized for parallel decoding capacity. Thus, claim 5 is not supported by the specification of the '777 patent in sufficient detail to convey to a POSITA that Patent Owner had possession of the subject matter of claim 5 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.

[0082] For at least these reasons, the Barsoum Patents fail to provide support for the features of claim 5 that recite “***each of the plurality of*** different non-uniform multidimensional symbol constellations ***is capable of providing a greater parallel decoding capacity at a specific SNR*** than the other symbol constellations in the plurality of multidimensional symbol constellations at the same SNR.” LGE1001, 14:65-15:3.

[0083] Claims 15 and 25 include claim features that correspond to the features of claim 5. Claims 15 and 25 lack support in the Barsoum Patents for the

same reasons set forth above with respect to claim 5.

[0084] Therefore, the claims 5, 15, and 25 are not entitled to priority date of the Barsoum Patents.

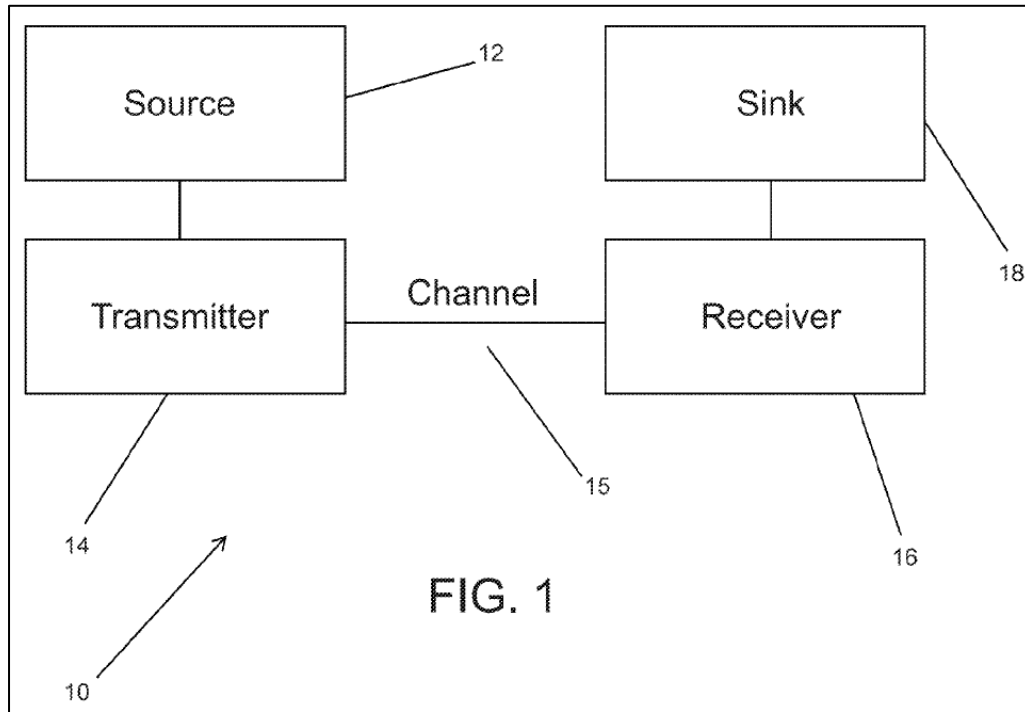
X. OVERVIEW OF THE '700 PATENT

A. Brief Description of the '700 Patent

[0085] The '700 Patent is directed to communication systems that use geometrically-shaped constellations. LGE1001, 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. The '700 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 '700 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.*, 2:29-34.

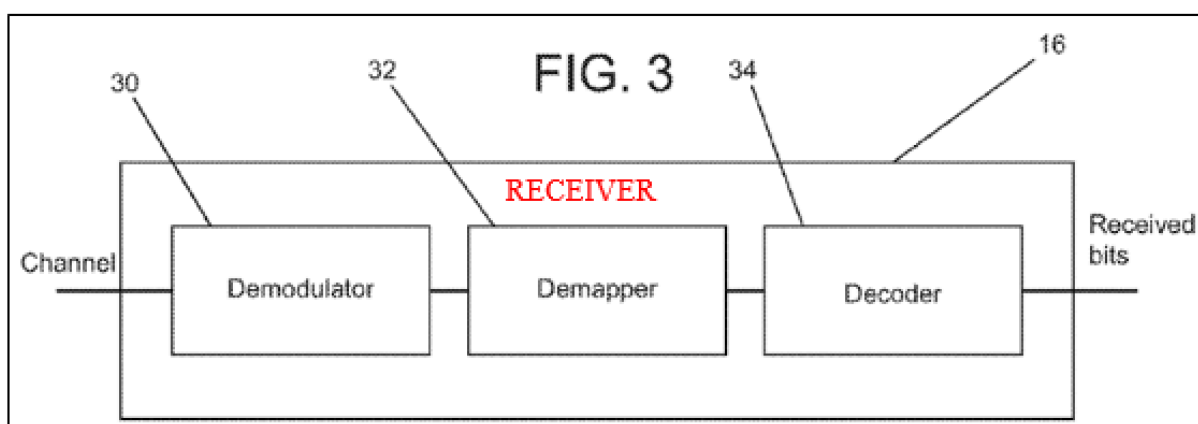
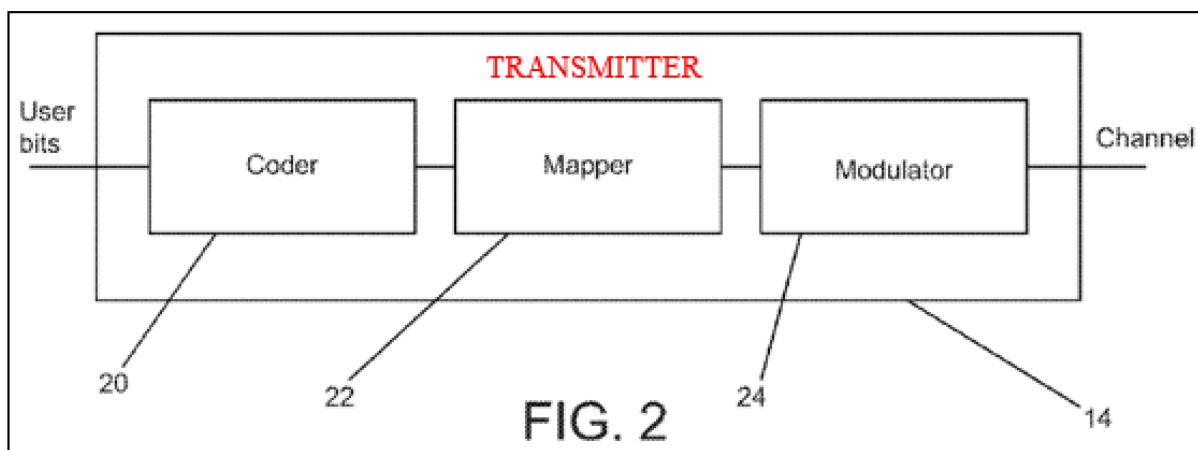
[0086] Figure 1 (reproduced below) shows a communication system 10 according to the '700 Patent, which includes “a source 12 that provides user bits to a transmitter 14,” which in turn “transmits symbols over a channel to a receiver 16 using a predetermined modulation scheme.” LGE1001, 5:32-35.

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.*, 5:33-35.



LGE1001, FIG. 1.

[0087] FIG. 2 (reproduced below) of the '700 Patent depicts the transmitter 14 and its components, which include a coder 20, a mapper 22, and a modulator 24. LGE1001, 3:45-46, 5:40-51. FIG. 3 (reproduced below) of the '700 Patent depicts the receiver 16 and its components, which include a demodulator 30, a demapper 32, and a decoder 34. LGE1001, 3:47-48, 5:53-59.



LGE1001, FIGS. 2-3.

[0088] 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, 5:40-44. 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.*, 2:52-55, 2:56-62, 4:66-5:3. 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.*, 7:52-54. The ’700 Patent explains that “capacity optimized constellation at low SNRs are geometrically shaped constellations that can achieve significantly higher performance gains (measured as reduction in minimum required SNR) than constellations that maximize d_{min} .” *Id.*, 8:25-29.

[0089] “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.*, 6:64-7:3. 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.*, 7:18-21.

[0090] 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, 5:54-58. 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.*, 5:58-60.

[0091] The ’700 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, 5:62-66. 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.*, 5:66-6:1, 6:7-8. The ’700 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.*, 6:8-13. 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.*, 6:25-32.

[0092] The '700 Patent explains that PAM constellations can be paired with specific code rates to optimize capacity. LGE1001, 10:10-29. For example, FIG. 8a shows the lower SNR required for optimized constellations relative to classic PAM constellations. *Id.* The '700 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, 11:9-16.

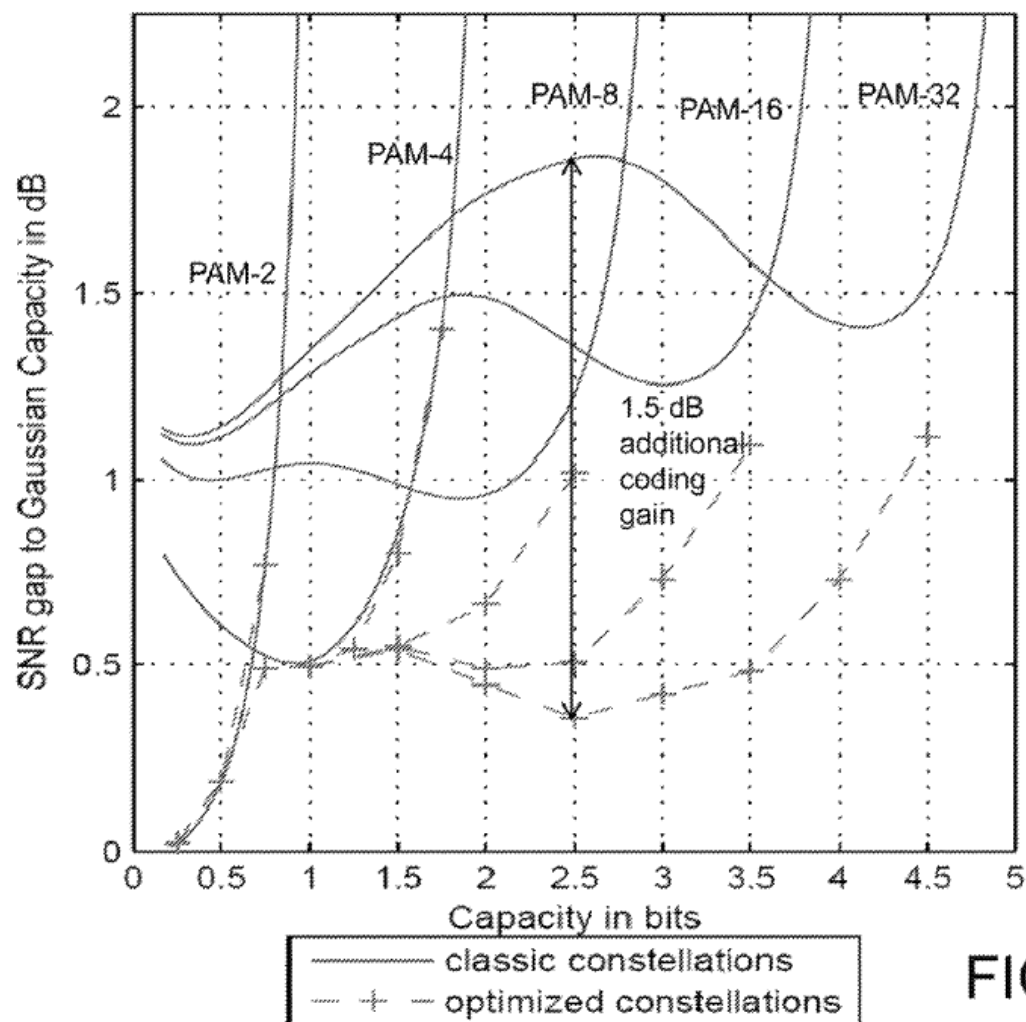


FIG. 8a

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.

