UNITED STATES PATENT AND TRADEMARK OFFICE

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BEFORE THE PATENT TRIAL AND APPEAL BOARD

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CISCO SYSTEMS, INC.,
Petitioner

U.S. Patent No. 8,441,721

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DECLARATION OF DR. DANIEL BLUMENTHAL, UNDER 37 C.F.R. § 1.68 IN SUPPORT OF PETITION FOR *INTER PARTES* REVIEW

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I, Daniel Blumenthal, do hereby declare as follows:

I. INTRODUCTION

1. I am making this declaration at the request of Cisco Systems, Inc. in the matter of the *Inter Partes* Review of U.S. Patent No. 8,441,721 ("the '721 patent") to White *et al*.

2. I am being compensated for my work in this matter at my usual hourly rate for this work. I am also being reimbursed for reasonable and customary expenses associated with my work and testimony in this investigation. My compensation is not contingent on the outcome of this matter or the specifics of my testimony.

3. I have been asked to provide my opinions regarding whether claims 1, 2, 4, 6, 19, and 21 ("the Challenged Claims") of the '721 patent are unpatentable as they would have been obvious to a person having ordinary skill in the art ("POSITA") at the time of the alleged invention, in light of the prior art. It is my opinion that all of the limitations of the Challenged Claims would have been obvious to a POSITA.

4. In the preparation of this declaration, I have studied:

a. the '721 patent, Ex.1001;

b. the prosecution history of the '721 patent ("'721 File History"), Ex.1002; and

c. U.S. Patent Publication No. 2004/019615 to Sugaya et al. ("Sugaya"), Ex.1005;

5. In forming the opinions expressed below, I have considered:

the documents listed above;

the relevant legal standards, including the standard for obviousness, and any additional authoritative documents as cited in the body of this declaration; and

my own knowledge and experience based upon my work in the field of optical communication as described below, as well as the following materials:

a. U.S. Patent No. 6,069,719 to Mizrahi ("Mizrahi"), Ex.1006;

b. "Optical Pump Control of Broadband Raman Amplifiers via Linear Programming," Roland W. Freund, Bell Labs Technical Memorandum, 2003 ("Freund"), Ex.1007;

c. "Optimal Design of Flat-Gain Wide-Band Fiber Raman Amplifiers," Victor E. Perlin et al. Journal of Lightwave Technology, Vol. 20, No. 2, February 2002 ("Perlin"), Ex.1008; and

d. "Flat-Gain Fiber Raman Amplifiers Using Equally Spaced Pumps," Jonathan Hu et al. Journal of Lightwave Technology, Vol. 22, No. 6, June 2004 ("Hu"), Ex.1009.

e. "Linear Algebra and its Applications," David C. Lay, 1997 ("Linear Algebra"), Ex.1010; and

f. "McGraw Hill Dictionary of Scientific and Technical Terms, Fifth Edition," 1994, Ex.1011.

6. Unless otherwise noted, all emphasis in any quoted material has been added.

II. QUALIFICATIONS AND PROFESSIONAL EXPERIENCE

7. My qualifications and professional experience are described in my *Curriculum Vitae*, a copy of which can be found in Exhibit 1004. The following is a brief summary of my relevant qualifications and professional experience.

8. My education and my experience in this and related areas span 42 years of professional and academic experience.

9. I am considered a pioneer in optical communications, packet switching, and integrated photonic and optical devices and several other optical application areas, each of which have some relationship to the subjects involved.

10. I received a B.S. degree in Electrical Engineering from the University of Rochester, Rochester, New York, in 1981, an M.S. degree in Electrical Engineering from Columbia University, New York, in 1988, and a Ph.D. degree in Electrical Engineering from the University of Colorado, Boulder, in 1993. From 1981 until 1984, I worked as an engineer at StorageTek, Louisville, Colorado, on

one of the world's first optical data storage products. From 1984 to 1985 I worked as a Senior Engineer at Sievers Research in the area of optical spectroscopy. From 1985 - 1988, I worked at Columbia University as a research engineer in the Center for Telecommunications, in the area of ultra-fast optical fiber communications and optical packet switching while pursuing at the same time my Masters degree in Electrical Engineering. While at Columbia I built one of the world's first optical packet switches. The Telecommunications Center was one of the National Science Foundation centers of excellence that launched the modern form of telecommunications networks layered communications and spawned a wide range of research from multi-media communications, to packet communications, to optical communications and network layered architectures. From 1988 to 1990 I worked in the Distributed Computing Systems Laboratory at the University of Pennsylvania. From 1990 I worked as a graduate student researcher while pursuing my PhD in the Optoelectronic Computing Center at the University of Colorado Boulder, where I built one of the world's first self-routing optical packet switches. From 1993 to 1997, I was an assistant professor in the School of Electrical and Computer Engineering at the Georgia Institute of Technology in Atlanta where I built a program in optical communications and packet switching and my focus on research in optical packet switching, optical network, optical wavelength conversion using semiconductor optical amplifiers (SOAs), optical label switching

and other related technologies led to groundbreaking innovations in these areas.

11. I am currently a Distinguished Professor in the Department of Electrical and Computer Engineering at the University of California, Santa Barbara (UCSB). I also serve as the Director of the Terabit Optical Ethernet Center (TOEC). My research areas are in optical communications, photonic packet switching and all-optical networks, all-optical wavelength conversion and regeneration, ultra-fast communications, indium phosphide Photonic Integrated Circuits (PICS) and nano-photonic device technologies.

12. I have authored or co-authored over 535 journal and conference publications, hold 23 issued US patents, and am a co-author of one book, Tunable Laser Diodes and Related Optical Sources (New York: IEEE–Wiley, 2005) as well as seven other book chapters. I have published multiple invited papers in world-re-known journals including two invited papers in the prestigious, broadly read, Proceedings of the IEEE and one invited paper in the prestigious broadly read Scientific American magazine. The Proceedings of the IEEE is the leading IEEE journal that provides in-depth review, survey, and tutorial coverage of the technical developments across all engineering areas including electronics, electrical and computer engineering, and computer science and is ranked as one of the top journals by Impact Factor, Article Influence Score and serves as a resource for engineers around the world. The first invited paper published in the Proceedings

was entitled "Photonic Packet Switches: Architectures and Experimental Implementations" in the 1994 special issue on Optical Computing Systems and is the highest cited paper in that special issue. The second invited paper in the Proceedings is in the 2018 Special Issue on Silicon Photonics entitled "Silicon Nitride in Silicon Photonics." In 2000, I was invited to write a seminal paper entitled "Routing Packets with Light," that appeared in the January 2001 issue of Scientific American, a popular science magazine that has had many famous scientists contribute, and with 170 years is the oldest continuously published monthly magazine in the United States.

13. I have served as the principal investigator for multiple large-scale research programs funded by the Defense Advanced Research Projects Agency (DARPA).

14. At the national scale, I contributed to multiple US based fiber optic Internet backbone projects. I served on the Board of Directors for National LambdaRail (NLR), a nation-wide fiber backbone, from 2003-2010. I was an elected Board Member for the Internet-2 Architecture & Operations Advisory Council from 2008-2012.

15. In addition to my industry experience at StorageTek and Sievers, I have co-founded three companies, Packet Photonics, Inc., Calient Technologies, Inc, and SiNoptiq, Inc.. Packet Photonics, Inc. provided network and data center

operators with photonic integrated wavelength tunable solutions to implement, install, operate, and maintain networks. Calient Technologies, Inc. provides software enabled adaptive MEMS mirror based photonic switching systems that enable dynamic optical layer switching and optimization. SiNoptiq provides integrate of lasers and optical technologies on chip to enable portable, low weight, and low power precision applications for communications, computing, position, and nagivigation.

16. I was elected as a Fellow of the National Academy of Inventors (NAI) in 2017. From the NAI website: "The program has 1,060 Fellows worldwide representing more than 250 prestigious universities and governmental and non-profit research institutes. Collectively, the Fellows hold more than 38,000 issued U.S. patents, which have generated over 11,000 licensed technologies and companies, and created more than 36 million jobs. In addition, over $1.6 trillion in revenue has been generated based on NAI Fellow discoveries. With the induction of the 2018 class, there are now more than 125 presidents and senior leaders of research universities and non-profit research institutes, 502 members of the National Academies of Sciences, Engineering, and Medicine; 40 inductees of the National Inventors Hall of Fame, 57 recipients of the U.S. National Medal of Technology and Innovation and U.S. National Medal of Science, 34 Nobel Laureates, 3 Queen Elizabeth Prize for Engineering recipients, 304 AAAS Fellows,

200 IEEE Fellows, and 164 Fellows of the American Academy of Arts & Sciences, among other awards and distinctions."

17. In 2020 I was the recipient of the prestigious Optical Society of America (now OPTIFCA) C.E.K. Mees medal. The medal was established in 1961 in memory of charter member C. E. K. Mees, to recognize achievements that exemplifies the thought that "optics transcends all boundaries". Prior to 2017 the medal was presented every two years since 1962, and it has been presented annually since 2017. Former recipients of the medal include Charles H. Townes, inventor of the laser and Nobel Laureate.

18. I am a Fellow of the IEEE (only 0.1% of the world-wide membership can be elected as Fellows in a given year: "According to IEEE Bylaw I-305.5, "The total number of Fellow recommendations in any one year must not exceed one-tenth of one percent of the IEEE voting membership on record as of 31 December of the year preceding.") and a Fellow of the Optical Society of America (OSA). I am the recipient of a 1999 Presidential Early Career Award for Scientists and Engineers (PECASE) from the White House. I also received a National Science Foundation Young Investigator (NYI) Award in 1994, and an Office of Naval Research Young Investigator Program (YIP) Award in 1997. The Presidential White House PECASE Award citation reads "For outstanding research and creative impact in multi-wavelength optical techniques."

19. I have had extensive contributions to the international scientific community in the form of internationally renowned special issue journals and international conferences. I served as the primary Guest Editor for the 2018 JSTQE Special Issue on "Ultra Low Loss Planar Waveguides and Their Applications," and have served as the primary Guest Editor for other special issues including the 1998 IEEE Journal of Lightwave Technology special issue on "Photonic Packet Switching Systems" and the 2003 IEEE Journal Of Selected Areas In Communications special issue on "High-Performance Optical/Electronic Switches/Routers for High-Speed Internet." I also served as one of the Guest Editors for the 2006 JSTQE Special Issue on "Ultra-Fast Integrated Photonics." In terms of regular journal editing, I was an Associate Editor for the IEEE Photonics Technology Letters and an Associate Editor for the IEEE Transactions on Communications for many years. I have organized and served on committees for internationally renowned conferences and topical meetings including as General Program Chair for the 2001 OSA Topical Meeting on Photonics in Switching and as Program Chair for the 1999 Meeting on Photonics in Switching. I have also served on numerous other technical program committees including the Conference on Optical Fiber Communications OFC (2018 – Present and 1997 – 2000), the Conference on Lasers and Electrooptics CLEO (1999-2000), the European Conference on Optical Communications ECOC (2004-2005) and SIGCOMM

2006.

20. In forming the opinions expressed in this Declaration, I have relied upon my education and my approximately 42 years of professional and academic experience.

III. LEVEL OF ORDINARY SKILL IN THE ART

21. I understand there are multiple factors relevant to determining the level of ordinary skill in the pertinent art, including (1) the levels of education and experience of persons working in the field at the time of the invention; (2) the sophistication of the technology; (3) the types of problems encountered in the field; and (4) the prior art solutions to those problems.

22. A person of ordinary skill in the art ("POSITA") in the field of the '721 patent, as of its earliest possible filing date of December 30, 2009, would have been someone knowledgeable and familiar with fiber optic communication technologies. That person would have a bachelor's degree in electrical engineering, physics, computer science, or equivalent training, and approximately two years of experience working in the field of optical communication systems. Lack of work experience can be remedied by additional education, and vice versa.

23. For purposes of this Declaration, in general, and unless otherwise noted, my statements and opinions, such as those regarding my experience and the understanding of a POSITA generally (and specifically related to the references I

consulted herein), reflect the knowledge that existed in the field as of the priority date of the ’721 patent. Unless otherwise stated, when I provide my understanding and analysis below, it is consistent with the level of a POSITA prior to the priority date of the ’721 patent.

IV. RELEVANT LEGAL STANDARDS

24. I am not an attorney. In preparing and expressing my opinions and considering the subject matter of the ’721 patent, I am relying on certain basic legal principles that counsel have explained to me. These principles are discussed below.

25. I understand that prior art to the ’721 patent includes patents and printed publications in the relevant art that predate the priority date of the alleged invention recited in the ’721 patent. For purposes of this Declaration, I am applying December 30, 2009 as the earliest possible priority date of the ’721 patent.

26. I have been informed that a claimed invention is unpatentable under 35 U.S.C. § 103 if the differences between the invention and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which the subject matter pertains. I have also been informed by counsel that the obviousness analysis takes into account factual inquiries including the level of ordinary skill in the art,

the scope and content of the prior art, and the differences between the prior art and the claimed subject matter.

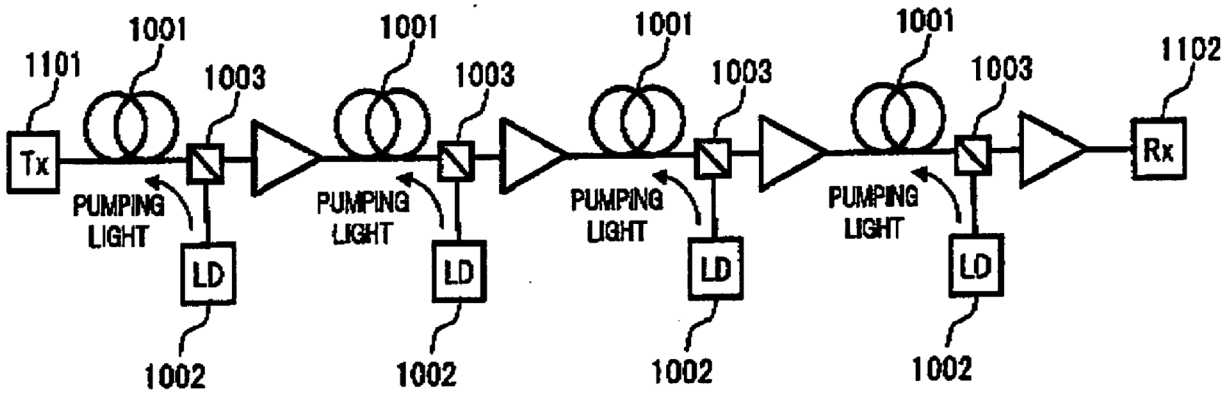
27. I have been informed by counsel that the Supreme Court has recognized several rationales for combining references or modifying a reference to show obviousness of claimed subject matter. Some of these rationales include the following: (a) combining prior art elements according to known methods to yield predictable results; (b) simple substitution of one known element for another to obtain predictable results; (c) use of a known technique to improve a similar device (method, or product) in the same way; (d) applying a known technique to a known device (method, or product) ready for improvement to yield predictable results; (e) choosing from a finite number of identified, predictable solutions, with a reasonable expectation of success; and (f) some teaching, suggestion, or motivation in the prior art that would have led one of ordinary skill to modify the prior art reference or to combine prior art reference teachings to arrive at the claimed invention.

