

UNITED STATES PATENT AND TRADEMARK OFFICE

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BEFORE THE PATENT TRIAL AND APPEAL BOARD

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LG ELECTRONICS, INC.

Petitioner

v.

CONSTELLATION DESIGNS, LLC

Patent Owner

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US Patent No. 10,693,700

Issue Date: June 23, 2020

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

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*Inter Partes* Review No.: IPR2023-00228

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**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 1, 4, 6-11, 14, 16-21, 24, and 26-30 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 Pub. No. 2004/0054960 to Erož et al. (LGE1004 or “Erož”)                                                                                                                                                                                                             |
| ETSI EN 300 744 V1.2.1, Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for digital terrestrial television, 1999-07 (LGE1005 or “DVB-T”)                                                                                                      |
| D. Sommer and G.P. Fettweis, <i>Signal Shaping by Non-Uniform QAM for AWGN Channels and Applications Using Turbo Coding</i> , January 2000 (LGE1006 or “Sommer”)                                                                                                                 |
| Ulrich Reimers et al., <i>DVB The Family of International Standards for Digital Video Broadcasting</i> , Second Edition, 2005 (LGE1008 or “Ulrich”)                                                                                                                              |
| ETSI EN 302 307 V1.1.2, <i>Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications</i> , June, 2006 (LGE1009 or “DVB-S2”) |

|                                                                                                                                                                                                                                         |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| U.S. Provisional application No. 60/933,319 (LGE1010 or “319 Provisional”)                                                                                                                                                              |
| ETSI TS 102 006 V1.2.1, <i>Digital Video Broadcasting (DVB); Specifications for System Software Update in DVB Systems</i> , October 2002 (LGE1013 or “DVB-TS”)                                                                          |
| 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”) |
| Proakis, John G. <i>Digital Communications</i> , Fourth Edition, 2000. (LGE1021 or “Proakis”)                                                                                                                                           |
| G. Robins, <i>Signal constellation design tool: A case study in user interface synthesis</i> , International Conference on Computer Assisted Learning, 1989. First Online: 01 January 2005. (LGE1016 or “Robins”)                       |

**[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 1, 8, 10-11, 18, 20-21, 28, and 30 are obvious over Eroz and DVB-T;
- 1B: Claims 1, 6, 8, 10-11, 16, 18, 20-21, 26, 28, and 30 are obvious over Eroz and DVB-T and DeGaudenzi;
- 2A: Claims 4, 14, and 24 are obvious over Eroz, DVB-T, and Sommer;
- 2B: Claims 4, 14, and 24 are obvious over Eroz, DVB-T, and Sommer and DeGaudenzi;
- 3A: Claims 7, 17, and 27 are obvious over Eroz, DVB-T, and DVB-S2;
- 3B: Claims 7, 17, and 27 are obvious over Eroz, DVB-T, and DVB-S2 and

DeGaudenzi; and

- 4A: Claims 9, 19, and 29 are obvious over Eroz, DVB-T, and DVB-TS; and
- 4B: Claims 9, 19, and 29 are obvious over Eroz, DVB-T, and DVB-TS and DeGaudenzi.

**[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]** I have not offered any opinions in this declaration regarding whether the '700 Patent is entitled to priority to June 5, 2007, but have used this date for my analysis as I noted above.

## **B. Background of the '700 Patent**

[0045] The '700 Patent is directed to communication systems that use “geometrically-shaped constellations” that have a capacity approaching the Shannon limit. LGE1001, 2:21-25, Abstract. In communication systems, the term “constellation” refers to “the possible symbols that can be transmitted by a typical digital communication system.” *Id.*, 1:42-44. When a transmitter transmits data symbols, a “receiver attempts to detect the symbols that were transmitted by mapping a received signal to the constellation.” *Id.*, 1:44-46. The '700 Patent explains that the “minimum distance ( $d_{min}$ ) between constellation points is indicative of the capacity of a constellation at high signal-to-noise ratios (SNRs),” so “constellations used in many communication systems are designed to maximize  $d_{min}$ ” to bring the constellation capacity closer to the Shannon limit. *Id.*, 1:46-50.

[0046] According to the '700 Patent, many communication systems have been designed to increase the capacity of a communication channel, or come near the theoretical capacity known as the Shannon limit. LGE1001, 1:55-60. “The Shannon limit can be thought of as being based upon a theoretical constellation known as a Gaussian distribution [constellation], which is an infinite constellation where symbols at the center of the constellation are transmitted

more frequently than symbols at the edge of the constellation.” *Id.*, 1:62-67.

Known methods to designs systems reaching the Shannon capacity limit include using coding techniques such as turbo codes or LDPC codes. *Id.*, 1:52-61:2:6.

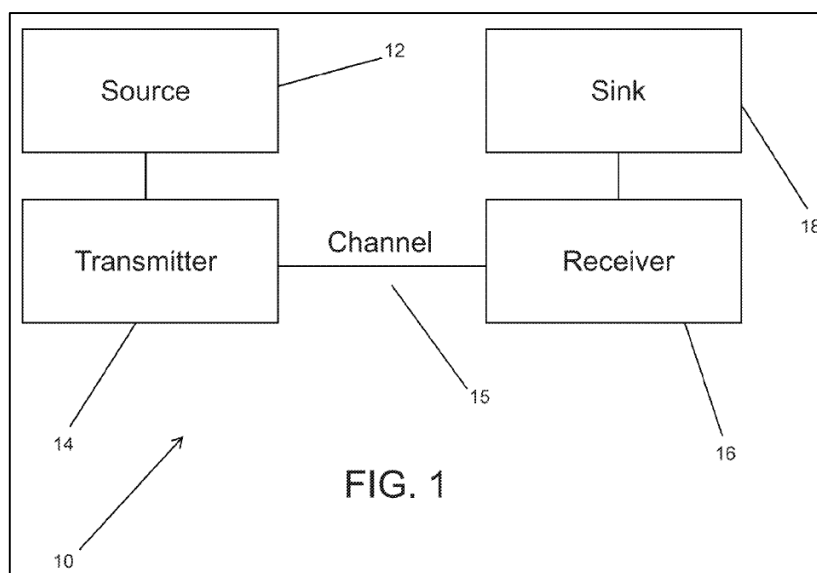
[0047] The ’700 Patent acknowledges that using unequally spaced constellations to design systems approaching the Shannon capacity limit is not new. LGE1001, 1:55-60, 2:6-17. One known system “uses unequally spaced constellations that are optimized to minimize the error rate of an uncoded system.” *Id.*, 2:6-9. “Another proposed system uses a constellation with equiprobable but unequally spaced symbols in an attempts[sic] to mimic a Gaussian distribution.” *Id.*, 2:10-12. Yet another known method “increases the dimensionality of a constellation or select[s] a new symbol to be transmitted taking into consideration previously transmitted symbols.” *Id.*, 2:13-15. Although the ’700 Patent contends that earlier “constellation[s] were still designed based on a minimum distance criteria,” known prior art systems that employed unequally spaced constellations without reliance on a minimum distance criteria also existed. *Id.*, 2:15-17; *see infra* Sections IX-X.

### **C. Brief Description of the ’700 Patent**

[0048] The ’700 Patent discloses “constructing a modulation such that the

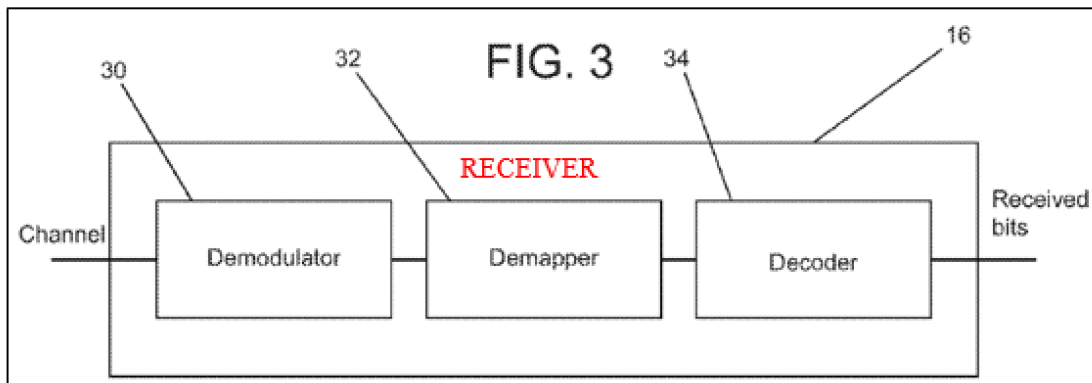
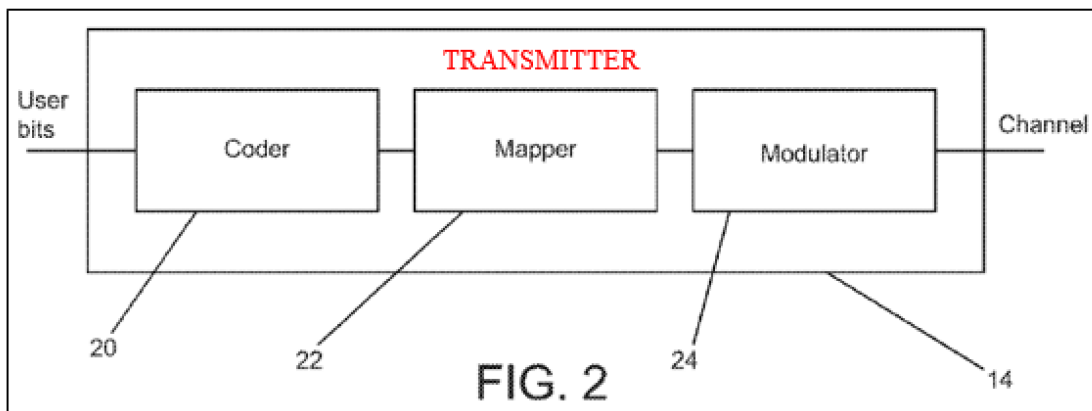
constrained capacity between a transmitter and a receiver approaches the Gaussian channel limit first described by Shannon.” LGE1001, 2:21-25. The ’700 Patent discloses a method for locating points (in a one or multiple dimensional space) in order to maximize capacity between the input and output of a bit or symbol mapper and demapper respectively.” *Id.*, 2:29-34.

[0049] 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.

[0050] 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.<sup>1</sup>

**[0051]** 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

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<sup>1</sup> I have annotated this and other figures in my declaration using colored text and/or marks.

“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.

**[0052]** “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. The PD capacity and Joint capacity can be compared with the Gaussian capacity, as illustrated in FIG. 6a-b of the ‘700 Patent.

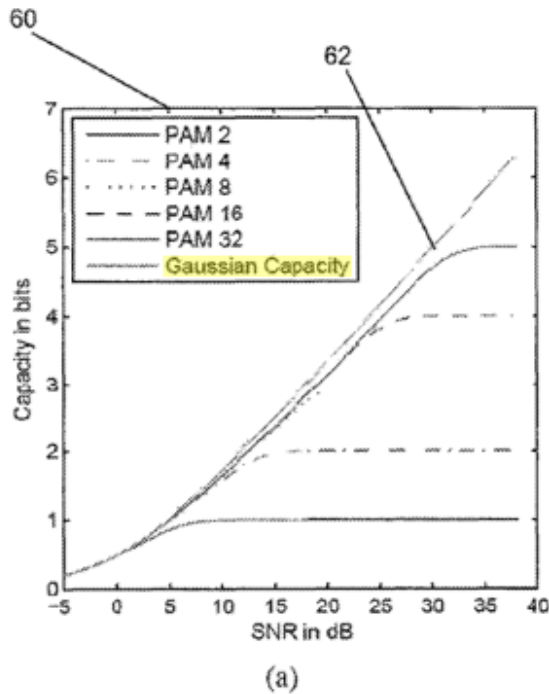


FIG. 6a

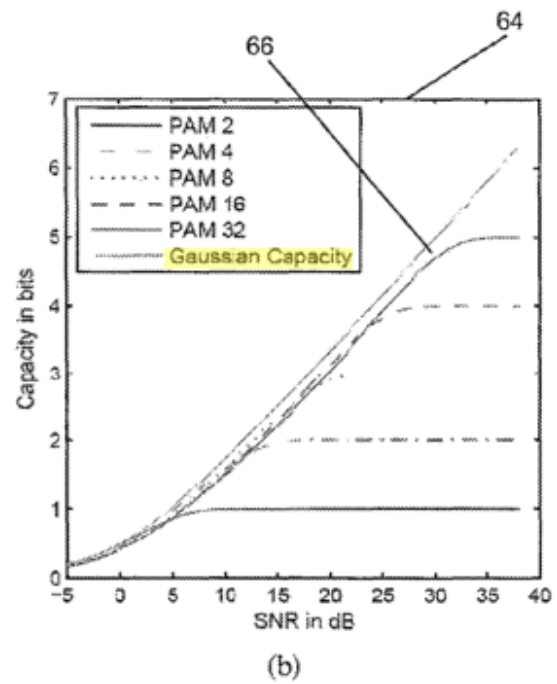


FIG. 6b

LGE1001, FIG. 6a (left), 6b (right).

[0053] 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.

**[0054]** 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.*, 5:66-6:20. 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.

**[0055]** 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 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, 11:8-16.

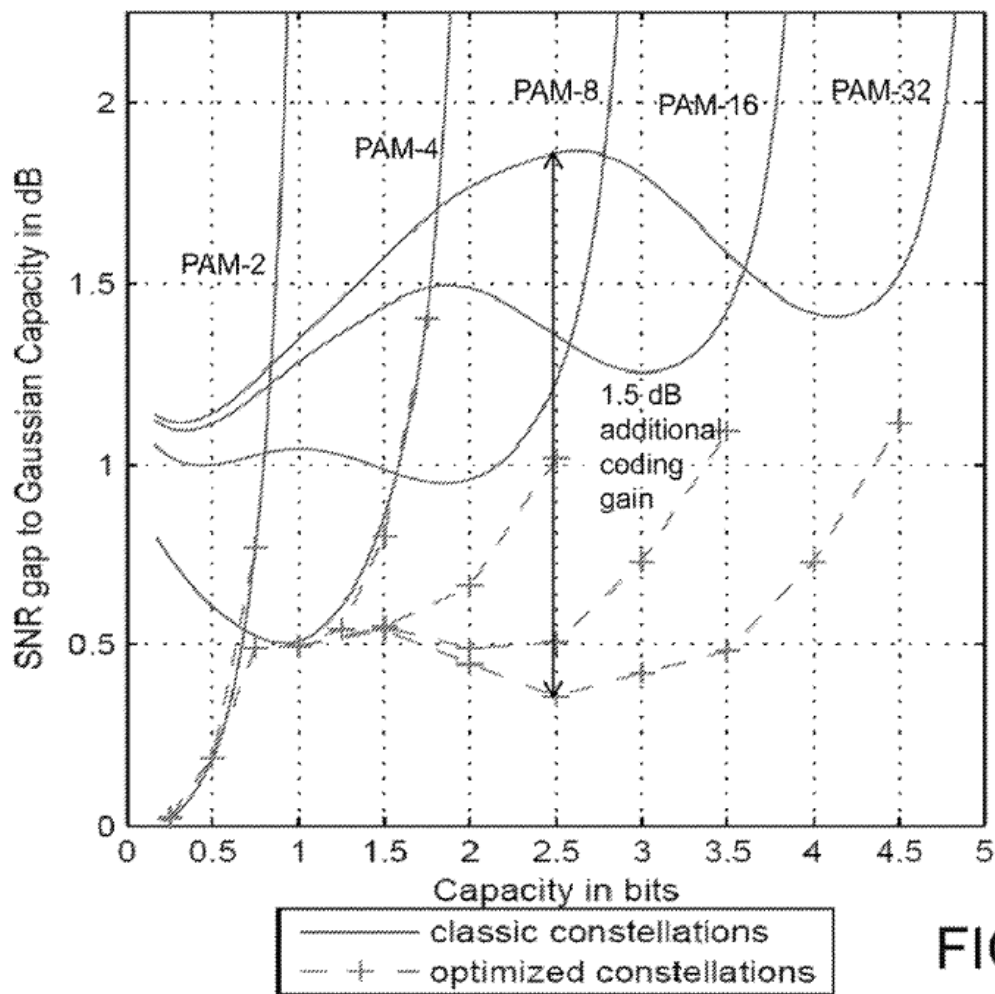


FIG. 8a

LGE1001, FIG. 8a.

#### **D. Summary of the Prosecution History of the '700 Patent**

**[0056]** The '700 Patent issued on June 23, 2020 and was filed as a Track 1 application on December 23, 2019. LGE1001, 1; LGE1002, 1, 1,153. Although several IDSs were submitted during prosecution, the Examiner did not rely on any reference cited in an IDS for rejections and did not issue any Office Action during prosecution. *See generally* LGE1002. The Examiner issued a Notice of Allowance and provided a generic reason for allowing the application, namely that “the arts of record fail to teach *in combinations of the claimed*” entirety of each of the 3 independent claims. LGE1002, 1,048-1,060, 1,118-1,121.

### **IX. OVERVIEW OF PRIOR ART REFERENCES AND COMBINATIONS**

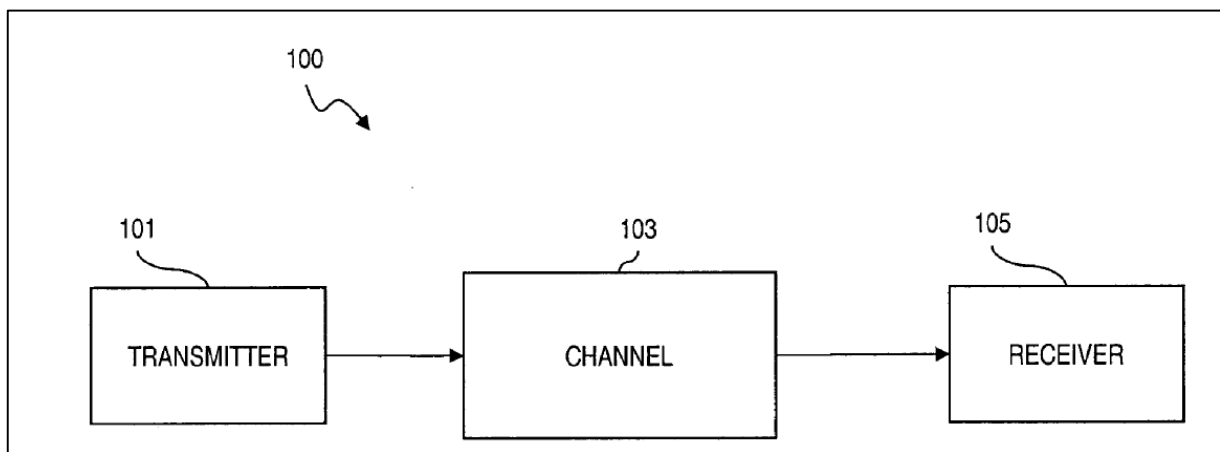
#### **A. Overview of Ero<sup>2</sup>**

**[0057]** Ero is a U.S. Patent Publication entitled “Method and System for providing Low Density Parity Check (LDPC) Encoding.” LGE1004, cover.

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<sup>2</sup> In my declaration, general descriptions I provide for prior art references and combinations thereof are incorporated into each subsection and mapping of the claims that includes citations to these references.

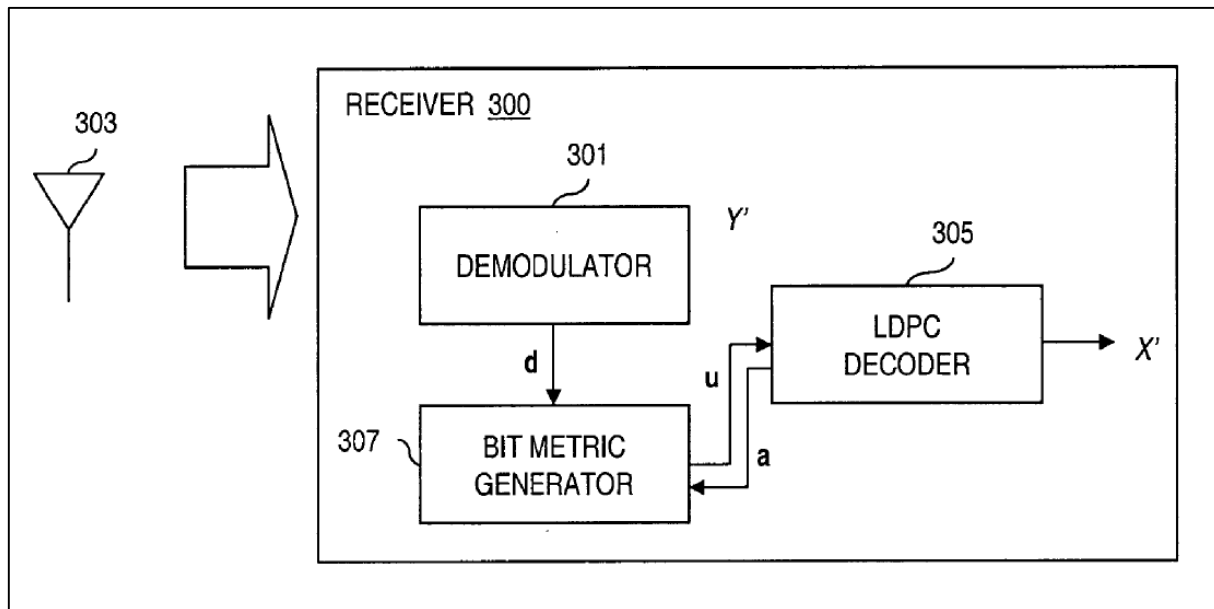
Like the '700 Patent, Eroz discloses that “a communications system configured to utilize Low Density Parity Check (LDPC) codes,” and that “generates signal waveforms across a communication channel to a receiver.” LGE1004, ¶[0030]; LGE1001, 4:62-5:51. Eroz’s FIG. 1 (reproduced below) depicts an example communication system 100 that “includes a transmitter 101 that generates signal waveforms across a communication channel 103 to a receiver 105.” LGE1004, ¶[0030], FIG. 1. The “signal waveforms are attenuated, or otherwise altered, by communications channel 103. *Id.* Transmitter 101 can include an LDPC encoder 203 and modulator 205 to transmit LDPC codes. LGE1004, ¶¶[0030]-[0058], FIGS. 2A, 2B.