B. Level of Ordinary Skill in the Art

[0093] For purposes of this IPR, Petitioner submits that a person of ordinary skill in the art at the time of the alleged invention (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. Superior education could compensate for a deficiency in work experience, and *vice-versa*. *Id.*

XI. APPLICATION OF PRIOR ART TO THE CHALLENGED CLAIMS

A. Ground 1A: ‘777 in view of ATSC322

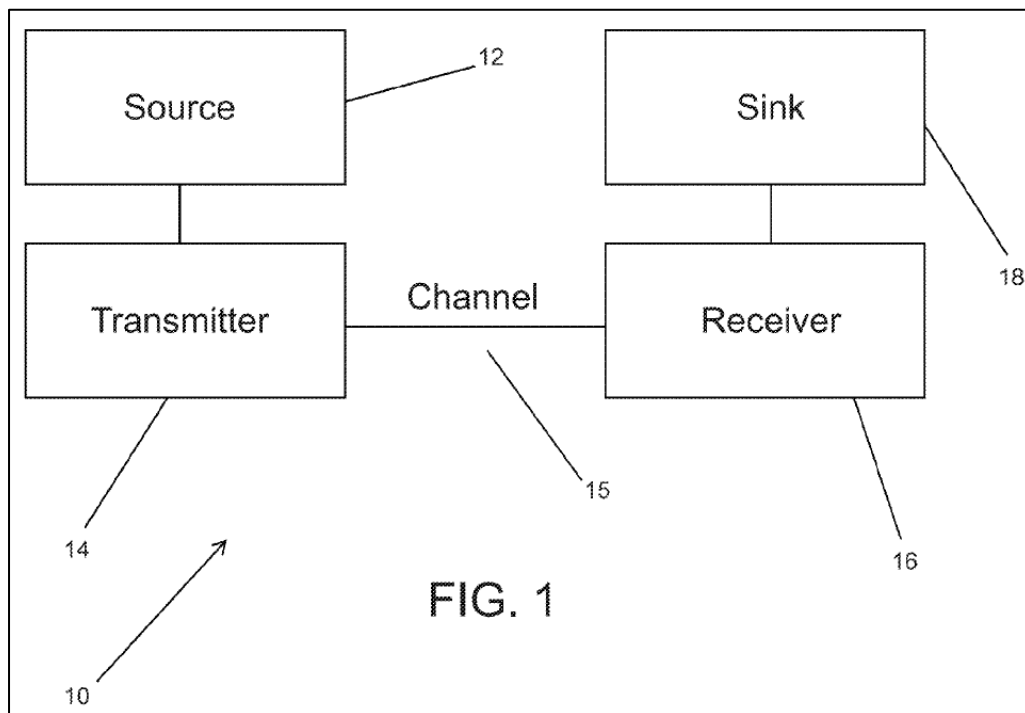
1. Overview of the ‘777 patent³

[0094] The ‘777 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.” LGE1015, 2:7-10. The

³ 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.

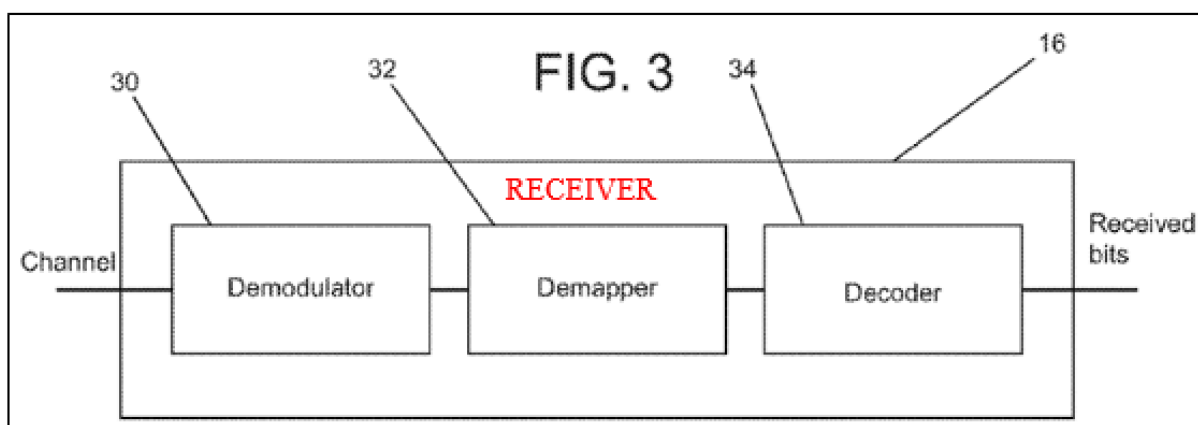
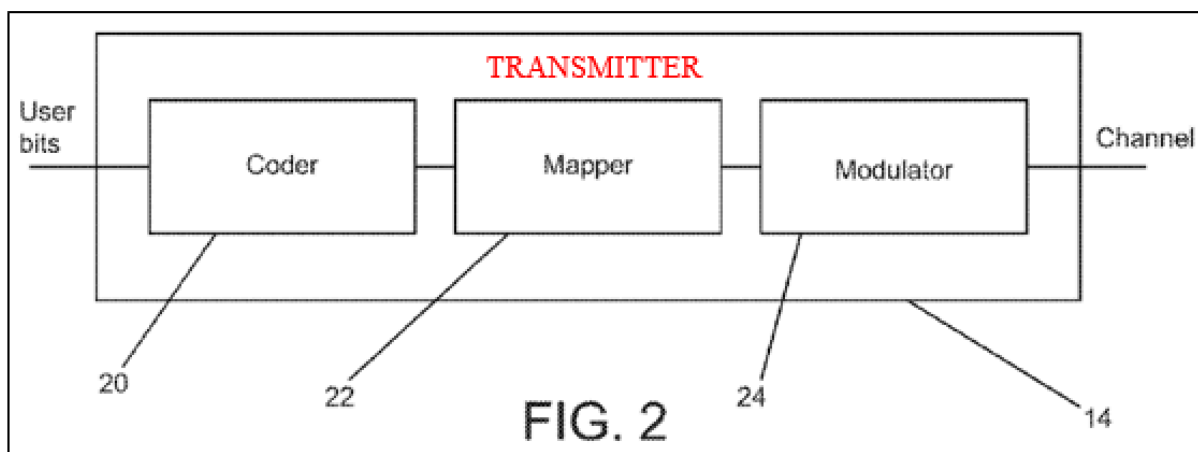
'777 Patent discloses “a method for locating points (in a one or multiple dimensional space) in order to maximize capacity between the input and output of a bit or symbol mapper and demapper respectively.” *Id.*, 2:17-20.

[0095] 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.” LGE1015, 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.



LGE1015, FIG. 1.

[0096] 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. LGE1015, 3:30-31, 5:22-34. FIG. 3 (reproduced below) of the '700 Patent depicts the receiver 16 and its components, which include a demodulator 30, a demapper 32, and a decoder 34. LGE1015, 3:32-33, 5:35-43.



[0097] 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. LGE1015, 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

⁴ Annotations to this and other figures in this petition are indicated by colored text and/or marks.

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

[0098] “Capacity measures that can be used in the selection of the location of constellation points include ... parallel decode (PD) capacity and joint capacity.” LGE1015, 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.

[0099] 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.” LGE1015, 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.

[0100] 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.” LGE1015, 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.

[0101] The '777 Patent explains that PAM constellations can be paired with specific code rates to optimize capacity. LGE1015, 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. LGE1015, 10:47-55.

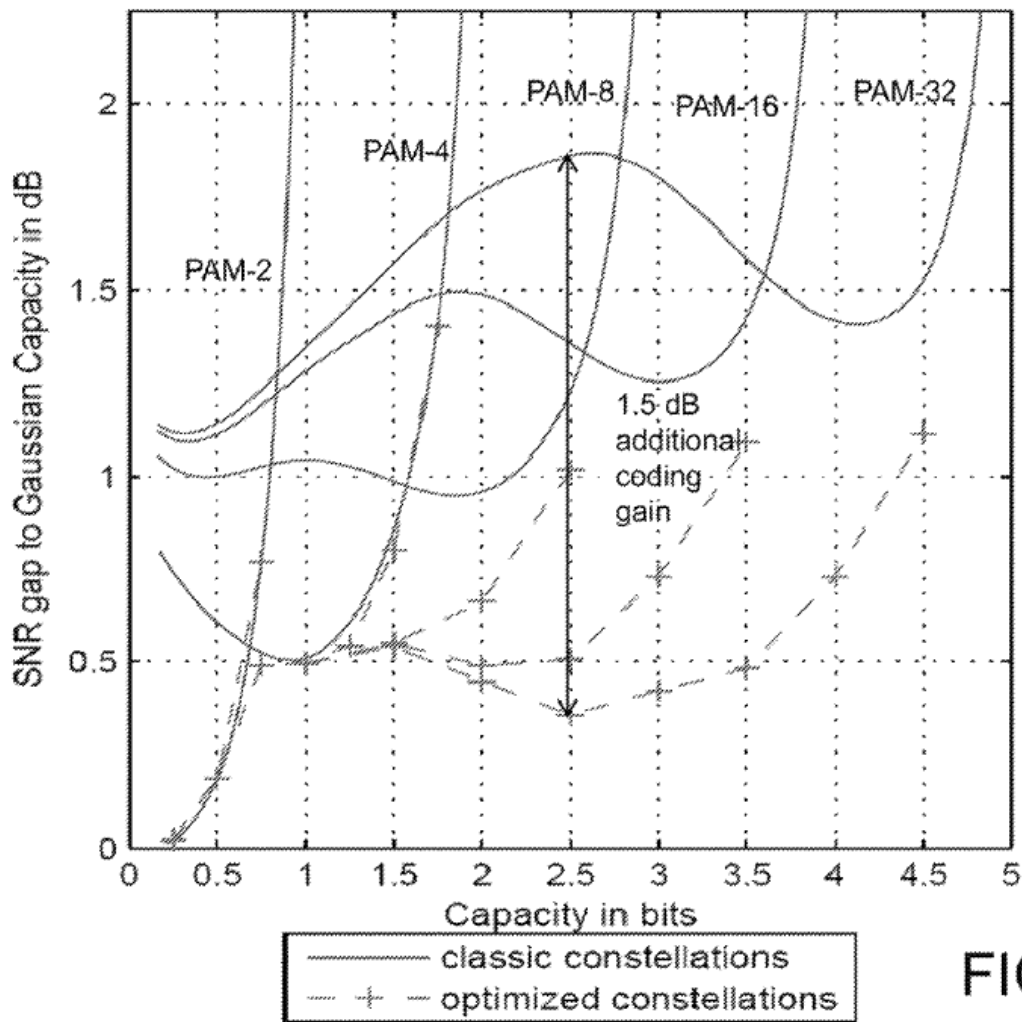


FIG. 8a

LGE1015, 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

LGE1015, 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

LGE1015, FIG. 11b.