V. BACKGROUND

A. Optical Communication

28. Optical communication systems use fiber optic cables to transmit data between an optical transmitter and an optical receiver over an optical signal that operates at a certain wavelength, frequency, or set of wavelengths. *See* Sugaya,

[0005]-[0007]. For example, as shown in the figure below, transmission path fibers 1001 extend between transmission station (Tx) 1101 and receiving station (Rx) 1102. *See* Sugaya, [0005].



Sugaya, Fig. 38.

29. It is known that "[o]ver appreciable distances, the optical signals become significantly attenuated. To address the attenuation, optical signals are amplified." Farmer, 1:21-24. Light propagating in the optical fiber experiences loss that can limit the transmission distance and/or bit rate at which data is transmitted. For longer transmission distances and higher bit rates, the optical signal may need to be optically amplified or regenerated, either at the transmitter output, receiver input, or at points in between. One type of well-known optical amplifier, the fiber Raman amplifier, uses the fiber itself as the amplifying medium. *See* Farmer, 1:26. The optical amplifier is realized by supplying one or more additional higher power optical signals in the same fiber to serve an energy source that boosts the power of

the data transmission optical signals. "A transmission path fiber 1001 is an optical transmission medium propagating the WDM light therethrough, and also functions as an optical amplification medium by being supplied with a pumping light." Sugaya, [0006].

B. Wavelength Division Multiplexing (WDM)

30. The data capacity of a single fiber can be increased by combining multiple parallel data streams onto multiple colors of light. This technical, called wavelength division multiplexing (WDM), allows deployed fiber to be upgraded to carry additional data capacity without installing new fiber. Typically, a WDM fiber transmission link is built by combing multiple transmitters at the link input, each transmitting at a unique wavelength (optical frequency), using a wavelength multiplexer component that merges the separate transmitters onto a single fiber. At the link output, a wavelength demultiplexer component is used to separate the individual data streams to their respective optical receivers.

31. A dense WDM system it one where the channel spacing in wavelength (or frequency) is close enough that the fiber transmission and optical amplifier can support greater than 64 channels and typically over 100 channels. It is common for more than one Raman amplifier to be employed for links that extend over long distances. Additionally, both forward and backward Raman pump amplifier configurations can be used to provide uniform gain over the fiber lengths

for long fiber spans.

32. "Recently, there has been introduced a wavelength division multiplexing (WDM) technology for achieving a large capacity and a high speed in a trunk optical transmission." Sugaya, [0004]. "Wavelength division multiplexing (WDM) is one technique used to increase the capacity of optical communication systems." Mizrahi, 1:15-18. "A wavelength division multiplexed optical communication system employs plural optical channels, each channel being assigned a particular channel wavelength." Mizrahi, 1:25-28. "In a WDM system, optical channels are generated, multiplexed to form an optical signal comprised of the individual optical channels, transmitted over a waveguide, and demultiplexed such that each channel wavelength is individually routed to a designated receiver." Mizrahi, 1:28-33.

33. In order to be cost efficient, it is desirable to also have optical amplifiers that can accommodate the addition of new wavelengths without needing to install new amplifiers along long lengths of optical fiber transmission systems. Several amplifier technologies exist that can achieve this goal including the erbium doped fiber amplifier (EDFA) and the Raman fiber amplifier. "Through the use of optical amplifiers, such as doped fiber amplifiers, plural optical channels are directly amplified simultaneously, facilitating the use of wavelength division multiplexing in long-distance optical systems." Mizrahi, 1:33-38.

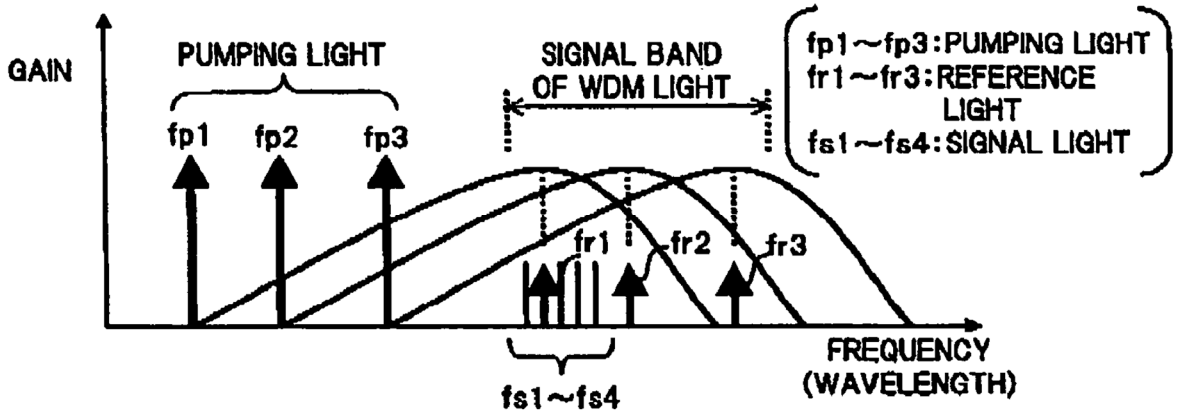
C. Optical Pumping

34. One type of optical amplifier is the fiber Raman amplifier. As "a core technique of WDM transmission technology, an optical amplification technique, such as a ... Raman amplifier and the like, has been in practical use." Sugaya, [0004]. The Raman amplifier utilizes a laser that acts as the pump to supply energy to the data transmission wavelength or WDM wavelengths to be amplified - "pumping light source (LD) 1002, which is formed by multiplexing by a multiplexer or the like, for example, transmission light from a laser diode or a plurality of laser diode, generates a pumping light for amplifying the WDM light." Sugaya, [0006].

35. The Raman scattering effect is a process in which light is frequency downshifted in a material. The frequency downshift results from a nonlinear interaction between light and the material." Farmer, 1:26-30. The Raman scattering effect is stimulated "[w]hen photons of two different wavelengths are present in an optical fiber." Farmer, 1:34-36. "This process is referred to as stimulated Raman scattering (SRS). In the SRS process, longer wavelength photons stimulate shorter wavelength photons to experience a Raman scattering event." Farmer, 36-39. "The shorter wavelength photons are destroyed and longer wavelength photons, identical to the longer wavelength photons present initially, are created." Farmer, 1:39-41. The addition of newly created longer wavelength photons to the longer wavelength

photons already present results in a net increase, or gain, in the longer wavelength photons - "The excess energy is conserved as an optical phonon (a lattice vibration). This process results in an increase in the number of longer wavelength photons and is referred to as Raman gain." Farmer, 1:41-45.

36. The Raman scattering effect "is useful for generating optical gain." Farmer, 1:66-67. As an example, light is pumped into the optical fiber at a shorter wavelength (higher energy) than the wavelength intended for amplification, as shown in the figure below. [1] The Raman nonlinear process acts to couple pump and signal energy through phonon interactions in the fiber. In this manner, the presence of both photons and a phonon mediates the transfer of energy from the pump wavelength to the signal wavelength, hence realizing optical gain.



Sugaya, Fig. 6.

[1] The x-axis, which is labeled "frequency (wavelength)" shows increasing wavelengths from left to right, decreasing frequencies from left to right.

37. It was well-known in the early 2000s that a Raman amplifier could be realized by using a dedicated spool of fiber and optical pump lasers, housed in a separate box from the transmission fiber, as a stand-alone or lumped optical amplifier that is connected to the transmission fiber. It was also well-known that the transmission fiber itself could also be used as the optical amplification medium, replacing the need for a separate fiber spool. Such amplifiers were known as distributed Raman fiber amplifiers. As was also well-known in the early 2000s, one could use a plurality of pumps wavelengths to extend the wavelength range over which the fiber Raman amplifiers operated, and even to serve as amplification for a large number of WDM channels in the same fiber. These plurality of pump wavelengths, also called wavelength division multiplexed pumps, were known to be appropriately power balanced and wavelength multiplexed onto the fiber containing the data transmission light channels: "Here, the pumping light generated in the pumping light source 1002 contains a plurality of lights having wavelengths different from each other. A WDM coupler 1003 introduces the pumping light generated in the pumping light source 1002 to the transmission path fiber 1001." Sugaya, [0006].

38. The background section of the '721 patent explains that Raman amplification is well-known. "Raman scattering, which is a well-known physical phenomenon, can be employed to build amplifiers to compensate for fiber loss in

optical transmission systems." '721 patent, 1:36-38. In order to provide Raman amplification (gain), the optical wavelength of the pump light must be a higher frequency (energy) than that of the optical signal light to be amplifier - "Raman amplification advantageously uses the fiber itself as the amplification medium. Specifically, the output from high-power (Raman) optical pumps lasers are launched into an optical fiber at a wavelength shorter (i.e., higher energy) than that of the signal(s) to be amplified." '721 patent, 1:39-43. The amplifier operation is based on the Stimulated Raman gain effect where the pump light causes energetic vibration in the glass molecules of the fiber and the molecules are excited to a higher energy level. The data (signal) photons are then able to stimulate these excited molecules down to an intermediate energy state, releasing a photon that is an exact copy of the signal photon, as well as a phonon (heat) when the molecule relaxes from the intermediate to ground state. The stimulated photon copies are the Raman gain. "Amplification then occurs when the pump photons are converted by the stimulated Raman effect into new photons at the signal wavelength(s)." '721 patent, 1:44-46.

39. Raman amplifiers pose many practical challenges, as was well-known in the early 2000s. Among those challenges included the fact that the Raman gain supplied from a single pump can provide gain to a wide range of optical wavelengths that overlap with that particular gain bandwidth. Another practical

issue is that data (signal) channels themselves can act as the pump light for other data channels, both decreasing the amount of light in the signal pumping channel as well as increasing the light in the other signal channel. This complex interaction between all pump and signal wavelengths leads to a dynamic multi-channel amplifier, that must be carefully balanced and controlled to achieve the desired final amplification of all signal (data) channels at the receiving end of the fiber link. The background section of the '721 patent explains some of the challenges of Raman amplification. "Because the process of Raman amplification is inherently non-linear, control of a Raman amplifier should take into account not only the target channel power, but also the distribution of input channel and pump powers." '721 patent, 1:49-52. In other words, pumping power into one channel will also affect other channels. "[T]he addition of a single channel can significantly affect the gain profile applied to the original channel set." '721 patent, 1:53-55. Accordingly, "[t]he complicated, non-linear nature of the Raman process requires a measurement and feedback based control scheme." '721 patent, 1:64-66.

D. Raman Pump Optimization

40. Optimizing the Raman pump powers has long been an endeavor of fiber optic transmission system engineering. *See generally,* Freund. Raman pumps are preferred because they "increase the transmission bandwidth" and "have better noise performance." Hu, 1. It is known that "One of the main difficulties is that

pump-to-pump and signal-to-signal Raman interactions make the system highly nonlinear." Perlin, 1. One goal of a using the fiber transmission medium as the optical amplifier is to balance the gain, or achieve a flat gain over the WDM signal wavelengths, for all of the operational WDM signals (channels). "While multiple pumps can be used to equalize gain over a large bandwidth, it has been a challenge to design FRAs [fiber Raman Amplifiers] with flat gain." Hu, 1. Accordingly, optimization procedures have been developed to choose pump powers that "achieve the best possible gain flatness over a specified signal bandwidth." Hu, 1. In other words, "[t]he powers of these pumps need to be adjusted dynamically, so that signal powers are as flat as possible, relative to some given power target." Freund, 2.

41. Since the interplay between multiple WDM pump wavelengths and multiple WDM signal wavelengths in a Raman amplified transmission fiber is complex and the total gain for all channels is itself non-linearly interdependent on all of the pump and signal powers, techniques to optimize (flatten) the output channel powers in a WDM Raman amplified system was a main point of interest in the early 2000s and earlier. As was well-known by the early 2000s, solving the Raman flat-gain problem involves optimization of the relationship between the Raman pump powers and the optical signal powers and other parameters like fiber length, channel spacing, etc. Such optimization can be achieved by first modeling

the relationship between the optical pumps, the optical fiber, and the optical signal channels. For a single channel (one pump and one signal wavelength), the amplified signal power is represented by a product of the pump power (P_{pump}) x signal power (P_{sig}) x Raman gain coefficient ($R_{pump,sig}$) for the particular wavelengths and powers that the pump and signal are at.

42. For a WDM system, one can expand this Raman gain model to represent the Raman pump powers and channel (signal) powers using pump power and channel power vector notation. In order to model the fact that the pump powers affects multiple signal channels, the relationship between the multiple pump powers and the multiple channel (signal) powers can be represented by a matrix. For example, a system having *n* channel (signal) wavelengths ($P_{sig,1}$, $P_{sig,i,}$ …, $P_{sig,n}$) and *m* pump wavelengths ($P_{pump,1}$, $P_{pump,j}$, …, $P_{pump,m}$) , may be represented by an *n* by *m* matrix, called the R matrix, as shown below.

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix}$$

Freund, 3.

43. The R matrix shown above is "the *n* x *m* Raman gain matrix whose entries R*ij* are nominal values for the Raman gain provided for channel *i* by pump

j." Freund, 5; *see also* Sugaya. Such a gain matrix represents the gain imparted to each of the signal channels for a set of Raman pumps and can be used to determine what pump powers should be used to achieve specific, or target, channel powers. *See generally* Sugaya.

E. Linear Algebra and Matrix Multiplication

44. Because the Raman pump optimization process uses matrices and vectors, I provide here a brief description of linear algebra and matrix multiplication. Those of skill in the art would have been familiar with the use of linear algebra to solve a system of linear equations.

45. Linear algebra can be used to solve a system of linear equations. "A system of linear equations (or a linear system) is a collection of one or more linear equations involving the same variables." Linear Algebra, 3.

$$\begin{aligned} 2x_1 - x_2 + 1.5x_3 &= 8 \\ x_1 \quad - \quad 4x_3 &= -7 \end{aligned} \tag{2}$$

Linear Algebra, 3.