LGE1004, FIG. 1.

[0058] Eroz’s FIG. 3 (reproduced below) depicts an example receiver 105/300

receiving signals via antenna 303. LGE1004, FIG. 3. The “receiver 300 includes a demodulator 301 that performs demodulation of received signals from transmitter 200,” “a decoder 305, which attempts to reconstruct the original source messages by generating messages,  $X'$ , in conjunction with a bit metric generator 307” that, in some implementations, is configured to “exchange[ ] probability information with the decoder 305.” LGE1004, ¶[0058].



LGE1004, FIG. 3.

[0059] Erooz discloses that:

At the receiving side, a receiver 300 includes a demodulator 301 that performs demodulation of received signals from transmitter 200. These

signals are received at a receive antenna 303 for demodulation. After demodulation, the received signals are forwarded to a decoder 305, which attempts to reconstruct the original source messages by generating messages, X', in conjunction with a bit metric generator 307. With non-Gray mapping, the bit metric generator 307 exchanges probability information with the decoder 305 back and forth (iteratively) during the decoding process, which is detailed in FIG. 10. Alternatively, if Gray mapping is used (according to one embodiment of the present invention), one pass of the bit metric generator is sufficient, in which further attempts of bit metric generation after each LDPC decoder iteration are likely to yield limited performance improvement. LGE1004, ¶[0058].

**[0060]** Eroz explicitly states that “[t]here is also a need for using LDPC codes efficiently to support high data rates, without introducing greater complexity” and includes claims directed to “modulating the LDPC coded signal according to a signal constellation that includes one of 8-PSK (Phase Shift Keying), 16-QAM (Quadrature Amplitude Modulation).” LGE1004, ¶[0006], claim 7.

## **B. Overview of DVB-T**

**[0061]** DVB-T is a standard document entitled “Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for digital terrestrial television.” LGE1005, 1. DVB-T describes details for inner and outer coding, mapping, constellations (uniform and non-uniform), modes of operation (e.g., 2K or 8K), and code rates in support of DVB communications over a communication network, and, particularly for “the adaptation of the baseband TV signals ... to the terrestrial channel characteristics.” *Id.*, 8-9.

**[0062]** DVB-T describes implementations in which different levels of QAM modulation and different inner code rates can be used to trade bit rate versus ruggedness. LGE1005, 9. In some implementations, DVB-T teaches the use of non-uniform constellations for QAM style modulation. For example, DVB-T discloses that “[a]ll data carriers in one OFDM frame are either QPSK, 16-QAM, 64-QAM, non-uniform-16-QAM or non-uniform-64-QAM using Gray mapping.” *Id.*, 20. Examples of four non-uniform constellations are shown below in Figures 9b and 9c. In particular, Figure 9b illustrates a non-uniform 16-QAM (top) and a non-uniform 64-QAM (bottom) when  $\alpha=2$ . *Id.*, 22. Figure 9C illustrates a non-uniform 16-QAM (top) and a non-uniform 64-QAM (bottom) when  $\alpha=4$ . *Id.*, 23.

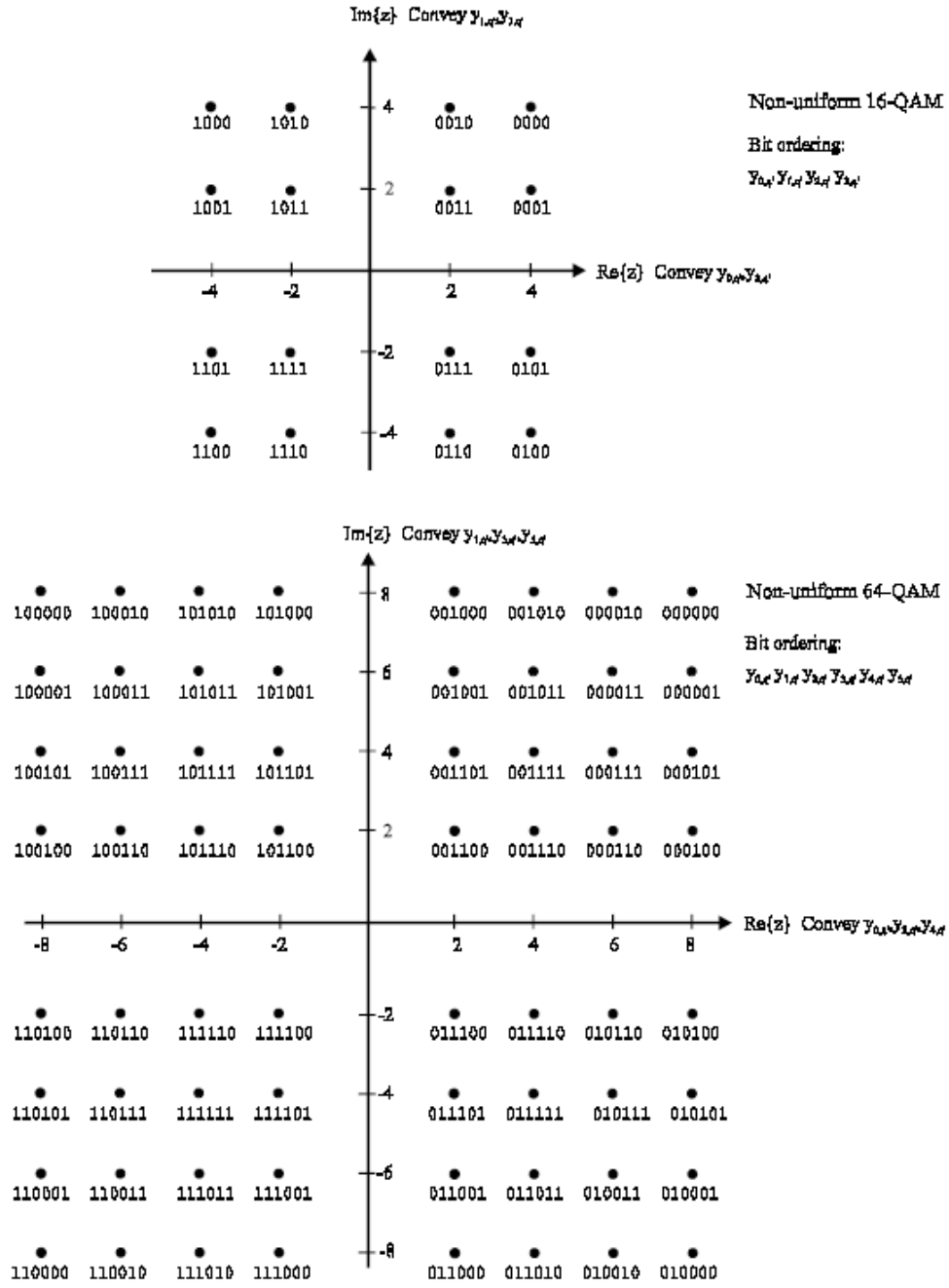


Figure 9b: Non-uniform 16-QAM and 64-QAM mappings with  $\alpha = 2$

LGE1005, FIG. 9b.

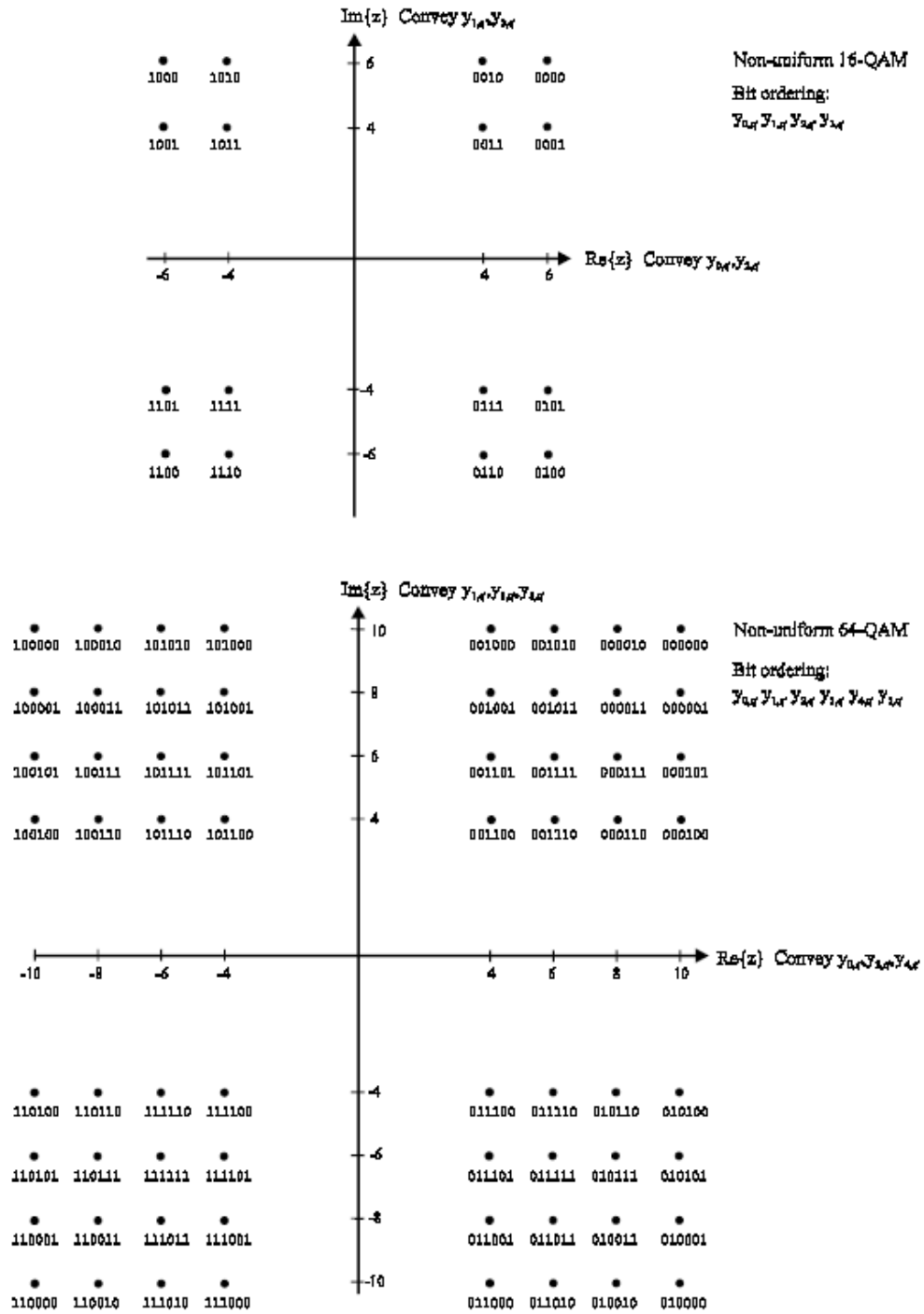


Figure 9c: Non-uniform 16-QAM and 64-QAM mappings with  $\alpha = 4$

LGE1005, FIG. 9c.

[0063] Alpha ( $\alpha$ ) is defined as a “constellation ratio which determines the QAM constellation for the modulation for hierarchical transmission.” *Id.*, 7. The value for  $\alpha$  can be set to configure the shape and uniformity of a constellation. DVB-T teaches that “the  $\alpha$  value defines the modulation based on the cloud spacing of a generalized QAM constellation. It allows specification of uniform and non-uniform modulation schemes covering QPSK, 16-QAM, and 64-QAM.” *Id.*, 29. For example, as shown in DVB-T’s Figure 9a below, when  $\alpha=1$ , a uniform constellation can be implemented. *Id.*, 21. However, the spacing between different points in the constellation (and axes) increases when  $\alpha$  is increased resulting in non-uniformity, as shown above in Figures 9b and 9c. *Id.*, 22-23.

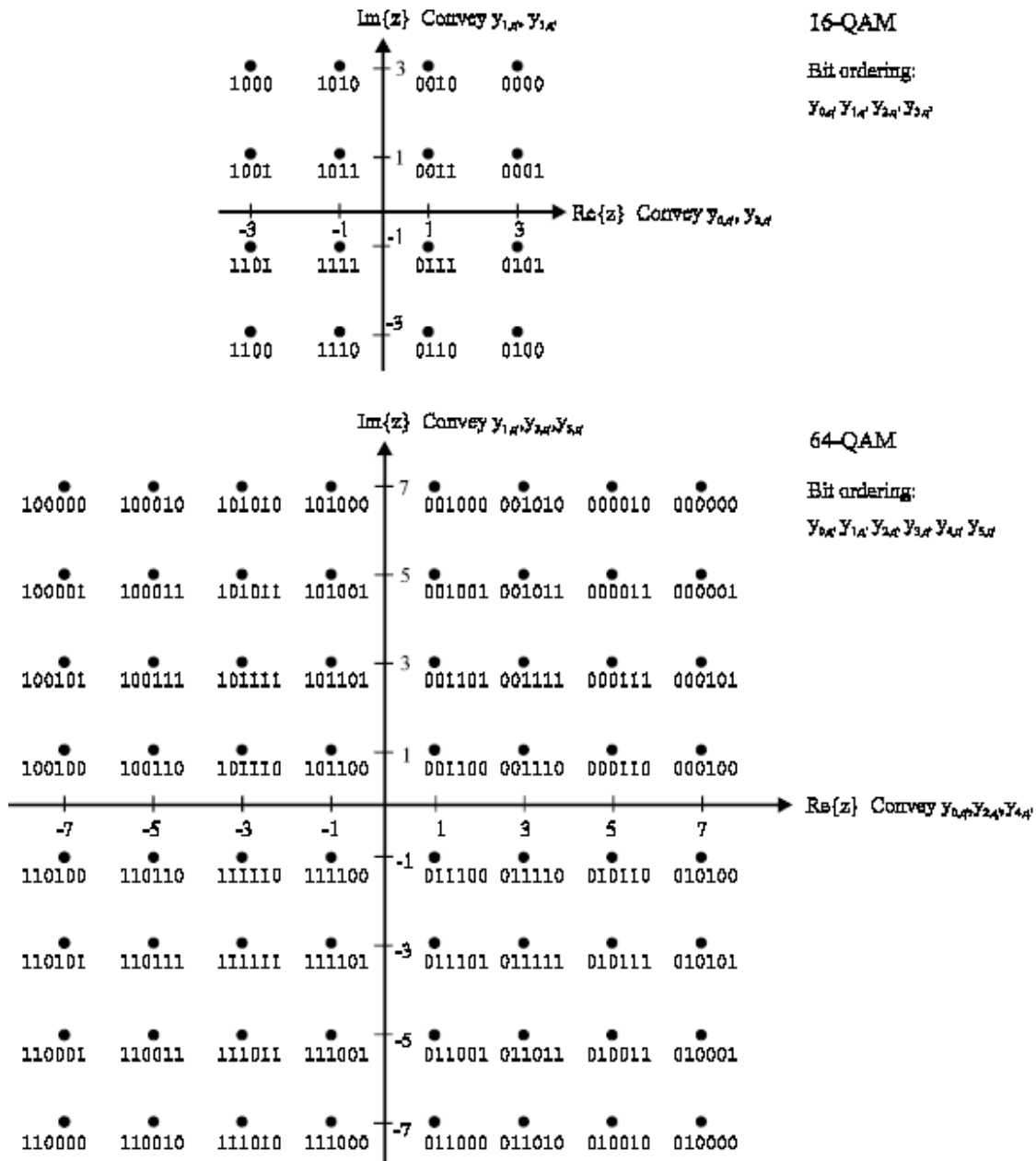


Figure 9a: The QPSK, 16-QAM and 64-QAM mappings and the corresponding bit patterns (non-hierarchical, and hierarchical with  $\alpha = 1$ )

LGE1005, FIG. 9a.

[0064] DVB-T also describes the use of Transmission Parameter Signaling

(TPS) in which “TPS carriers are used for the purpose of signalling parameters related to the transmission scheme, i.e. to channel coding and modulation,” to the receiver. LGE1005, 29. “The TPS carriers convey information on: a) modulation including the a value of the QAM constellation pattern ...; b) hierarchy information; c) guard interval (not for initial acquisition but for supporting initial response of the receiver in case of reconfiguration); d) inner code rates; e) transmission mode (2K or 8K, not for the initial acquisition but for supporting initial response of the receiver in case of reconfiguration); and f) frame number in a super-frame.” *Id.*, 29.

### **C. Combination of Eroz and DVB-T**

[0065] It would have been obvious for a POSITA to combine the teachings of Eroz and DVB-T such that Eroz’s LDPC communication system, including its transmitter and receiver, are modified to implement teachings of the DVB-T standard, such as (1) non-uniform QAM constellations with  $\alpha=2$  or  $\alpha=4$  and different coding rates, as described in more detail in DVB-T and below in Sections X.A.[1e]-[1f]; and (2) DVB-T’s use of signaling information, such as the TPS, to signal to a receiver the modulation, code rate, and constellation ratio being used for signal transmission. Doing so would have predictably resulted

in LDPC-encoded DVB data being communicated from a transmitter to a receiver over a terrestrial digital video broadcasting communication system. EDC would have still used Erož's LDPC coding in a "variety of digital video applications, such as MPEG (Motion Pictures Expert Group)" and DVB-T's "adaptation of the baseband TV signals from the output of the MPEG-2 transport multiplexer." LGE1004, [0057], LGE1005, 8.

**[0066]** In combining the teachings of Erož and DVB-T, it would have been obvious to a POSITA that the EDC system would have used the same or similar code rates, constellation ratios, and constellation types, as disclosed by DVB-T, to obtain the benefits of the DVB-T standard while using LDPC codes. For example, in the EDC system, it would have been obvious to a POSITA that the same or similar code rate range values of  $1/2$ ,  $2/3$ ,  $3/4$ ,  $5/6$ , and  $7/8$  can be used to transmit LDPC codes from Erož's transmitter to receiver. LGE1005, 32. In a related DVB standard that incorporates LDPC codes, a similar but expanded code rate range of  $1/4$  to  $9/10$  is used. LGE1009, 6.

**[0067]** In addition, while Erož discloses the use of standard constellations, such as 8-PSK and QAM, modifying the constellations (e.g., by applying a constellation ratio,  $\alpha$ , as prescribed by DVB-T) would have been obvious and easily implemented by a POSITA. The log-likelihood calculations for decoding

the standard PSK/QAM constellations in Eroz would similarly be modified to perform decoding in the EDC system. It would also have been obvious to a POSITA that the constellation ratio  $\alpha$  impacting the spacing of points in a constellation could also be the same or similar to the constellation ratios disclosed in DVB-T. LGE1005, 31.

**[0068]** A POSITA looking to utilize Eroz's system in a terrestrial digital video broadcasting environment would have looked towards the DVB-T standard and implemented features of the standard. This would have allowed devices in Eroz's system to be more compliant with the requirements of the DVB-T standard. In fact, by using Eroz's LDPC coding with features (e.g., modulation type, code rates, TPS) of the DVB-T standard, the combined system would have yielded an improved performance even relative to other DVB-T systems because LDPC codes have better performance and capacities that enable a system to operate closer to the Shannon limit than convolutional codes generally used in the DVB-T standard. Indeed, a subsequent DVB standard eventually released in 2006 used LDPC codes. LGE1009, 6.

**[0069]** A POSITA would have also incorporated DVB-T's use of signaling information, such as TPS carriers, in Eroz's system to help provide signal transmission information from a transmitter to a receiver in the EDC system.

Doing so would allow Eroz's receiver to obtain information (e.g., modulation type, code rate, hierarchy information, guard interval, transmission mode) about a signal and configure its settings to optimize reception of incoming signals from a transmitter.

**[0070]** As can be appreciated from the foregoing, combining the teachings of Eroz and DVB-T would have simply involved combining prior art elements according to known methods to yield predictable results. A POSITA would have implemented the teachings of DVB-T in Eroz's system without much difficulty and in a predictable manner because making such modifications would have merely involved implementing software code for configuring the desired code rates, modulation and constellation types, which was well-known in the art. Since the essential communication system structure of Eroz, which combines one or more channel codes with a constellation, is the same as is done in the DVB-T standard, the effort and understanding needed to combine these references is no more than the effort to understand either Eroz or DVB-T alone.

**[0071]** Indeed, implementing such software code would have been foreseeable and predictable for a POSITA and well within the capabilities of a POSITA. For example, Ulrich, a book by one of the chairpersons of the DVB standard, explains that manufactures would create devices for multiple applications and

adapt the software. For example, control software could “be adapted, which usually is rather simply done...” LGE1008, 267. Ulrich continues to describe that “[f]or various reasons, manufacturers need to be able to update the receiver’s software, of products which are already on the market.” LGE1008, 299. As can be appreciated from the foregoing, combining the teachings of Eroz and DVB-T would have involved combining prior art elements according to known methods to yield predictable results.