2. Overview of the ATSC322

[0102] ATSC322 is a technical standard that “describes RF/Transmission of a physical layer waveform.” LGE1023, 1. “The ATSC physical layer protocol is intended to offer the flexibility to choose among many different operating modes depending on desired robustness/efficiency tradeoffs.” LGE1023, 6. The ATSC 3.0 Standards is “built on the foundation of OFDM modulation with a suite of LDPC FEC codes, of which there are 2 code lengths and 12 code rates defined. *Id.*

[0103] ATSC322 describes “bit interleaved coding and modulation (BICM). LGE1023, 17. BICM is a form of parallel encoding of information for transmission or parallel decoding of encoded information that has been received. A block diagram of a BICM block is reproduced below:

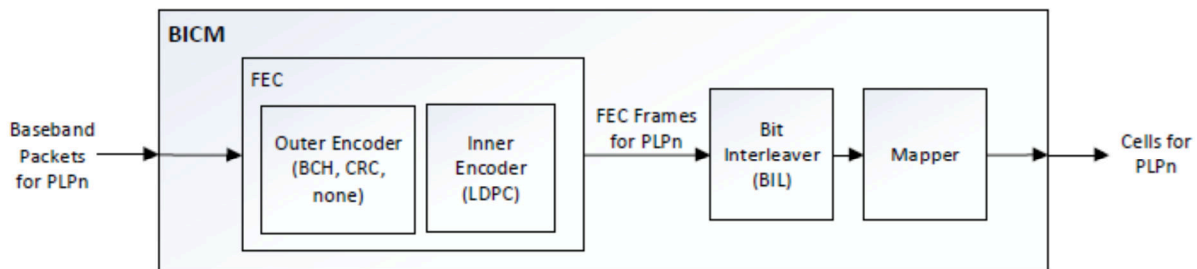


Figure 6.1 Block diagram of BICM.

LGE1023, Figure 6.1

[0104] ATSC322 explains that “[t]he L1-Basic and L1-Detail signaling are protected by a concatenation of BCH Outer Code and LDPC Inner Code.”

LGE1023, 39. “To provide various robustness levels suitable for wide SNR range, the protection level of L1-Detail signaling is categorized into 7 modes based on LDPC codes, modulation order and shortening/puncturing parameter, i.e., a ratio of bits to be punctured to the number of bits to be shortened.” LGE1023, 39.

[0105] ATSC322 further describes design of a mapper that “*map[s] ... FEC encoded and bit interleaved bits to complex valued quadrature amplitude modulation (QAM) constellation points* on the IQ Plane.” LGE1023, 29 (emphasis added). “The input to the constellation mapping block is a stream of bit-interleaved FEC Frames and the output is cells, grouped as a FEC Block when necessary.” *Id.*

[0106] According the design described by ATSC322, “[t]he Mapper consists of a DeMultiplexer block which followed by a bit-to-IQ mapping block.” *Id.* “A block diagram of the Mapper is shown in Figure 6.10,” which is reproduced below:

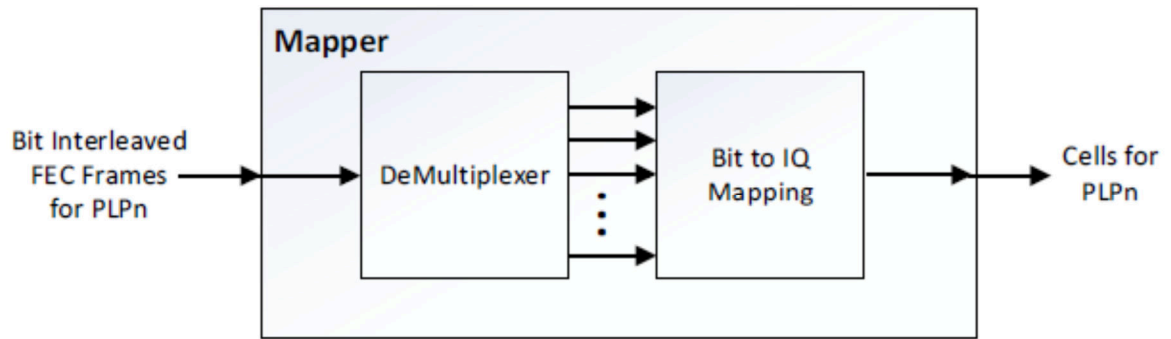


Figure 6.10 Mapper structure.

LGE1023, 30

[0107] LGE1023, 29-30. “The details for each type of modulation are described in Section 6.3.4.1 for QPSK, Section 6.3.4.2 for 16QAM to 256QAM and Section 6.3.4.3 for 1024 and 4096 QAM.” *Id.*

[0108] The design of ATSC322 can transmit “uniform QPSK modulation and *five non-uniform constellations (NUC) sizes; 16QAM, 64QAM, 1024QAM, and 4096QAM respectively.*” *Id.* “The non-uniform constellations 16QAM, 64QAM and 256QAM are 2-dimensional (2D) quadrant-symmetric QAM constellations and are constructed by symmetry from a single quadrant.” *Id.* To reduce the complexity during QAM de-mapping at the receiver, *the 1024QAM and 4096QAM constellations are derived from non-uniform 1-dimensional (1D) PAM (pulse amplitude modulation) constellations* for both in-phase (I) and quadrature (Q) components.” *Id.* (emphasis added).

[0109] ATSC322 specifies a plurality of **QAM** constellation and code rate pairs in Table 6.12 and 6.13 (reproduced below):

Table 6.12 Mandatory Modulation and Coding Combinations $N_{inner} = 64800$ Bits

Code Rate/ Constellation	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 6.13 Mandatory Modulation and Coding Combinations $N_{inner} = 16200$ Bits

Code Rate/ Constellation	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				✓		✓	✓	✓	✓	✓	✓	✓

LGE1023, 31

[0110] ATSC322 provides an example of constructing a NUC position vector for 16QAM constellation, code rate 6/15, and $\mathbf{w} = (0.5115+j1.2092, 1.2092+j0.5115, 0.2663+j0.4530, 0.4530+j0.2663)$. LGE1023, 33. With $j=\sqrt{-1}$ being the imaginary unit and assuming the input data cell word is $(y_0, s, \dots, y_{\eta \text{MOD } -1}, s) = (1100)$, the corresponding QAM constellation point at time index s is $z_s = x_{12} = -w_0 = -0.5115-j1.2092$. *Id.* “The complete constellation for this NUC position vector is shown in Figure 6.12,”

reproduced below:

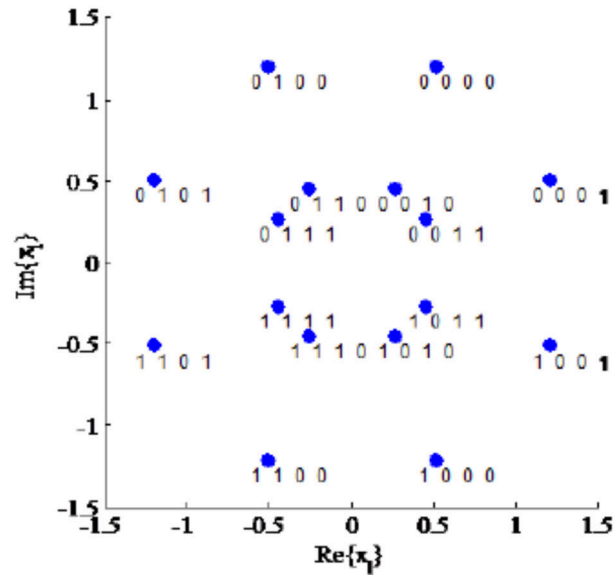


Figure 6.12 Example 16-NUC for code rate 6/15.

LGE1023, 33.

[0111] ATSC322 also provides an example of constructing a NUC position vector for 1024QAM constellation, code rate 6/15, and $\mathbf{u} = (u_0, \dots, u_{15}) = (0.1275, 0.1276, 0.1294, 0.1295, 0.3424, 0.3431, 0.3675, 0.3666, 0.6097, 0.6072, 0.7113, 0.7196, 0.9418, 1.0048, 1.2286, 1.5031)$. LGE1023, 33.

“Assuming the input data cell $(y_{0,s}, \dots, y_{\eta \text{MOD}-1,s}) = (0010011100)$ the corresponding QAM constellation point z_s has $\text{Im}(z_s) = u_3 = 0.1295$ (defined by even index bit labels, i.e., 01010) and $\text{Re}(z_s) = u_{11} = 0.7196$ (defined by odd index bit label, i.e., 00110).” LGE1023, 33-34. “The complete

constellation for this NUC position vector is shown in Figure 6.13,” which is reproduced below:

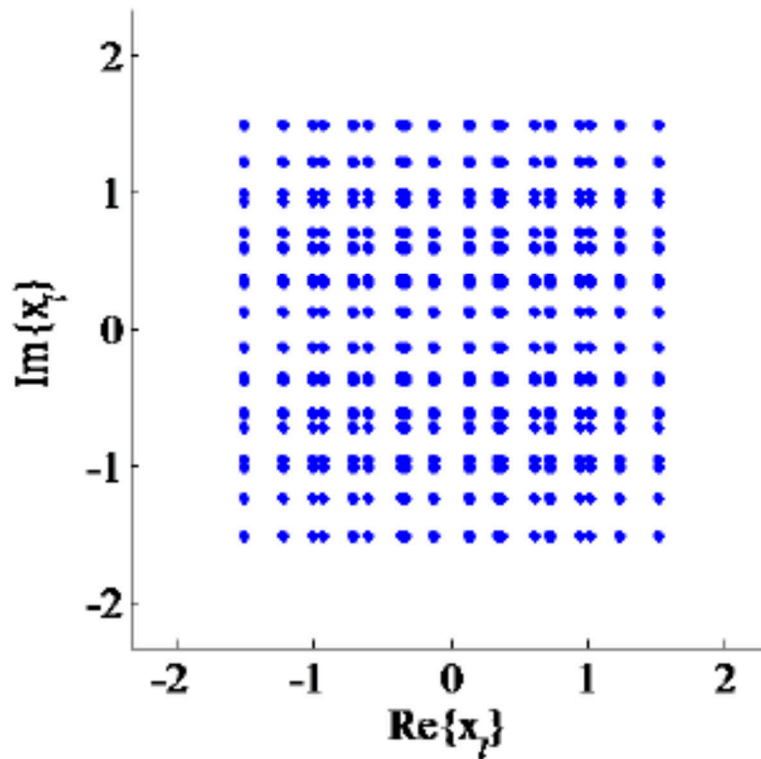


Figure 6.13 Example 1024-NUC for code rate 6/15.

3. The '777-ATSC322 Combination

[0112] The '777-ATSC322 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. LGE1015, 4:60-5:11, 5:35-43, FIG. 3; LGE1023, 29-31.

[0113] 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.” LGE1015, 5:45-49. The mapper of the transmitter encodes bits to symbols in a PAM 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. The ’777 Patent explains that PAM constellations can be paired with specific code rates to optimize capacity. LGE1015, 9:52-10:3. Then, using knowledge of the modulation scheme, the communication system of the ’777 patent uses a receiver 16, decodes the signal, and provides the decoded bits to a sink device 18 connected to the receiver 16. *Id.*, 5:18-21.

[0114] 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.” LGE1015, 5:4-7. In addition, the ’777 patent provides a number of one dimensional constellation design tables. LGE1015, 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. LGE1015, 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. LGE1015, 10:47-55, FIGs. 11a, 11b, 10:58-62, FIGs. 13a, 13b. The '777 Patent also explains to a POSITA that that ***QAM*** constellations can be derived from ***PAM*** constellations. LGE1015, 3:9-19, 12:11-16.