46. "The essential information of a linear system can be recorded compactly in a rectangular array called a matrix." Linear Algebra, 4.

$$\begin{aligned} x_1 - 2x_2 + x_3 &= 0 \\ 2x_2 - 8x_3 &= 8 \\ -4x_1 + 5x_2 + 9x_3 &= -9 \end{aligned} \tag{3}$$

with the coefficients of each variable aligned in columns, the matrix

$$\begin{bmatrix} 1 & -2 & 1 \\ 0 & 2 & -8 \\ -4 & 5 & 9 \end{bmatrix}$$

Linear Algebra, 4.

47. "A fundamental idea in linear algebra is to view a linear combination of vectors as the product of a matrix and a vector." Linear Algebra, 39. A vector is essentially a matrix with a single column or a single row. *See* Linear Algebra, 27.

If A is an $m \times n$ matrix, with columns $\mathbf{a}_1, \ldots, \mathbf{a}_n$, and if $\mathbf{x}$ is in $\mathbb{R}^n$, then the **product of A and $\mathbf{x}$**, denoted by $A\mathbf{x}$, is **the linear combination of the columns of A using the corresponding entries in $\mathbf{x}$ as weights**, that is,

$$A\mathbf{x} = \begin{bmatrix} \mathbf{a}_1 & \mathbf{a}_2 & \cdots & \mathbf{a}_n \end{bmatrix} \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix} = x_1\mathbf{a}_1 + x_2\mathbf{a}_2 + \cdots + x_n\mathbf{a}_n$$

Linear Algebra, 39.

48. The example below shows the product of a matrix with a vector.

Solution From the definition,

$$\begin{bmatrix} 2 & 3 & 4 \\ -1 & 5 & -3 \\ 6 & -2 & 8 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = x_1 \begin{bmatrix} 2 \\ -1 \\ 6 \end{bmatrix} + x_2 \begin{bmatrix} 3 \\ 5 \\ -2 \end{bmatrix} + x_3 \begin{bmatrix} 4 \\ -3 \\ 8 \end{bmatrix}$$
$$= \begin{bmatrix} 2x_1 \\ -x_1 \\ 6x_1 \end{bmatrix} + \begin{bmatrix} 3x_2 \\ 5x_2 \\ -2x_2 \end{bmatrix} + \begin{bmatrix} 4x_3 \\ -3x_3 \\ 8x_3 \end{bmatrix} \quad (7)$$
$$= \begin{bmatrix} 2x_1 + 3x_2 + 4x_3 \\ -x_1 + 5x_2 - 3x_3 \\ 6x_1 - 2x_2 + 8x_3 \end{bmatrix}$$

Linear Algebra, 43.

49. As shown in the figure above, a 3x3 matrix multiplied by a 3x1 vector results in a 3x1 vector.

50. Because matrices are useful for representing systems of linear equations, they are useful for representing a Raman amplified system where the gain interaction between the signals and pumps (each represented by vectors) are represented by a Raman gain matrix. As explained above, the power applied to a single Raman pump affects multiple channels. Thus, a matrix can be used to represent how a set of Raman pump powers produce a set of output powers for a given of signal channels.

VI. OVERVIEW OF THE '721 PATENT

A. Summary of the '721 patent

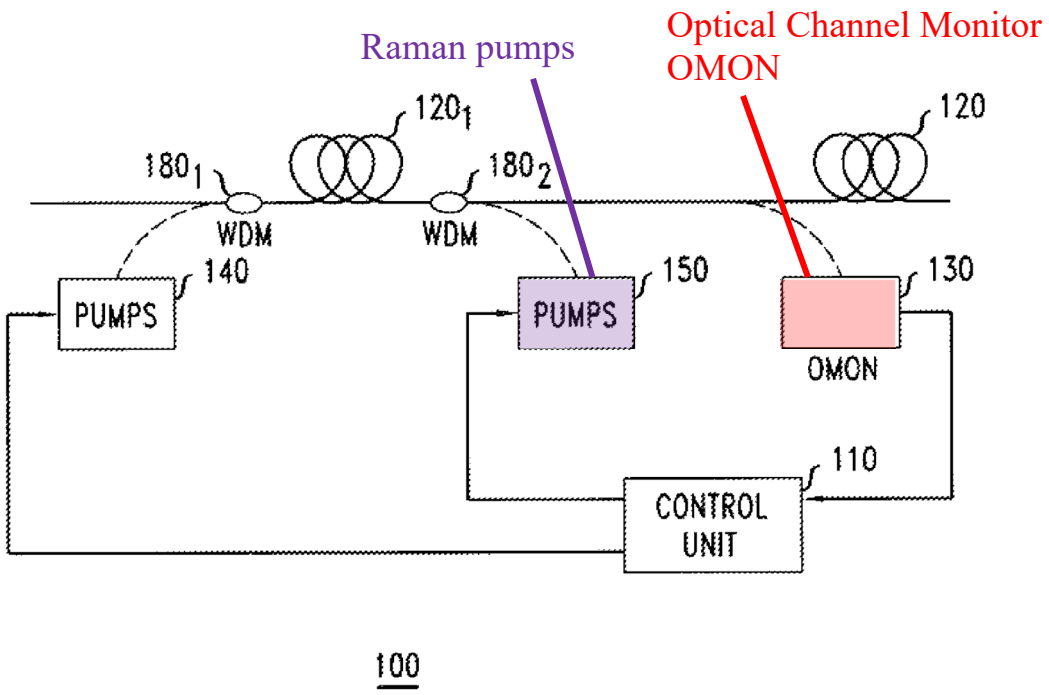
51. The '721 patent describes and claims a matrix multiplication technique for optimizing Raman pump settings. The '721 patent "relates to Raman

amplification, and more specifically to the control of Raman amplification via the adjustment of the power levels of Raman pump lasers which may be used to compensate for fiber loss in broadband optical transmission systems." '721 patent, 1:6-10. The '721 patent seeks to "enhance the stability and convergence of Raman amplifier control methodologies as compared to conventional embodiments." '721 patent, 2:61-63.

52. The purported novelty of the '721 patent is a matrix multiplication technique that multiplies (i.e., projects) a measured error vector with a gain matrix (i.e., space) that represents the capabilities of the Raman pumps. As the '721 patent explains, "a measured error vector is projected into the space of correctable deviations." '721 patent, 3:16-17. The measured error matrix represents the difference between a target set of signal power (or signal power variation) and a set of measured signal powers. "The projection is enabled by expressing the basic Raman physics as a matrix vector multiplication." '721 patent, 3:17-19. As such, the "matrix defines the space of possible Raman gain profiles achievable given a set of channels and pump lasers." '721 patent, 3:21-22. The matrix multiplication technique can be used to optimize the pump settings for a Raman pump system.

53. The '721 patent's matrix multiplication technique is applied to a conventional Raman pump system. Fig. 1, for example, illustrates "a Raman-pumped Dense Wavelength-Division-Multiplexed (DWDM) system 100

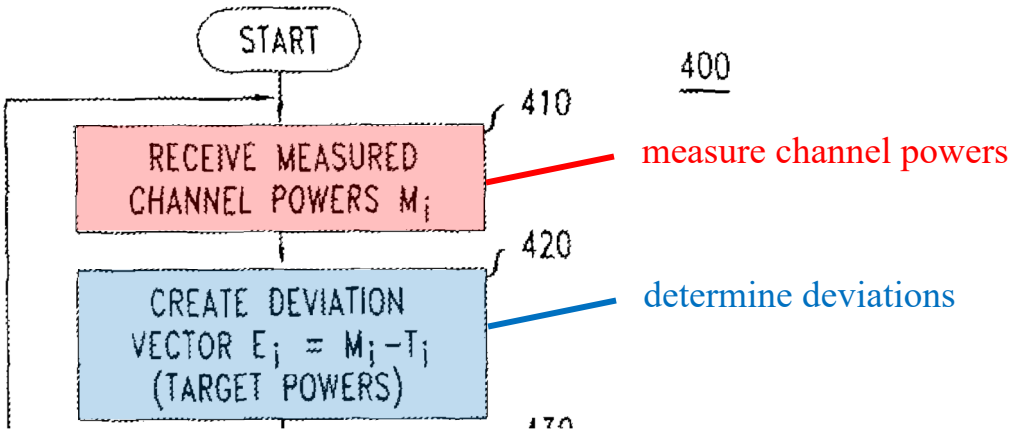
employing Raman amplification." '721 patent, 5:52-54. "As can be seen from FIG.1, all entering optical signals pass through fiber span 120, where they may be amplified by the three forward Raman pumps 140 and the six backward Raman pumps 150." '721 patent, 6:6-9. At each point where the Raman pumps are coupled to the fiber, there is hardware to combine the pumps with the signal light launched or transmitted in the fiber: "The Raman pump waves of the Raman pump sets 140 and 150 are coupled into the fiber span by WDMs 180 and 180." '721 patent, 6:9-11. "After the optical signal is amplified, a first gain profile is determined by the OMON 130." 6:14-16. The system 100 is shown in Fig. 1 below. This may be done, for example, based on knowledge of the launch signal power for each wavelength at the transmitter end, the fiber loss for each wavelength, and the measured power for each wavelength by a channel monitor located at pre-determined point in the span after amplification.



'721 patent, Fig. 1 (annotated).

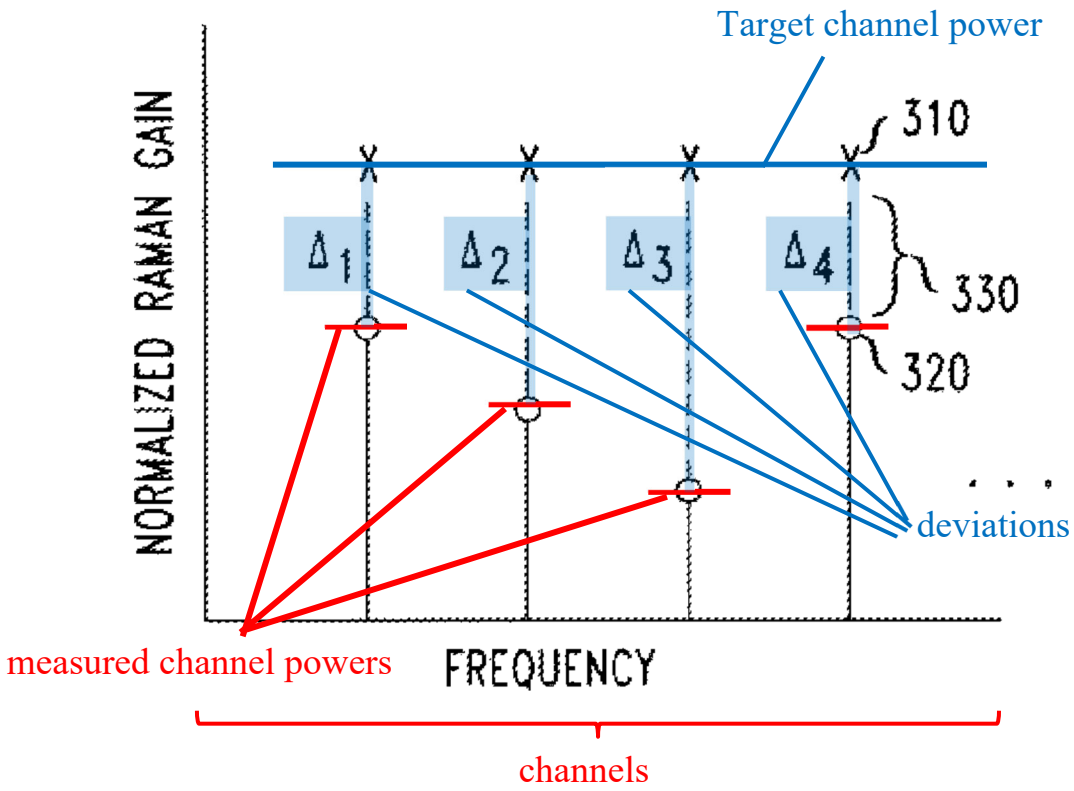
54. The channel monitor (OMON) is used to measure the power level of each channel and a control unit is then used to calculate the difference between the measured power and a stored target power, for each channel: "[T]he control unit 110, receives power measurements (Mi) for a plurality of optical channels. The power measurement may be made by an OMON and provided to the control unit." '721 patent, 10:7-11. At this point, the control unit determines the deviations between the measured power values and target values: "At step 420, deviation measurements (E_i) representing a difference between respective power measurements and corresponding power targets (T_i) for the plurality of optical channels are created ($E_i=M_i-T_i$). After the measurement and comparison, the

deviation vector E, may be calculated by subtracting the measured channel powers from the target channel powers." 10:11-16. The measuring step, and deviation vector calculation step are illustrated in Fig. 4 below.



'721 patent, Fig. 4 (partial, annotated).

55. The '721 patent provides an illustration of the deviations between the measured power values and the target power values. "FIG. 3 is a graphical illustration of target and measured power for a plurality of channels in an example embodiment." '721 patent, 9:43-45. Fig. 3 is shown below.

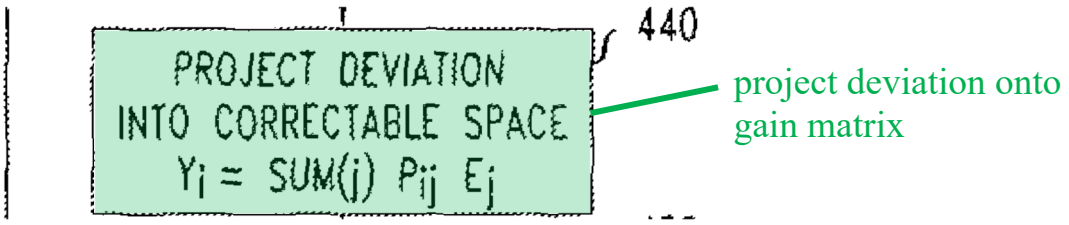


'721 patent, Fig. 3 (annotated).

56. In '721, Fig. 3 is described as follows: "For each channel of a plurality of channel noted in the frequency domain, the illustrated Raman gain profile has a target power 310 (indicated by an X)." '721 patent, 9:45-48. "For each channel of the plurality of channels, a measured power 320 (indicated by an 'O') is determined, for example through use of the OMON as illustrated in FIG.1." '721 patent, 9:48-51. "There is a deviation 330 (Δ_1, Δ_2, Δ_3, Δ_4, etc.) between the measured power and the target power for each channel (four channels being shown for ease of illustration)." '721 patent, 9:51-54. These measured deviations can then be used in the matrix multiplication technique "to minimize the sum of the

deviations." '721 patent, 9:54-55.