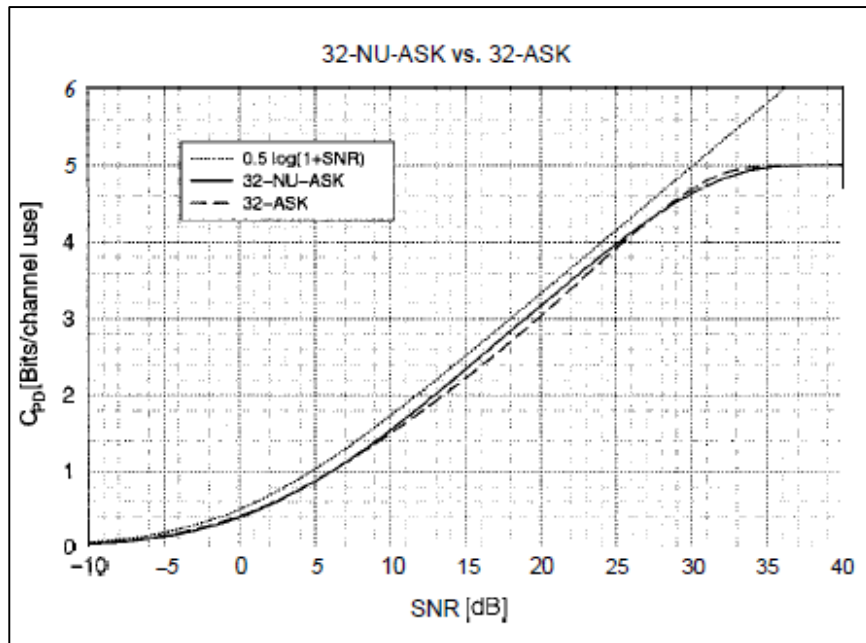
[0072] EDC would also have been predictable because elements of the combined system would have performed similar functions that had been known prior to the combination. For example, Eroz’s communication system (with a transmitter and a receiver) would still perform in the same or similar manner but use the constellation and code rate pairs specified by DVB-T.

#### **D. Overview of Sommer**

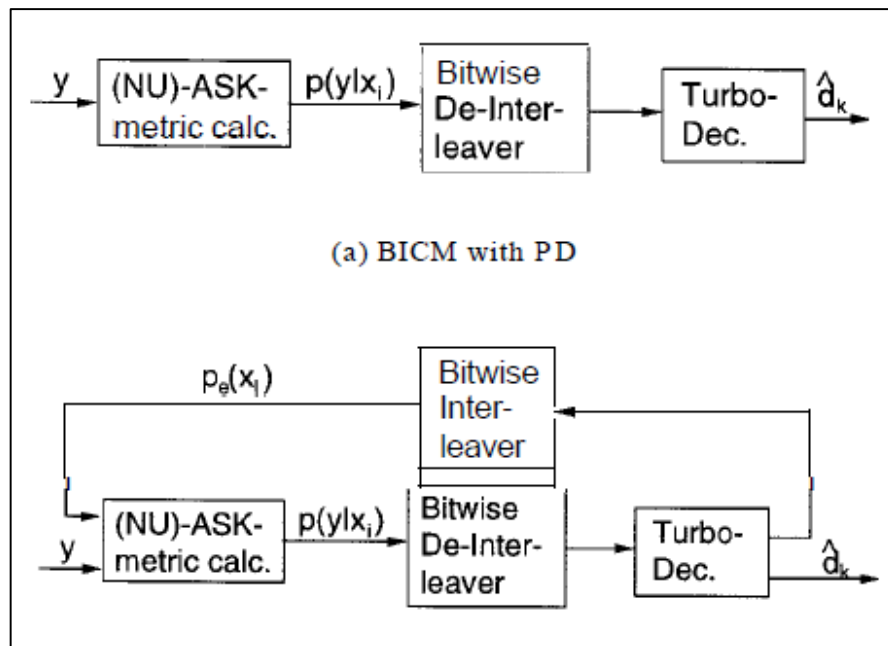
[0073] Sommer, titled *Signal Shaping by Non-Uniform QAM for AWGN Channels and Applications Using Turbo Coding*, is directed to a “non-uniform signal set constellation [] used in order to provide shaping gain,” where shaping gain is understood as “the gain in SNR of a NU-ASK [(non-uniform amplitude shift keying)] compared to a uniform ASK at a certain capacity.” LGE1006, 1,

3. Sommer explains that “[n]on-uniform (NU) signal point constellations have a long tradition, e.g., in order to create a signal set for hierarchical (rate adaptive) transmission.” LGE1006, 1.

**[0074]** Sommer discloses combining “the (NU) signal point constellation” with coding, such as “bit-interleaved coded modulation (BICM) ... in conjunction with Gray labeling,” which “provides similar gain when ... simple parallel decoding of the different bit levels is used.” LGE1006, 1. Sommer also compares the performance of “non-uniform signal set constellation[s]” (e.g., NU-QAM or NU-ASK) over uniform constellations (e.g., classical QAM and ASK), using BICM or parallel decoding (PD) capacity in added white Gaussian noise (AWGN) channels. *Id.*, 1, 3 (“we use the term PD for BICM”). FIG. 3(b) shows the PD capacity for NU-ASK versus ASK constellations. *Id.* FIG.4(a) explicitly shows, for the PD capacity ( $C_{PD}$ ), a “Decoder structure” for “BICM with PD” that has no “AFD, additional feedback decoding,” as opposed to the decoder structure of “BICM with AFD” for signal set capacity ( $C_{PD}$ ) in FIG.4(b). *Id.*, 2-4.



LGE1006, FIG. 3b.



LGE1006, FIG. 4.

### **E. Combination of EDC and Sommer**

**[0075]** It would have been obvious for a POSITA to combine the teachings of EDC with Sommer such that the EDC's plurality of non-uniform multidimensional symbol constellations EDC device would have benefited from 1) using equally likely signal points with unequal spacing in its non-uniform constellations and using more points at the lower power levels and less at higher, and 2) assigning the labeling and spacing of constellation points to achieve a desired shaping gain, as taught by Sommer. LGE1006, 1, 3, 5. The EDC device would have utilized Sommer's teachings by updating the tables of constellation points and code rates and implementing grey labeling (a feature already disclosed in Erož's non-uniform constellations). LGE1004, ¶[0058]. Since the EDC device already utilizes constellation points, channel codes with code rates, and labelling of constellation points, such a combination would have simply involved combining prior art elements according to known methods to yield predictable results, and would have been well within the capabilities of a POSITA who would have been familiar with configuring and/or programming of constellations. For example, a POSITA seeking to improve channel performance, would have implemented the EDC combination and optimized the non-uniform constellations, as taught by Sommer, to improve channel

performance, closer to the Shannon limit.

**[0076]** Moreover, a POSITA would have been able to combine the teachings of EDC and Sommer with a foreseeable chance of success and in a predictable manner. For example, Sommer discloses that shaping gains do “not entail any additional computational effort. Only the lookup tables for single transmission and metric calculation have to be replaced, so signal shaping with gain up to about 1dB has been demonstrated without changing the coder/decoder structure.” LGE1006, 5. A POSITA would understand that the updating of these tables can be accomplished through software updates, which, as noted above, Ulrich reveals “is rather simply done” by manufacturers. LGE1008, 267, 299.

**[0077]** The combination would also have been predictable because elements of the combined system would have performed similar functions that had been known prior to the combination. For example, EDC’s communication system (with a transmitter and a receiver) would still perform in the same or similar manner but using constellations shaped according to Sommer’s method.

**[0078]** In addition to the above, AWGN was commonly used to simulate background noise of a channel under study, in addition to multipath, terrain blocking, interference, ground clutter and self-interference that modern radio

systems encounter in terrestrial operation. Thus, applying Sommer's teachings (related to non-uniform QAMs in AWGN channels) in EDC would have also allowed a system designer to estimate or determine the background channel noise and interferences in terrestrial operations of the EDC system.

[0079] Although Sommer is not specifically focused on LDPC codes, the teachings of Sommer incorporated into EDC would have also been beneficial for the LDPC encoded data in EDC. For instance, a POSITA would have known that the benefits of shaping gains and greater parallel decoding capacity of non-uniform constellations would have also been achieved in EDC's LDPC coded data system by using equally likely signal points with unequal spacing and more points at the lower power levels and less at higher. Further, the EDC combination already utilizes non-uniform or unequally spaced constellations, and thus the incorporation of Sommer's teachings to enhance performance closer to the Shannon limit would have been predictable and obvious to a POSITA.

#### **F. Overview of DeGaudenzi**

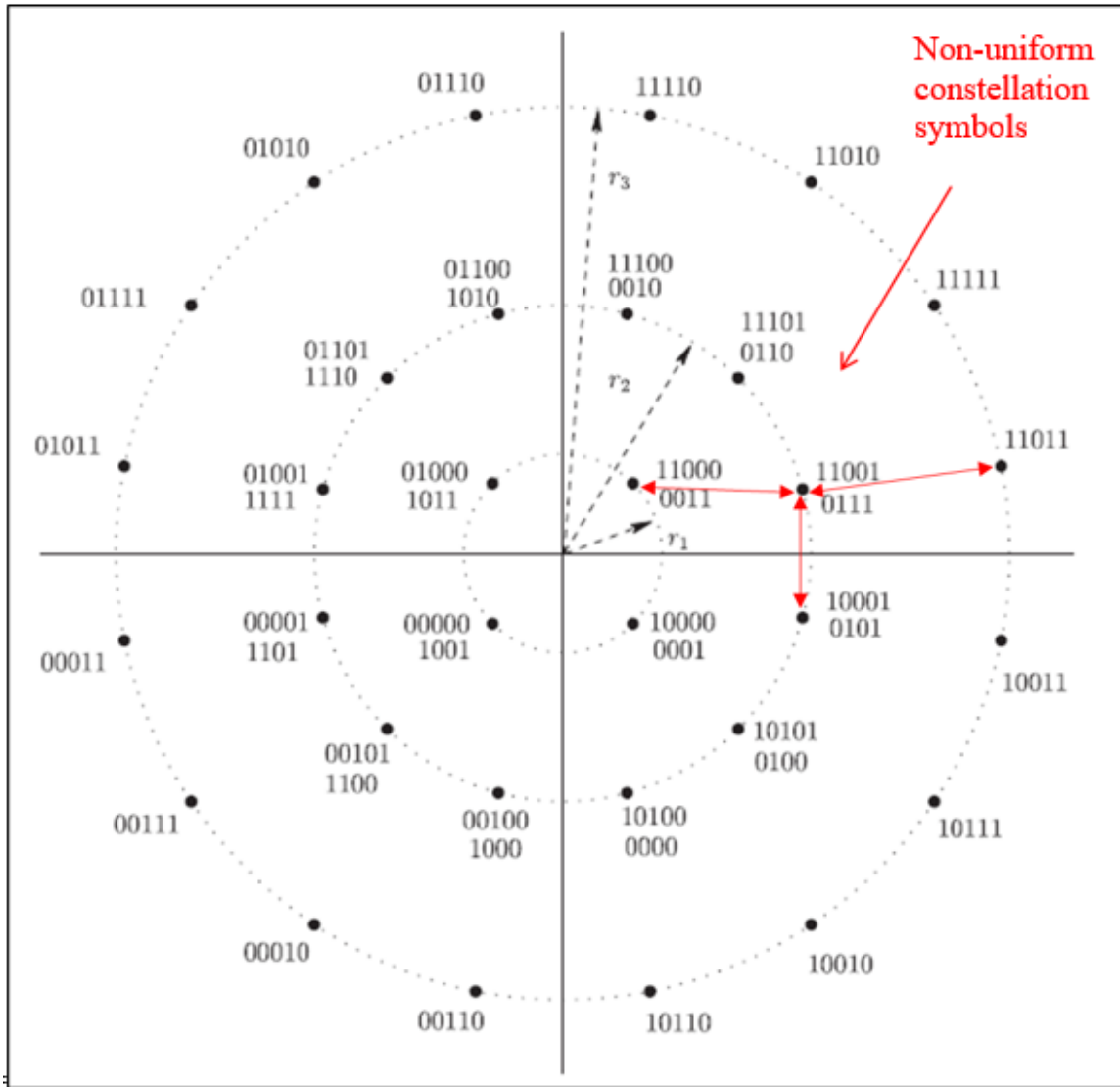
[0080] DeGaudenzi, titled *Turbo-coded APSK modulations design for satellite broadband communications*, is directed to "coded modulations based on

amplitude phase shift keying (APSK) modulation.” LGE1014, 261. DeGaudenzi is specifically related to the optimization of constellations based on the “mutual information” or capacity, which generates an optimum constellation for a given signal to noise ratio (SNR) or spectral efficiency. *Id.*, 261, 266. DeGaudenzi uses Forward Error Correction (FEC) encoding and bit-interleaved coded modulation (“BICM,” also referred to interchangeably in the art with the term “parallel decoding”) because “[a]n additional advantage of BICM is its inherent flexibility, as a single mother code *can be used for several modulations*, an appealing feature for broadband satellite communication systems where a large set of spectral efficiencies is needed.” *Id.*, 262-263; LGE1006, 3; LGE1001, 6:53-67 (“[e]xpressed another way, the PD capacity of a channel can be viewed in terms of the mutual information”); LGE1001, 6:64-65; LGE1014, 262, 272.

[0081] DeGaudenzi “propose[s a] new criteria for the design of digital QAM constellations of 16 and 32 points, with special emphasis on the behavior on nonlinear channels,” and does so by providing examples of *M*-APSK constellations. LGE1014, 264. In general, “*M*-APSK constellations are composed of  $n_R$  concentric rings” with each  $l$ th ring having a number of points ( $n_l$ ), a radius ( $r_l$ ) and a relative phase shift ( $\theta_l$ ). LGE1014, 264. The

number of concentric rings ( $n_R$ ), the number of points ( $n_l$ ), the radius ( $r_l$ ) and the relative phase shift ( $\theta_l$ ) can vary and be optimized for capacity, for a fixed constellation size  $M$ .

**[0082]** DeGaudenzi's FIG. 1 (reproduced below) depicts an example of a 16- and 32-APSK constellation. LGE1014, 265. For the 32-APSK, the optimized constellation has 3 rings, with 4, 12, and 16 constellation points, respectively. The 16-APSK has 4 and 12 constellation points in its two rings. *Id.* In FIG. 1, although DeGaudenzi discloses uniformly-spaced PSK points around each of its concentric rings, the radii of the rings are not uniformly spaced, nor are the numbers of points on individual rings equal or multiples of each other, hence making the resulting APSK constellation, as a whole, unequally spaced or non-uniform. LGE1014, 264. As depicted in FIG. 1, the numbers of constellation points are unequal and unequally spaced, and the radii of the rings are not multiples of a particular number.



LGE1014, FIG.1.

[0083] DeGaudenzi explains that “*for a given SNR, or equivalently, for a given spectral efficiency  $R$ ; an optimum constellation* can be obtained, a procedure we apply in the following to 16- and 32-ary constellations.” LGE1014, 266. DeGaudenzi’s “Table I provides the optimized 16- and 32-APSK parameters for

various coding rates, giving an optimum constellation for each given spectral efficiency,” or, in other words, at a given SNR. LGE1014, 268. Table I (reproduced below) lists 11 different constellations having two types of modulation orders, namely 4+12 APSK and 4+12+16-APSK. LGE1014, 271. The optimized coding rate, spectral efficiency, and radii ratio ( $\rho_2$  and  $\rho_3$ ) associated with the second and third rings is provided in the table. Because the optimized  $\rho_2$  and  $\rho_3$  have different values, each of the listed constellations has a different shape and size.

#### 16(4+12) Non-uniform symbol constellations points

Constellation and predetermined code rate pair

| Modulation order | Coding rate, $r$ | Spectral eff. (bps/Hz) | $\rho_1^{opt}$ | $\rho_2^{opt}$ | $\rho_3^{opt}$ |
|------------------|------------------|------------------------|----------------|----------------|----------------|
| 4 + 12-APSK      | 2/3              | 2.67                   | 3.15           | N/A            |                |
| 4 + 12-APSK      | 3/4              | 3.00                   | 2.85           | N/A            |                |
| 4 + 12-APSK      | 4/5              | 3.20                   | 2.75           | N/A            |                |
| 4 + 12-APSK      | 5/6              | 3.33                   | 2.70           | N/A            |                |
| 4 + 12-APSK      | 8/9              | 3.56                   | 2.60           | N/A            |                |
| 4 + 12-APSK      | 9/10             | 3.60                   | 2.57           | N/A            |                |
| 4 + 12 + 16-APSK | 3/4              | 3.75                   | 2.84           | 5.27           |                |
| 4 + 12 + 16-APSK | 4/5              | 4.00                   | 2.72           | 4.87           |                |
| 4 + 12 + 16-APSK | 5/6              | 4.17                   | 2.64           | 4.64           |                |
| 4 + 12 + 16-APSK | 8/9              | 4.44                   | 2.54           | 4.33           |                |
| 4 + 12 + 16-APSK | 9/10             | 4.50                   | 2.53           | 4.30           |                |

#### 32(4+12+16) Non-uniform symbol constellations points

LGE1014, Table I<sup>3</sup>.

[0084] DeGaudenzi achieves this performance improvement by “show[ing] that the degrees of freedom in the design of an APSK modulation can be exploited thanks to the mutual information maximization, and this has been applied to the design of 16- and 32-ary constellations. This technique has been shown to extend the standard minimum Euclidean distance maximization, yielding a small but significant improvement.” LGE1014, 279. Of particular significance, is not just the distance between individual points, but between the concentric rings. “The constellation geometry clearly indicates that the distances to consider are between points belonging to the same ring, or between points in adjacent rings.” LGE1014, 265. DeGaudenzi found that by adjusting the distances between rings, “small but significant improvement” could be achieved. LGE1014, 266, 279. Specifically, “the best offset between rings

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<sup>3</sup> Table I (shown above) has a typographical error. DeGaudenzi defines  $\rho_l$  (see LGE1014, 264) as the relative radii of the  $l$ th ring with respect to first ring i.e.,  $r_1$ ,  $\rho_l = r_l/r_1$ . Thus for  $l = 1$ ,  $\rho_1$  will always be  $r_1/r_1=1$ . Hence,  $\rho_1$  and  $\rho_2$  should be replaced with  $\rho_2$  and  $\rho_3$  as  $\rho_1$  always has a unity value. LGE1014, 264.

happens when  $\emptyset_2 = \frac{\pi}{n_2}$ .” LGE1014, 266. In addition to the improvements made through spacing, DeGaudenzi introduces a “new method [that] generates an optimum constellation for each spectral efficiency.” LGE1014, 261. The optimum constellation for each spectral efficiency “can easily be evaluated using the Gauss-Hermite quadrature rules, making numerical evaluations very simple.” LGE1014, 266. As, DeGaudenzi explains, “the two-dimensional optimization can be done by simply finding the  $\rho_2$  that maximizes mutual information” and that “the optimum constellation separates the rings by a distance larger than the number of points in the ring itself, so that the relative phase  $\phi$  has no significant impact in the distance spectrum of the constellation.” LGE1014, 267-268. All of this information can be pre-calculated and formatted into a table, such as Table I. LGE1014, 268.

**[0085]** DeGaudenzi discloses that “the optimization method based on the mutual information ... can be easily extended to the case of the BICM mutual information [13](sic, [14]) with almost identical results assuming Gray mapping.” LGE1014, 272. The spacing and locations (e.g., the radii and phase shifts) and labels (e.g., using Gray labeling/mapping) of constellation points are assigned *to maximize parallel decode capacity* (e.g., BICM mutual information/capacity) of the symbol constellation at a given signal-to-noise

ratio. *Id.*, 264, 266, 272-273. In particular, DeGaudenzi discloses “[c]onstellation optimization” in “finding an [optimized] APSK constellation” via “[m]utual information maximization” or maximization of parallel decoding capacity by varying the parameters  $\boldsymbol{\rho} = (\rho_1, \dots, \rho_{n_R})$  and  $\boldsymbol{\phi} = (\phi_1, \dots, \phi_{n_R})$ , i.e., the relative radii and phase shifts (i.e., locations) of the constellation points. *Id.*, 264, 266. Additionally, DeGaudenzi shows example optimized 16- and 32-APSK constellations with coding “for various coding rates” in Table I. LGE1014, 268, 271, Table I. Although DeGaudenzi provides certain examples of particular types of constellations, its disclosure is broad and can be applied to different types of coding and modulation types. This is also confirmed by DeGaudenzi’s use of BICM, expressly, for its flexibility and ability to be used with several modulations. LGE1014, 262-263.

[0086] For example, although the examples provided in Table I and FIG. 1 related to an APSK, DeGaudenzi’s teachings can be applied to QAMs. LGE1014, 264 (“[w]e propose new criteria for the design of digital QAM constellations of 16 and 32 points”). Indeed, QAMs can be considered a subset of APSKs because all QAM schemes modulate both the amplitude and phase of the carrier. The distinction between the two is in their production, e.g., because a QAM is produced from two orthogonal signals. With respect to coding

techniques, DeGaudenzi is directed to FEC code designs. LGE1014, 272. It well-known in the art that FEC coding refers to a variety of different coding schemes including LDPC, Polar, Turbo, and convolutional codes. *See e.g.*, LGE1014, 262. Thus, it would have been obvious to a POSITA that the teachings of DeGaudenzi would have applied to systems using LDPC coding.