[0115] Also in the combination, the system of the '777 patent is modified with the teachings of ATSC322 to pair multidimensional ***QAM*** constellations with specific code rates. LGE1023, 29-34. In the communication system of the combination, the teachings of the ATSC322 are used to enable the communication system to transmit “uniform QPSK modulation and ***five non-uniform constellations (NUC) sizes; 16QAM, 64QAM, 1024QAM, and 4096QAM respectively.***” *Id.* “The non-uniform constellations 16QAM, 64QAM and 256QAM are 2-dimensional (2D) quadrant-symmetric QAM constellations and are constructed by symmetry from a single quadrant.” *Id.*

To reduce the complexity during QAM de-mapping at the receiver, *the 1024QAM and 4096QAM constellations are derived from non-uniform 1-dimensional (1D) PAM (pulse amplitude modulation) constellations* for both in-phase (I) and quadrature (Q) components.” *Id.* (emphasis added).

[0116] In the combination, the communication system of the '777 patent is configured to optimize multidimensional **QAM** constellations to have a specific code rate, thus creating **QAM** constellation and code rate pair, using the **QAM** constellation and code rate pairs in Table 6.12 and 6.13 from ATSC322 (reproduced below):

Table 6.12 Mandatory Modulation and Coding Combinations $N_{inner} = 64800$ Bits

Code Rate/ Constellation	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 6.13 Mandatory Modulation and Coding Combinations $N_{inner} = 16200$ Bits

Code Rate/ Constellation	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				✓		✓	✓	✓	✓	✓	✓	✓

LGE1023, 31

[0117] Though the teachings of ATSC322 are described from the perspective of a transmitting device, the '777-ATSC322 combination is not so limited. To

the contrary, the '777-ATSC combination also includes use of the multidimensional QAM constellations and code rate pairs by a receiving device in the communication system of the combination, as POSITA armed with the teachings of ATSC322 would have found it obvious to implement a receiving device that demaps and decodes data that is encoded and transmitted by the transmitter of the ATSC322. LGE1008, 198, 255 (“On reception of the signals transmitted from the satellite, the processing steps that were carried out at the encoder have to be reversed”).

4. Reasons to Combine the '777 patent and ATSC322

[0118] It would have been obvious for a persons of ordinary skill in the art (POSITA) to modify the teachings of the '777 patent with the teachings of the ATSC322 Standard for a number of reasons. First, the ATSC322 is a technical standards document that “describes RF/Transmission of a physical layer waveform.” LGE1023, 1. Thus, a POSITA working with a communication system such as the communication system of the '777 patent would have looked to standards documents to identify solutions to problems in the field.

[0119] Second, a POSITA would have looked to the teachings of the ATSC322 standard because the design of the ATSC322 standard “offer the flexibility to choose among many different operating modes depending on desired

robustness/efficiency tradeoffs.” LGE1023, 6. For example, ATSC322 provides a finite list of multiple different non-uniform multidimensional QAM constellation-code rate pairs as listed in, for example, Tables 6.12, 6.13. 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. This is especially true since the ATSC322 standard discloses that “[f]or efficiency, new forward error correcting options with the adoption of non-uniform constellations has brought the operation of the BICM closer to the theoretical Shannon Limit; offering over 1dB of gain compared to the use of uniform constellations using the same operating parameters.” LGE1023, 10. Hence, a POSITA would understand that ATSC322 addresses coding and modulation optimizations that are similar to those disclosed in the ‘777 patent.

[0120] Corroborating this is Loghin who states: “When optimizing NUCs of a given constellation size m for a transmission system using a BICM chain, we need to maximize the BICM capacity CB NUCs for ATSC3.0 have been optimized both with respect to performance over flat AWGN channel and over

independent and identically distributed Rayleigh fading with perfect side information at receiver side. To further optimize the combination of coding and modulation, the bit interleaver was carefully optimized as well for each combination of constellation size and code rate.... Since CB depends on the channel transition probabilities $p(rk|sk = xl)$, this optimization has to be performed for each particular channel. In particular, a different optimum NUC may result for an AWGN channel for each SNR value.” LGE1024, 199.

[0121] Third, a POSITA would have been motivated to design a system that uses the particular operating modes of the ATSC322 Standard 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.

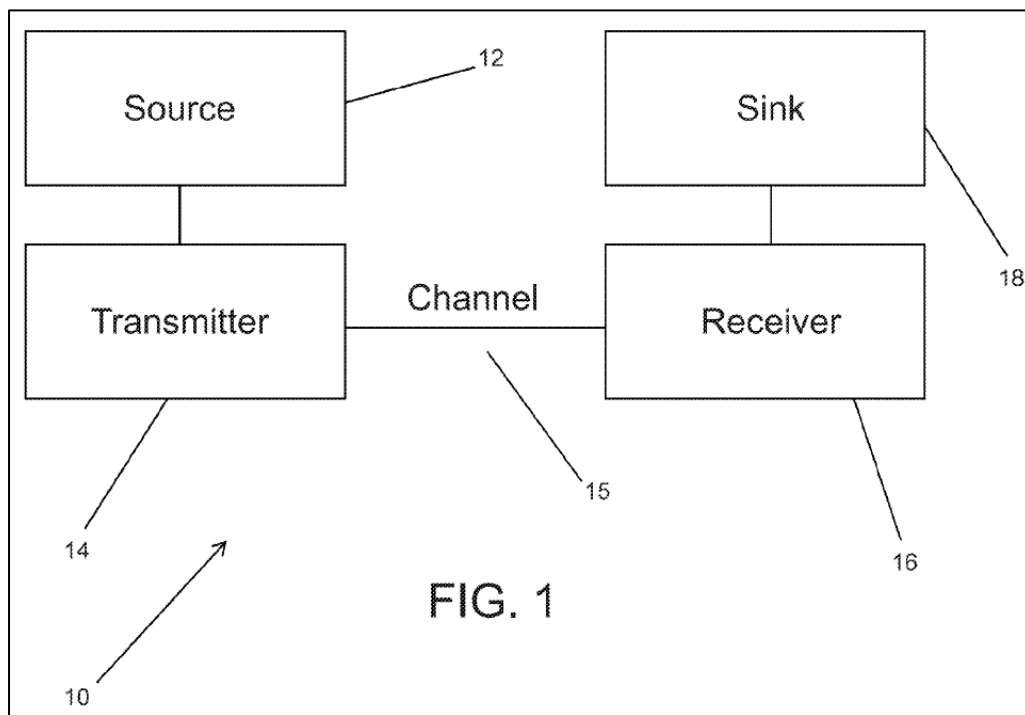
5. Manner in which '777-ATSC322 renders the Challenged Claims obvious

Claim 1⁵

⁵ Because claim 2 depends from claim 1, this Petition also includes a mapping of the prior art references against claim 1 (and similarly other independent claims).

[1pre] A communication system, comprising:

[0122] The '777 patent discloses a communication system. *LGE1015, 5:16-21, abstract, FIGs. 1-3*. For example, the '777 patent discloses “a digital communications system including a transmitter transmitting signal via a communications channel...” LGE1015, abstract. The digital communication system 10 of the '777 patent is depicted by FIG. 1 (reproduced below):

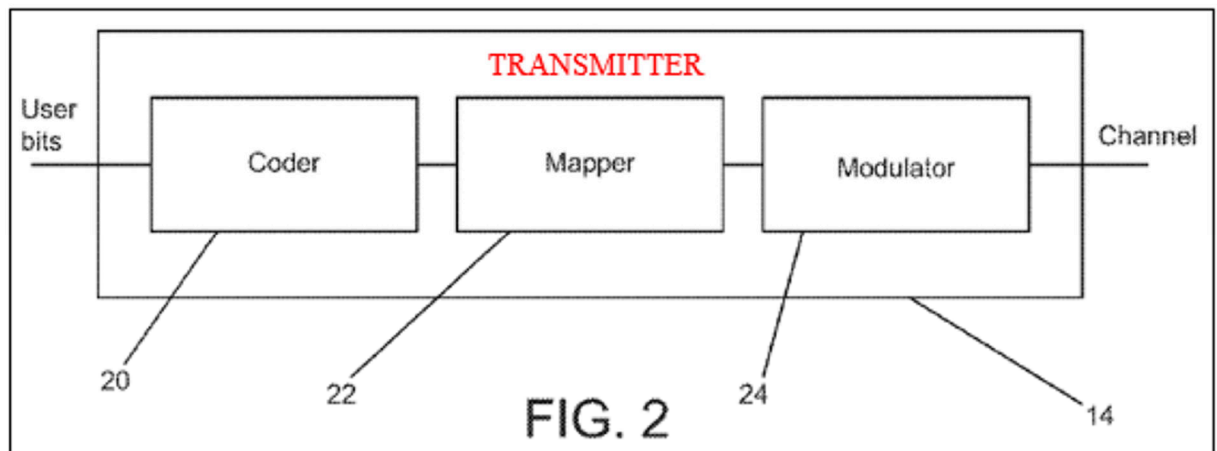


LGE1015, FIG. 1.

In Grounds 1A and 1B, this petition is relying on the '777 patent as disclosing all the features of claim 1.

[0123] 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.” LGE1015, 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.

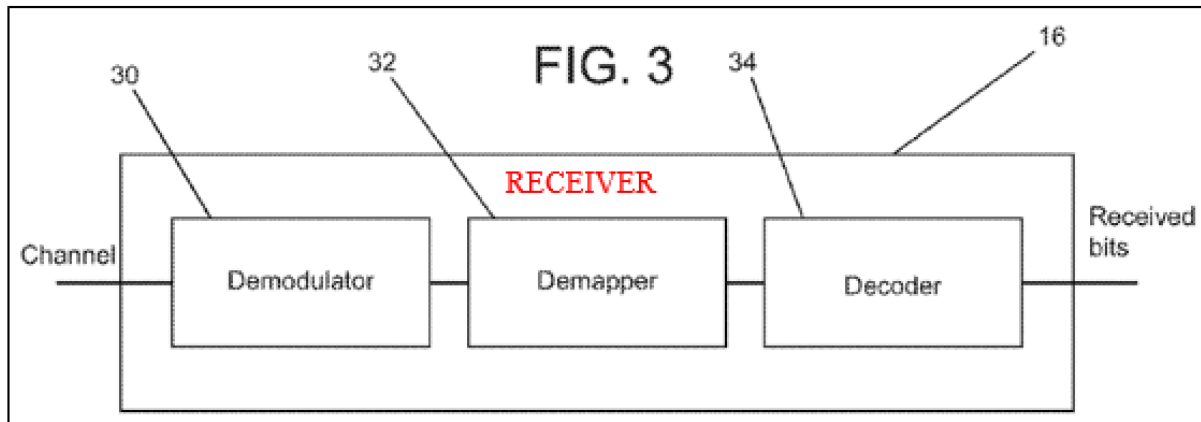
[0124] The transmitter 14 of the communication system 10 includes a coder 20, a mapper 22, and a modulator 24. LGE1015, 3:30-31, 5:22-34. The transmitter 14 is shown in FIG. 2 of the '777 patent (reproduced below):



LGE1015, FIG. 2.