57. The measured deviations for each channel, expressed as a vector, are then multiplied by a "gain matrix" that represents the effect that these deviations, in combination with the Raman pumps, will have on the projection deviation. '721 patent, 10:25-30. "The projection is enabled by expressing the basic Raman physics as a matrix vector multiplication through a manipulation and integration of the basic Raman equations." '721 patent, 3:17-20. The '721 describes this projection technique using the following equation: "Y_i = Sum(j) P_{ij} E_j wherein ij, are channel numbers of one of the plurality of channels, Pij is a projector into the subspace represented by the columns of the Raman gain matrix, and E is the deviation measurement for channelj.)." '721 patent, 10:30-35. This step is illustrated as 440 in Fig. 4 below.



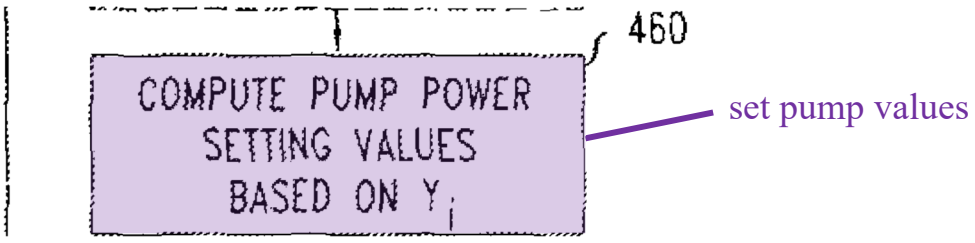
'721 patent, Fig. 4 (partial, annotated).

58. The projector Pij represents the gain matrix, and multiplying it by a channel power vector, will return the amplified channel powers. "The projector P_{ij} is a square (mxm) matrix which when multiplied with a vector of channel powers (these vectors are of length m) will produce a new vector (also of length m) of the

channel powers which are correctable via pump changes." '721 patent, 11:63-67.

59. The error vector can be multiplied by the R matrix and the resulting changes on the amplified channel powers can be determined. "When a vector (like the error vector E_i) is multiplied by P_{ij}, one finds the portion of that vector which is representable by the set of orthogonal vectors—which is the changes that can be impacted by changing the pumps." '721 patent, 12:9-13. By performing these calculations, the corrections to channel power that can be expected by adjusting the Raman pumps can be estimated. "In this manner, the contributions to a deviation vector that are correctable through adjustment of Raman pumps can be utilized as a control." '721 patent, 12:13-16.

60. The '721 patent then describes using the result of the matrix projection—which it refers to as the projected deviations—to determine the updated pump power settings. "At step 460, a pump setting for a plurality of pumps is determining based upon the correctable deviations for each channel (Yi)." '721 patent, 10:46-48. This step is illustrated as step 460 in Fig. 4 below.



'721 patent, Fig. 4 (partial, annotated).

61. However, as will be explained in detail below, it was already known

to multiply an error vector (differences between measured and target powers) with a Raman gain matrix to determine the updated Raman pump settings that will move the actual (measured) power levels closer to a target power level.

B. Prosecution History of the '721 patent.

62. The '721 patent was filed December 30, 2009. The original patent included claims 1-20. In the first Office Action, the Examiner allowed claims 1-12 and 19, rejected claims 13-17 and 20, and objected to claims 15 and 18. Ex.1002, 27. The rejected claims were found to be anticipated by U.S. Patent No. 6,590,700 to Seydnejad et al.

63. The Applicant then amended claims 13 and 20 and added new claims 21-23. The Office then allowed the remaining claims and the '721 patent issued on May 14, 2013.

64. The Challenged Claims in this proceeding were thus all allowed in the first office action. For the reasons explained below, the subject matter recited within those claims was already known, as evidenced by Sugaya.

VII. CLAIM CONSTRUCTION

65. It is my understanding that in order to properly evaluate the '780 patent, the terms of the claims must first be interpreted. It is my understanding that for the purposes of this *inter partes* review, the claims are to be construed under the so-called *Phillips* standard, under which claim terms are given their ordinary

and customary meaning as would be understood by one of ordinary skill in the art in light of the specification and prosecution history, unless the inventor has set forth a special meaning for a term. I do not believe any of the terms require express construction.

VIII. IDENTIFICATION OF HOW THE CLAIMS ARE UNPATENTABLE

66. I have been asked to provide my opinion as to whether the Challenged Claims of the ’721 patent would have been obvious in view of the prior art. The discussion below provides a detailed analysis of how the prior art references identified below teach the limitations of the Challenged Claims of the ’721 patent.

67. As part of my analysis, I have considered the scope and content of the prior art and any differences between the alleged invention and the prior art. I describe in detail below the scope and content of the prior art, as well as any differences between the alleged invention and the prior art, on an element-by-element basis for each Challenged Claims of the ’721 patent.

68. As described in detail below, the alleged invention of the Challenged Claims would have been obvious in view of the teachings of the identified prior art references as well as the knowledge of a POSITA.

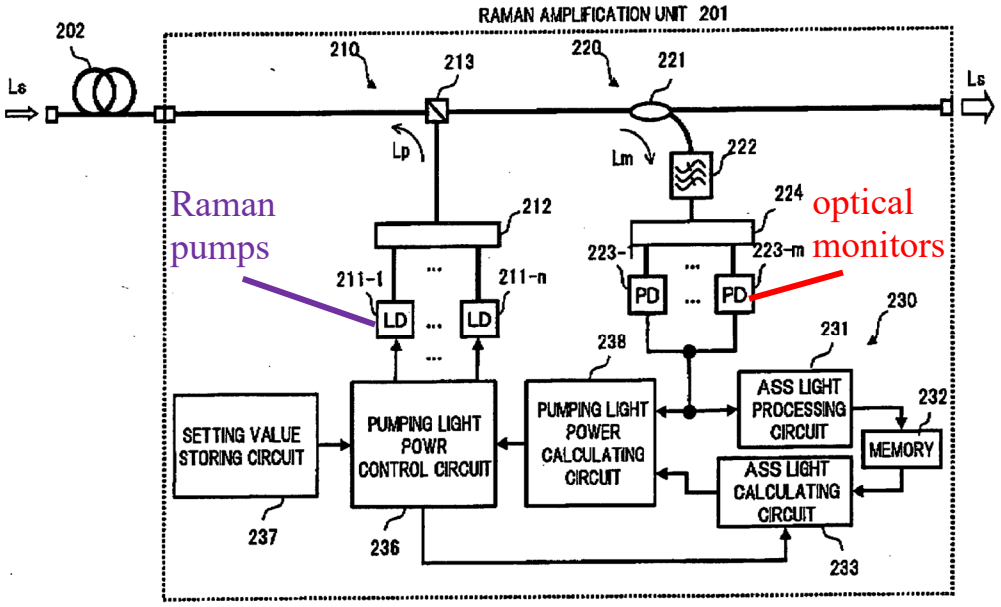
A. Ground 1: Claims 1, 2, 4, 6, 19, and 21 are anticipated by or rendered obvious by Sugaya.

1. Summary of Sugaya

69. Sugaya discloses the same matrix multiplication technique for solving

the same Raman pump optimization problem described and claimed in the '721 patent. *Compare* '721 patent *with* Sugaya. Like the '721 patent, Sugaya "relates to an optical amplifier which supplies a pumping light to an optical amplification medium to amplify a signal light, and an optical transmission system using the same, and in particular, to a technology for controlling a supply condition of pumping light in the optical amplifier." Sugaya, [0002].

70. Sugaya describes a conventional Raman pump system. Ex.1005, Fig. 38, [0005]-[0007]. As shown in Fig. 17 below, a Raman amplification unit 201 includes the amplifying optical fiber, Raman pumps LD and optical monitors PD, and associated power taps and combiners and filters.



Sugaya, Fig. 17 (annotated).

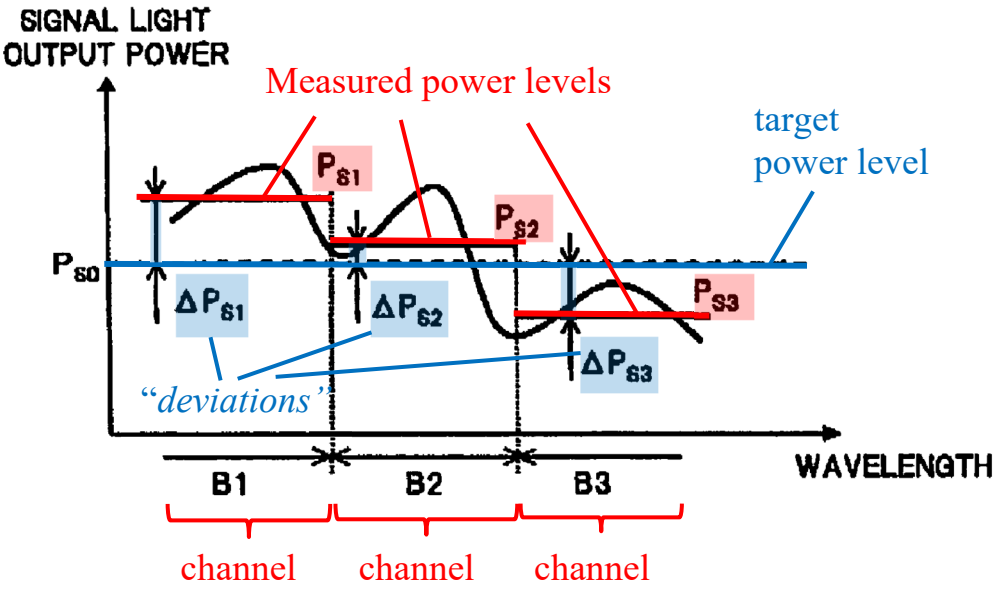
71. The Raman pumps 211 are used to amplify the optical signals, via the

Raman gain mechanism in the fiber itself. "The pumping light supply section 210 comprises, for example, in pumping light sources (LD) 211-1 to 211-n." Sugaya, [0129]. By supplying a set of pump lights operating at different wavelengths, the fiber can be used as an amplifying medium for sets of wavelengths propagating over the optical fiber. "The respective pumping light sources 211-1 to 211-n generate lights of required wavelength bands capable of Raman amplifying a signal light L_S transmitted over the optical transmission path 202." Sugaya, [0129].

72. The Raman amplification unit 201 also includes optical monitors for measuring the optical powers at various channels. "The output light monitoring section 220 comprises, for example, a branching device 221, an optical filter 222 and a light receiving element (PD) 223." Sugaya, [0131]. In Fig. 17, there are "m light receiving elements 223-1 to 223-m" which "are provided so that the monitor light Lim passed through the optical filter 221 can be divided into m wavelength blocks to be monitored." Sugaya, [0168]. These light receiving elements are used to monitor the power in each of the signal channels propagating in the optical fiber, for each wavelength block, in order to access the signal power and required adjustments of optical Raman gain through the pump light powers. "In step 213, the pumping light sources 211-1 to 211-n are driven for each group corresponding to each wavelength block, and the signal light average output power for each wavelength block is measured." Sugaya, [0175]. "Here, the signal light average

output powers" are expressed as "P_{S1}, P_{S2} and P_{S3}." Sugaya, [0175].

73. Sugaya also describes determining the difference between the signal light average output powers and a target power level P_{S0}. "[D]ifferences between the signal light average output powers P_{S1}, P_{S2} and P_{S3}, and the target power level P_{S0} are **ΔP_{P1}, ΔP_{P2} and ΔP_{P3}**." Sugaya, [0181]. The deviations between the measured channel powers and the target channel powers are illustrated in Fig. 19 shown below. This is a very basic function that must be performed in order to access how to control the gain in order to adjust the signal power to a desired target level.



Sugaya, Fig. 19 (annotated).

74. The differences between the measured values and the target values are expressed as a vector: ΔP_{S1}, ΔP_{S2} and ΔP_{S3}. This vector is then multiplied by a gain matrix to determine the pump setting changes that will be used to minimize these

differences. This matrix multiplication is shown below.

$$\begin{bmatrix} \Delta P_{P1} \\ \Delta P_{P2} \\ \Delta P_{P3} \end{bmatrix} = \begin{bmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{23} \\ B_{31} & B_{32} & B_{33} \end{bmatrix}^{-1} \begin{bmatrix} \Delta P_{S1} \\ \Delta P_{S2} \\ \Delta P_{S3} \end{bmatrix} \quad (2.12)$$

pump setting changes

gain matrix

Measured differences

Sugaya, Equation 2.12 (annotated).

75. Sugaya states that the actual measured signal light can be measured and the difference from a desired target power can be calculated, and gain matrix can be used in combination to compute the required change in pump power setting for all pumps in order to achieve the desired target signal powers. A POSITA would have understood, that using the basic concepts of linear algebra, the matrix represents all possible Raman gain coefficients between all pairs of signal and pump wavelengths. A POSITA would also have understood that this matrix represents the cross-coupling of all signal and pump powers based on measured values.

76. As Sugaya explains, "the reduction of wavelength characteristic deviation of the Raman amplified WDS signal light means that, as shown in FIG. 19 for example, the signal light average output powers P_{S1}, P_{S2} and P_{S3} corresponding to the respective wavelength blocks B_1, B_2 and B_3 approach a

desired target power level P_{S0}." Sugaya, [0181]. Sugaya states that there is a change in pump power vector that can be computed from the measured difference in signal power and the Raman gain matrix. "If differences between the signal light average output powers P_{S1}, P_{S2} and P_{S3} and the target power level P_{S0} are ΔP_{S1}, ΔP_{S2} and ΔP_{S3} **differences of the pumping light power necessary for making up the differences** ΔP_{S1}, ΔP_{S2} and ΔP_{S3} **are ΔP_{P1}, ΔP_{P2} and ΔP_{P3}**." Sugaya, [0181].

77. Accordingly, Sugaya shows that it was known to multiply an error vector (differences between measured and target powers) with a gain matrix that represents the effect of the Raman pumps to determine the Raman pump settings that will bring the actual power levels closer to a target power level. It is thus clear from Sugaya, and a POSITA would understand, that this process can be continued via a well-known feedback process, to converge if desired on an optimal set of Raman pump powers that minimize the difference between actual and target signal channel power for all the signal wavelengths.

2. Claim 1

[1.0] ***A method comprising:***

78. Sugaya describes a "*method*" for operating an optical amplifier that supplies pumping light to an optical amplification medium.

> The present invention relates to an optical amplifier which **supplies a pumping light to an optical amplification medium to amplify a signal light**, and an optical transmission system using the same, and in

> particular, to a technology for **controlling a supply condition of pumping light in the optical amplifier**.