#### **G. Combination of EDC and DeGaudenzi**

[0087] A POSITA would have combined the teachings of DeGaudenzi with the EDC so that the parallel decoding capacities of EDC's plurality of different non-uniform multidimensional symbol constellations (e.g., EDC's non-uniform-16-QAM constellations) would have been optimized. In particular, a POSITA would have incorporated DeGaudenzi's teachings to configure constellation designs (including the labels and spacing of points) to maximize the parallel decoding capacity of each of a plurality of constellation and also realize an optimal spectral efficiency or SNR, as shown above in DeGaudenzi's Table I. LGE1014, 271. As I described in the previous section, DeGaudenzi's teachings would have also applied to QAM constellations and LDPC coding. Thus, it would have been obvious for a POSITA to turn to DeGaudenzi's teachings and combine its teachings with EDC's system, which utilizes Eroz's LDPC coding.

Indeed, Erozi compares the performance LDPC with turbo codes to show the advantages of LDPC coding. LGE1004 ¶[0033].

[0088] Advantageously, by maximizing the parallel decoding capacity and optimizing the spectral efficiency/SNR, EDC's system can realize constellations that are power and spectrally efficient, and thereby increase the capability of using such constellations in various communication systems (e.g., systems that include terrestrial and satellite communications). LGE1014, 261-262. Indeed, DeGaudenzi also suggests that its optimization technique would allow EDC's terrestrial system to perform better if complemented with satellite communication systems. *Id.*

[0089] A POSITA would have combined EDC and DeGaudenzi as described above by modifying EDC's system, e.g., the constellation designing software, to include code that can implement DeGaudenzi's optimization method and achieve the maximum parallel decoding capacity outcome noted above. Amending the software in EDC's system to incorporate the teachings of DeGaudenzi would have been well within the knowledge and capabilities of a POSITA and would have simply involved implementing optimization formulas, codes, and tables for the same/similar types of constellations (e.g., QAM) disclosed by both EDC and DeGaudenzi. As stated earlier, Ulrich disclosed that

manufactures would create devices for multiple applications and adapt the software. For example, control software could “be adapted, which usually is rather simply done...” LGE1008, 267. Ulrich continues to describe that “[f]or various reasons, manufacturers need to be able to update the receiver’s software, of products which are already on the market.” LGE1008, 299. Accordingly, combining the teachings of EDC and DeGaudenzi would have simply involved combining prior art elements according to known methods to yield predictable results.

**[0090]** Moreover, the combination of EDC and DeGaudenzi would also have been predictable with a foreseeable chance of success. As noted in DeGaudenzi, a new standard, namely the Digital Video Broadcasting standard for satellite communications (which is described in the next section) was released around the same time that DeGaudenzi was published/written and focused on applying similar techniques in satellite communication systems. Thus, the application of DeGaudenzi’s teachings to extend or complement the DVB-T standard, as noted above, would not only have been obvious and predictable for the reasons noted above, but it would also have been foreseeable as it was actually being done at the time of the DeGaudenzi publication and disclosed in DeGaudenzi as a way to provide digital broadcasting data to scarcely populated regions. LGE1014,

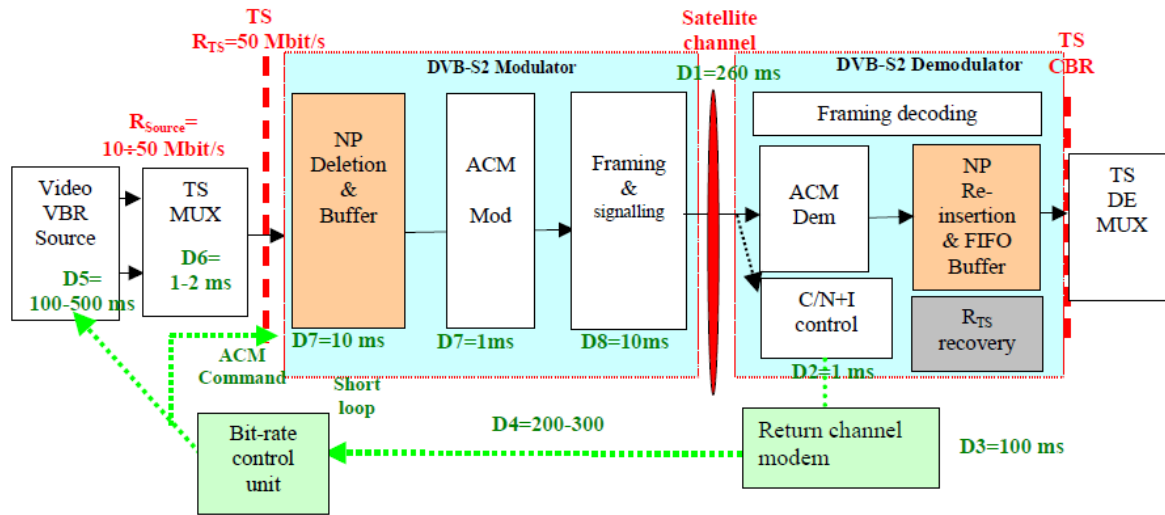
261-262.

## **H. Overview of DVB-S2**

**[0091]** DVB-S2 is a standard document entitled “Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications.” LGE1009, 1. DVB-S2 is in the same family of standards and produced by the same committee as the DVB-T standard of the EDC combination (*See supra* Section IX.C). LGE1005, 1, LGE1008, 1. DVB-S2 teaches a method of transmitting digital television signals using variable coding and modulation, adaptive coding modulation, Forward Error Correction (FEC), and Low-Density Parity Checks (LDPC) codes. For example, DVB-S2 describes the use of Quadrature Phase Shift Keying (QPSK), Quadrature Amplitude Modulation (QAM).

**[0092]** DVB-S2 employs Variable Coding Rate (VCM), which “may be combined with the use of return channels, to achieve Adaptive Coding and Modulation (ACM).” LGE1009, 6. An example of ACM is provided in DVB-S2’s Figure H.6 (reproduced below), which depicts a DVB-S2 communication system including a receiver that receives a signal from a transmitter over a

channel. The receiver can transmit information regarding the channel conditions including carrier to noise plus interference ratio (C/N+I or CNI), via a return channel, back to the transmitter. *Id.*, 6, 66-69.



LGE1009, 67.

[0093] ACM utilizes receivers to provide feedback on signal quality. LGE1009, 6. “This technique provides more exact channel protection and dynamic link adaptation to propagation conditions, targeting each individual receiving terminal. ACM systems promise satellite capacity gains of up to 100%-200%. In addition, service availability may be extended compared to a constant protection system (CCM) such as DVB-S or DVB-DSNG. Such gains are achieved by informing the satellite up-link station of the channel condition (e.g. C/N+I) of each receiving terminal via the satellite or terrestrial return channels.”

*Id.*, 6.

## **I. Combination of EDC and DVB-S2**

[0094] It would have been obvious to a POSITA to combine the EDC system with the teachings of DVB-S2 such that a return channel to transmit information regarding the channel conditions including (C/N+I) from the receiver back to the transmitter, as disclosed by DVB-S2, is implemented in the EDC system. LGE1009, 6, 66-69. DeGaudenzi corroborates that teachings from satellite transmission methods (DVB-S2) are valuable in terrestrial transmission methods (DVB-T) by stating: “[s]atellite systems also provide a unique way to complement the terrestrial telecommunication infrastructure in scarcely populated regions.” LGE1014, 262. Combining the teachings of EDC and DVB-S2 in this manner would have merely involved combining prior art elements according to known methods to yield predictable results. Here, the predictable and foreseeable result would have been that Erož’s communication system would also have a return channel between the receiver to the transmitter. Incorporating the return channel feature would have been beneficial because the channel feedback information would have provided the transmitter with configuration information, such as modulations, code rates, constellations,

constellation ratios ( $\alpha$ ), and related details to configure LDPC-encoded DVB data from a transmitter to a receiver over a communication channel. By configuring the transmission based on information related to the quality of the communication channel, communication performance between the transmitter and receiver would have improved, for example, by reducing data loss, increasing data throughput, increasing capacity gains, and using code rate and constellations that are more suitable for the existing channel conditions.

**[0095]** Moreover, this combination would have been predictable and foreseeable for several reasons. First, a user or system designer of the EDC system would have desired a system in which the transmitter can obtain information about and respond to channel conditions and signal quality indicators to minimize signal noise and loss and, more generally, to achieve the benefits noted in the preceding paragraph. This is a common goal of system designers and would have made this combination foreseeable.

**[0096]** Second, DVB-S2 and DVB-T belong to the same family of ETSI DVB standards and the DVB-S2 standard uses LDPC coding like the EDC system. LGE1009, 1-6, 12, 13; LGE1005, 1-5; *See supra* Section IX.C. While DVB-S2 is directed to satellite communications and DVB-T is directed to terrestrial communications, combining aspects of different standards or even

implementing multiple standards in a single device or system would have been obvious and was already being practiced. LGE1009, 1; LGE1005, 1. For example, Ulrich, a book by one of the chairpersons of the DVB standard, explains that DVB-T receivers were used in various devices and would “often have to be ‘world receivers’” when used in certain types of devices such as handheld devices, PDAs, and car receivers. LGE1008, 257-258, v-x. “World receivers” refers to receivers that “allow[ ] reception in all possible environments (frequency range, channel arrangement, bandwidth)” and “features other reception standards, like analogue TV, ATSC or ISDB-T.” LGE1008, 258. Indeed, a technology referred to as Network Interface Module (NIM) technology was developed to receive all types of DVB signals including DVB satellite and DVB terrestrial signals. LGE1008, 267. Ulrich explains that some of advantages of NIM were that “[i]t has all the technology and the related know-how ‘on board’, in one module,” and “exactly the same receiver [can be used] for all DVB systems.” LGE1008, 267-268. As such, modifying the EDC system and devices therein to implement multiple standards, such as DVB-T, DVB-S2, and incorporate the return channel, as disclosed by DVB-S2, in the EDC system would have been obvious, predictable, and foreseeable, and, according to Ulrich, would have been achievable using a receiver that is already

configured for all DVB systems.

[0097] A POSITA would have combined EDC and DVB-S2 without much difficulty and in the above-noted predictable manner at least because such technology was already being implemented (e.g., the Network Interface Modulation (NIM) technology described above) and similar products were already in the market (*see e.g.*, NIM chip from Philips shown below in FIG. 11.14). LGE1008, 268. Ulrich further states that “NIMs from various manufactures can be interchanged. The control software needs to be adapted, which usually is rather simply done...” *Id.*, 267 “Since NIMs are available for different DVB transmission systems, namely satellite, cable, and terrestrial, they allow for the design of exactly the same receiver for all DVB systems.” (emphasis added) *Id.*, 268. For at least the foregoing reasons, a POSITA would have found it obvious to combine EDC and DVB-S2.

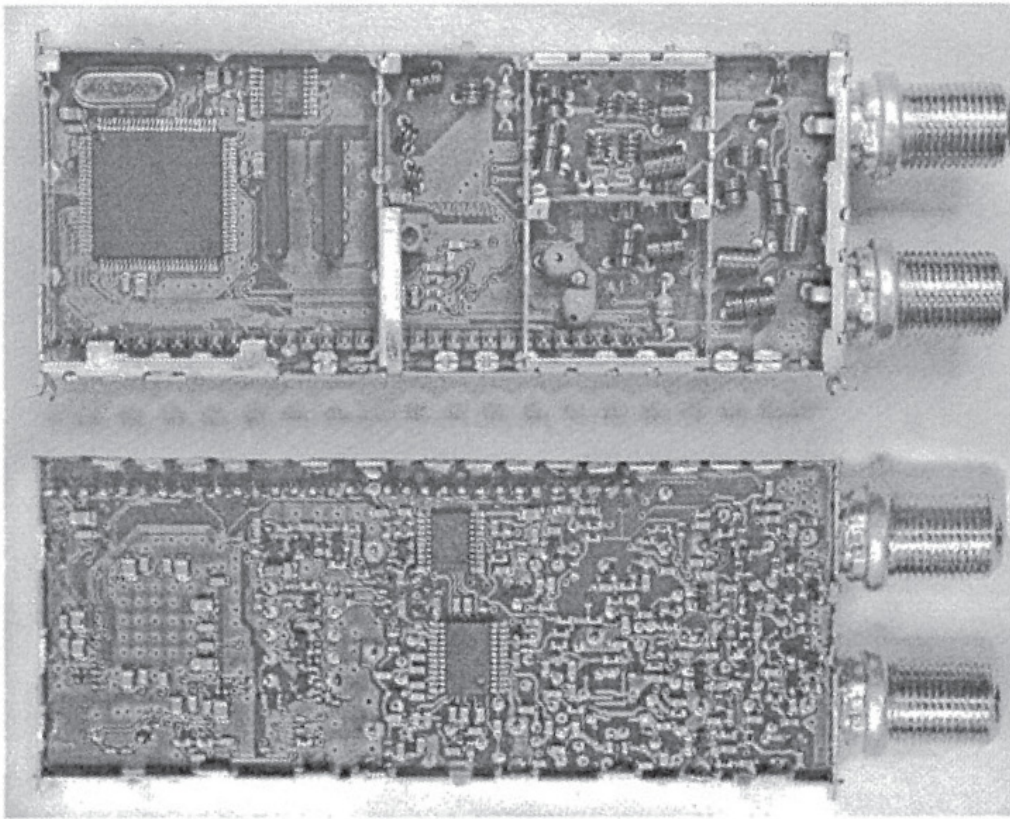


**Fig. 11.14** Network Interface Module (NIM) from Philips<sup>4</sup> (top and bottom view)

LGE1008, 268.

## **J. Overview of DVB-TS**

[0098] DVB-TS is a technical specification in the family of DVB Standards. It “defines agreements on which to base interoperability for system software update services and receivers.” LGE1013, 5. DVB-TS “specifies a standard mechanism for signalling a software update service and the means to carry the

data for such a software update service.” *Id.*, 7. Among its various features and teachings, DVB-TS:

- “defines the signalling information that can be used to locate the transport stream containing the system software update service”;
- “defines the options for transmitting the actual system software update service in either a proprietary data transfer format, or a standardized 2-layer DVB data carousel”; and
- “defines a recommended format for exchanging the system software update data from receiver manufacturer to the network (or multiplex) operator for subsequent transmission.” LGE1013, 5-6.

#### **K. Combination of EDC and DVB-TS**

[0099] As noted above in Section IX.J DVB-TS describes how system software can be updated in services and receivers in DVB systems. LGE1013, 1-7, cover. DVB-TS explains that “[i]n order to guarantee the functionality of a receiver as well as increasing its functionality once deployed in the field a software update service is required.” *Id.*, 7.

[0100] It would have been obvious to a POSITA to combine EDC with the teachings of DVB-TS so that software updates would have been made to communication network devices, such as the receiver described in EDC. A

standard is necessary to specify how such updates would be implemented in a network-independent manner since a variety of transmitters and receivers of various manufacturers can exist within the same network. Because DVB-TS is a standard that discloses methods for specifying updates, it would have been obvious for users of related DVB standards to turn to DVB-TS for guidance on how to implement software updates. Further, it has been shown that Ulrich supports this perspective and cites both manufactures and developers when describing a need for software update capabilities. [cite]

**[0101]** Combining the teachings of EDC and DVB-TS would have merely involved combining prior art elements according to known methods to yield predictable and foreseeable results. Here, combining the teachings of EDC and DVB-TS would have predictably allowed a device, such as EDC's receiver, to receive updates so that corrects software bugs, and continues to increase its functionality as necessary based on consumer requirements. For example, when a system is initially designed for a particular terrestrial network and environment and over time the network and environment changes (along with devices and software), it would have been obvious to update the receiver's software to adapt to the network and environmental changes and address technological issues (e.g., software bugs, new constellation designs). A POSITA understands that it

is advantageous to implement as much of a receiver's functionality in software as practical since this software can be changed more readily and inexpensively than the hardware. Indeed, as I mentioned above, Ulrich also explains that, in DVB systems, "control software needs to be adapted, which usually is rather simply done" and that "[f]or various reasons, manufacturers need to be able to update the receiver's software, of products which are already on the market." LGE1008, 267, 299. Accordingly, incorporating the DVB-TS's disclosure of updates in EDC would have been predictable and foreseeable consistent with well-known practices as of June 5, 2007.

[0102] As I explain in the next section, the Challenged Claims are obvious in view of the references and combinations described in this section.

## **X. APPLICATION OF THE PRIOR ART TO THE REFERENCES**

### **A. Ground 1A: Eroz and DVB-T render claims 1, 8, 10-11, 18, 20-21, 28, and 30 obvious**

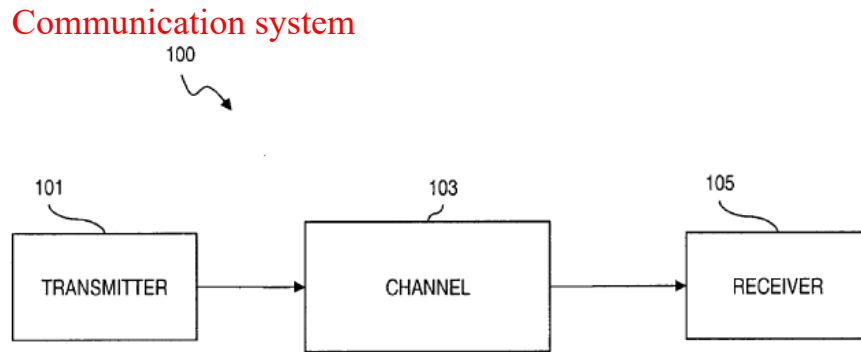
#### **Claim 1**

[1pre] *A communication system, comprising:*

[0103] To the extent the preamble is limiting, EDC renders [1pre] obvious. Eroz is directed to a communication system for providing LDPC encoding. LGE1004, cover, ¶[0030]. An example of Eroz's communication system is

illustrated in Eroz's FIG. 1 (reproduced below).

FIG. 1



LGE1004, FIG. 1

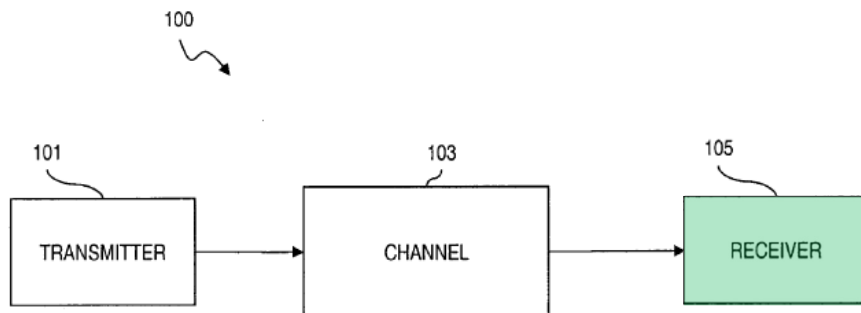
[0104] Ero­z’s communication system 100 “includes a transmitter 101 that generates signal waveforms across a communication channel 103 to a receiver 105.” LGE1004, ¶[0030].

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

[0105] As noted above in [1pre] and shown below in FIG. 1, Ero­z discloses a receiver 105 that is capable of receiving signals via communication channel 103 from transmitter 101. LGE1004, ¶[0030]. It is known in the art that a communication channel between a transmitter and receiver has a channel signal-to-noise ratio (SNR). A POSITA would have recognized that the signal propagates through the channel, and the noise would have come through that

same channel as interference or be added at the receiver electronics. Erož teaches that “communication channels exhibit a fixed capacity that can be expressed in terms of bits per symbol at certain signal to noise ratio (SNR).” LGE1004, ¶[0003]; *see also* FIG. 7. Moreover, a POSITA would have understood that such an SNR is usually computed with the power of the signal of interest in the numerator and the power of the noise (or noise-plus-interference) in the denominator, and that the SNR plays an important role in determining a communication system’s performance. Accordingly, it would have been obvious to a POSITA that Erož’s communication channel 103 has a SNR.