[0125] The receiver 16 of the communication system 10 includes a demodulator 30, a demapper 32, and a decoder 34. LGE1015, 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):



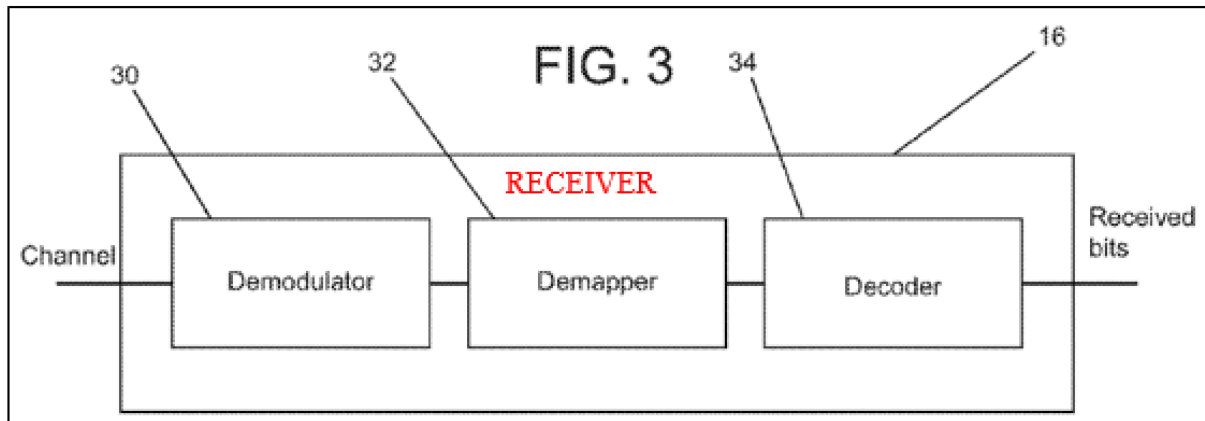
LGE1015, FIG. 3.

[0126] The “receiver 16 includes a demodulator 30 that demodulates a signal received via the channel to obtain symbol or bit likelihoods.” LGE1015, 5:35-43, FIG. 3. The “demapper uses knowledge of the geometrically shaped symbol constellation used by the transmitter to determine these likelihoods.” LGE1015, 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.” LGE1015, 5:41-43.

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

[0127] The '777 patent discloses ***a receiver 16 that is capable of receiving signals via a communication channel.*** LGE1015, 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):



LGE1015, FIGS. 3.

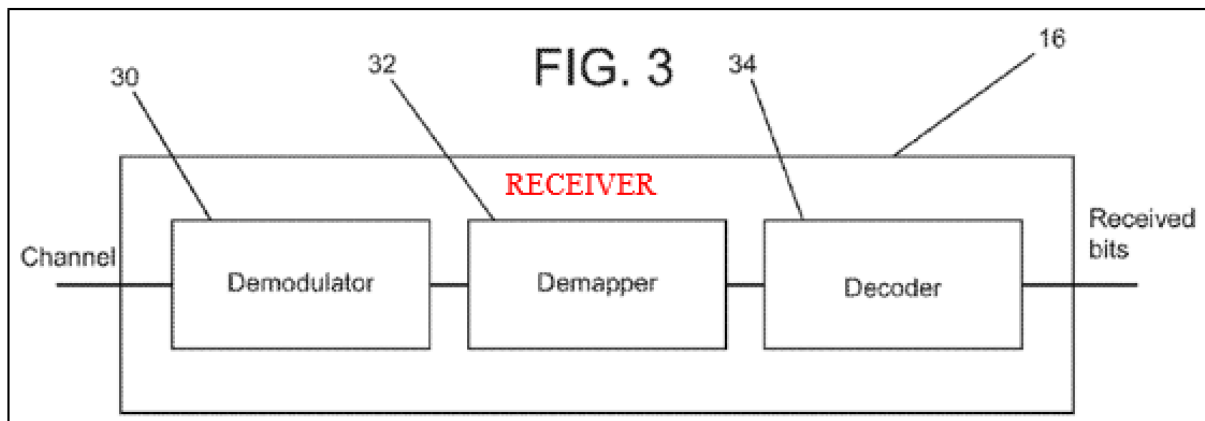
[0128] It is known in the art that a communication channel has a channel signal-to noise ration (SNR). The ’777 patent alludes to this, for example, in explaining that the receiver 16 is configured to select a constellation “to provide increased capacity at a predetermined range of channel signal-to-noise ratios (SNR).” LGE1015:4:54-56; 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.

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

[0129] The ’777 patent discloses ***a demodulator capable of demodulating a***

received signal into a demodulated signal. LGE1015, 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. LGE1015, 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):

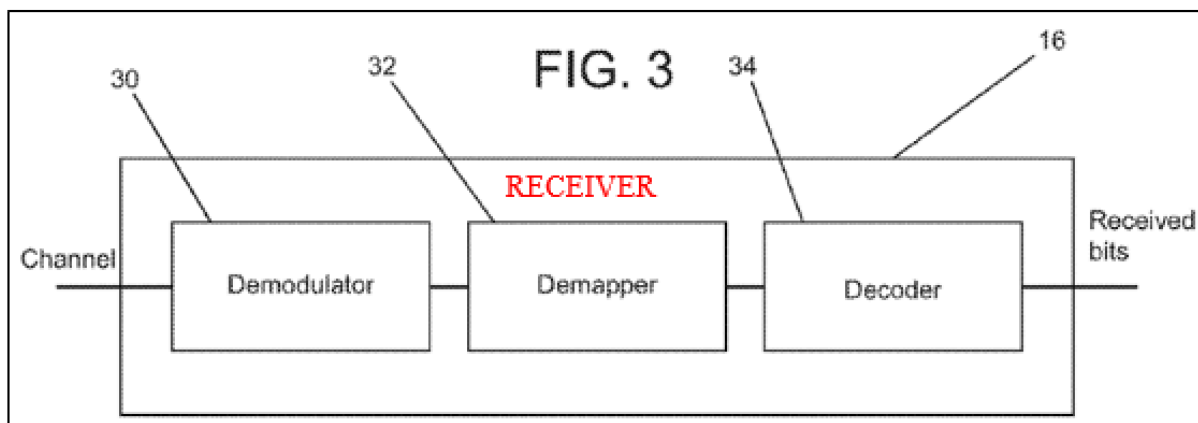


LGE1015, FIG. 3.

[1c] a demapper, coupled to the demodulator, capable of determining likelihoods using the demodulated signal and a multidimensional symbol constellation selected from a plurality of multidimensional symbol constellations; and

[0130] The ’777 patent discloses *a demapper coupled to the demodulator.*

LGE1015, 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):



LGE1015, FIGS. 3.

[0131] The '777 patent discloses *a demapper that is capable of determining likelihoods using the demodulated signal and a multidimensional symbol constellation*. LGE1015, 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.” LGE1015, 5:35-43. The '777 patent discloses that the geometrically shaped symbol constellation can be a “QAM constellation.” LGE1015, 3:11-19; 4:29-31; 12:12-16; FIG. 21. QAM constellations are multidimensional symbol constellations. LGE1015, 12:38-49.

[0132] The '777 patent discloses that *the multidimensional symbol constellation [was] selected from a plurality of multidimensional symbol constellations*. LGE1015, 2:56-58, 5:54-6:4, 7:8-10, 8:7-15, 8:47-54, 12:12-16. For example, the '777 patent discloses that “...a geometrically shaped

constellation is used to replace a conventional constellation...” and that “...a geometrically shaped constellation *is selected* in conjunction with a code rate to meet specific performance requirements...” LGE1015, 5:54-6:4. The ’777 patent also discloses that the selected geometrically shaped (i.e., unequally spaced or non-uniform) constellations may be selected from a plurality of geometric constellations. LGE1015, 2:56-58, 5:54-6:4, 7:8-10, 8:7-15, 8:47-54, 12:12-16; 3:61-64, 4:5-8, 4:12-14, 4:19-21, 9-21, FIGs. 11a, 11b, 13a, 13b, 15a, 15b, 17a, 17b.

[0133] 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

LGE1015, FIG. 11b

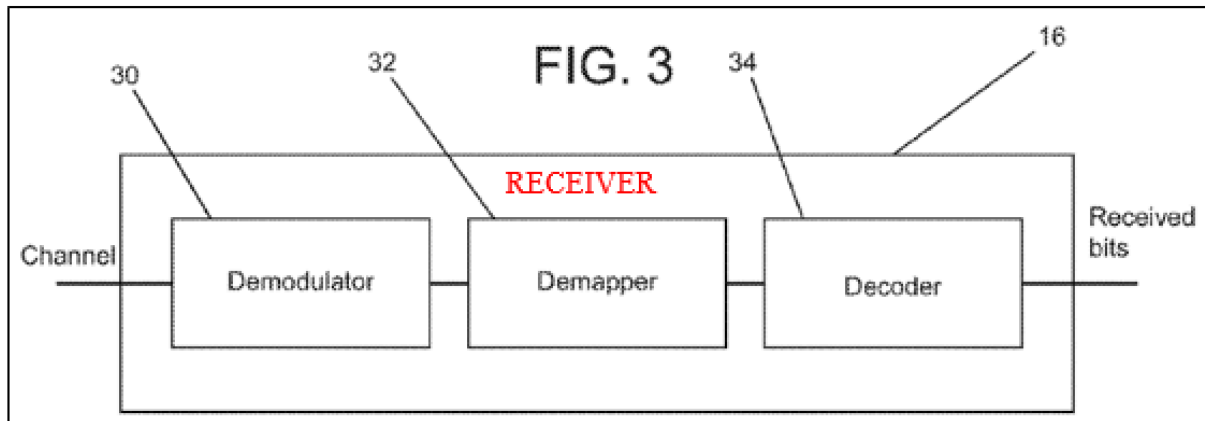
[0134] Each column in the constellation design table of FIG. 11b corresponds to a specific geometric (i.e., unequally spaced or non-uniform) constellation. LGE1015, 10:47-55. A POSITA would understand that one of these geometric (i.e., unequally spaced or non-uniform) constellations would have been selected by the receiver 16 during geometric constellation selection operations described by the '777 patent. LGE1015, 5:56-6:4. Likewise, a POSITA would have understood that a geometric constellation could have also been selected from one of the geometric constellations provided in, for example, FIGs. 13b, 15b, 17b. *Id.*

[0135] Nonetheless, the constellations of FIG. 11b, 13b, 15b, 17b are one dimensional PAM constellations. However, the '777 patent explains that one dimensional geometric PAM constellations can be optimized into multidimensional QAM constellations. LGE1015, 3:11-19; 4:29-31; 12:12-16; 12:38-49. Thus, selecting a multidimensional symbol constellation from a plurality of multidimensional symbol constellations as recited by [1c] would have been obvious to a POSITA.

[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;

[0136] The '777 patent discloses a decoder coupled to the demapper.

LGE1015, 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):



LGE1015, FIG. 3.

[0137] 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. LGE1015, 5:41-43; 13:31-33; 13:50-51. 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.” LGE1015, 5:41-43. The encoded bitstream that the decoder decodes is encoded using an “encoder (such as an LDPC encoder) at the transmitter.” LGE1015, 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.” See also LGE1008, 198, 255 (“On reception of the

signals transmitted from the satellite, the processing steps that were carried out at the encoder have to be reversed”). 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.

[1e] wherein the plurality of multidimensional symbol constellations comprises a plurality of different non-uniform multidimensional symbol constellations having the same number of constellation points, where the constellation points are non-uniformly spaced in each degree of freedom available to the multidimensional symbol constellations;

[0138] The ’777 patent discloses wherein the plurality of multidimensional symbol constellations comprises a plurality of different non-uniform multidimensional symbol constellations having the same number of constellation points for at least the reasons set forth with respect to limitation [1c] above. LGE1015, 2:56-58, 5:54-6:4, 7:8-10, 8:7-15, 8:47-54, 12:12-16; 3:61-64, 4:5-8, 4:12-14, 4:19-21, 9-21, FIGs. 11a, 11b, 13a, 13b, 15a, 15b, 17a, 17b. For example, a POSITA would have understood that the geometric (i.e., non-uniform) one dimensional constellations of FIG. 11b having the same number of constellation points (i.e., 4) would have been capable of being optimized into four respective geometric (i.e., non-uniform) multidimensional constellations and then one selected therefrom for use by the receiver 16. Id..