Sugaya, [0002].

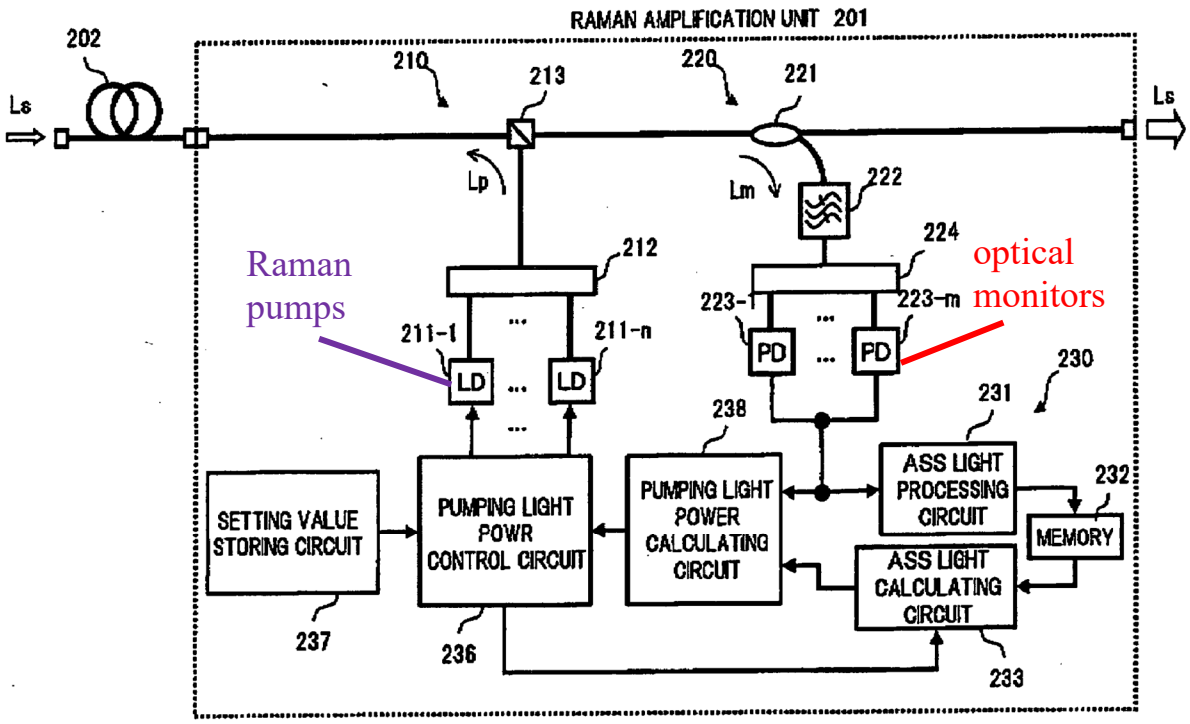
79. Sugaya illustrates one example of such an optical amplifier in Fig. 17. The amplifier is described as including Raman pumps 211 and light receiving elements 223.

> **The pumping light supply section 210 comprises, for example, n pumping light sources (LD) 211-1 to 211-n,** a combining device 212 and a WDM coupler 213. **The respective pumping light sources 211-1 to 211-n generate lights of required wavelength bands capable of Raman amplifying a signal light LS transmitted over the optical transmission path 202,** to output them to the combining device 212. The combining device 212 combines output lights from the respective pumping light sources 211-1 to 211-n, to generate a pumping light Lp, and outputs the pumping light L_P to the WDM coupler 213. The WDM coupler 213 outputs the pumping light L_P output from the combining device 212, to the optical transmission path 202 connected with a signal light input end of the Raman amplification unit 201, and also transmits the signal light L_S input from the optical transmission path 202, to the output light monitoring section 220 at a latter stage. Thus, the present Raman amplifier has a backward pumping configuration in which a propagation direction of the pumping light L_P is opposite to a propagation direction of the signal light L_S.

Sugaya, [0129].

> In FIG. 17, the Raman amplifier in the embodiment 2-3 is constituted such that, in the Raman amplifier in the embodiment 2-1, there is provided a function of controlling the supply condition of the pumping light Lp so that the Raman amplified signal light Ls has a desired wavelength characteristic. To be specific, the configuration of the present Raman amplifier differs from that of the embodiment 2-1 in that, in the output light monitoring section 220, a demultiplexer 224 and **m light receiving elements 223-1 to 223-m are provided so that the monitor light Lm passed through the optical filter 221 can be divided into m wavelength blocks to be monitored**, and also a pumping light power calculating circuit 238 is provided instead of the ALC circuit 234 and the shutdown circuit 235 that have been used in the embodiment 2-1. Note, other components other than the above are similar to those of the embodiment 2-1, and therefore, the descriptions thereof are omitted here.

Sugaya, [0168].



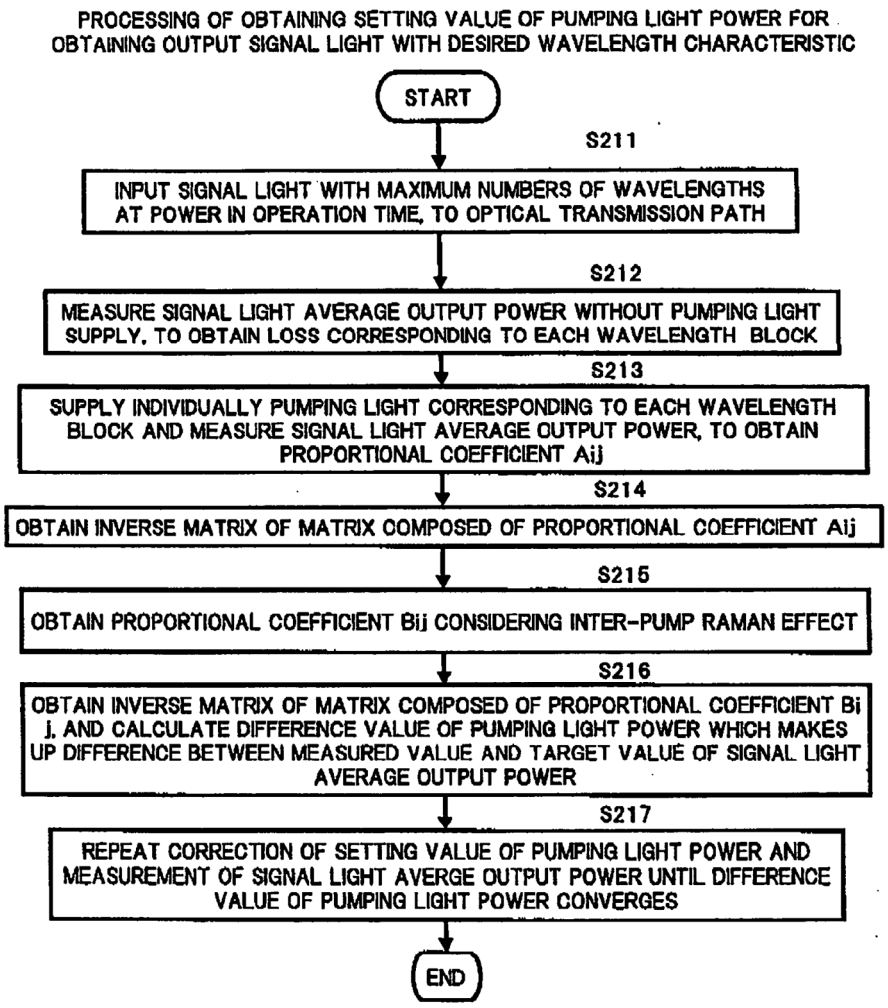
Sugaya, Fig. 17 (annotated).

80. Sugaya's method is described in one example with respect to Fig. 18. Fig. 18 shows a flowchart further describes the method for operating the optical amplifier. This flowchart and description describe very clearly, as would be understood by a POSITA, the steps needed to be taken to turn on channels in a fiber transmission system and then calibrate a multi-channel Raman pump amplifier in the same fiber, and measure the resulting signals with feedback to adjust the Raman pumps to minimize the difference between measured signal power and desired signal power for all of the signal wavelengths. Sugaya through the text and flowchart, states how the vectors and gain matrix are used to calculate the power in the Raman pumps, in a feedback cycle, to converge on a set of pump

powers that minimizes the difference in the measured signal powers from their target values.

> Here, **a specific setting method of the pumping light power will be described referring to a flowchart of FIG. 18**. In the following description, consideration is made on the case where the output signal light Ls is divided into three wavelength blocks, **to calculate the setting value of the pumping light power**. However, the number of divided wavelength blocks is not limited to the above example.

Sugaya, [0172].



Sugaya, Fig. 18 (annotated).

81. Thus, because Sugaya describes a method for controlling pumping light to an optical amplifier, Sugaya renders obvious "*a method*" as claimed.

[1.1] ***receiving measured channel powers;***

82. **First**, Sugaya's method includes measuring the average power received at each wavelength block ("*channel[s]*").

> In step 213, the pumping light sources 211-1 to 211-n are driven for each group corresponding to each wavelength block, **and the signal**

> **light average output power for each wavelength block is measured**. Here, the pumping light powers corresponding to the respective wavelength blocks are P_{P1}, P_{P2} P_{P3}. Then, a correction value of the ASS light power corresponding to each of the pumping light powers P_{P1}, P_{P2} and P_{P3} is calculated by the ASS light calculating circuit 233, and the calculation result is transmitted to the pumping light power calculating circuit 238. In the pumping light power calculating circuit 238, in accordance with the correction value calculated by the ASS light calculating circuit 233, the correction of the ASS light component is performed on the signal light average output power of each wavelength block measured by the output light monitoring section 220. **Here, the signal light average output powers subjected the ASS light correction are P_{S1}, P_{S2} and P_{S3}**. These signal light average output powers P_{S1}, P_{S2} and P_{S3} can be expressed by a relationship shown in the next (2.9) formula, using the pumping light powers P_{P1}, P_{P2} and P_{P3} corresponding to the respective wavelength blocks and the losses L1, L2 and L3 calculated in step 212.

Sugaya, [0175].

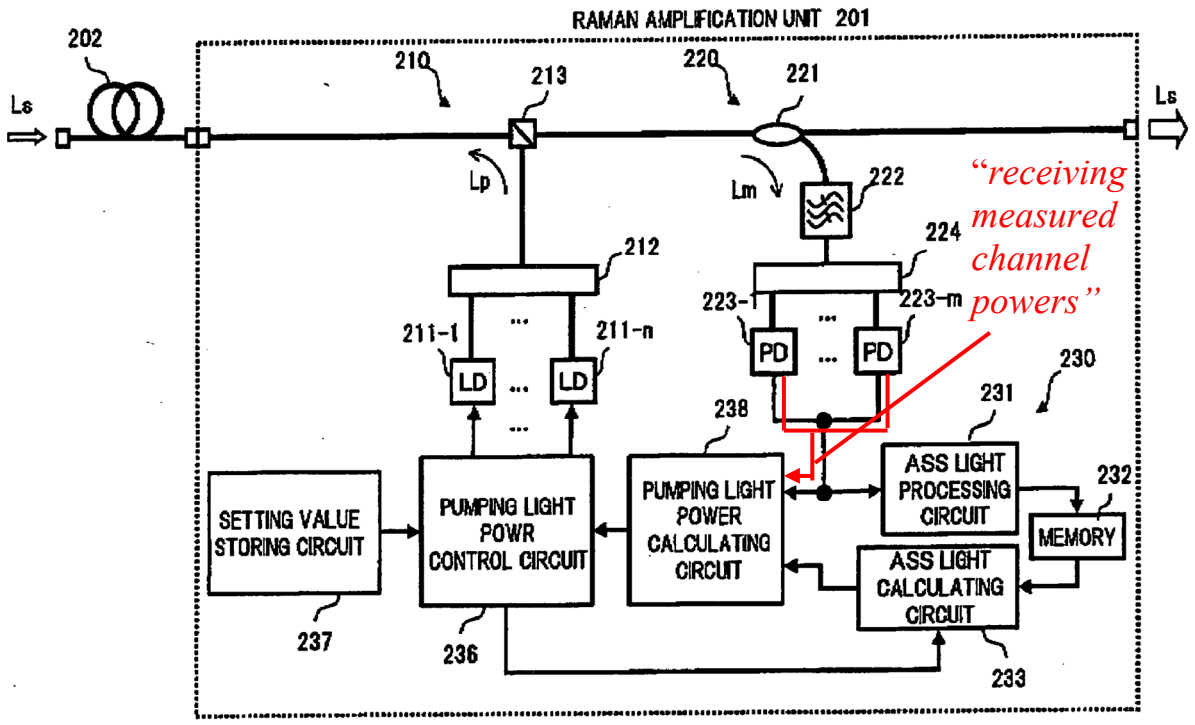
83. Because the measured average output powers P_{S1}, P_{S2}, and P_{S3} correspond to different wavelength blocks, they are "*measured **channel** powers*" as claimed. Different wavelengths have different frequencies and thus are different channels on the optical transmission fiber.

84. **Second**, the measured average output powers P_{S1}, P_{S2}, and P_{S3} ("*measured channel powers*") are measured by the light receiving elements 223-1

and *received* by the pumping light power calculating circuity 238.

> The demultiplexer 224 provided in the output light monitoring section 220 receives, at one input port thereof, the monitor light Lm passed through the optical filter 221, and demultiplexes the monitor light Lm into m wavelength blocks, to output the lights of the wavelength blocks via corresponding output ports thereof, to the light receiving elements 223-1 to 223-m. **The respective light receiving elements 223-1 to 223-n**, which are connected with the respective output ports of the demultiplexer 224, **each converts the monitor light Lm demultiplexed for each wavelength block by the demultiplexer 224 into an electric monitor signal**, to output it. **The monitor signal output from each of the respective light receiving elements 223-1 to 223-m is sent to the ASS light processing circuit 231 and also the pumping light power calculating circuit 238**.

Sugaya, [0169].



Sugaya, Fig. 17 (annotated).

85. Accordingly, the pumping light power calculating circuit 238 is "*receiving*" the "*measured channel powers*" as claimed.

86. Thus, because Sugaya describes a pumping light power calculating unit that receives measured average signal powers P_{S1}, P_{S2}, and P_{S3} for multiple wavelength blocks, Sugaya renders obvious "*receiving measured channel powers*" as claimed.

[1.2] ***determining deviations of respective measured channel powers from respective target channel powers;***

87. **First**, Sugaya then determines the difference between the measured powers and a target level P_{S0}. These differences ("*deviations*") are expressed in Sugaya as ΔP_{S1}, ΔP_{S2} and ΔP_{S3}.