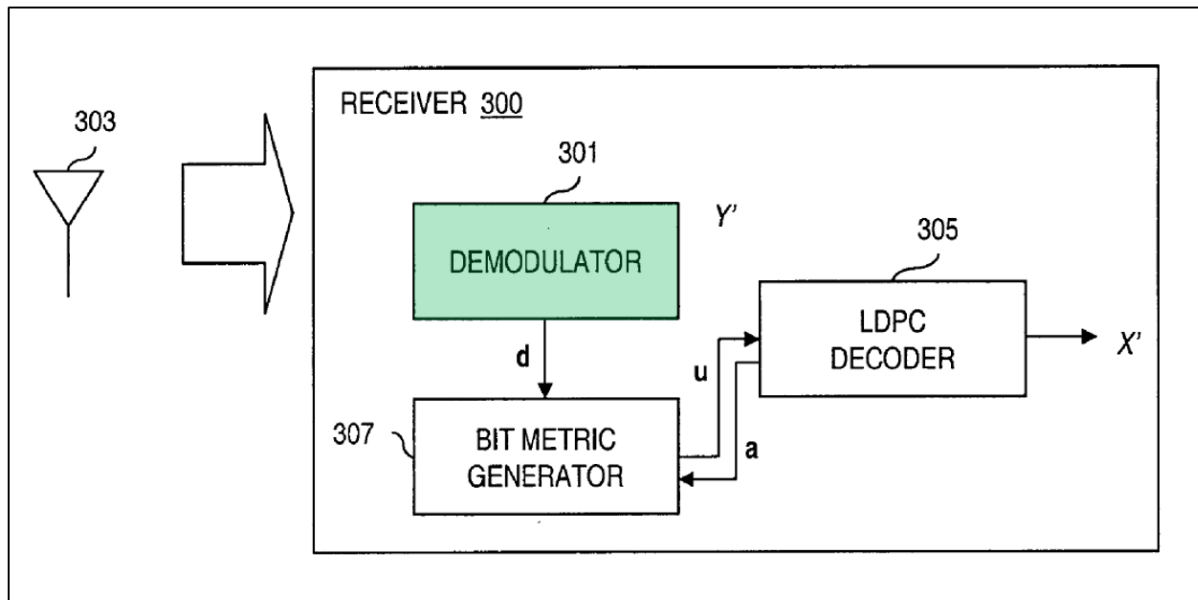
FIG. 1



LGE1004, FIG. 1

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

[0106] Eroz’s “FIG. 3 is a diagram of an exemplary receiver in the system of FIG. 1.” LGE1004, ¶[0058]. As explained above in Section IX.A and shown in Eroz’s FIG. 3 below, Eroz teaches that “receiver 300 includes a demodulator 301 that performs demodulation of received signals from transmitter.” *Id.* A demodulated signal generated by the demodulator 301 is provided to the bit metric generator 307 and LDPC decoder 305. *Id.*

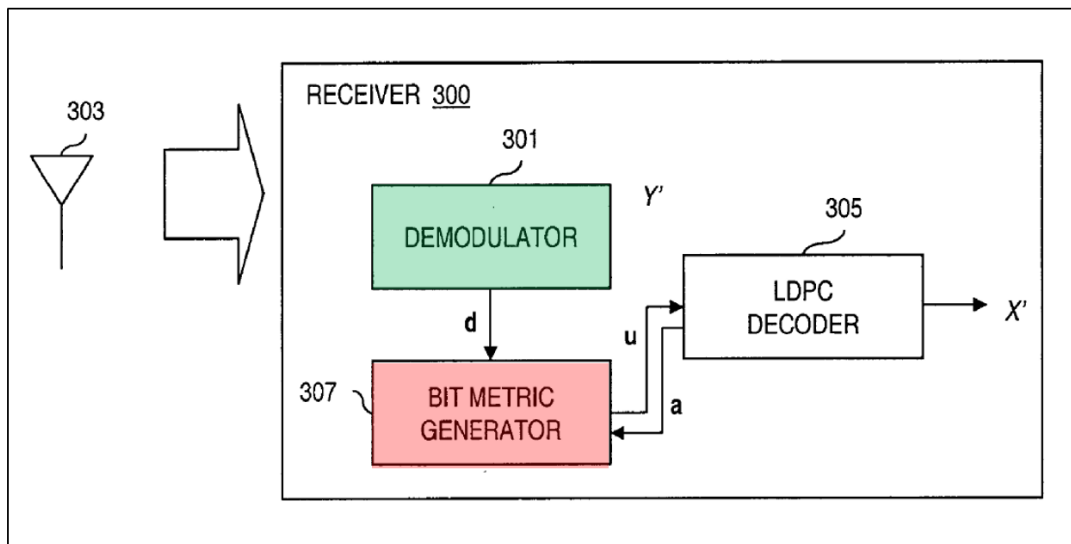


LGE1004, FIG. 3.

**[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**

[0107] As shown in Eroz’s FIG. 3 below, Eroz’s receiver 300 includes bit metric

generator 307 (“*a demapper*”) that is coupled to demodulator 301. LGE1004, ¶[0058], FIG. 3. Based on the signal received from the demodulator 301, the bit metric generator 307 exchanges probability information with the decoder 305 iteratively when non-Gray mapping is used or in a single iteration when Gray mapping is used. LGE1004, ¶[0058], FIGS. 10-11.



LGE1004, FIG. 3.

[0108] In one example, an 8-PSK modulation is used to communicate data, and Erož’s “bit metric generator 307 communicates with the LDPC decoder 305 to exchange a priori probability information and a posteriori probability information, which respectively are represented as  $u$ , and  $a$ . That is, the vectors  $u$  and  $a$  respectively represent a priori and a posteriori probabilities of log likelihood ratios of coded bits.” LGE1004, ¶¶[0076]-[0077]. A POSITA would

recognize that the vector  $u$  is created, in part, using the constellation demapper.

**[0109]** Next, the bit metric generator 307 determines symbol probabilities using a lookup table, and determines a priori log likelihood ratios of the coded bits, which are provided to the LDPC decoder 305. LGE1004, ¶¶[0076]-[0082].

**[0110]** In addition to the 8-PSK modulation example described above, Eroz discloses that its system can utilize a plurality of multidimensional symbol constellations. For example, Eroz's claim 7 recites "modulating the LDPC coded signal according to a signal constellation that includes one of 8-PSK (Phase Shift Keying), 16-QAM (Quadrature Amplitude Modulation), QPSK (Quadrature Phase Shift Keying), 16-APSK (Amplitude Phase Shift Keying) and 32-APSK." LGE1004, claim 7. Eroz explains that its modulator 205 in transmitter 101/200 can map encoded messages from encoder 203 to signal waveforms that are transmitted to a transmit antenna 207, and "[t]he transmissions from the transmit antenna 207 propagate to a receiver." LGE1004, ¶¶[0034]-[0036], FIGS. 2A, 2B. It would have been understood by a POSITA that the modulator 205 would have selected one of the plurality of multidimensional symbol constellations noted above to modulate data to be transmitted, and that the receiver would make a similar selection to ensure it demodulates the data according to the modulation used by the transmitter.

[0111] Indeed, DVB-T confirms this understanding. For example, DVB-T teaches that a transmitter uses transmission parameter signaling (TPS) carriers “for the purpose of signalling parameters related to the transmission scheme, i.e. to channel coding and modulation.” LGE1005, 29. “The TPS carriers convey information on: a) modulation including the  $\alpha$  value of the QAM constellation pattern ... b) hierarchy information; ... d) inner code rates; e) transmission mode.” *Id.* “The  $\alpha$  value defines the modulation based on the cloud spacing of a generalized QAM constellation. It allows specification of uniform and non-uniform modulation schemes, covering QPSK, 16-QAM, and 64-QAM.” *Id.* The constellation type, hierarchy information including the  $\alpha$  value, and code rate to be used in a transmission can be signaled to the receiver by using designated sets of bits, as shown in DVB-T’s Tables 11-13 below. LGE1005, 31-32.

**Table 11: Signalling format for the possible constellation patterns**

| Bits $s_{25}, s_{26}$ | Constellation characteristics |
|-----------------------|-------------------------------|
| 00                    | QPSK                          |
| 01                    | 16-QAM                        |
| 10                    | 64-QAM                        |
| 11                    | reserved                      |

LGE1005, Table 11

**Table 12: Signalling format for the  $\alpha$  values**

| Bits $s_{27}, s_{28}, s_{29}$ | $\alpha$ value   |
|-------------------------------|------------------|
| 000                           | Non hierarchical |
| 001                           | $\alpha = 1$     |
| 010                           | $\alpha = 2$     |
| 011                           | $\alpha = 4$     |
| 100                           | reserved         |
| 101                           | reserved         |
| 110                           | reserved         |
| 111                           | reserved         |

LGE1005, Table 12

**Table 13: Signalling format for each of the code rates**

| Bits<br>$s_{30}, s_{31}, s_{32}$ (HP stream)<br>$s_{33}, s_{34}, s_{35}$ (LP stream) | Code rate |
|--------------------------------------------------------------------------------------|-----------|
| 000                                                                                  | 1/2       |
| 001                                                                                  | 2/3       |
| 010                                                                                  | 3/4       |
| 011                                                                                  | 5/6       |
| 100                                                                                  | 7/8       |
| 101                                                                                  | reserved  |
| 110                                                                                  | reserved  |
| 111                                                                                  | reserved  |

LGE1005, Table 13

**[0112]** The above-noted tables provide information on the values of the various transmission parameters that can be used to configure a transmission scheme. A more comprehensive list of transmission parameters that can be provided by the TPS carriers is shown below in Table 9. This shows the breadth of capability in the transmitter and the receiver in coordinating the constellation, code rate,

and more. This TPS formatting lays the framework from which the transmitter and receiver can choose the modulation scheme, constellation, code rate, and uniformity (via the hierarchical modulation value of  $\alpha$ ). LGE1005, 30.

**Table 9: TPS signalling information and format**

| Bit number                     | Format                                  | Purpose/Content         |
|--------------------------------|-----------------------------------------|-------------------------|
| $s_0$                          | see subclause 4.6.2.1                   | Initialization          |
| $s_1$ - $s_{16}$               | 0011010111101110 or<br>1100101000010001 | Synchronization word    |
| $s_{17}$ - $s_{22}$            | 010 111                                 | Length indicator        |
| $s_{23}$ , $s_{24}$            | see table 10                            | Frame number            |
| $s_{25}$ , $s_{26}$            | see table 11                            | Constellation           |
| $s_{27}$ , $s_{28}$ , $s_{29}$ | see table 12                            | Hierarchy information   |
| $s_{30}$ , $s_{31}$ , $s_{32}$ | see table 13                            | Code rate, HP stream    |
| $s_{33}$ , $s_{34}$ , $s_{35}$ | see table 13                            | Code rate, LP stream    |
| $s_{36}$ , $s_{37}$            | see table 14                            | Guard interval          |
| $s_{38}$ , $s_{39}$            | see table 15                            | Transmission mode       |
| $s_{40}$ - $s_{53}$            | all set to "0"                          | Reserved for future use |
| $s_{54}$ - $s_{67}$            | BCH code                                | Error protection        |

LGE1005, Table 9

[0113] It would have been obvious to a POSITA that the same or similar signaling information can be used when LDPC codes are being communicated in the EDC system. For instance, the  $\alpha$  and code rates values could be the same for LDPC and non-LDPC codes. Yet, as explained above in Section IX.C, the LDPC codes may also include additional MODCOD (Modulation and Coding) combinations and values. Even though these table values could be the same, a POSITA would understand that the inclusion of the LDPC code in place of the convolutional code in the DVB-T standard would yield improved performance

such as lower error rates for a given SNR. For instance, a POSITA may seek to optimize performance of the system by combining particular constellations with particular code rates based on performance of those constellations at a given SNR.

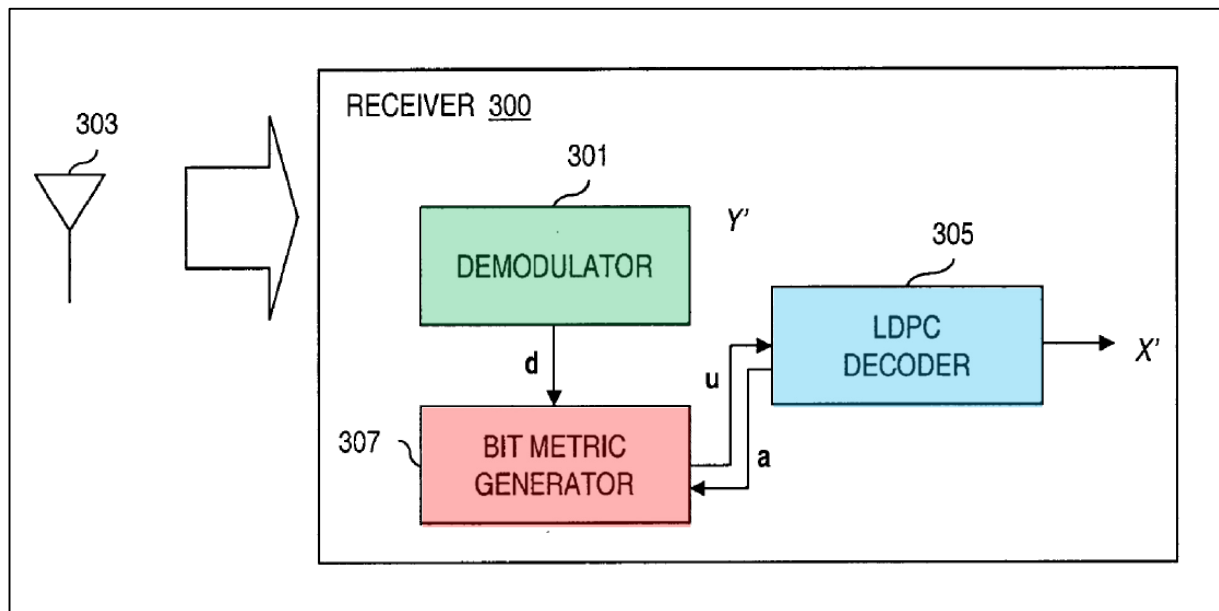
**[0114]** Eroo’s method of receiving a signal and reversing the encoding process to determine received bit values was well known in the art. For example, Ulrich, a textbook that describes technical features of digital video broadcasting systems and methods, also explains that at the receiver of a communication system, “processing steps that were carried out at the encoder have to be reversed.” LGE1008, 198. That is, when a particular type of modulation, mapping, and encoding is used on the transmitter, a corresponding modulation, mapping, and decoding is performed at the receiver to recover the information bits. For example, if a 16-QAM modulation with  $\alpha=2$  is used to modulate data at a transmitter, the receiver would have received transmission parameter information and configured itself to demodulate a received signal using 16-QAM demodulation and  $\alpha=2$ .

**[0115]** Based on the foregoing, it would have been obvious to a POSITA that EDC teaches “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.”

**[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;**

**[0116]** As shown in Erož’s FIG. 3 below, Erož’s receiver 300 includes a LDPC decoder 305 that is coupled to the bit metric generator 307 (demapper).  
LGE1004, ¶[0058], FIG. 3.



LGE1004, FIG. 3.

**[0117]** The decoder 305 uses the probability information (likelihoods) determined by the bit metric generator 307 (demapper) to reconstruct the

original source messages. LGE1004, ¶[0058]; *see supra* [1c]. In particular, the LDPC decoder 305 “is considered a message passing decoder, whereby the decoder 305 aims to find the values of bit nodes” (“*a sequence of received bits based upon a low density parity check (LDPC) code*”). LGE1004, ¶¶[0061]-[0063], [0076]; *see also* FIGS. 10-11, ¶¶[0083]-[0107] (describing specifics of decoding non-Gray and Gray codes).

[0118] Using the likelihoods determined by the demapper to provide a sequence of received bits would also have been obvious to a POSITA because it was well-known in the art. For example, Ulrich explains that a common approach to determine the likelihood that a received bit was either a 1 or a 0 was to use probability densities, as shown below in Ulrich’s FIG. 6.16. LGE1008, 136

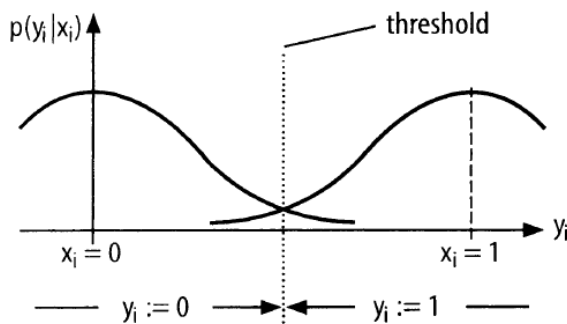


**Fig. 6.16.** Probability density of the received signal and hard-decision threshold

LGE1008, 136.

[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;*

[0119] As noted above in [1c], Eroo and DVB-T disclose using a constellation from among a plurality of multidimensional symbol constellations. LGE1004, claim 7; LGE1005, 31-32. In particular, DVB-T discloses that the constellations can also include non-uniform-16-QAM or non-uniform-64-QAM, as shown in DVB-T's Figures 9b and 9c below. LGE1005, 20-24. Figures 9B and 9C illustrate non-uniform-16-QAM and non-uniform-64-QAM constellations at  $\alpha$  equals to 2 and 4, respectively, resulting in different constellations. Two of these plurality of constellations have 16 points (*"a plurality of different non-uniform multidimensional symbol constellations having the same number of constellation points"*), and the two others have 64 points. Accordingly, EDC renders obvious [1e].

[0120] Moreover, as shown in Figures 9b and 9c below, "the constellation points are non-uniformly spaced in each degree of freedom available to the multidimensional symbol constellations." For example, in the non-uniform-QAMs shown in Figure 9b, the constellation points are non-uniformly spaced along the real axis by 2 or 4 (note:  $\alpha=2$ ), and along the imaginary axis by 2 or 4. In the non-uniform-QAMs shown in Figure 9c, the constellation points are non-

uniformly spaced along the real axis by 2 or 8 (note:  $\alpha=4$ ), and along the imaginary axis by 2 or 8. LGE1005, 20-24

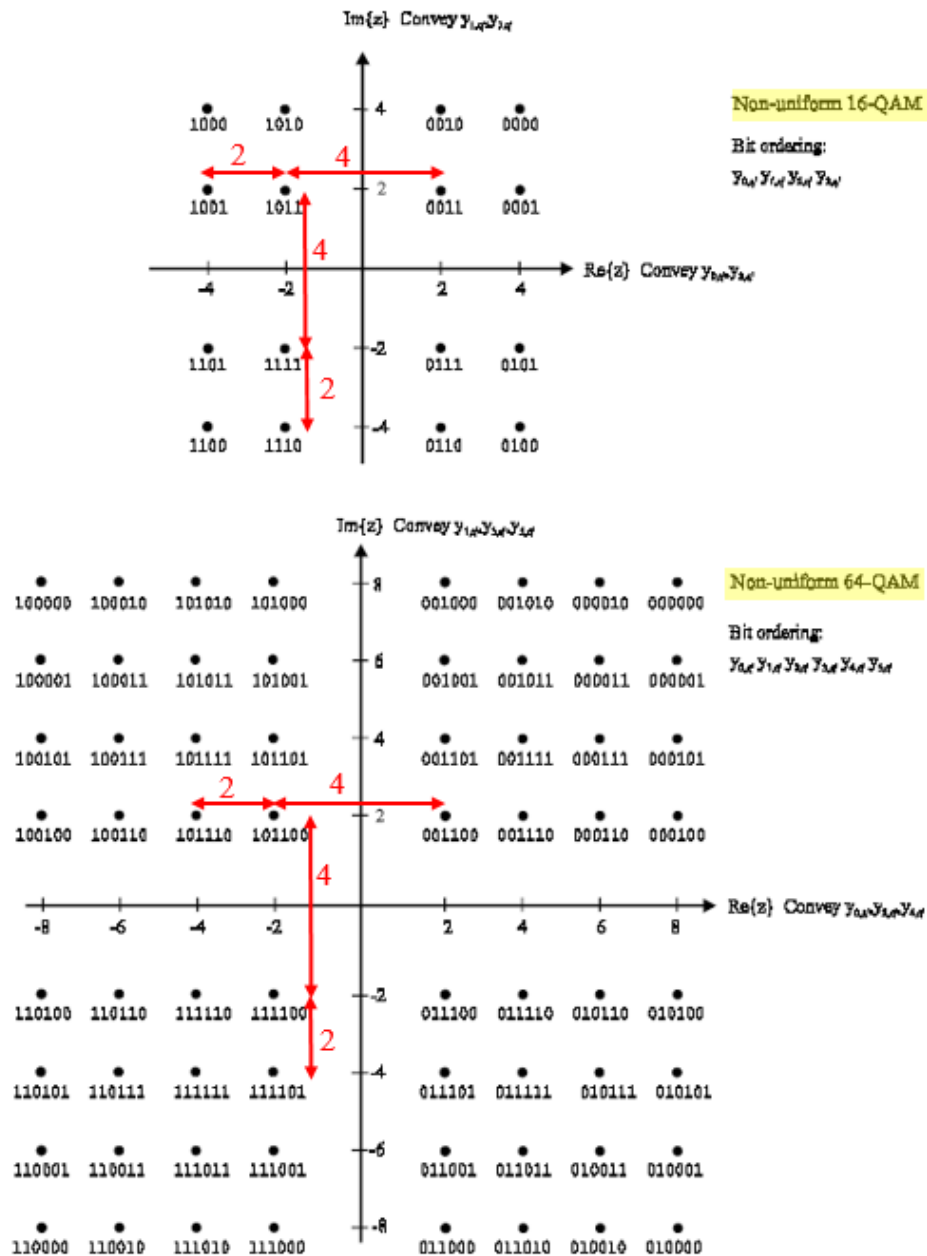


Figure 9b: Non-uniform 16-QAM and 64-QAM mappings with  $\alpha = 2$

LGE1005, Figure 9b.