[0139] The '777 patent discloses where the constellation points are non-uniformly spaced in each degree of freedom available to the multidimensional symbol constellations for at least the reasons set forth with respect to limitation [1c] above. LGE1015, 2:56-58, 5:54-6:4, 7:8-10, 8:7-15, 8:47-54, 12:12-16; 3:61-64, 4:5-8, 4:12-14, 4:19-21, 9-21, FIGs. 11a, 11b, 13a, 13b, 15a, 15b, 17a, 17b. In addition, a POSITA would have understood that when optimizing the geometric (i.e., non-uniform) one dimensional PAM constellation points into geometric (i.e., non-uniform) multidimensional QAM constellation points that the non-uniformity of the resulting constellation points would carry over into each degree of freedom added. LGE1015, 12: 38-44. Therefore, a POSITA would have found the limitations of [1e] obvious in view of the teachings of the '777 patent. Id.

[1f] wherein the receiver is capable of selecting an LDPC code rate and multidimensional symbol constellation pair from a plurality of predetermined LDPC code rate and multidimensional symbol constellation pairs, where each of the plurality of different non-uniform multidimensional symbol constellations is only included in one of the plurality of predetermined LDPC code rate and multidimensional symbol constellation pairs.

[0140] The '777 patent discloses wherein the receiver is capable of selecting an LDPC code rate and multidimensional symbol constellation pair from a plurality of predetermined LDPC code rate and multidimensional symbol

constellation pairs for at least the reasons set forth above with respect to limitation 1[c] above.

[0141] 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

LGE1015, FIG. 11b

[0142] As described in [1c] and [1e] 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 (i.e., non-uniform) multidimensional QAM constellations having the same number of constellation points and non-uniformity in each degree of freedom. *See* [1c]; [1e].

[0143] Also implicit in the constellation design tables such as those in 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 by 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:

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

wherein M is, as best understood by Petitioner, the number of constellation points. LGE1010, 2. Here, η is the capacity in bps provided in FIG. 11b, N_{dim} is the number of dimensions (e.g., 1 for FIG. 11b or 2 for multidimensional QAM constellation), and M is number of points (e.g., 4 for FIG. 11b or 16 for the optimized multidimensional QAM constellation). LGE1015, FIG. 11b; LGE1010, 2. Thus, a POSITA would have understood that each column of FIG. 11b comprises geometric (i.e., non-uniform) one dimensional constellation and LDPC code rate pairs. As explained in [1c] and [1e] above,

a POSITA would have understood that these one dimensional constellation and LDPC code rate pairs would have been capable of being optimized into multidimensional constellation and code rate pairs. Therefore, the bolded features of [1f] above would have been obvious to a POSITA in view of the '777 patent.

[0144] The '777 patent discloses *where each of the plurality of different non-uniform multidimensional symbol constellations is only included in one of the plurality of predetermined LDPC code rate and multidimensional symbol constellation pairs* for at least the reasons set forth above with respect to limitation 1[c] and the analysis of features of [1f] above. As explained above at [1c], [1e], and [1f], each column in an optimized version of FIG. 11b that results from converting the geometric (i.e., non-uniform) one-dimensional PAM constellation-code rate pairs into respective geometric (i.e., non-uniform) multidimensional QAM constellation-code rate pairs is a single geometric (i.e., non-uniform) multidimensional QAM constellation-code rate pair. See [1c], [1e], and [1f]. And, in that plurality of geometric (i.e., non-uniform) multidimensional QAM constellation-code rate pairs, each geometric (i.e., non-uniform) multidimensional QAM constellation-code rate pair occurs only once. LGE1015, FIG. 11b, 13b, 15b, 17b. Therefore, the

bolded features of [1f] above would have been obvious to a POSITA in view of the '777 patent.

Claim 2

[2a] The communication system of claim 1, wherein: the demodulator is capable of using a demodulation scheme that is based on quadrature amplitude modulation (QAM) and the degrees of freedom available to the multidimensional symbol constellations are in phase and quadrature components;

[0145] In the combination, the '777 patent discloses wherein the demodulator is capable of using a demodulation scheme that is based on quadrature amplitude modulation (QAM) and the degrees of freedom available to the multidimensional symbol constellations are in phase and quadrature components for at least the reasons set forth above in [1c], [1e], and [1f]. For example, in view of the teachings of the '777 patent, a POSITA would have understood that the geometric (i.e., non-uniform) one dimensional PAM constellations would have been capable of being optimized into a geometric (i.e., non-uniform) multidimensional quadrature amplitude modulation (QAM) constellation “inphase and quadrature components” and having “degrees of freedom presented by an extra spatial dimension.” LGE1015, 12:12-16, 12:37-44; see also [1c], [1e], and [1f]. Indeed, the '777 patent explains that “it is possible to take direct advantage in the optimization step

of the additional degree of freedom presented by an extra spatial dimension.”

LGE1015, 12:39-42. A POSITA would have understood that the geometric (i.e., non-uniform) one dimensional PAM constellations orthogonalized into QAM constellations, the demodulator of the receiver 16 would be capable of using the optimized geometric (i.e., non-uniform) multidimensional QAM constellations. LGE1015, 12:12-14; 12:39-42. Therefore, the features of [2a] above would have been obvious to a POSITA in view of the ’777 patent-ATSC322 combination.

[2b] each of the plurality of different non-uniform multidimensional symbol constellations is a sixteen point quadrature amplitude modulated (QAM) symbol constellation; and

[0146] In the combination, the ’777 patent discloses each of the plurality of different non-uniform multidimensional symbol constellations is a sixteen point quadrature amplitude modulated (QAM) symbol constellation for at least the reasons set forth above with respect to [1c], [1e], and [1f]. A POSITA would have understood that when the geometric (i.e., non-uniform) one dimensional PAM-4 constellations of FIG. 11b were orthogonalized into a geometric (i.e., non-uniform) multidimensional QAM constellation, the resulting geometric (i.e., non-uniform) multidimensional QAM constellation would be a geometric (i.e., non-uniform) multidimensional 16 point QAM

constellation (i.e., a geometric (i.e., non-uniform) multidimensional QAM-16 constellation). LGE1015 12:26-33. Therefore, the features of [2a] above would have been obvious to a POSITA in view of the '777 patent-ATSC322 combination.

[2c] the LDPC code rate and multidimensional symbol constellation pairs that include one of the plurality of different non-uniform multidimensional symbol constellations have an LDPC code rate that is equal to or greater than 3/8 and less than or equal to 6/8.

[0147] The '777 patent does not disclose that the LDPC code rate and multidimensional symbol constellation pairs that include one of the plurality of different non-uniform multidimensional symbol constellations have an LDPC code rate that is equal to or greater than 3/8 and less than or equal to 6/8. However, in the combination, ATSC322 discloses not only the pairs of constellations and code rates, but that the LDPC code rate and multidimensional symbol constellation pairs that include one of the plurality of different non-uniform multidimensional symbol constellations have an LDPC code rate that is equal to or greater than 3/8 and less than or equal to 6/8. LGE1023, 29-34, Tables 6.12, 6.13; Annex C, 164, 172. For example, ATSC322 discloses in a non-uniform multidimensional QAM – code rate pair combination comprising (i) a non-uniform multidimensional QAM-16

constellation and (ii) an LDPC code rate of 7/15 in Tables 6.12 and 6.13 (annotated and reproduced below):

Table 6.12 Mandatory Modulation and Coding Combinations $N_{inner} = 64800$ Bits

Code Rate/ Constellation	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 6.13 Mandatory Modulation and Coding Combinations $N_{inner} = 16200$ Bits

Code Rate/ Constellation	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				✓		✓	✓	✓	✓	✓	✓	✓

LGE1023, 31.

[0148] The LDPC code rate of 7/15 falls within the claimed range of an ***LDPC code rate that is equal to or greater than 3/8 and less than or equal to 6/8.***

LGE1023 30-31. Therefore, the features of [2c] above would have been obvious to a POSITA in view of the '777 patent-ATSC322 combination.

Claim 3

[3a] The communication system of claim 2, wherein: the plurality of multidimensional symbol constellations further comprises an additional plurality of different non-uniform multidimensional symbol constellations that are quadrature amplitude modulated (QAM) symbol constellations and 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;

[0149] The '777-ATSC322 combination renders obvious all of the limitations of claim 2 above. Also in the combination, the '777 patent discloses *wherein: the plurality of multidimensional symbol constellations further comprises an additional plurality of different non-uniform multidimensional symbol constellations that are quadrature amplitude modulated (QAM) symbol constellations and comprises multiple different sixty-four-point symbol constellations* for at least the reasons set forth in the [1c], [1e], [1f], and [2b]. For example, the '777 patent discloses geometric (i.e., non-uniform) one dimensional PAM-8 constellations of FIG. 13b. LGE1015, 10:56-62, FIG. 13b. However, the '777 patent explains that one dimensional geometric PAM constellations can be orthogonalized into multidimensional QAM constellations. LGE1015, 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). LGE1015 12:26-33, FIG. 21. A 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. LGE1015, 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.

[0150] 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 a QAM-64, to then repeat the process for orthogonalizing a PAM-16 into a QAM-256 and a PAM-32 into a QAM-1024. LGE1015 12:26-33, FIG. 21.

[0151] In the combination, the '777 patent discloses wherein the additional plurality of different non-uniform multidimensional symbol constellations further comprises multiple different two-hundred-fifty-six-point symbol constellations for at least the reasons set forth in the [1c], [1e], [1f], and [2b]. For example, the '777 patent discloses geometric (i.e., non-uniform) one dimensional PAM-16 constellations of FIG. 15b. LGE1015, 11:8-10, FIG. 15b. However, the '777 patent explains that one dimensional geometric PAM constellations can be optimized into multidimensional QAM constellations. LGE1015, 3:11-19; 4:29-31; 12:12-16; 12:38-49. A POSITA would have

understood in view of the teachings of the '777 patent that optimizing the geometric (i.e., non-uniform) one dimensional PAM-16 constellations of FIG. 15b into respective multidimensional QAM constellations would yield multiple different geometric (i.e., non-uniform) multidimensional QAM-256 constellations. A 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-256 constellations. LGE1015, 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.

[0152] In the combination, the '777 patent discloses wherein the additional plurality of different non-uniform multidimensional symbol constellations further comprises multiple different one-thousand-twenty-four-point symbol constellations for at least the reasons set forth in the [1c], [1e], [1f], and [2b]. For example, the '777 patent discloses geometric (i.e., non-uniform) one dimensional PAM-32 constellations of FIG. 17b. LGE1015, 11:11-13, FIG. 17b. However, the '777 patent explains that one dimensional geometric PAM constellations can be optimized into multidimensional QAM constellations. LGE1015, 3:11-19; 4:29-31; 12:12-16; 12:38-49. A POSITA would have understood in view of the teachings of the '777 patent that optimizing the

geometric (i.e., non-uniform) one dimensional PAM-32 constellations of FIG. 17b into respective multidimensional QAM constellations would yield multiple different geometric (i.e., non-uniform) multidimensional QAM-1024 constellations. A 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-1024 constellations. LGE1015, 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.