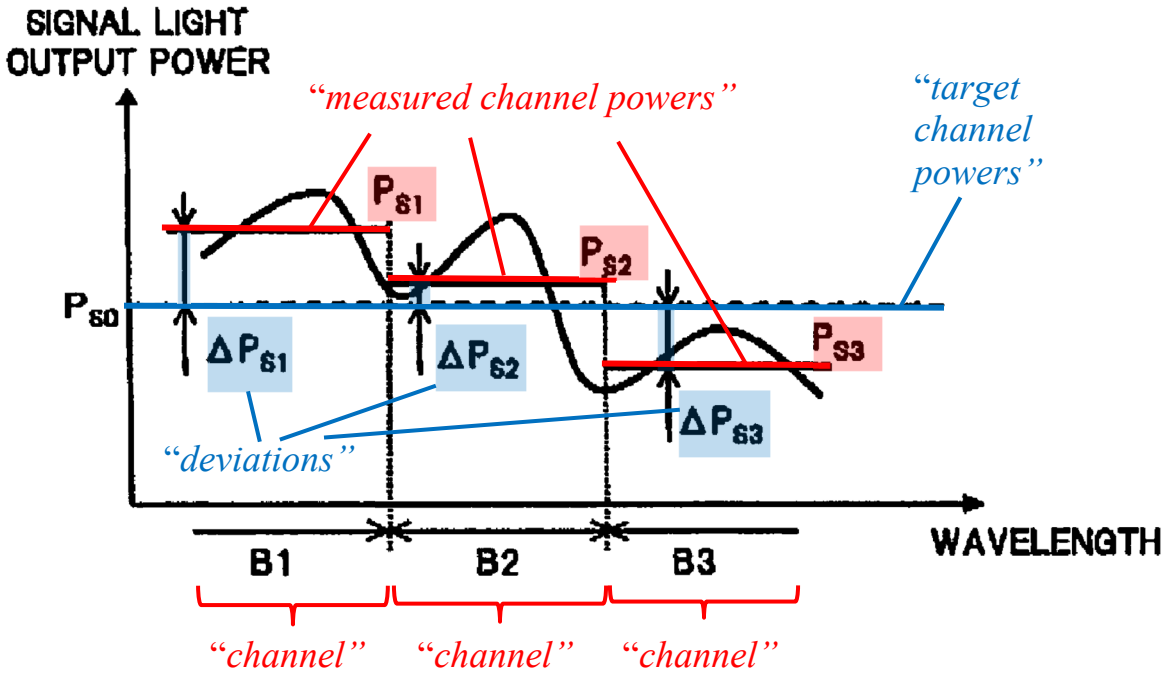
In step 215, for (2.10) formula, a proportional coefficient considering the inter-pump Raman effect is obtained. That is, the proportional coefficient Aij is a gain coefficient for each wavelength block, but does not include the inter-pump Raman effect. Since the Raman amplification is actually performed by driving simultaneously the pumping light sources corresponding to a plurality of wavelengths blocks, it is necessary to obtain a gain coefficient considering the inter-pump Raman effect. Therefore, the pumping light powers P_{P1}, P_{P2} and P_{P3} of the respective wavelength blocks are obtained in accordance with (2.10) formula shown in the above, to supply the pumping light corresponding to all of the wavelength blocks in the power setting described above, to the optical transmission path 202. Then, the power of the pumping light corresponding to all of the wavelength blocks is changed by 10 mW, for example, and a change amount of the signal light average output power relative to the change amount of the pumping light power, is measured**. By this measurement, as shown in the next (2.11) formula, a proportional coefficient Bij (i, j=1, 2, 3) expressing a relationship of the change amounts ΔP_{S1}, ΔP_{S2} and ΔP_{S3} of the signal light average output powers to the change amounts ΔP_{P1}, ΔP_{P2} and ΔP_{P3} of the pumping light powers, is obtained.**

Sugaya, [0179].

To be specific, the reduction of wavelength characteristic deviation of the Raman amplified WDS signal light means that, as shown in FIG. 19 for example, the signal light average output powers PS1, PS2 and PS3 corresponding to the respective wavelength blocks B1, B2 and B3

approach a desired target power level PS0**. If differences between the signal light average output powers P_{S1}, P_{S2} and P_{S3} and the target power level P_{S0} are ΔP_{S1}, ΔP_{S2} and ΔP_{S3} differences of the pumping light power necessary for making up the differences ΔP_{S1}, ΔP_{S2} and ΔP_{S3} are ΔP_{P1}, ΔP_{P2} and ΔP_{P3}**.

Sugaya, [0181].



Sugaya, Fig. 19 (annotated).

88. Because Sugaya describes calculating the deviations ΔP_{S1}, ΔP_{S2} and ΔP_{S3} between the measured values P_{S1}, P_{S2} and P_{S3} and a target level P_{S0}, Sugaya renders obvious "*determining deviations of respective measured channel powers from respective target channel powers*" as claimed.

[1.3] ***projecting the deviations into a space that defines Raman gain profiles achievable with a set of channels and pump lasers whereby projected deviations are formed; and***

89. Sugaya describes the same matrix multiplication technique described and claimed in the '721 patent. A measured error vector (ΔP_{S1}, ΔP_{S2} and ΔP_{S3}) ("*deviations*") is multiplied by (projected onto) the gain matrix Bij representing the Raman pump profiles ("*space that defines Raman pump capabilities*") to determine a set of pump power differences (ΔP_{P1}, ΔP_{P2} and ΔP_{P3}) ("*projected deviations*"). This matrix multiplication is illustrated in equation 2.12 below.

$$\begin{bmatrix} \Delta P_{P1} \\ \Delta P_{P2} \\ \Delta P_{P3} \end{bmatrix} = \begin{bmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{23} \\ B_{31} & B_{32} & B_{33} \end{bmatrix}^{-1} \begin{bmatrix} \Delta P_{S1} \\ \Delta P_{S2} \\ \Delta P_{S3} \end{bmatrix} \qquad (2.12)$$

"*projected deviations*" "*space that defines Raman gain profiles*" "*deviations*"

Sugaya, Equation 2.12 (annotated).

90. **First**, the measured error vector (ΔP_{S1}, ΔP_{S2} and ΔP_{S3}) represents "*deviations*" as claimed. As explained above at [1.2], Sugaya describes measuring the optical powers at each wavelength block ("*channel*") and comparing them with a target power P_{S0}. Accordingly, the values ΔP_{S1}, ΔP_{S2} and ΔP_{S3} represent "*deviations*" from that target power level.

91. **Second**, the gain matrix B_{ij}^{-1} represents the inter-pump Raman effect of the system's Raman pump wavelengths collectively on the set of signal (channel) wavelengths ("*space that defines Raman gain profiles achievable with a*

set of channels and pump lasers"). This gain matrix B_{ij}^{-1} represents the relationship between a change in light provided by the Raman pumps (ΔP_{P1}, ΔP_{P2} and ΔP_{P3}) and deviations from the target power (ΔP_{S1}, ΔP_{S2} and ΔP_{S3}). Sugaya describes the manner in which the gain matrix B_{ij}^{-1} is obtained.

> In step 215, for (2.10) formula, **a proportional coefficient considering the inter-pump Raman effect is obtained**. That is, the proportional coefficient Aij is a gain coefficient for each wavelength block, but does not include the inter-pump Raman effect. **Since the Raman amplification is actually performed by driving simultaneously the pumping light sources corresponding to a plurality of wavelengths blocks, it is necessary to obtain a gain coefficient considering the inter-pump Raman effect**. Therefore, the pumping light powers P_{P1}, P_{P2} and P_{P3} of the respective wavelength blocks are obtained in accordance with (2.10) formula shown in the above, to supply the pumping light corresponding **to all of the wavelength blocks in the power setting described above**, to the optical transmission path 202. Then, the power of the pumping light corresponding to all of the wavelength blocks is changed by 10 mW, for example, and a change amount of the signal light average output power relative to the change amount of the pumping light power, is measured. By this measurement, as shown in the next (2.11) formula, **a proportional coefficient B_{ij} (i, j=1, 2, 3) expressing a relationship of the change amounts ΔP_{S1}, ΔP_{S2} and ΔP_{S3} of the signal light average output powers to the change amounts ΔP_{P1}, ΔP_{P2} and ΔP_{P3} of the pumping light powers, is obtained**.

Sugaya, [0179]

92. The matrix B_{ij}^{-1} represents the gains that are "*achievable*" using a specific set of Raman pumps on a specific set of channels ("*gain profiles achievable with a set of channels and pump lasers*"). These gains are known to be achievable because they are obtained by applying power levels to the specific set of Raman pumps and measuring the specific set of channel output powers. In other words, Sugaya obtains the matrix B_{ij}^{-1} by measuring the changes in deviations with respect to changes in Raman pump powers. First, Sugaya uses the measurements to create matrix B_{ij}. This results in "a proportional coefficient B_{ij} (i, j=1, 2, 3) expressing a relationship of the change amounts ΔP_{S1}, ΔP_{S2} and ΔP_{S3} of the signal light average output powers to the change amounts ΔP_{P1}, ΔP_{P2} and ΔP_{P3} of the pumping light powers." This relationship is shown in equation 2.11 below.

$$\begin{bmatrix} \Delta P_{S1} \\ \Delta P_{S2} \\ \Delta P_{S3} \end{bmatrix} = \begin{bmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{23} \\ B_{31} & B_{32} & B_{33} \end{bmatrix} \begin{bmatrix} \Delta P_{P1} \\ \Delta P_{P2} \\ \Delta P_{P3} \end{bmatrix} \quad (2.11)$$

Sugaya, Equation 2.11.

93. Thus, the matrix B_{ij} can be used to predict how much deviation between the output powers and a target level will occur at different pump powers. The inverse of matrix B_{ij} (which is B_{ij}^{-1}) allows one to predict the reverse—how much change in the Raman pump powers is needed to achieve a desired change in

the output powers. *See* Sugaya, [0180]. This is the key aspect to operation and doing so allows one to determine how to control the Raman pump powers to achieve the desired minimal deviations across the different channels.

> In step 216, **an inverse matrix of a matrix composed of the proportional coefficient Bij obtained in step 215, is calculated, to lead out a relational expression considering the inter-pump Raman effect** as shown in (2.12) formula.

Sugaya, [0180].

$$\begin{bmatrix} \Delta P_{P1} \\ \Delta P_{P2} \\ \Delta P_{P3} \end{bmatrix} = \begin{bmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{23} \\ B_{31} & B_{32} & B_{33} \end{bmatrix}^{-1} \begin{bmatrix} \Delta P_{S1} \\ \Delta P_{S2} \\ \Delta P_{S3} \end{bmatrix} \quad (2.12)$$

"*projected deviations*" "*space that defines Raman gain profiles*" "*deviations*"

Sugaya, Equation 2.12 (annotated).

94. Accordingly, Sugaya's matrix B_{ij}^{-1} represents the capabilities of the Raman pumps across multiple channels, considering the inter-pump Raman effect. In other words, matrix B_{ij}^{-1} represents ("*a space that defines Raman gain profiles achievable with a set of channels and pump lasers*."). A POSITA would have understood that this process is not limited to case where the number of measurements is equal to the number of Raman pumps. *See e.g.,* Farmer, 9:8-11 ("It shall be appreciated that the differential gain matrix, δ_{ji} is not typically a square

matrix, since the number of emitters 59-i does not necessarily equal the number of signal wavelengths."). For example, if the number of measured wavelength blocks is greater than the number of Raman pumps, then the matrix multiplication technique will result in a smaller vector than the measured error vector.

95. A POSITA would have understood that a matrix is a "*space*" in mathematical terms because the term space refers to an ordered set of data. *See* Technical Dictionary, 1873.

96. **Third**, the result vector of Sugaya's matrix multiplication technique (ΔP_{P1}, ΔP_{P2} and ΔP_{P3}) are "*projected deviations*" as claimed. Because the values ΔP_{P1}, ΔP_{P2} and ΔP_{P3} result from the matrix multiplication (i.e., projection) they are "***projected*** *deviations*" as claimed. Additionally, because they represent changes in the Raman pump powers, they are "*projected* ***deviations***") as claimed.

97. The claimed step of "*projecting*" the deviations onto the space that defines Raman gain profiles refers to the matrix multiplication operation described in Sugaya. Indeed, the '721 describes this projecting step as a matrix multiplication operation. "The projection is enabled by expressing the basic Raman physics as a matrix vector multiplication through a manipulation and integration of the basic Raman equations. Within this formulation, the matrix defines the space of possible Raman gain profiles achievable given a set of channels and pump lasers." '721 patent, 3:16-22.

98. Accordingly, Sugaya describes the same matrix multiplication technique described and claimed in the '721 patent. A measured error vector (ΔP_{S1}, ΔP_{S2} and ΔP_{S3}) ("*deviations*") is multiplied by (projected onto) the gain matrix B_{ij}^{-1} representing the Raman pump profiles ("*space that defines Raman pump capabilities*") to determine a set of pump power differences (ΔP_{P1}, ΔP_{P2} and ΔP_{P3}) ("*projected deviations*").

$$\begin{bmatrix} \Delta P_{P1} \\ \Delta P_{P2} \\ \Delta P_{P3} \end{bmatrix} = \begin{bmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{23} \\ B_{31} & B_{32} & B_{33} \end{bmatrix}^{-1} \begin{bmatrix} \Delta P_{S1} \\ \Delta P_{S2} \\ \Delta P_{S3} \end{bmatrix} \quad (2.12)$$

"*projected deviations*" "*space that defines Raman gain profiles*" "*deviations*"

Sugaya, Fig. 17 (annotated).

99. Thus, because Sugaya describes a multiplication technique that projects the measured pump power deviations from a target power onto a gain matrix that defines the capabilities of the Raman pumps, Sugaya renders obvious "*projecting the deviations into a space that defines Raman gain profiles achievable with a set of channels and pump lasers whereby projected deviations are formed*" as claimed.

[1.4] ***determining power setting values for the pump lasers based on the projected deviations.***

100. First, as described above at [1.3], Sugaya performs a matrix multiplication technique to determine the adjustments in the pump powers that are needed to cause the measured powers to be closer to a target values. These adjustments are defined as (ΔP_{P1}, ΔP_{P2} and ΔP_{P3}). These values are the "*projected deviations*" as claimed.

101. Second, Sugaya describes using these values ("*projected deviations*") to change the Raman pump settings. Indeed, the purpose of the method described in Fig. 18 is to determine the power setting values for the Raman pumps.