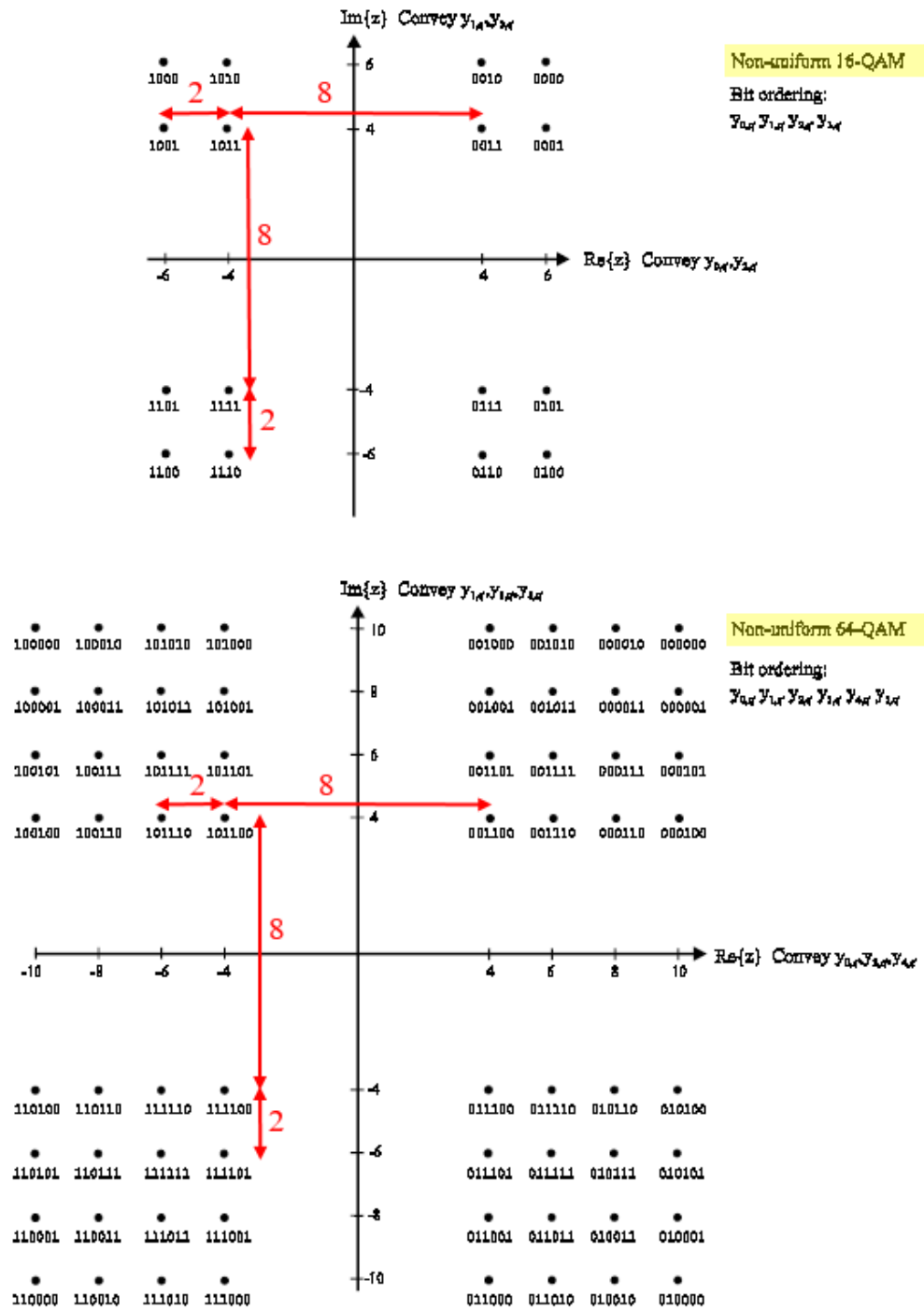


Figure 9c: Non-uniform 16-QAM and 64-QAM mappings with  $\alpha = 4$

LGE1005, Figure 9c.

**[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.**

**[0121]** As explained in [1c], the receiver receives TPS carriers with transmission parameter information used to configure signals received by the receiver. LGE1005, 29-34. The information includes the modulation type, code rate, and  $\alpha$  value, which “allows specification of uniform and non-uniform modulation schemes, covering QPSK, 16-QAM, and 64-QAM.” LGE1005, 29. The receiver selects the same modulation type, code rate, and  $\alpha$  value specified in the transmission parameter information to demodulate, demap, and decode the received signal (“*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*”). See *supra* [1c]; LGE1008, 198. Recall that EroZ is directed to LDPC encoding and decoding and that EDC also would have performed LDPC encoding and decoding. See *supra* §§X.A.[1pre]-[1b]; LGE1004, Abstract, ¶¶[0029]-[0039], [0058]-[0061].

**[0122]** As noted above in [1d], DVB-T’s Figures 9b and 9c disclose examples of four non-uniform constellations, namely non-uniform-16-QAM and non-

uniform-64-QAM when  $\alpha$  equals 2 or 4. LGE1005, 20-24. These constellations can also be used at different code rates. For example, the TPS carrier can specify a QAM modulation (16- or 64- point),  $\alpha$  value (non-uniform 2 or 4), and a code rate (1/2-7/8) to specify a particular constellation from among a plurality of constellations.

**[0123]** While a plurality of constellation and code rate pairs can be used in a communication system, in some cases, an optimized set of constellation-code rate pairs would have been obvious and desirable to use. For instance, while it was known in the art that a constellation can be utilized with different code rates and, more generally, can be configured in various suitable ways, configuring constellation and code rate pairs that have been optimized for SNR or spectral efficiency would have been desirable so that inefficient constellation and code rate pairs are not utilized in EDC's system. Accordingly, it would have been obvious to a POSITA that, in EDC, *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*. In this manner, whichever constellation-code rate pair is selected by the EDC system, the selected constellation-code rate pair is one that will perform with the highest efficiency. Such a system would have been obvious to a

POSITA because selecting a constellation with optimized configurations (e.g., the best efficiency) would have been desirable to maximize performance of the EDC system. The obviousness of such a system is corroborated in DeGaudenzi, as described in more detail below in §X.B.[1f].

**Claim 8**

***[8] The communication system of claim 1, wherein the demodulator is capable of using a demodulation scheme that is based on phase shift keying and the degrees of freedom available to the multidimensional symbol constellations are amplitude and phase.***

**[0124]** As noted above in [1c], EroZ discloses that its system can utilize a plurality of multidimensional symbol constellations including constellations based on phase shift keying modulation. For example, EroZ’s claim 7 recites “modulating the LDPC coded signal according to a signal constellation that includes one of 8-PSK (Phase Shift Keying), 16-QAM (Quadrature Amplitude Modulation), QPSK (Quadrature Phase Shift Keying), 16-APSK (Amplitude Phase Shift Keying) and 32-APSK.” LGE1004, claim 7. Moreover, EroZ discloses two examples of 8-PSK modulated constellations in FIGS. 8A (non-Gray) and 8B (Gray) and explains how demodulator 301 can receive and demodulate a 8-PSK modulated signal and provide the demodulated signal to the bit metric generator 307 (demapper) and decoder 305. LGE1004, ¶¶[0058],

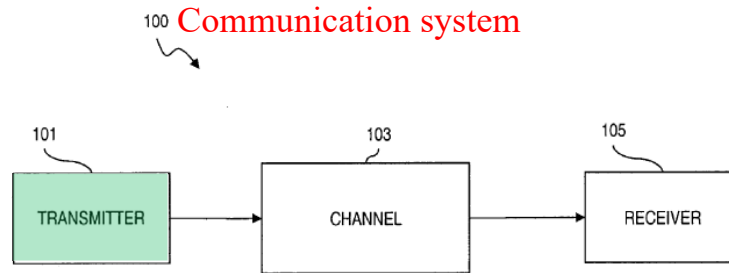
[0068]-[0093]. APSK is a digital modulation scheme that, by definition, conveys data by modulating both the amplitude and the phase of a signal. APSK generally is specified by rings of points wherein the rings are not necessarily spaced uniformly from each other. LGE1014, 264, LGE1021, 174-175, 277-278.. Accordingly, EDC renders obvious “*the demodulator is capable of using a demodulation scheme that is based on phase shift keying.*” It would also have been obvious to a POSITA that “*the degrees of freedom available to the multidimensional symbol constellations are amplitude and phase*” at least because the EDC system can process (modulate and demodulate) APSK constellations.

#### **Claim 10**

**[10pre] *The communication system of claim 1, further comprising a transmitter capable of transmitting signals via the communication channel, where the transmitter comprises:***

**[0125]** As explained above in [1pre] and [1b], Erož’s communication system 100 includes a transmitter 101 that is capable of transmitting signals via communication channel 103. LGE1004, ¶[0030], FIG. 1. The “signal waveforms are attenuated, or otherwise altered, by communications channel 103. *Id.*”

FIG. 1

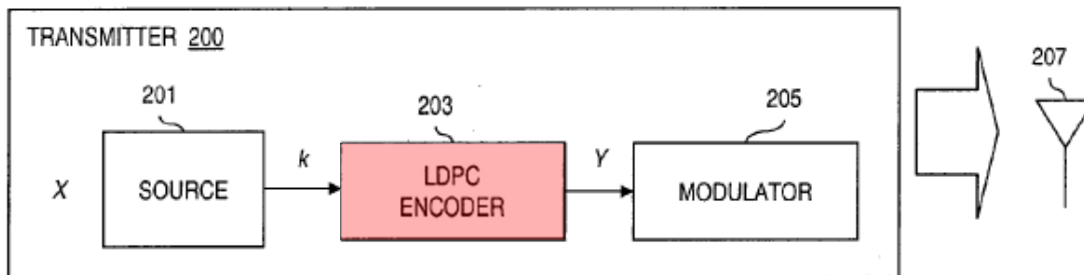


LGE1004, FIG. 1.

**[10a] a coder capable of receiving bits and outputting encoded bits using the Low Density Parity Check (LDPC) code;**

**[0126]** Details of Erož's transmitter 101/200 are shown in Erož's FIG. 2A (reproduced below). LGE1004, ¶¶[0030], [0034]. Erož's transmitter 200 includes a LDPC encoder 203 ("coder") that is capable of receiving bits from  $k$  signals. LGE1004, ¶[0034]. The bits are encoded using a LDPC code. LGE1004, ¶[0034]. LDPC encoder 203 outputs encoded bits (using alphabet  $Y$ ) and provides signals with the encoded bits to modulator 205. LGE1004, ¶[0035].

FIG. 2A

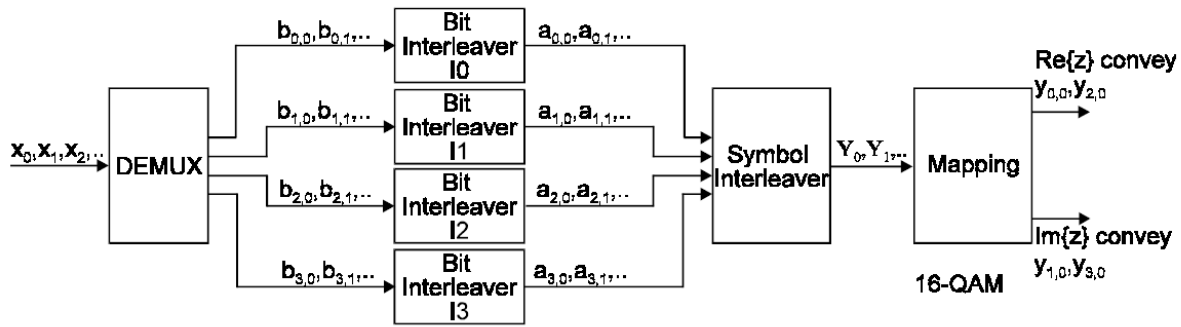


LGE1004, FIG. 2A.

**[10b] a mapper, coupled to the coder, capable of mapping the encoded bits to symbols in the selected multidimensional symbol constellation; and**

**[0127]** Eroz generally discloses the use of symbols and provide several examples utilizing 8-PSK symbols. LGE1004, ¶¶[0003], [0071], [0074]-[0075], [0108]. Although not explicitly shown in Eroz’s transmitter 200, it would have been obvious to a POSITA that a mapper is used in Eroz’s transmitter so that bits can be mapped to symbols in a particular, selected multidimensional symbol constellation. DVB-T corroborates this obvious teaching and more explicitly discloses that bitstreams “are mapped onto the signal constellation by the Mapper and Modulator.” LGE1005, 9. Several examples of such mappings utilized in 16-QAM uniform and non-uniform constellations are described by DVB-T, and one example of mapping symbols in a 16-QAM is illustrated below

in Figure 7a. LGE1005, 14-20.



LGE1005, Figure 7a.

[0128] For instance, in Figure 7a above, a bitstream is demultiplexed into 4 substreams for a 16-QAM constellation. LGE1005, 14. The mapper can then select a hierarchical or non-hierarchical scheme to modulate the bits according to the following example:

| 16-QAM non-hierarchical transmission: | 16-QAM hierarchical transmission: |
|---------------------------------------|-----------------------------------|
| $x_0$ maps to $b_{0,0}$               | $x'_0$ maps to $b_{0,0}$          |
| $x_1$ maps to $b_{2,0}$               | $x'_1$ maps to $b_{1,0}$          |
| $x_2$ maps to $b_{1,0}$               | $x''_0$ maps to $b_{2,0}$         |
| $x_3$ maps to $b_{3,0}$               | $x''_1$ maps to $b_{3,0}$         |

LGE1005, 15.

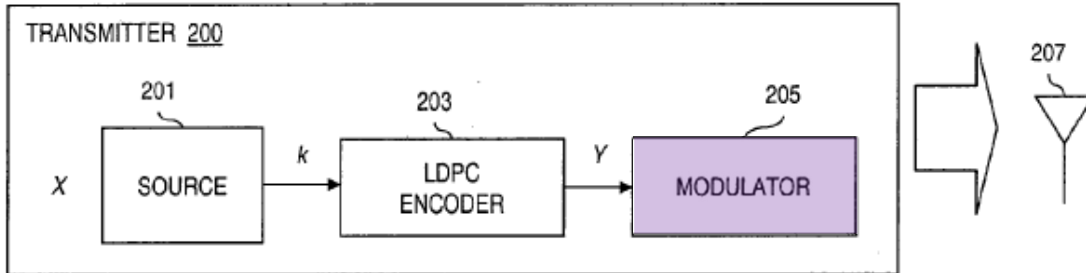
[0129] Although not shown, it would have been obvious to a POSITA that EroZ's transmitter also includes a mapper. In general, there are a few suitable design

options for placing the mapper. In several known systems, such as the one in DVB-T and Ulrich, a mapper can be implemented prior to performing modulation so that mapped symbols can be modulated for transmission. LGE1008, 245-246; LGE1005, 14-17. Accordingly, it would have been obvious to a POSITA that Eroz's LDPC encoded bits would have been input into a mapper, such as DVB-T's mapper, so that bits-to-symbol mapping may be performed. The mapped symbols would have then been used by a modulator to generate signals for transmission to a receiver over a communication channel. LGE1004, ¶¶[0034]-[0036], FIGS. 1-4;

**[10c] *a modulator, coupled to the mapper, capable of generating a signal for transmission via the communication channel based upon symbols selected by the mapper.***

**[0130]** Eroz discloses that modulator 205 generates “signal waveforms that are transmitted to a transmit antenna 207, which emits these waveforms over the communication channel 103” (“**modulator ... capable of generating a signal for transmission via the communication channel**”). LGE1004, ¶[0036].

FIG. 2A



LGE1004, FIG. 2A

[0131] As explained in [10b], in EDC, the modulator 205 is coupled to a mapper between the encoder 203 and the modulator 205, and the signals generated by modulator 205 for transmission are based upon symbols selected by the mapper.

**Claim 11**

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

[0132] *See supra §§X.A.[1pre].*

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

[0133] *See supra §§X.A.[1a].*

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

[0134] *See supra §§X.A.[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**

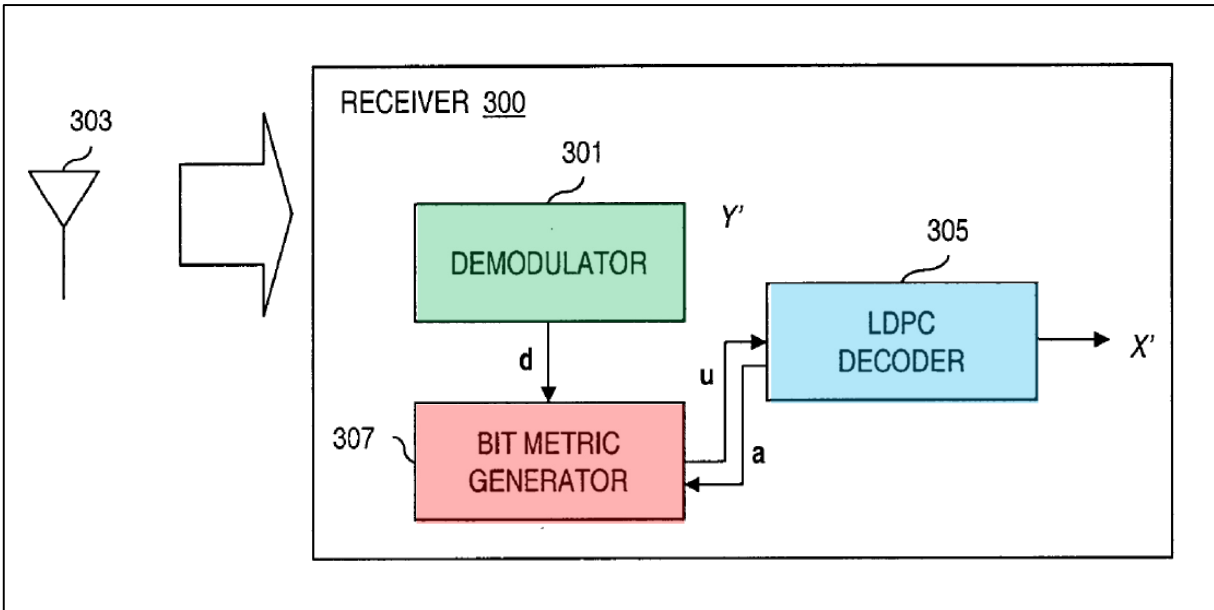
**[0135]** See *supra* §§X.A.[1c].

**[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;**

**[0136]** See *supra* §§X.A.[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;**

**[0137]** As explained above in [1b]-[1d] and shown in Eroz's FIG. 3, EDC's bit metric generator 307 (demapper) is interposed between the demodulator 301 and the LDPC decoder 305, receives information from the demodulator 301 and provides information to the LDPC decoder 305. LGE1004, ¶¶[0058], [0061]-[0063], [0076]-[0077].



LGE1004, FIG. 3.

[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;

[0138] See *supra* §§X.A.[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.

[0139] See *supra* §§X.A.[1f].

### Claim 18

**[18] *The communication system of claim 11 , wherein the demodulator uses a demodulation scheme that is based on phase shift keying and the degrees of freedom available to the multidimensional symbol constellations are amplitude and phase.***

**[0140]**    *See supra [8].*

**Claim 20**

**[20pre] *The communication system of claim 11, further comprising a transmitter that transmits signals via the communication channel, where the transmitter comprises:***

**[0141]**    *See supra [10pre].*

**[20a] *a coder that receives bits and outputs encoded bits using the Low Density Parity Check (LDPC) code;***

**[0142]**    *See supra [10a].*

**[20b] *a mapper that maps the encoded bits to symbols in the selected multidimensional symbol constellation; and***

**[0143]**    *See supra [10b].*

**[20c] *a modulator that generates a signal for transmission via the communication channel based upon symbols selected by the mapper;***

**[0144]**    *See supra [10c].*

**[20d] *wherein the mapper is interposed between the modulator and the coder and the mapper receives information from the coder and provides information to the modulator.***

**[0145]**    *See supra [10d].*

**Claim 21**

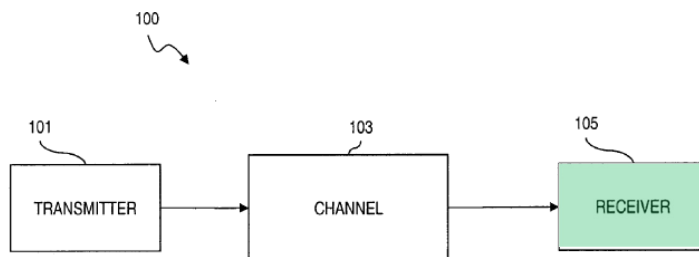
**[21pre] A communication system, comprising:**

**[0146]** See *supra* §§X.A.[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;**

**[0147]** For the reasons noted above in [1a] and [1c], EDC 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. LGE1004, ¶¶[0030]-[0036], [0058] [0076]-[0082], FIGS. 2A, 2B, 3, 10-11, 1 (reproduced below).

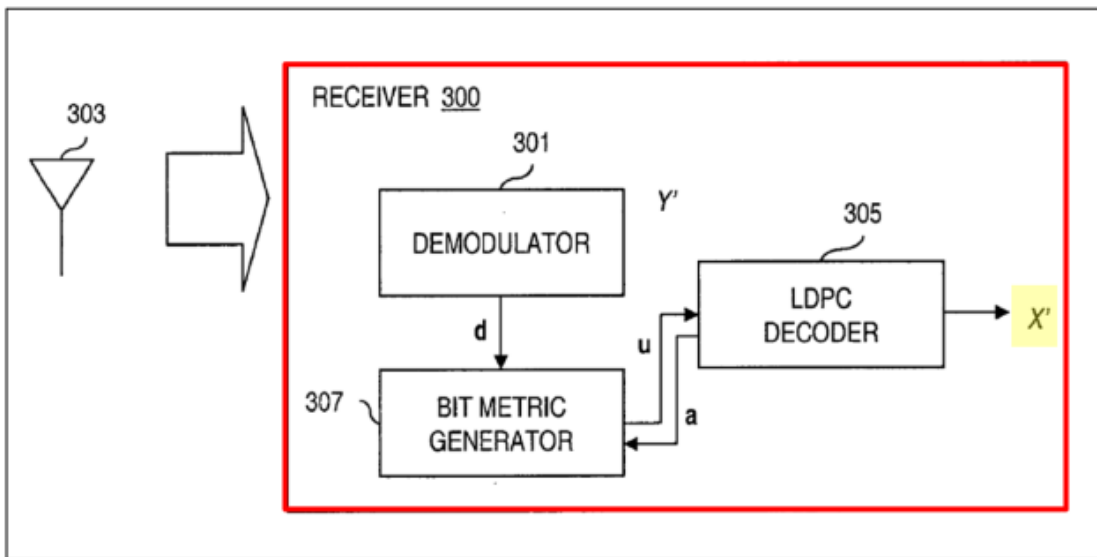
FIG. 1



LGE1004, FIG. 1

**[0148]** Moreover, as explained above in [1a]-[1d], Erozi also discloses “wherein the receiver uses a multidimensional symbol constellation to transform the

received signals into received bits.” For instance, by using its demodulator 301, demapper (bit metric generator 307), and decoder 305 (see Erož’s FIG. 3 below, which depicts a receiver), Erož’s receiver “reconstruct[s] the original source messages by generating messages, X’.” LGE1004, ¶¶[0035], [0058]. The messages would have been understood by a POSITA to be composed of the received bits. Indeed, Erož corroborates this understanding by teaching that the LDPC decoder 305 “is considered a message passing decoder, whereby the decoder 305 aims to find the *values of bit nodes*.” LGE1004, ¶¶[0061]-[0063], [0076]; *see also* FIGS. 10-11, ¶¶[0083]-[0107].