[3b] the constellation points of the additional plurality of different non-uniform multidimensional symbol constellations are non-uniformly spaced in each degree of freedom available to the multidimensional symbol constellation;

[0153] The '777-ATSC combination renders obvious that the constellation points of the additional plurality of different non-uniform multidimensional symbol constellations are non-uniformly spaced in each degree of freedom available to the multidimensional symbol constellation for at least the same reasons set forth in 1[e]. LGE1015, 2:56-58, 5:54-6:4, 7:8-10, 8:7-15, 8:47-54, 12:12-16; 3:61-64, 4:5-8, 4:12-14, 4:19-21, 9-21, FIGs. 11a, 11b, 13a, 13b, 15a, 15b, 17a, 17b. For example, a POSITA would have understood in view of the teachings of the '777 patent that when orthogonalizing the geometric (i.e., non-uniform) one dimensional PAM constellation points into

geometric (i.e., non-uniform) multidimensional QAM constellation points as described in limitation [3a] that the non-uniformity of the resulting constellation points would “replicate a complete set of PAM-8 points in the in-phase dimension.” LGE1015, 12: 38-44. Thus the orthogonalization gives the resulting constellation “in-phase and quadrature components,” or degrees of freedom. LGE1015 12:33-34. The ‘777 patent states that when “designing constellations in 1-D (PAM for instance) and then extending to 2-D (QAM), it is possible to take direct advantage in the optimization step of the additional degree of freedom presented by an extra spatial dimension.” LGE1015 12: 39-43. Therefore, a POSITA would have found the limitations of [1e] obvious in view of the teachings of the ’777-ATSC322 combination. Id.

[3c] each of the additional plurality of different non-uniform multidimensional symbol constellations is only included in one of the plurality of predetermined LDPC code rate and multidimensional symbol constellation pairs;

[0154] The ’777-ATSC combination discloses that each of the additional plurality of different non-uniform multidimensional symbol constellations is only included in one of the plurality of predetermined LDPC code rate and multidimensional symbol constellation pairs for at least the reasons set forth in the [1c], [1e], [1f], [2b], and [3a]. For example, each constellation design table shown in FIGs. 11b, 13b, 15b, and 17b, respectively, have a plurality of

columns with each respective column corresponding to a geometric (i.e., non-uniform) one dimensional PAM constellation and code rate pair for at least the reasons set forth in [1f]. A POSITA would have understood that once the respective geometric (i.e., non-uniform) one dimensional PAM constellations of FIGs. 11b, 13b, 15b, and 17b were orthogonalized into their respective geometric (i.e., non-uniform) multidimensional QAM form as set forth above in [3a], each of the non-uniform QAM constellations would still correspond to a single LDPC code rate and multidimensional symbol constellation pair. Therefore, a POSITA would have found the limitations of [3c] obvious in view of the '777-ATSC322 combination.

[3d] the LDPC code rate and multidimensional symbol constellation pairs that include one of the multiple different sixty-four-point symbol constellations have an LDPC code rate that is equal to or greater than $2/6$ and less than or equal to $5/6$;

[0155] The '777 patent does not disclose that the LDPC code rate and multidimensional symbol constellation pairs that include one of the multiple different sixty-four-point symbol constellations have an LDPC code rate that is equal to or greater than $2/6$ and less than or equal to $5/6$.

[0156] However, in the combination, ATSC322 discloses an LDPC code rate and multidimensional symbol constellation pairs that include one of the

multiple different sixty-four-point symbol constellations have an LDPC code rate that is equal to or greater than $2/6$ and less than or equal to $5/6$. LGE1023, 29-34, Tables 6.12, 6.13; Annex C, 165, 173. For example, ATSC322 discloses in a non-uniform multidimensional QAM – code rate pair combination comprising (i) a non-uniform multidimensional QAM-64 constellation and (ii) an LDPC code rate of $7/15$ in Tables 6.12 and 6.13 (annotated and reproduced below):

Table 6.12 Mandatory Modulation and Coding Combinations $N_{inner} = 64800$ Bits

Code Rate/ Constellation	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 6.13 Mandatory Modulation and Coding Combinations $N_{inner} = 16200$ Bits

Code Rate/ Constellation	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				✓		✓	✓	✓	✓	✓	✓	✓

[0157] The LDPC code rate of $7/15$ falls within the claimed range of an **LDPC code rate that is equal to or greater than $2/6$ and less than or equal to $5/6$.**

Therefore, the features of [3d] above would have been obvious to a POSITA in view of the '777 patent-ATSC322 combination.

[3e] the LDPC code rate and multidimensional symbol constellation pairs that

include one of the multiple different two-hundred-fifty-six-point symbol constellations have an LDPC code rate that is equal to or greater than 3/8 and less than or equal to 7/8;

[0158] The '777 patent does not disclose that the LDPC code rate and multidimensional symbol constellation pairs that include one of the multiple different two-hundred-fifty-six-point symbol constellations have an LDPC code rate that is equal to or greater than 3/8 and less than or equal to 7/8.

[0159] However, in the combination, ATSC322 discloses the LDPC code rate and multidimensional symbol constellation pairs that include one of the multiple different two-hundred-fifty-six-point symbol constellations have an LDPC code rate that is equal to or greater than 3/8 and less than or equal to 7/8 LGE1023, 29-34, Tables 6.12, 6.13, Annex C, 166-168, 173. For example, ASC322 discloses in a non-uniform multidimensional QAM – code rate pair combination comprising (i) a non-uniform multidimensional QAM-256 constellation and (ii) an LDPC code rate of 7/15 in Tables 6.12 and 6.13 (annotated and reproduced below):

Table 6.12 Mandatory Modulation and Coding Combinations $N_{inner} = 64800$ Bits

Code Rate/ Constellation	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 6.13 Mandatory Modulation and Coding Combinations $N_{inner} = 16200$ Bits

Code Rate/ Constellation	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				✓		✓	✓	✓	✓	✓	✓	✓

[0160] The LDPC code rate of 7/15 falls within the claimed range of an ***LDPC code rate that is equal to or greater than 3/8 and less than or equal to 7/8.***

Therefore, the features of [3d] above would have been obvious to a POSITA in view of the '777 patent-ATSC combination.

[3f] the LDPC code rate and multidimensional symbol constellation pairs that include one of the multiple different one-thousand-twenty-four-point symbol constellations have an LDPC code rate that is equal to or greater than 4/10 and less than or equal to 9/10.

[0161] The '777 patent does not disclose that the LDPC code rate and multidimensional symbol constellation pairs that include one of the multiple different one-thousand-twenty-four-point symbol constellations have an LDPC code rate that is equal to or greater than 4/10 and less than or equal to 9/10.

[0162] However, in the combination, ATSC322 discloses that the LDPC code rate and multidimensional symbol constellation pairs that include one of the multiple different one-thousand-twenty-four-point symbol constellations have an LDPC code rate that is equal to or greater than 4/10 and less than or equal to 9/10. LGE1023, 29-34, Tables 6.12, 6.13, Annex C, 169, 174. For example, ATSC Standard 3.0 discloses in a non-uniform multidimensional QAM – code rate pair combination comprising (i) a non-uniform multidimensional QAM-1024 constellation and (ii) an LDPC code rate of 7/15 in Tables 6.12 (annotated and reproduced below):

Table 6.12 Mandatory Modulation and Coding Combinations $N_{inner} = 64800$ Bits

Code Rate/ Constellation	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						✓		✓		✓	✓	✓

[0163] The LDPC code rate of 7/15 falls within the claimed range of an **LDPC code rate that is equal to or greater than 4/10 and less than or equal to 9/10**. Therefore, the features of [3f] above would have been obvious to a POSITA in view of the '777 patent-ATSC322 combination.

Claims 11⁶

[11pre] A communication system, comprising:

[0164] *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:

[0165] *See supra [1a].*

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

[0166] *See supra [1b].*

[11c] a demapper that determines likelihoods using the demodulated signal and a multidimensional symbol constellation selected from a plurality of multidimensional symbol constellations; and

[0167] *See supra [1c].*

[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;

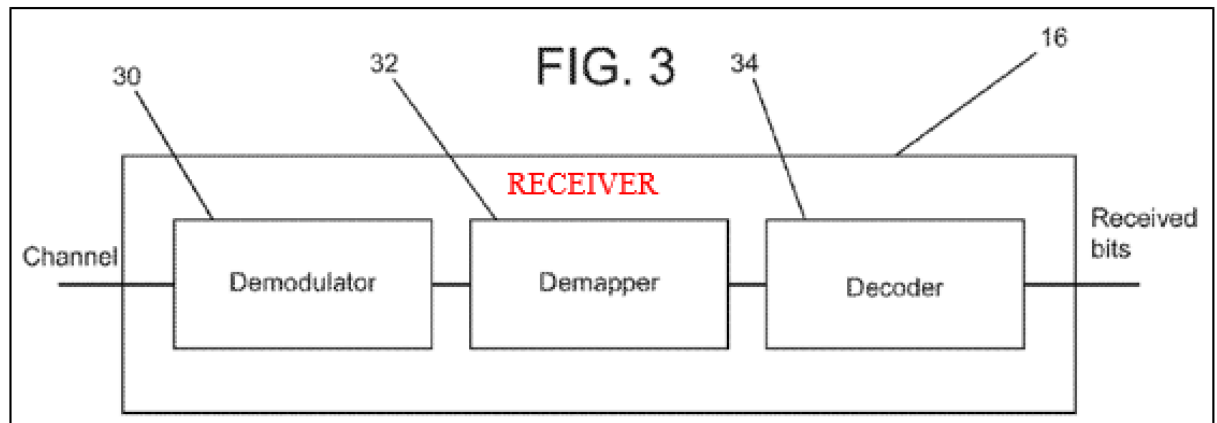
[0168] *See supra [1d].*

[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;

⁶ Because claim 12 depends from claim 11, this Petition also includes a mapping of the prior art references against claim 11 (and similarly other independent claims).

[0169] See supra [1a] to [1d].

[0170] The receiver 16 of the communication system 10 is shown in FIG. 3 of the '777 patent (reproduced below), where *the demapper is interposed between the demodulator and the decoder.*



LGE1015, FIG. 3.

[0171] 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.” LGE1015, 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.

[11f] wherein the plurality of multidimensional symbol constellations comprises a plurality of different non-uniform multidimensional symbol constellations having

the same number of constellation points, where the constellation points are non-uniformly spaced in each degree of freedom available to the multidimensional symbol constellations;

[0172] See supra [1e].

[11g] wherein the receiver selects an LDPC code rate and multidimensional symbol constellation pair from a plurality of predetermined LDPC code rate and multidimensional symbol constellation pairs, where each of the plurality of different non-uniform multidimensional symbol constellations is only included in one of the plurality of predetermined LDPC code rate and multidimensional symbol constellation pairs.

[0173] See supra [1f].

Claim 12

[12a] The communication system of claim 11, wherein: the demodulator uses a demodulation scheme that is based on quadrature amplitude modulation (QAM) and the degrees of freedom available to the multidimensional symbol constellations are in phase and quadrature components;

[0174] See supra [2a].

[12b] each of the plurality of different non-uniform multidimensional symbol constellations is a sixteen point quadrature amplitude modulated (QAM) symbol constellation; and

[0175] See supra [2b].

[12c] the LDPC code rate and multidimensional symbol constellation pairs that include one of the plurality of different non-uniform multidimensional symbol

constellations have an LDPC code rate that is equal to or greater than 3/8 and less than or equal to 6/8.

[0176] See supra [2c].

Claim 13

[13a] The communication system of claim 12, wherein: the plurality of multidimensional symbol constellations further comprises an additional plurality of different non-uniform multidimensional symbol constellations that are quadrature amplitude modulated (QAM) symbol constellations and 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;

[0177] See supra [3a].

[13b] the constellation points of the additional plurality of different non-uniform multidimensional symbol constellations are non-uniformly spaced in each degree of freedom available to the multidimensional symbol constellations;

[0178] See supra [3b].

[13c] each of the additional plurality of different non-uniform multidimensional symbol constellations is only included in one of the plurality of predetermined LDPC code rate and multidimensional symbol constellation pairs;

[0179] See supra [3c].