> Here, **a specific setting method of the pumping light power will be described** referring to a flowchart of FIG. 18. In the following description, consideration is made on the case where the output signal light L_S is divided into three wavelength blocks, to calculate the setting value of the pumping light power. However, the number of divided wavelength blocks is not limited to the above example.

Sugaya, [0172].

> By performing the series of processing shown in step 211 to step 217, based on the measurement result using the optical transmission path 202 to be actually used, **the setting values of the pumping light powers for obtaining the output signal light LS having the desired wavelength characteristic are obtained**. Such calculation processing of the setting values of the pumping light powers can be executed before starting the operation of the present Raman amplifier, to store the calculation result in a memory or the like. Further, it is also possible

> that the calculation processing of the setting values of the pumping light powers is executed after starting the operation, and then the wavelength characteristic of the output signal light LS is controlled sequentially.

Sugaya, [0183].

102. Thus, because Sugaya uses the result of the matrix multiplication technique to determine the power settings for the Raman pumps, Sugaya renders obvious "*determining power setting values for the pump lasers based on the projected deviations*" as claimed.

3. Claim 2

[2.1] ***The method of claim 1 further comprising: applying the power setting values determined to the pump lasers.***

103. **First**, as explained above at [1.4], Sugaya's technique describes determining the power settings for the Raman pumps.

104. Second, Sugaya explicitly describes using the determined settings.

> By performing the series of processing shown in step 211 to step 217, based on the measurement result using the optical transmission path 202 to be actually used, the setting values of the pumping light powers for obtaining the output signal light LS having the desired wavelength characteristic are obtained. Such calculation processing of the setting values of the pumping light powers can be executed before starting the operation of the present Raman amplifier, to store the calculation result in a memory or the like. Further, it is also possible that the calculation processing of the setting values of the pumping light powers is executed

> after starting the operation, **and then the wavelength characteristic of the output signal light LS is controlled sequentially**.
>
> As described in the above, according to the Raman amplifier of the embodiment 2-3, before starting the operation, the correction value of the ASS light power is calculated in accordance with the modeling formula for which the coefficient is determined using the optical transmission path 202 to be actually used, and using the correction value, the setting value of the pumping light power corresponding to each wavelength block is calculated. **Thus, it becomes possible to execute reliably the control of the wavelength characteristic of the output signal light LS with excellent accuracy.**

Sugaya, [0183].

105. Thus, because Sugaya describes executing control of the output signals using the calculated Raman power settings, Sugaya renders obvious "*applying the power setting values determined to the pump lasers*" as claimed.

4. Claim 4

[4.1] ***The method of claim 1 further comprising: compensating the deviations for fiber propagation loss.***

106. Sugaya's technique takes into account the power loss from the optical transmission path. At the start of Sugaya's optimization process as outlines in Fig. 18, each of the signals at each wavelength block transmitted in the fiber are all turned on to allow for measuring their power at the power monitoring point. With this step, the fiber loss for each wavelength can be measured and is known. The

process of obtaining the gain matrix B_{ij} includes measuring the fiber loss.

> In step 212, in a state where the pumping light Lp is not supplied to the optical transmission path 202, respective powers of the output signal light LS divided into three wavelength blocks are measured by the output light monitoring section 220. Then, using the input power of the signal light LS in step 211 and the measured signal light average output power, **average losses L1, L2 and L3 in the optical transmission path 202 corresponding to the respective wave length blocks are calculated**.

Sugaya, [0174].

> In step 213, the pumping light sources 211-1 to 211-n are driven for each group corresponding to each wavelength block, and the signal light average output power for each wavelength block is measured. Here, the pumping light powers corresponding to the respective wavelength blocks are P_{P1}, P_{P2} P_{P3}. Then, a correction value of the ASS light power corresponding to each of the pumping light powers P_{P1}, P_{P2} and P_{P3} is calculated by the ASS light calculating circuit 233, and the calculation result is transmitted to the pumping light power calculating circuit 238. In the pumping light power calculating circuit 238, in accordance with the correction value calculated by the ASS light calculating circuit 233, the correction of the ASS light component is performed on the signal light average output power of each wavelength block measured by the output light monitoring section 220. Here, the signal light average output powers subjected the ASS light correction are P_{S1}, P_{S2} and P_{S3}. These signal light average output powers P_{S1}, P_{S2} and P_{S3} can be expressed by a relationship shown in the next (2.9)

formula, using the pumping light powers P_{P1}, P_{P2} and P_{P3} corresponding to the respective wavelength blocks and the losses L1, L2 and L3 calculated in step 212.

Sugaya, [0175].

$$\begin{bmatrix} P_{S1} \\ P_{S2} \\ P_{S3} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \begin{bmatrix} P_{P1} \\ P_{P2} \\ P_{P3} \end{bmatrix} + \begin{bmatrix} L_1 \\ L_2 \\ L_3 \end{bmatrix} \quad (2.9)$$

"fiber propagation losses"

Sugaya, Equation 2.9.

Accordingly, by giving the respective values obtained by the above measurement to (2.9) formula, a matrix composed of a proportional coefficient Aij (i, j=1, 2, 3) corresponding to each wavelength block is obtained.

Sugaya, [0176].

107. Accordingly, Sugaya's measured signal powers P_{S1}, P_{S2}, and P_{S3} take into account the fiber propagation loss. Because the measured error vector ("*deviations*") represent the differences between the target values and the measured values (which consider the fiber propagation loss), Sugaya is "*compensating the deviations for fiber propagation loss*" as claimed.

108. Thus, because Sugaya's measurement of the optical output powers considers the losses in the fiber optic transmission lines, Sugaya renders obvious "*compensating the deviations for fiber propagation loss*" as claimed.

5. Claim 6

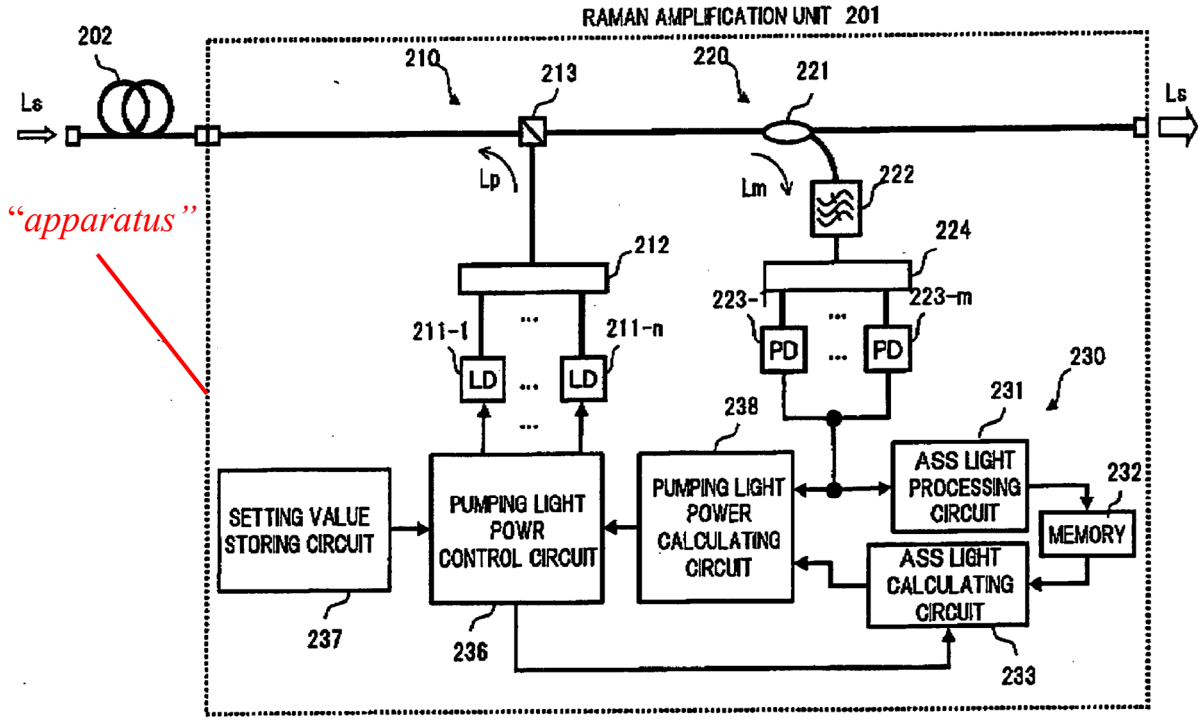
[6.1] ***The method of claim 1 further comprising: measuring channel power for a plurality of channels.***

109. As explained above at [1.1] and [1.2], Sugaya describes measuring channel powers for a plurality of wavelength blocks. Accordingly, Sugaya renders obvious "*measuring channel power for a plurality of channels*" as claimed.

6. Claim 19

[19.0] ***An apparatus comprising:***

110. As explained above at [1.0], Sugaya describes a Raman amplification unit 201 ("*apparatus*").



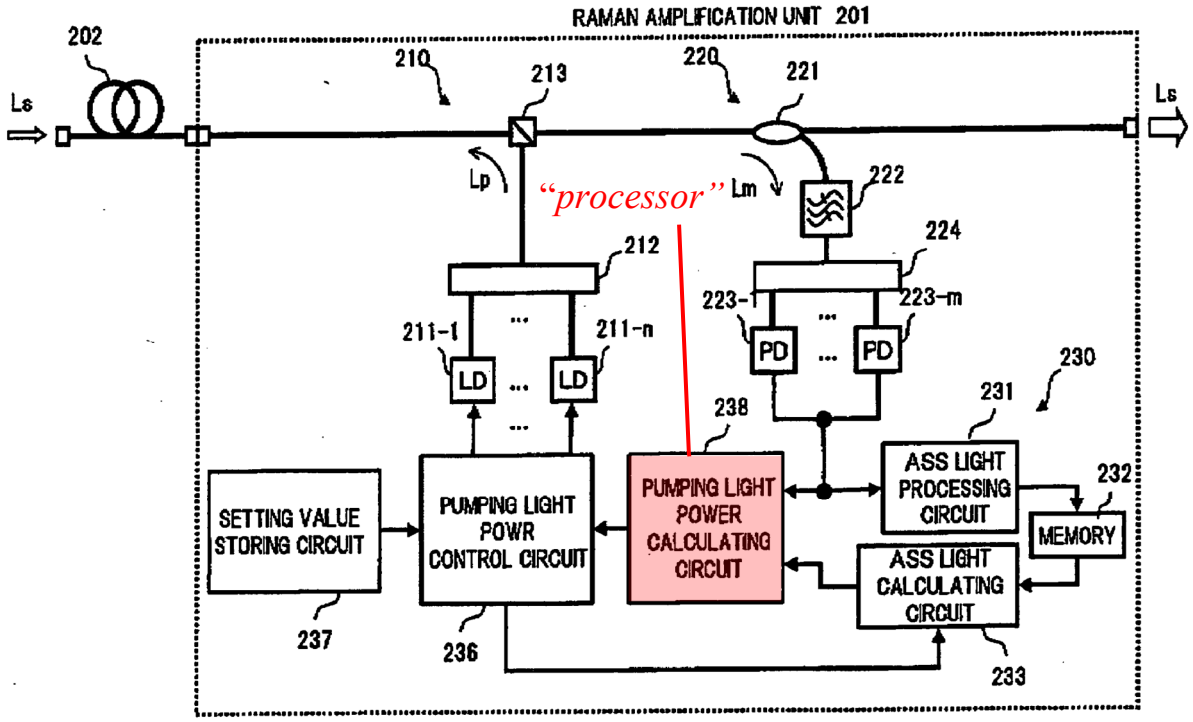
Sugaya, Fig. 17 (annotated).

111. Thus, Sugaya's Raman amplification unit 201 teaches "*an apparatus*"

as claimed.

[19.1] ***a processor configured to receive measured channel powers and,***

112. **First**, as explained above at [1.1], Sugaya's Raman amplification unit 201 includes pumping light power calculating circuity 238 ("a processor").



Sugaya, Fig. 17 (annotated).

113. **Second**, for the reasons explained above at [1.1], Sugaya's pumping light power calculating circuit 238 receives measured channel powers.

114. Thus, because Sugaya describes a pumping light power calculating circuit 238 that receives measured channel powers, Sugaya renders obvious "a processor configured to receive measured channel powers"

[19.2] ***to determine deviations of respective measured channel powers from respective target channel powers,***

115. **First**, for the reasons explained above at [1.2], Sugaya's pumping light power calculating circuit 238 "*determine[s] deviations of respective measured channel powers from respective target channel powers*" as claimed.

116. **Second**, Sugaya's determining of the deviations is part of the process for determining power pump settings. *See* Sugaya, Fig. 18, [0172]-[0183]. Sugaya also explains that calculating the power pump settings is performed by a light power calculating circuit 238 ("processor"): "The pumping light power calculating circuit 238 receives the monitor signal corresponding to each wavelength block ... and based on these signals, calculates the setting value of the pumping light power capable of achieving the output signal light LS having the desired wavelength characteristic." Sugaya, [0170].

117. Thus, Sugaya's light power calculating circuit 238 "*determine[s] deviations of respective measured channel powers from respective target channel powers*" as claimed.

[19.3] ***wherein the processor is further configured to project the deviations into a space that defines Raman gain profiles achievable with a set of channels and pump lasers whereby projected deviations are formed, and***

118. First, for the reasons explained above at [1.3], Sugaya's pumping light power calculating circuit 238 is "*further configured to project the deviations into a space that defines Raman gain profiles achievable with a set of channels and pump lasers whereby projected deviations are formed*" as claimed.

119. **Second**, Sugaya's matrix multiplication technique is part of the process for determining power pump settings. *See* Sugaya, Fig. 18, [0172]-[0183]. Sugaya also explains that calculating the power pump settings is performed by a light power calculating circuit 238 ("*processor*"): "The pumping light power calculating circuit 238 receives the monitor signal corresponding to each wavelength block ... and based on these signals, calculates the setting value of the pumping light power capable of achieving the output signal light LS having the desired wavelength characteristic." Sugaya, [0170].

120. Thus, Sugaya's pumping light power calculating circuit 238 is "*further configured to project the deviations into a space that defines Raman gain profiles achievable with a set of channels and pump lasers whereby projected deviations are formed*" as claimed.

[19.4] ***wherein the processor is further configured to determine power setting values for the pump lasers based on the projected deviations.***

121. **First**, for the reasons explained above at [1.4], Sugaya's pumping light power calculating circuit 238 is "*further configured to determine power setting values for the pump lasers based on the projected deviations*" as claimed.