LGE1004, FIG. 3.

[0149] A POSITA would also have understood that EDC renders obvious “wherein the receiver uses a multidimensional symbol constellation to

transform the received signals into received bits” based on the teachings of DVB-T and the understanding a POSITA would have had of how receivers and transmitters in communication systems work. For instance, DVB-T discloses that “bitstreams are mapped onto the signal constellation by the Mapper and Modulator.” LGE1005, 9. In this manner, DVB-T’s transmitter, similar to Erož’s mapper, transforms bits to signals using a constellation. And recall that Ulrich explains that operations performed on the transmitter/encoder side have be reversed on the receiver/decoder side. LGE1008, 225. Accordingly, it would have been obvious to a POSITA that in the EDC system in which bits are transformed to signals using a constellation at the transmitter side, a receiver would have performed the opposite and transformed the received signals to received bits using a multidimensional symbol constellation. .

**[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;**

**[0150]** See *supra* §§X.A.[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.**

[0151] *See supra* §§X.A.[1f].

**Claim 28**

**[28] *The communication system of claim 21, wherein the receiver uses a demodulation scheme that is based on phase shift keying and the degrees of freedom available to the multidimensional symbol constellations are amplitude and phase.***

[0152] *See supra* [8].

**Claim 30**

**[30] *The communication system of claim 21, further comprising a transmitter that transmits signals via the communication channel, where the transmitter uses the selected multidimensional symbol constellation to transform encoded bits into the transmitted signals.***

[0153] *See supra* [10pre]-[10c].

**B. Ground 1B: Eroz and DVB-T and DeGaudenzi render claims 1, 6, 8, 10-11, 16, 18, 20-21, 26, 28, and 30 obvious**

**Claim 1**

[1pre]-[1e]

[0154] *See supra* §§X.A.[1pre]-[1e].

**[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.**

[0155] The mapping of claim 1 other than [1f] under Grounds 1A and 1B is the same. Although [1f] would have been obvious in view of the teachings of the EDC system, to the extent the obviousness of such a feature is disputed by the Patent Owner, EDC in combination with DeGaudenzi also renders [1f] obvious.

[0156] In particular, as described above in §IX.F, DeGaudenzi discloses optimizing the spectral efficiency or SNR of non-uniform symbol constellations by optimizing their parameters such as the location of the constellation points and the code rates. LGE1014, 279. For example, as shown in DeGaudenzi's Table I, the spectral efficiency/SNR of a number of 32-ary APSKs has been optimized. LGE1014, 271. Each 32-ary APSK in Table I has different  $\rho_2$  and  $\rho_3$  indicating that each of the listed constellations is a unique non-uniform constellation. LGE1014, 268.

16(4+12) Non-uniform  
symbol constellations points

Table I. Optimized constellation parameters for 16- ary and 32-ary APSK.

| Modulation order | Coding rate, $r$ | Spectral eff. (bps/Hz) | $\rho_1^{opt}$ | $\rho_2^{opt}$ | $\rho_3^{opt}$ |
|------------------|------------------|------------------------|----------------|----------------|----------------|
| 4 + 12-APSK      | 2/3              | 2.67                   | 3.15           | N/A            |                |
| 4 + 12-APSK      | 3/4              | 3.00                   | 2.85           | N/A            |                |
| 4 + 12-APSK      | 4/5              | 3.20                   | 2.75           | N/A            |                |
| 4 + 12-APSK      | 5/6              | 3.33                   | 2.70           | N/A            |                |
| 4 + 12-APSK      | 8/9              | 3.56                   | 2.60           | N/A            |                |
| 4 + 12-APSK      | 9/10             | 3.60                   | 2.57           | N/A            |                |
| 4 + 12 + 16-APSK | 3/4              | 3.75                   | 2.84           | 5.27           |                |
| 4 + 12 + 16-APSK | 4/5              | 4.00                   | 2.72           | 4.87           |                |
| 4 + 12 + 16-APSK | 5/6              | 4.17                   | 2.64           | 4.64           |                |
| 4 + 12 + 16-APSK | 8/9              | 4.44                   | 2.54           | 4.33           |                |
| 4 + 12 + 16-APSK | 9/10             | 4.50                   | 2.53           | 4.30           |                |

Constellation and predetermined code rate pair

32(4+12+16) Non-uniform  
symbol constellations points

LGE1014, Table I

[0157] It would have been obvious to a POSITA that when the teachings of DeGaudenzi (such as Table I) are incorporated into EDC's system (for the reasons I explained above in §IX.G), each of the plurality of different non-uniform multidimensional symbol constellations would only be included in one of the plurality of predetermined LDPC code rate and multidimensional symbol constellation pairs in EDC's system. For instance, there is only one 4+12+16 APSK constellation with  $\rho_2 = 2.72$  and  $\rho_3 = 4.87$  that is included in the list of predetermined constellation-code rate pairs.

[0158] As I had explained above in §IX.F, DeGaudenzi's teachings are broad, are not limited to APSKs, and can be applied to LDPC encoded signals and

QAM constellations. LGE1014, 262-264 (“[w]e propose new criteria for the design of digital QAM constellations of 16 and 32 points”). Accordingly, in the combination of EDC and DeGaudenzi, a table similar to DeGaudenzi’s Table I but with optimized 16-QAM or 64-QAM constellations and corresponding parameters (e.g., code rate,  $\alpha$ , spectral efficiency) would have been provided. Accordingly, EDC-De Gaudenzi renders [1f] obvious.

#### **Claim 6**

**[6] *The communication system of claim 1, wherein each of the plurality of different non-uniform multidimensional symbol constellations are characterized by the assignment of labels and spacing of constellation points so as to maximize parallel decoding capacity at a specific SNR subject to at least one constraint.***

[0159] Eroz teaches that signals received by its receiver use Gray mapping, which is a well-known method of coding in which two successive bit values differ by only one bit LGE1004, ¶[0058]. For example, Eroz teaches that “[w]hen Gray labeling is used, bit metrics are advantageously generated only once before the LDPC decoder.” LGE1004, ¶[0093]. It would have been obvious to a POSITA that when Gray labeling is used, points in a constellation would have been assigned labels based on the Gray mapping scheme (e.g., because successive points can only differ by one bit value).

[0160] It was also known in the art that Grey labeling can be used to maximize

parallel decoding capacity. LGE1006, 3 (“Gray labeling maximizes the [parallel decoding] capacity”). Thus, it would have been obvious to a POSITA that by assigning labels to points using Gray labeling, parallel decoding capacity was maximized in Eroz.

**[0161]** Moreover, as described above in [1pre]-[1f], EDC teaches configuring the constellations by using  $\alpha$ , which impacts the uniformity and spacing of the constellations. For example, as noted above in [1e], when  $\alpha=2$ , the constellation in the EDC system would have been a non-uniform 16-QAM or 64-QAM. Such QAMs would have been labeled based on the Gray labeling. Thus, EDC renders obvious “each of the plurality of different non-uniform multidimensional symbol constellations are characterized by the assignment of labels and spacing of constellation points so as to maximize parallel decoding capacity.”

**[0162]** As described above in Sections IX.F-IX.G, DeGaudenzi also teaches maximizing the parallel decoding capacity of constellations for a given spectral efficiency/SNR. LGE1014, 246, 266. More specifically, DeGaudenzi discloses that the locations and labels of non-uniform constellation points are assigned using Gray labeling and optimized using DeGaudenzi’s optimization technique to maximize parallel decoding capacity of the symbol constellation at a given SNR. LGE1014, 263, 266-269 (§3.2.2), 279 , FIG.1., FIG. 7. For instance, as

shown below in DeGaudenzi's Table I, each listed constellation has been optimized at a particular spectral efficiency Furthermore, DeGuadenzi Figure 5 shows the constellations (including their values of radii  $\rho$ ) that maximize the parallel capacity as a function of SNR.. and achieves a maximum parallel decoding capacity. As part of the optimization, the spacing of points is determined by the radii ratios ( $\rho_2$  and  $\rho_3$ ). It would have been obvious to a POSITA, that in a non-uniform QAM constellation, the spacing of points would have similarly been determined (though not necessarily through  $\rho$  values) to optimize spectral efficiency/SNR and maximize parallel decoding capacity.

#### 16(4+12) Non-uniform symbol constellations points

Table I. Optimized constellation parameters for 16- ary and 32-ary APSK.

| Modulation order | Coding rate, $r$ | Spectral eff. (bps/Hz) | $\rho_1^{opt}$ | $\rho_2^{opt}$ | $\rho_3^{opt}$ |
|------------------|------------------|------------------------|----------------|----------------|----------------|
| 4 + 12-APSK      | 2/3              | 2.67                   | 3.15           | N/A            | N/A            |
| 4 + 12-APSK      | 3/4              | 3.00                   | 2.85           | N/A            | N/A            |
| 4 + 12-APSK      | 4/5              | 3.20                   | 2.75           | N/A            | N/A            |
| 4 + 12-APSK      | 5/6              | 3.33                   | 2.70           | N/A            | N/A            |
| 4 + 12-APSK      | 8/9              | 3.56                   | 2.60           | N/A            | N/A            |
| 4 + 12-APSK      | 9/10             | 3.60                   | 2.57           | N/A            | N/A            |
| 4 + 12 + 16-APSK | 3/4              | 3.75                   | 2.84           | 5.27           |                |
| 4 + 12 + 16-APSK | 4/5              | 4.00                   | 2.72           | 4.87           |                |
| 4 + 12 + 16-APSK | 5/6              | 4.17                   | 2.64           | 4.64           |                |
| 4 + 12 + 16-APSK | 8/9              | 4.44                   | 2.54           | 4.33           |                |
| 4 + 12 + 16-APSK | 9/10             | 4.50                   | 2.53           | 4.30           |                |

Constellation and predetermined code rate pair

#### 32(4+12+16) Non-uniform symbol constellations points

LGE1014, Table I

[0163] In the EDC-DeGaudenzi system, a table similar to Table I would have

been generated and would have listed each of the plurality of different non-uniform multidimensional symbol constellations (e.g., non-uniform 16 QAM), a corresponding coding rate, the specific spectral efficiency or SNR, and the location of the points in the QAM. Gray labeling would have been used to assign labels to each point. In this manner, the EDC-DeGaudenzi combination would have rendered obvious the “plurality of different non-uniform multidimensional symbol constellations are characterized by the assignment of labels and spacing of constellation points so as to maximize parallel decoding capacity at a specific SNR,” as recited in claim 6.

[0164] DeGaudenzi also teaches that its optimization method for maximizing parallel decoding capacity *is subject to at least one constraint*. DeGaudenzi utilizes multiple constraints (e.g., a given SNR, a given constellation size, a number of rings, a number of constellations points in the each ring, mutual information, conditional entropy, peak-to-average power ratio, and an assumption of “equiprobable symbols”) in implementing its optimization method. LGE1014, 266 (Section 3.2.2 Mutual information maximization). DeGaudenzi’s optimization method is also subject to an optimization constraint on average power of the symbol constellation such that  $E[|x|^2] = 1$ . LGE1014, 263-264. DeGaudenzi expressly states that “[f]urther work on mutual

information for modulations *with average and peak power constraints* is reported in Reference [8].” *Id.*, 262.

[0165] For at least the foregoing reasons, the EDC-DeGaudenzi combination renders [6] obvious.

**Claim 16**

[16] *The communication system of claim 11, wherein each of the plurality of different non-uniform multidimensional symbol constellations are characterized by the assignment of labels and spacing of constellation points so as to maximize parallel decoding capacity at a specific SNR subject to at least one constraint.*

[0166] *See supra* [6].

**Claim 26**

[26] *The communication system of claim 21, wherein each of the plurality of different non-uniform multidimensional symbol constellations are characterized by the assignment of labels and spacing of constellation points so as to maximize parallel decoding capacity at a specific SNR subject to at least one constraint.*

[0167] *See supra* [6].

**Claims 8, 10-11, 18, 20-21, 28, and 30**

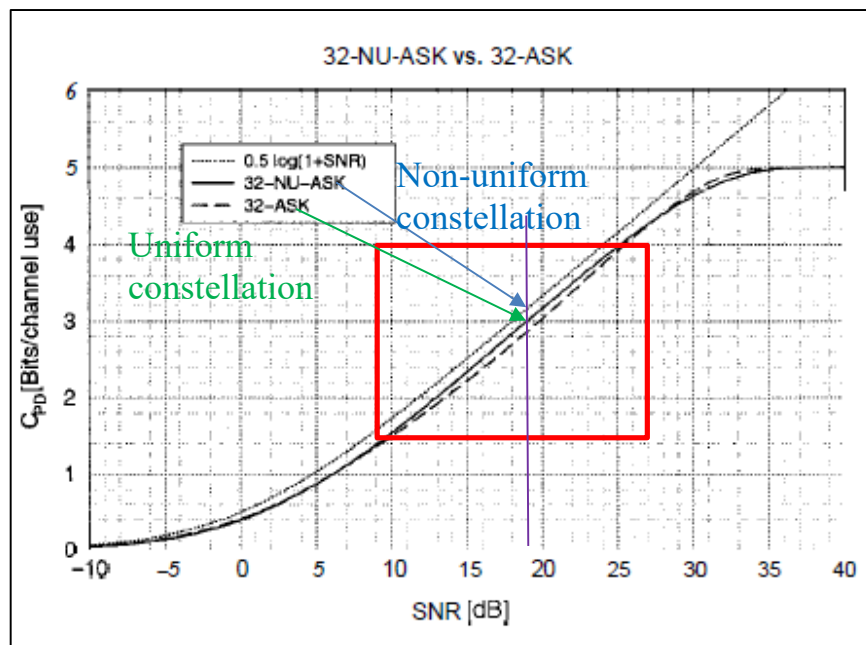
[0168] Claims 8, 10-11, 18, 20-21, 28, and 30 are obvious under Ground 1B for the same reasons noted above in Ground 1A (§§X.A) for these claims.

**C. Ground 2A: EDC and Sommer render claims 4, 14, and 24 obvious**

**Claim 4**

**[4/ 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 a similar multidimensional symbol constellation at the same SNR, where the similar multidimensional symbol constellation differs only in that the constellation points in the similar multidimensional symbol constellation are uniformly spaced in each degree of freedom.**

**[0169]** Sommer teaches that the parallel decoding capacity of a non-uniform constellation is greater than a similar uniform constellation at the same SNR. For example, Sommer compares the performance of “non-uniform signal set constellation[s]” (e.g., NU-QAM or NU-ASK) with uniform constellations (e.g., classical QAM and ASK), using BICM or parallel decoding (PD) capacity. See LGE1006, 3 (“we use the term PD for BICM”). FIG. 3(b) shows the PD capacity for 32-NU-ASK versus 32-ASK constellations. LGE1006, 2-4.



**[0170]** As shown above in FIG. 3(b), the parallel decoding capacity of the non-uniform constellation (32-ASK / 1024-QAM) is greater than the parallel decoding capacity of a similar uniform constellation at the same SNR. For example, at a SNR of 20 dB, the non-uniform constellation has a greater parallel decoding capacity than the uniform constellation. Relatedly, Sommer's Table 3 also explains that the required SNR for non-uniform constellations is almost 0.5-1 dB less than the required SNR for uniform constellations, confirming that non-uniform constellations can provide better SNR and parallel decoding capacity performance compared to their uniform constellation counterparts. For example, this table shows that for  $R = 0.5$  (code rate =  $\frac{1}{2}$ ), with a 16-ASK signal, which corresponds to a capacity of 2 bits/symbol, that the non-uniform constellation (NU-ASK) improves on the uniform constellation (ASK) by 0.5 dB in SNR (13.25 dB – 12.75 dB). Equivalently, for specific SNR = 13.25 dB,  $C_{PD} > 2$  for the NU-ASK, which is larger than  $C_{PD} = 2$  for the ASK.

| SNR (dB)          | $C_{SS}(\text{NU-ASK})$ | $C_{SS}(\text{ASK})$ |
|-------------------|-------------------------|----------------------|
| 16-ASK (256-QAM)  | 11.94                   | 12.53                |
| 32-ASK (1024-QAM) | 15.05                   | 15.87                |
| 64-ASK (4096-QAM) | 18.10                   | 19.10                |
|                   | $C_{PD}(\text{NU-ASK})$ | $C_{PD}(\text{ASK})$ |
| 16-ASK (256-QAM)  | 12.75                   | 13.25                |
| 32-ASK (1024-QAM) | 15.96                   | 16.77                |
|                   |                         |                      |

Table 3. Capacity at  $R = 0.5$

LGE1006, Table 3

[0171] In view of the foregoing, it would have been obvious to a POSITA that in the EDC-Sommer system in which constellations can be further optimized for shaping gains consistent with Sommer's teachings, *"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 a similar multidimensional symbol constellation at the same SNR, where the similar multidimensional symbol constellation differs only in that the constellation points in the similar multidimensional symbol constellation are uniformly spaced in each degree of freedom."*

**Claim 14**

**[14] *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 a similar multidimensional symbol constellation at the same SNR, where the similar multidimensional symbol constellation differs only in that the constellation points in the similar multidimensional symbol constellation are uniformly spaced in each degree of freedom.***

**[0172]**    *See supra* [4].

**Claim 24**

**[24] *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 a similar multidimensional symbol constellation at the same SNR, where the similar multidimensional symbol constellation differs only in that the constellation points in the similar multidimensional symbol constellation are uniformly spaced in each degree of freedom.***

**[0173]**    *See supra* [4].

**D. Ground 3A: EDC and DVB-S2 render claims 7, 17, and 27 obvious**

**Claim 7**

**[7a] *The communication system of claim 1, wherein: the receiver is capable of measuring the quality of the communication channel;***

**[0174]**    DVB-T explains that data received by the receiver includes scattered pilot

cells, continual pilot carriers, TPS carriers, and that these pilots can be used for various purposes, including, channel estimation. LGE1005, 24. Similarly, DVB-S2 states that when utilizing “ACM modes, the receiver shall signal the reception quality via an available return channel...” LGE1009, 52. A POSITA would have understood that channel estimation is one method of measuring the quality of the communication channel, especially where the magnitude or square-magnitude of the pilot or channel is indicative of the SNR (CNI) of the channel. This understanding is corroborated by Ulrich, a textbook on Digital Video Broadcasting, which explains that “the receiver will be able to perform a nearly continuous analysis of the frequency and the temporal plane, which can be used for the evaluation of the current channel condition (‘channel estimation’)” using pilots. ; LGE1008, 253, 255-256, 265. For example, Ulrich explains that various estimation techniques can be used to measure “the channel frequency response for attenuation and phase ... on the basis of the continual pilots and on the scattered pilots.” *Id.*

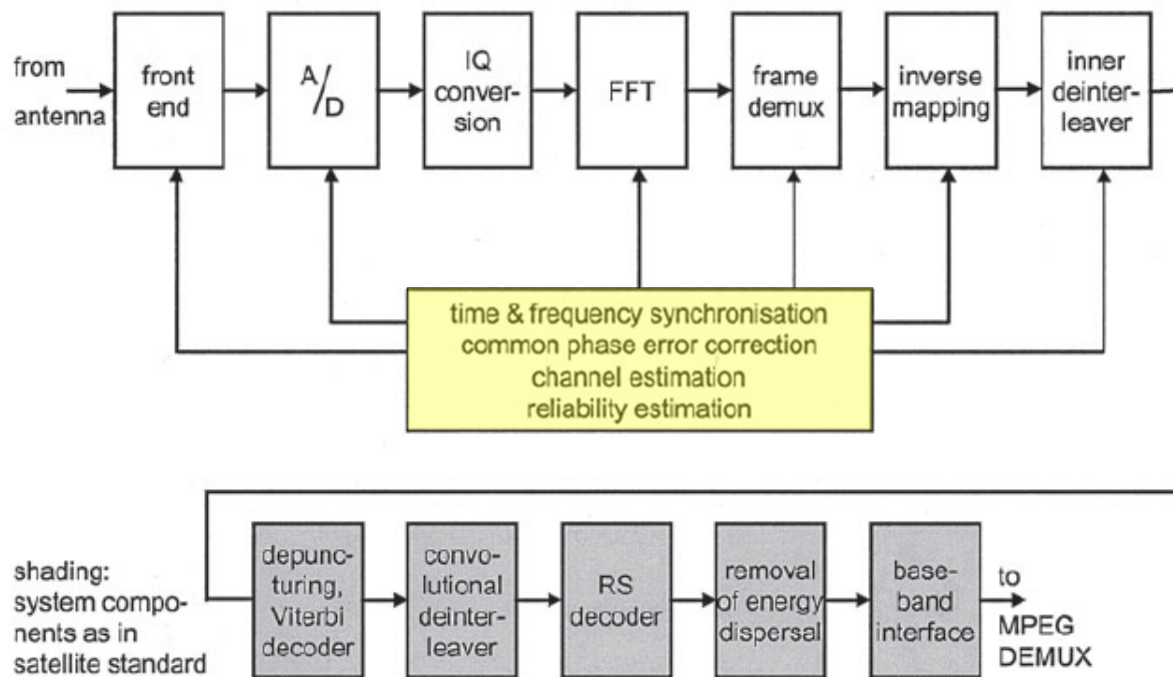


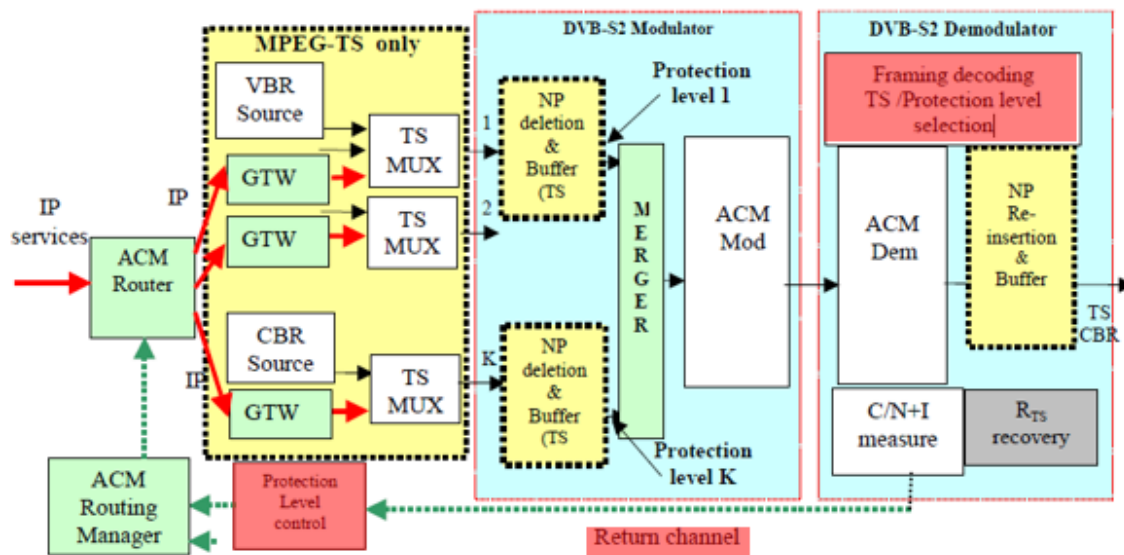
**Fig. 11.6.** Block diagram of signal processing at the receiving end

LGE1008, 255.