[13d] the LDPC code rate and multidimensional symbol constellation pairs that include one of the multiple different sixty-four-point symbol constellations have an LDPC code rate that is equal to or greater than 2/6 and less than or equal to 5/6;

[0180] See supra [3d].

[13e] the LDPC code rate and multidimensional symbol constellation pairs that include one of the multiple different two-hundred-fifty-six-point symbol constellations have an LDPC code rate that is equal to or greater than 3/8 and less than or equal to 7/8;

[0181] See supra [3e].

[13f] the LDPC code rate and multidimensional symbol constellation pairs that include one of the multiple different one-thousand-twenty-four-point symbol constellations have an LDPC code rate that is equal to or greater than 4/10 and less than or equal to 9/10.

[0182] See supra [3f].

Claim 21⁷

[21pre] A communication system, comprising:

[0183] See supra [1pre].

[21a] a receiver that receives signals via a communication channel having a channel signal-to-noise ratio (SNR), wherein the receiver uses a multidimensional symbol constellation to transform the received signals into received bits and the multidimensional symbol constellation is selected from a plurality of multidimensional symbol constellations;

[0184] See supra [1a] to [1d].

[0185] For the reasons noted above in [1a] and [1c], '777 patent-ATSC322

⁷ Because claim 22 depends from claim 21, this Petition also includes a mapping of the prior art references against claim 21 (and similarly other independent claims).

combination renders obvious a receiver that receives signals via a communication channel having a channel signal-to-noise ratio (SNR) and the multidimensional symbol constellation is selected from a plurality of multidimensional symbol constellations, respectively, as recited in claim 21. LGE1015, 5:35-43; 13:37-38; 4:54-56; 7:26-33; 7:47-49; 13:34-38;

[0186] It is known in the art that a communication channel has a channel signal-to noise ration (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).*” LGE1015:4:54-56; 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.

[0187] For the reasons noted above in [1c] and[1d], '777 patent-ATSC322 combination renders obvious a receiver uses a multidimensional symbol constellation to transform the received signals into received bits and the multidimensional symbol constellation is selected from a plurality of multidimensional symbol constellations. For example, the '777 patent discloses a “receiver 16 includes a demodulator 30 that demodulates a signal received via the channel to obtain symbol or bit likelihoods.” And that “...a

geometrically shaped constellation is selected in conjunction with a code rate to meet specific performance requirements...” LGE1015, 5:35-43; 13:37-38; 5:54-6:4.

[21b] wherein the plurality of multidimensional symbol constellations comprises a plurality of different non-uniform multidimensional symbol constellations having the same number of constellation points, where the constellation points are non-uniformly spaced in each degree of freedom available to the multidimensional symbol constellations;

[0188] See supra [1e].

[21c] wherein the receiver selects an LDPC code rate and multidimensional symbol constellation pair from a plurality of predetermined LDPC code rate and multidimensional symbol constellation pairs, where each of the plurality of different non-uniform multidimensional symbol constellations is only included in one of the plurality of predetermined LDPC code rate and multidimensional symbol constellation pairs.

[0189] See supra [1f].

Claim 22

[22a] The communication system of claim 21, wherein: the receiver uses a demodulation scheme that is based on quadrature amplitude modulation (QAM) and the degrees of freedom available to the multidimensional symbol constellations are in phase and quadrature components;

[0190] See supra [2a].

[22b] each of the plurality of different non-uniform multidimensional symbol constellations is a sixteen point quadrature amplitude modulated (QAM) symbol constellation; and

[0191] See supra [2b].

[22c] the LDPC code rate and multidimensional symbol constellation pairs that include one of the plurality of different non-uniform multidimensional symbol constellations have an LDPC code rate that is equal to or greater than 3/8 and less than or equal to 6/8.

[0192] See supra [2c].

Claim 23

[23a] The communication system of claim 22, wherein: the plurality of multidimensional symbol constellations further comprises an additional plurality of different non-uniform multidimensional symbol constellations that are quadrature amplitude modulated (QAM) symbol constellations and 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;

[0193] See supra [3a].

[23b] the constellation points of the additional plurality of different non-uniform multidimensional symbol constellations are non-uniformly spaced in each degree of freedom available to the multidimensional symbol constellations;

[0194] See supra [3b].

[23c] each of the additional plurality of different non-uniform multidimensional symbol constellations is only included in one of the plurality of predetermined LDPC code rate and multidimensional symbol constellation pairs;

[0195] See supra [3c].

[23d] the LDPC code rate and multidimensional symbol constellation pairs that include one of the multiple different sixty-four-point symbol constellations have an LDPC code rate that is equal to or greater than $2/6$ and less than or equal to $5/6$;

[0196] See supra [3d].

[23e] the LDPC code rate and multidimensional symbol constellation pairs that include one of the multiple different two-hundred-fifty-six-point symbol constellations have an LDPC code rate that is equal to or greater than $3/8$ and less than or equal to $7/8$;

[0197] See supra [3e].

[23f] the LDPC code rate and multidimensional symbol constellation pairs that include one of the multiple different one-thousand-twenty-four-point symbol constellations have an LDPC code rate that is equal to or greater than $4/10$ and less than or equal to $9/10$.

[0198] See supra [3f].

B. Ground 1B: the ‘777 patent in view of ATSC327

1. Overview of the ATSC327

[0199] ATSC327 is titled *Guidelines for the Physical Layer Protocol* and states that it is a supplement to the ATSC322 reference LGE1023.

[0200] “This document provides recommended practices for the ATSC 3.0 physical layer protocol standards 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." LGE1022, 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." LGE1022, 1. Where ATSC322 "provides distinct features and description of the physical layer technologies," ATSC327 teaches the implementation of those technologies. LGE1022, 6.

[0201] 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." LGE1022, 6.

[0202] ATSC327 uses a fixed number of these channel coding schemes by limiting the modulation and code rate (ModCod) combinations to 120. LGE1022, 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.” LGE1023 42.

[0203] 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. LGE1022, 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				✓		✓	✓	✓	✓	✓	✓	✓

LGE1022, Table 4.7-4.8, 19

[0204] 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.” LGE1022, 18. For example,

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

LGE1022, Table 4.3-4.4, 18

2. The '777-ATSC327 Combination

[0205] 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. LGE1015, 4:60-5:11, 5:35-43, FIG. 3; LGE1022, 18-19; LGE1023 Annex C; LGE1024, 199. Since A327 is a guideline to A322, it can be understood that the constellations are optimized. This is especially

true since the ATSC322 standard discloses that “[f]or efficiency, new forward error correcting options with the adoption of non-uniform constellations has brought the operation of the BICM closer to the theoretical Shannon Limit; offering over 1dB of gain compared to the use of uniform constellations using the same operating parameters.” LGE1023, 10. Hence, the ATSC322 addresses coding and modulation optimizations that are similar to those disclosed in the ‘777 patent.

[0206] 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.” LGE1015, 5:45-49. The ’777 Patent explains that PAM constellations can be paired with specific code rates to optimize capacity. LGE1015, 9:52-10:3.

[0207] 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.” LGE1015, 5:4-7. In addition, the ’777 patent provides a number of one dimensional constellation design tables. LGE1015, 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. LGE1015, 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. LGE1015, 10:47-55, FIGs. 11a, 11b, 10:58-62, FIGs. 13a, 13b. The '777 Patent also explains to a POSITA that that **QAM** constellations can be derived from **PAM** constellations. LGE1015, 3:9-19, 12:11-16.

[0208] Also in the combination, the system of the '777 patent is modified with the teachings of ATSC327 to pair to pair multidimensional **QAM** constellations with specific code rates and compare the SNR. LGE1022, 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.” LGE1022, 32. In this table, “There is one non-uniform constellation (NUC) defined for each ModCod combination.” LGE1022, 32.

[0209] 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

LGE1022, Table 4.3-4.4, 18

[0210] 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. LGE1022, 19.

3. Reasons to Combine the '777 patent with ATSC327

[0211] It would have been obvious for a 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 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.” LGE1022, 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.

[0212] 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.” LGE1022, 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. LGE1022, 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 suits the needs of the system designed by the POSITA.

[0213] 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.

4. Manner in which '777-ATSC327 renders the Claims 5, 15, and 25 obvious

Claim 5

[5] The communication system of claim 1, wherein each of the plurality of different non-uniform multidimensional symbol constellations is capable of providing a greater parallel decoding capacity at a specific SNR than the other symbol constellations in the plurality of multidimensional symbol constellations at the same SNR.

[0214] The '777 patent discloses several features of claim 5 for the reasons set forth above. See [1pre] to [1f]. However, the '777 patent does not disclose *wherein each of the plurality of different non-uniform multidimensional symbol constellations is capable of providing a greater parallel decoding capacity at a specific SNR than the other symbol constellations in the*

plurality of multidimensional symbol constellations at the same SNR.

[0215] In the '777-ATSC327 combination, ATSC327 discloses these limitations of [5]. LGE1022, 18, Table 4.3, 4.4. ATSC327 is used to enable the communication system to have “a look-up table with the defined constellation mapping for each ModCod combination.” LGE1022, 32. In this table (e.g., Tables 4.3), “[t]here is one non-uniform constellation (NUC) defined for each ModCod combination.” LGE1022, 32.

[0216] A POSITA would have understood how to implement Table 4.3 (reproduced below) as a look-up table that includes a ***plurality of different non-uniform multidimensional symbol constellations*** that are optimized for capacity at ***a specific SNR***. LGE1022, 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 their respective optimized 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 the SNR) ***providing a greater capacity than the other symbol constellation***. LGE1022, 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

LGE1022, Table 4.3-4.4, 18

[0217] 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).

[0218] 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). LGE1022, 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						✓		✓		✓	✓	✓

LGE1022, 19

[0219] 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. LGE1022, 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.

[0220] 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. 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.

[0221] 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.

[0222] 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).

[0223] 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..

[0224] Therefore, the limitations of [5] would have been obvious to a POSITA in view of the '777-ATSC327 combination.

Claims 15

[15] The communication system of claim 11, wherein each of the plurality of different non-uniform multidimensional symbol constellations has a greater parallel decoding capacity at a specific SNR than the other symbol constellations in the plurality of multidimensional symbol constellations at the same SNR.

[0225] See supra [5].

Claims 25

[25] The communication system of claim 21, wherein each of the plurality of different non-uniform multidimensional symbol constellations has a greater parallel decoding capacity at a specific SNR than the other symbol constellations in the plurality of multidimensional symbol constellations at the same SNR.

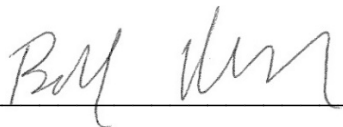
[0226] See supra [5].

XII. CONCLUSION

[0227] All the Challenged Claims are obvious in view of the above-noted grounds and references.

[0228] 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

Bertrand M. Hochwald

Department of Electrical Engineering
University of Notre Dame
275 Fitzpatrick Hall
Notre Dame, IN 46556
voice: 574-631-8875, cell: 574-261-1857
e-mail: bhochwald@nd.edu, bhochwald@gmail.com

home:
1329 E. Jefferson Blvd
South Bend, IN 46617
tel: 574-520-1600

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.
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Bertrand M. Hochwald

Department of Electrical Engineering
University of Notre Dame
275 Fitzpatrick Hall
Notre Dame, IN 46556
voice: 574-631-8875, cell: 574-261-1857
e-mail: bhochwald@nd.edu, hochwald@ieee.org

home:
1329 E. Jefferson Blvd
South Bend, IN 46617
tel: 574-520-1600

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