**[7b]** *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 based at least in part on a quality measurement;*

**[0175]** DVB-T explain that TPS signaling information is used by the receiver to configure itself to receive data from the transmitter. LGE1008, 254, LGE1005, 29-31. For instance, the receiver uses bits  $s_{25}$ - $s_{32}$  to select a modulation type,  $\alpha$  value, and code rate. LGE1005, 29-32. As noted above in [7a], the receiver also performs channel estimation to determine channel frequency response for attenuation and phase. LGE1008, 253, 255-256, 265. DVB-S2 teaches the use

of Variable Coding Rate (VCM) and a return channel (as shown in DVB-S2's Figure H.8 below) to create Adaptive Coding and Modulation (ACM). *Id.*, 6. The ACM method utilizes the received signal quality to affect the coding and modulation scheme of the channel. *Id.*, 69.



LGE1009, 69 (Figure H.8).

[0176] “In ACM modes, the receiver shall signal the reception quality via an available return channel.” LGE1009, 52. “The receiver shall evaluate quality-of-reception parameters, in particular carrier to noise plus interference ratio in dB available at the receiver.” LGE1009, 53. “CNI and other optional reception quality parameters (such as for example the BER on the channel”) can be evaluated. “A possible method to evaluate CNI is by using symbols known a-

priori at the receiver, such as those in the SOF field of the PLFRAME Headers and, when available, pilot symbols.” *Id.* The receiver then selects MODCOD information and sends the MODCOD information (in a request message MODCOD\_RQ) along with the CNI through an ACM command to a transmitter (gateway). LGE1009, 53, 48. The MODCOD information includes 5 bits set according to Table 12 (reproduced below) that “identify[ ] code rates in the set  $\eta_C = [1/4, 1/3, 2/5, 1/2, 3/5, 2/3, 3/4, 4/5, 5/6, 8/9, 9/10]$  and modulations in the set of spectrum efficiencies  $\eta_{MOD} = [2, 3, 4, 5]$ .” *Id.*, 29.

**Table 12: MODCOD coding**

| Mode     | MOD COD        | Mode      | MOD COD         | Mode        | MOD COD         | Mode          | MOD COD         |
|----------|----------------|-----------|-----------------|-------------|-----------------|---------------|-----------------|
| QPSK 1/4 | 1 <sub>D</sub> | QPSK 5/6  | 9 <sub>D</sub>  | 8PSK 9/10   | 17 <sub>D</sub> | 32APSK 4/5    | 25 <sub>D</sub> |
| QPSK 1/3 | 2 <sub>D</sub> | QPSK 8/9  | 10 <sub>D</sub> | 16APSK 2/3  | 18 <sub>D</sub> | 32APSK 5/6    | 26 <sub>D</sub> |
| QPSK 2/5 | 3 <sub>D</sub> | QPSK 9/10 | 11 <sub>D</sub> | 16APSK 3/4  | 19 <sub>D</sub> | 32APSK 8/9    | 27 <sub>D</sub> |
| QPSK 1/2 | 4 <sub>D</sub> | 8PSK 3/5  | 12 <sub>D</sub> | 16APSK 4/5  | 20 <sub>D</sub> | 32APSK 9/10   | 28 <sub>D</sub> |
| QPSK 3/5 | 5 <sub>D</sub> | 8PSK 2/3  | 13 <sub>D</sub> | 16APSK 5/6  | 21 <sub>D</sub> | Reserved      | 29 <sub>D</sub> |
| QPSK 2/3 | 6 <sub>D</sub> | 8PSK 3/4  | 14 <sub>D</sub> | 16APSK 8/9  | 22 <sub>D</sub> | Reserved      | 30 <sub>D</sub> |
| QPSK 3/4 | 7 <sub>D</sub> | 8PSK 5/6  | 15 <sub>D</sub> | 16APSK 9/10 | 23 <sub>D</sub> | Reserved      | 31 <sub>D</sub> |
| QPSK 4/5 | 8 <sub>D</sub> | 8PSK 8/9  | 16 <sub>D</sub> | 32APSK 3/4  | 24 <sub>D</sub> | DUMMY PLFRAME | 0 <sub>D</sub>  |

LGE1009, 29.

[0177] It would have been obvious to a POSITA that to signal MODCOD information to the transmitter, the receiver would have to select a constellation and code rate pair first. Such a selection would, in part, be based on a quality measurement such as the CNI. For example, the DVB-T standard specifies bit-

error rates as a function of the modulation and coding and the CNI. LGE1005, 39. Accordingly, in the EDC-DVB-S2 combination, it would have been obvious to a POSITA that the receiver is capable of selecting parameters, such as the constellation and LDPC code rate pair based at least in part on the CNI and related channel estimation measurements (“*at least in part on a quality measurement*”).

[0178] In addition to the above, the receiver in the EDC-DVB-S2 system may also perform a selection of an LDPC code rate and multidimensional symbol constellation pair from a plurality of predetermined LDPC code rate and multidimensional symbol constellation pairs based on the TPS signaling information, as explained above in Sections IX.B, IX.C, [1c], and [1f]. LGE1005, 29-32, 40.

**[7c] *the receiver is capable of sending a request to a remote transmitter to use a selected LDPC code rate and multidimensional symbol constellation pair.***

[0179] DVB-S2 teaches that “the receiver shall signal the reception quality via an available return channel, according to the various DVB interactive systems.” LGE1009, 52. As explained above, DVB-S2 teaches that “[t]he receiver shall evaluate quality-of-reception parameters, in particular carrier to noise plus interference ratio in dB available at the receiver, indicated as CNI,” and that

MODCOD and other parameter information would be sent to a transmitter (gateway device). LGE1009, 53; *See supra* [7b]. “As a minimum, the CNI and MODCOD\_RQ parameters shall be sent to the satellite network operator Gateway every time the protection on the DVB-S2 channel has to be changed. When no modification of the protection level is requested, the optional message from the terminal to the Gateway shall indicate MODCOD\_RQ = actual MODCOD and pilot configuration of the frames received by the terminal.” *Id.*; *see also* LGE1009, 67, 69. “[T]he gateway may acknowledge the reception of the message and the execution of the command by a message containing the new adopted MODCOD, coded according to table 12” (reproduced above). LGE1009, 53.

[0180] Accordingly, it would have been obvious to a POSITA that EDC-DVB-S2’s receiver is capable of determining the quality of the received signal, determining a level of protection desired (modulation and code rate), and sending a request (MODCOD\_RQ) to a remote transmitter to use a selected LDP code rate and multidimensional constellation pair. LGE1009, 48, 66-69.

### **Claim 17**

[17a] *The communication system of claim 11, wherein: the receiver measures the quality of the communication channel;*

[0181] *See supra* [7a].

[17b] *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 based at least in part on a quality measurement;*

[0182] *See supra* [7b].

[17c] *the receiver sends a request to a remote transmitter to use a selected LDPC code rate and multidimensional symbol constellation pair.*

[0183] *See supra* [7c].

#### **Claim 27**

[27a] *The communication system of claim 21, wherein:  
the receiver measures the quality of the communication channel;*

[0184] *See supra* [7a].

[27b] *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 based at least in part on a quality measurement; and*

[0185] *See supra* [7b].

[27c] *the receiver sends a request to a remote transmitter to use a selected LDPC code rate and multidimensional symbol constellation pair.*

[0186] *See supra* [7c].

**E. Ground 4A: EDC and DVB-TS, render claims 9, 19, and 29 obvious**

**Claim 9**

**[9] *The communication system of claim 1, wherein the receiver is capable of substituting the plurality of multidimensional symbol constellations by an upgrade to at least one of the receiver software and firmware.***

**[0187]** DVB-TS discloses that “[r]eceiver software is increasingly complex. In order to guarantee the functionality of a receiver as well as increasing its functionality once deployed in the field a software update service is required. The present document specifies a standard mechanism for signalling a software update service and the means to carry the data for such a software update service.” LGE1013, 7.

**[0188]** A POSITA would have understood that to keep the receiver software updated and continue to “increase[e] its functionality” (see LGE1013, 7), various aspects of the receiver software would have been continuously or periodically updated. A POSITA would have been understood that with the progression of technology over time, higher modulation rates, bit rates, code rates, and different constellation types would be introduced or used in the network to increase the receiver’s functionality and keep it updated. In addition, changes in network configuration, devices, and environment may also require different constellations to be used. Thus, a POSITA interested in increasing the

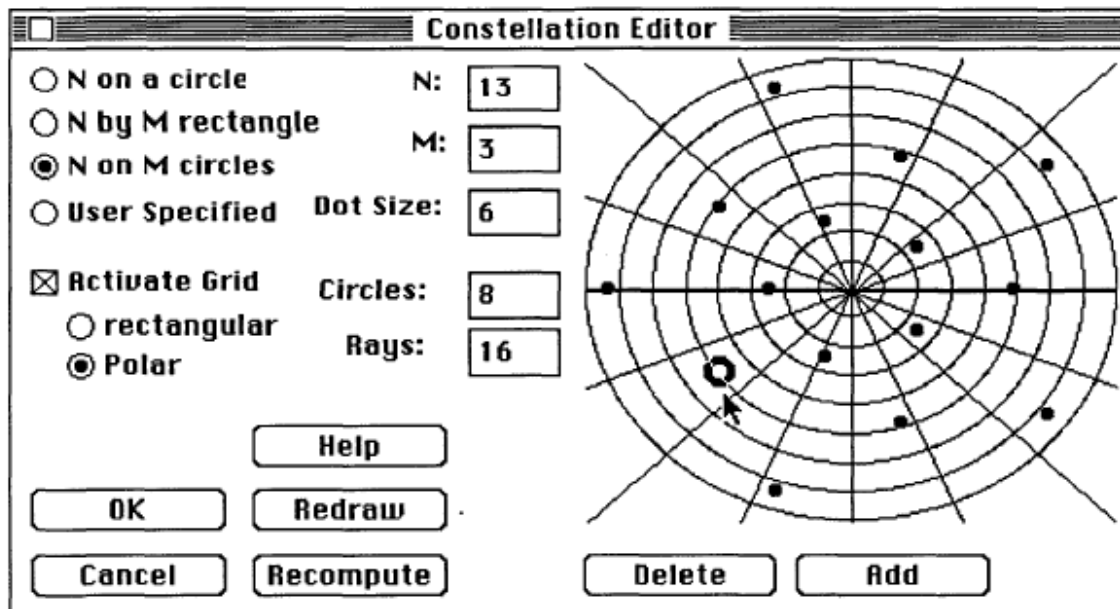
functionality and use of the receiver in EDC's communication system would have incorporated the teachings of DVB-TS to allow the receiver to update software over time to remain consistent with current technology and operating conditions.

**[0189]** It would also have been obvious to a POSITA that a receiver's software includes various programs and files including programs and files used to configure the constellations that the receiver is capable of receiving and processing. Accordingly, it would have been obvious to a POSITA that that an update to software in a receiver would have also included an update of the constellations used by the receiver. For example, as previously-used constellations ("*the plurality of multidimensional symbol constellations*") are no longer used, such constellations would have been substituted by other, newer, or more suitable constellations "*by an upgrade to at least one of the receiver software and firmware.*" Again as Ulrich states: "NIMs from various manufactures can be interchanged. The control software needs to be adapted, which usually is rather simply done..." *Id.*, 267 Because of this, a POSITA would have found it obvious to utilize the teachings of DVB-TS in combination with EDC to achieve this outcome.

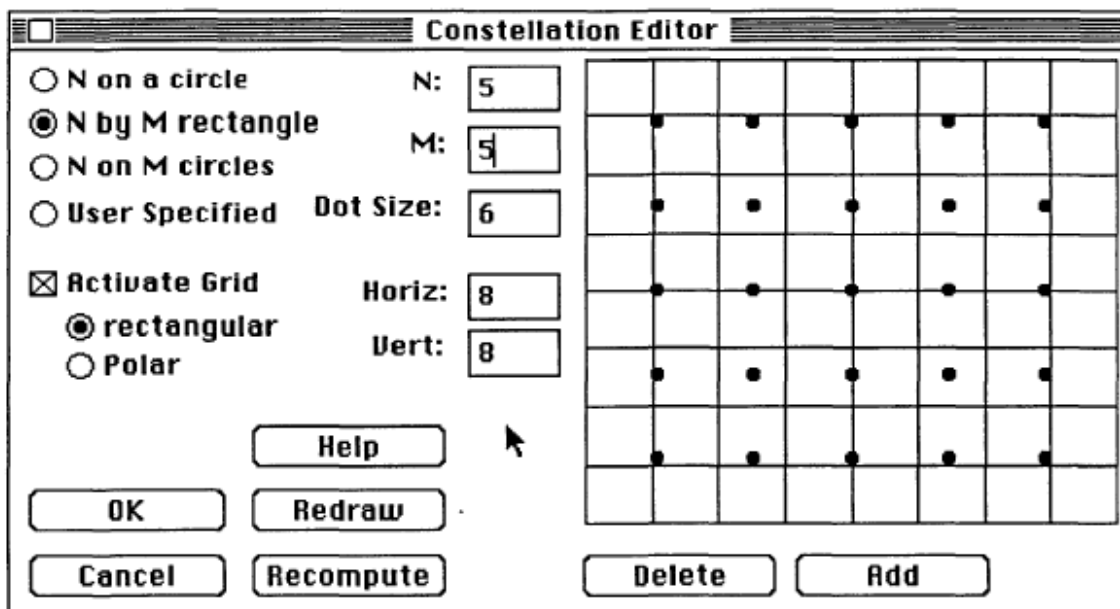
**[0190]** Although it is well known that software can be used to configure and

design constellations, to the extent such knowledge in the art is challenged as known by the Patent Owner, Robins, a published conference paper, explicitly discloses that constellations can be configured and designed through software. LGE1016, 1. Robins explains that “the actual code that simulates signal constellations is rather trivial.” LGE1016, 1.

**[0191]** According to Robins, “[s]ignal constellation design is a major part of constructing an efficient communication system. This task essentially entail trading off error frequency against information throughput...” LGE1016, 1. In particular, Robins “signal constellation design tool” can be used to design constellations of various shapes and sizes. *Id.*, 5. Robins discloses “an interactive [software] tool for designing and simulating arbitrary signal constellations.” *Id.*, 1. Robins explains that constellations can be designed to address concerns about the “...effects of noise and other kind of interference on the system... .” *Id.*, 2. As noted above, Robins explains that “the actual code that simulates signal constellations is rather trivial.” *Id.*, 1. The figures represented below depict portions of Robins’ user interface used to design constellations.



LGE1016, 5.



LGE1016, 6.

[0192] As shown by Robins' figures, software can be used to control the type of constellation, the number of points, and various other design aspects of constellations. Robins discloses that constellation design changes are made by software. And because constellation design would have been an obvious part of a receiver's software, the combination of EDC and DVB-TS (and its teachings of software updates in receivers) would have rendered obvious a receiver that is capable of substituting the plurality of multidimensional symbol constellations by an upgrade to at least one of the receiver software and firmware.

**Claim 19**

**[19] *The communication system of claim 11, wherein the receiver can substitute the plurality of multidimensional symbol constellations by an upgrade to at least one of the receiver software and firmware.***

[0193] See *supra* [9].

**Claim 29**

**[29] *The communication system of claim 21, wherein the receiver can substitute the plurality of multidimensional symbol constellations by an upgrade to at least one of the receiver software and firmware.***

[0194] See *supra* [9].

## **F. Grounds 2B-4B**

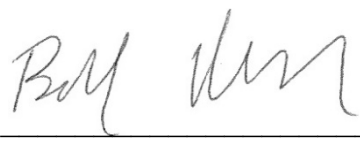
**[0195]** Grounds 2B-4B render claims [4], [7], [9], [14], [17], [19], [24], [27], and [29] obvious for the same reasons noted under Grounds 2A-4A (§§X.C-X.E). In particular, Grounds 2B-4B address dependent claims that depend from the independent claims that have been mapped to the prior art references under Grounds 1A and 1B. Relative to Ground 1A, Ground 1B additionally addresses claims 6, 16, and 26, and also relies on DeGaudenzi to map to feature [1f], [11g], and [21c]. And because the claims addressed under Grounds 2A-4B include claims depending from the independent claims challenged in Grounds 1A and 1B, Grounds 2B-4B are similar to Grounds 2A-4A but additionally include DeGaudenzi as part of the asserted combination.

## **XI. CONCLUSION**

**[0196]** All the Challenged Claims are obvious in view of the above-noted grounds and references.

**[0197]** 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 8, 2022

BY: \_\_\_\_\_

Bertrand Hochwald

# **APPENDIX A**

**Bertrand M. Hochwald**

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**Degrees:**

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

**Experience:**

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

**Honors:**

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

**Honors (cont'd):**

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

**Research Gifts, Grants and Contracts:**

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

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

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

**Patents:**

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

**Patents (cont'd):**

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

**Patents (cont'd):**

“Adaptive Transmit Beamforming for Frequency Division Duplexing Systems,”

#9537684, January 3, 2017.

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

#10819405, October 27, 2020.

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

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

- “Multiple Antennas: How a Point-to-Point Advantage Becomes a Multi-user Advantage.” Plenary Speaker at the *22nd Biennial Symposium on Communications*, Queens University, Kingston, Ontario, June 2004.
- “A Random-Channel Graph-Theoretic Perspective of Wireless Networks.” Plenary Speaker at the *2006 Seventh Annual IEEE Workshop on Signal Processing Advances in Wireless Communication*, Cannes, France, July 2006.
- “The Role of MIMO in Fourth-Generation Mobile Wireless Systems and Beyond.” Plenary Speaker at the *2009 IEEE Communication Theory Workshop*, Napa, California, May 2009.
- “What Have We Learned So Far About MIMO in Mobile Wireless Systems?” Plenary Speaker at the *2009 Tenth Annual IEEE Workshop on Signal Processing Advances in Wireless Communication*, Perugia, Italy, June 2009.
- “Bandwidth of Large-Scale Multiport Radio-Frequency Systems.” Plenary Speaker at the *20th International ITG Workshop on Smart Antennas*, Munich, Germany, March 2016.
- “Building a Better Phone,” University of Notre Dame web page feature story, 2016:  
<https://www.nd.edu/stories/building-a-better-phone/>
- “Notre Dame Researchers Target Cell Phone Radiation,” WSBT television feature story, 2016:  
<https://wsbt.com/news/local/notre-dame-researchers-target-cell-phone-radiation>.  
<https://engineering.nd.edu/news-publications/engineering-in-the-news/notre-dame-researchers-target-cell-phone-radiation>
- Principle Investigator for the *RadioHound Spectrum Sensing System*, 2015–present:  
<https://wireless.nd.edu/research/radiohound-distributed-spectrum-sensing>

## Editorial, Panelist, and Professional Service Activities

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

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

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

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

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

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

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

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

## University Service Activities

Graduate Admissions Committee, 2012–present.

Graduate Committee, 2012–2013, 2016–2018.

College Council, 2014–2017.

Committee for Appointments and Promotions, 2016–2017.

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

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

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

**Past Co-Advised PhD Students:**

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

**MS and PhD Students at University of Notre Dame:**

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

**Courses, Book Chapters, Tutorials**

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

## Theses and Journal Papers

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

## Journal Papers (cont'd)

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

## Journal Papers (cont'd)

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

### Journal Papers (cont'd)

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

## Conference Papers

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

## Conference Papers (cont'd)

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