122. **Second**, Sugaya's determining of pump setting adjustments is part of the process for determining power pump settings. *See* Sugaya, Fig. 18, [0172]-[0183]. Sugaya also explains that calculating the power pump settings is performed by a light power calculating circuit 238 ("processor"): "The pumping light power

calculating circuit 238 receives the monitor signal corresponding to each wavelength block ... and based on these signals, calculates the setting value of the pumping light power capable of achieving the output signal light LS having the desired wavelength characteristic." Sugaya, [0170].

123. Thus, for the reasons explained above at [1.4], Sugaya's pumping light power calculating circuit 238 is "further configured to determine power setting values for the pump lasers based on the projected deviations" as claimed.

7. Claim 21

[21.1] ***The apparatus of claim 19 wherein the processor is configured to compensate the deviations for fiber propagation loss.***

124. For the reasons explained above at [4.1], Sugaya's pumping light power calculating circuit 238 is "*configured to compensate the deviations for fiber propagation loss*" as claimed.

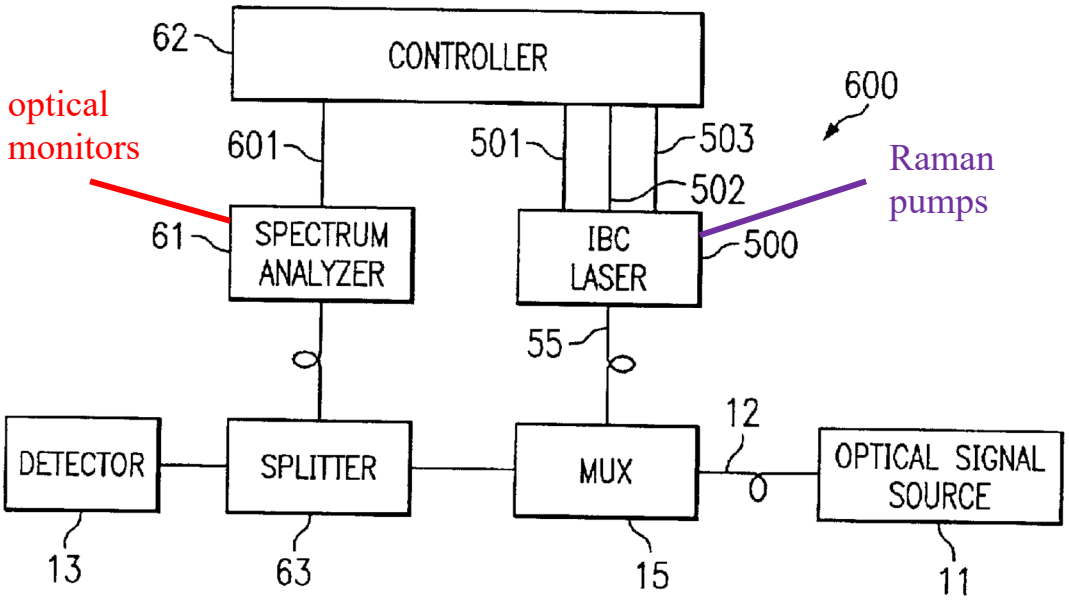
B. Ground 2: Claims 1, 2, 4, 6, 19, and 21 are rendered obvious by Sugaya in view of Farmer.

125. To the extent it is argued that Sugaya's disclosure of wavelength blocks is insufficient to render obvious measuring the power of individual wavelengths, this idea is rendered obvious by the combination of Sugaya and Farmer. Farmer expressly teaches measuring individual signal wavelengths. *See* Farmer, 9:13-35.

1. Summary of Farmer

126. Farmer also describes using a matrix multiplication technique to solve the Raman pump optimization problem addressed in the Challenged Claims of the '721 patent. *Compare* '721 patent *with* Farmer. Like the '721 patent, Farmer "is directed to a system and method which provide a Raman pump which is spectrally tailored in response to feedback from control structure associated with the Raman pump source." Farmer, abstract.

127. Farmer describes a conventional Raman pump system for pumping light power into a fiber optic medium. Farmer, Fig. 6, [0005]-[0007]. One example of a Raman pump system is shown in Fig. 6 below. As shown in Fig. 6, an optical system 600 includes an "IBC laser 500 which can be adapted to produce a tailored Raman pump spectrum." Farmer, 5:25-26. The system 600 also includes a "Spectrum analyzer 61 [that] analyzes the spectral content of the amplified optical signal," thus serving as an optical monitor. Farmer, 7:32-33.



Farmer, Fig. 6 (annotated).

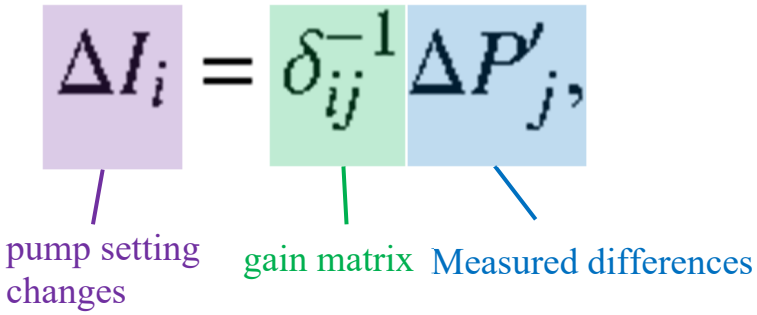
128. The Raman pumps of the IBC laser are used to amplify the optical signals passing through the fiber. "IBC laser 500 is shown as incorporating emitter device 50. Emitter device 50 comprises a plurality of emitters 59-1 through 59-N." Farmer, 5:27-29. Additionally, the degrees of freedom provided by the pump wavelengths and power allows the Raman pump to be specifically spectrally tailored. "By controlling the wavelengths and output power of emitters 59-1 through 59-N, IBC laser 500 can be utilized to provide a dynamically spectrally tailored Raman pump." Farmer, 6:56-59.

129. The optical system 61 also includes optical monitors in the form of the spectrum analyzer. *See* Farmer, 7:4-29. "Spectrum analyzer 61 analyzes the spectral content of the amplified optical signal." Farmer, 7:21-22. "Utilizing the

power information from cables 502 and 503 and the spectral information from cable 601, controller 62 varies the drive currents to emitters 59-1 through 59-N as necessary to maintain Raman gain flatness." Farmer, 7:24-27. Using the spectrum analyzer, the "processor 91 of controller 62 actuates changes in current supplied to emitters 59-1 through 59-N through cable 501 to measure accompanying changes in the power of signal wavelengths through input cable 601." Farmer, 8:46-49.

130. Farmer also describes determining the difference between the measured signal power and a target power. "[T]he desired change in power for each signal wavelength is determined that will result in reasonably flat Raman gain. This can be determined by measuring the deviation of power of each signal wavelength from a desired power." Farmer, 9:13-17.

131. The differences between the measured values and the target values are expressed as a vector: "The desired change in power for each signal wavelength is represented by ΔP_j'." Farmer, 9:19-20. This vector is then multiplied by a gain matrix to determine the pump setting changes that will minimize those differences. Ex.1012, 9:30-35. This matrix multiplication is shown below.



Farmer, 9:30-35 (annotated).

132. As Farmer explains, this matrix multiplication "provides the change in emitter currents that will result in the desired change in signal wavelength power." Farmer, 36-37.

133. Accordingly, like Sugaya, Farmer shows that it was known to multiply an error vector (differences between measured and target powers) with a gain matrix that represents the effect of the Raman pumps to determine the Raman pump settings that will bring the actual power levels closer to a target power level.

2. Reasons to Combine Farmer with Sugaya

134. A POSITA would have found it obvious for Sugaya's optimization technique to optimize at individual signal wavelengths as taught by Farmer.

135. Sugaya describes a known technique in which the signal powers at discrete wavelength blocks are measured and compared to a target power which is a form of well-known optimization problems: "The differences between the signal light average output powers P_{S1}, P_{S2} and P_{S3} and the target power level P_{S0} are ΔP_{S1}, ΔP_{S2} and ΔP_{S3}." Sugaya, [0181]. The deviations between the measured signal

powers and the target power are then represented by a vector and multiplied by a gain matrix. *See* Sugaya, Equation 2.12. By multiplying that vector with a gain matrix, the system determines the Raman pump settings that will flatten the spectrum (i.e., bring the signal powers closer to the target power) can be determined. *See* Sugaya, [0183].

136. Farmer describes a similar technique in which the signal powers at specific "signal wavelengths" are measured. Farmer describes "measuring the deviation of power of each **signal wavelength** from a desired power." Farmer, 9:13-17. The differences between the measured signal powers at each signal wavelength and a target power are then expressed as a vector. Farmer, 9:19-20. Like in Sugaya, Farmer's vector is similarly multiplied by a gain matrix to determine the Raman pump settings that will flatten the signal powers. Farmer, 9:30-36.

137. Accordingly, to the extent Sugaya's "wavelength blocks" do not correspond to signal wavelengths, it would have been obvious for Sugaya's system to measure and optimize the powers at individual signal wavelengths as taught by Farmer. A POSITA would have found it beneficial to optimize at specific wavelengths as taught by Farmer. As Farmer explains, "embodiments of the present invention may monitor spectral information associated with signal wavelengths. When Raman gain associated with the signal wavelengths becomes

uneven, suitable control algorithms can be employed to **equalize Raman gain across the signal wavelengths**." Farmer, 11:13-18. Farmer's technique further "allows reasonably flat Raman gain to be dynamically achieved across a broad spectrum of wavelengths." Farmer, 11:19-25. Moreover, given the "nonlinear interaction between light and the [fiber optic] material," a POSITA would have found it beneficial to utilize a more "spectrally tailored Raman pump" such as the one described by Farmer. Farmer, 1:30, 2:52.

138. The proposed combination predictably results in determining the Raman pump settings at specific wavelengths. The results would have been predictable at least because Farmer uses the same matrix multiplication technique used by Sugaya. *Compare* Sugaya, Equation 2.12 *with* Farmer, 9:30-36.

$$\begin{bmatrix} \Delta P_{P1} \\ \Delta P_{P2} \\ \Delta P_{P3} \end{bmatrix} = \begin{bmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{23} \\ B_{31} & B_{32} & B_{33} \end{bmatrix}^{-1} \begin{bmatrix} \Delta P_{S1} \\ \Delta P_{S2} \\ \Delta P_{S3} \end{bmatrix} \quad (2.12)$$

pump setting changes — gain matrix — Measured differences

Sugaya, Equation 2.12 (annotated).

$$\Delta I_i = \delta_{ij}^{-1} \Delta P'_j,$$

pump setting changes — gain matrix — Measured differences

Farmer, 9:30-35 (annotated).

139. A POSITA would have had a reasonable expectation of success because Farmer's gain matrix is obtained in a manner similar to Sugaya's. Sugaya explains that the gain matrix is obtained by measuring the signal powers at various frequency blocks at various pump powers to create a matrix. Sugaya, [0175]-[0179]. The inverse of that matrix is then used in the multiplication technique. Sugaya, [0180], Equation, 2.12; *see also* [1.3], Ground 1.

140. Farmer similarly describes measuring the signal powers at various frequency blocks at various pump powers to create a matrix. Farmer, 8:53-9:12. Farmer explains that "the current to each emitter 59-i is individually varied by a small amount, ΔI_i. The resulting change in power, ΔP_j, for each signal wavelength is measured each time that current is varied for an individual emitter 59-i. The information gathered in this manner is used to generate the differential gain matrix, δ_{ji}." Farmer, 8:67-9:4. Thus, the "differential gain matrix, δ_{ji}, provides the relationship between the change in signal wavelength power that results from any change in emitter currents." Farmer, 9:6-8. Then, "[b]y finding the inverse of the differential gain matrix, δ_{ji}, the required change in emitter currents that results in the desired change in signal wavelength power can be determined." Farmer, 9:24-27. Like Sugaya, Farmer uses the inverse matrix to determine the desired pump settings. *See* Sugaya, [0180], Equation 2.12; Farmer, 9:30-36. Accordingly, a POSITA would have expected success in using Sugaya's technique to optimize for

individual signal wavelengths as taught by Farmer.

141. Accordingly, the combination of Sugaya and Farmer is merely applying a known technique (Farmer's optimization at individual signal wavelengths) to a known method (Sugaya's matrix multiplication optimization technique) ready for improvement to yield predictable results (optimizing the pump settings to achieve a flattened gain across signal wavelengths).

3. Claim 1

[1.0] ***A method comprising:***

142. See [1.0], Ground 1.

143. In addition, Farmer similarly describes a "*method*" that "provide[s] a Raman pump which is dynamically spectrally tailored in response to feedback from control structure." Farmer, abstract. "An error signal can be generated by measuring the power levels of the optical signal as the optical signal exits the amplifier. The power levels can be compared to a desired power level." Farmer, abstract. "By employing suitable control algorithms with this error signal, the desired gain can be maintained dynamically." Farmer, abstract.

[1.1] ***receiving measured channel powers;***

144. **First**, as explained above in [1.1], Ground 1, Sugaya's method includes measuring the average output power at varying wavelength blocks ("*channel[s]*"). "In step 213, the pumping light sources 211-1 to 211-n are driven

for each group corresponding to each wavelength block, **and the signal light average output power for each wavelength block is measured**." Sugaya, [0175]. "Here, the signal light average output powers ... are P_{S1}, P_{S2} and P_{S3}." Sugaya, [0175]. Because the measured average signal powers P_{S1}, P_{S2}, and P_{S3} correspond to different wavelength blocks, they are "*measured **channel** powers*" as claimed.

145. Second, to the extent that it is argued that Sugaya's wavelength blocks do not correspond to channels, it would have been obvious for Sugaya's technique to be applied such that individual channels, or signal wavelengths, are measured and optimized, as evidenced by Farmer. Indeed, while Sugaya's example uses three wavelength blocks, Sugaya explains that "the number of divided wavelength blocks is not limited to the above example." Sugaya, [0172].

146. Farmer explains that "the desired change in power for each **signal wavelength** is determined that will result in reasonably flat Raman gain. This can be determined by measuring the deviation of power of **each signal wavelength** from a desired power." Farmer, 9:13-17.

> After building the differential gain matrix, δ_{ji}, the desired change in power for each signal wavelength is determined that will result in reasonably flat Raman gain. This can be determined by measuring the deviation of power of each signal wavelength from a desired power. The desired change in power for each signal wavelength is represented by $\Delta P_j'$. Obtaining reasonably flat Raman gain involves minimization of the vector norm, where the vector norm is given by:

$$\rho=\|\delta_{ji}\Delta I_i-\Delta P_j'\|.$$

Farmer, 9:13-23.

147. The measured deviations can then be received by a controller.

FIG. 6 depicts exemplary optical system 600 which includes IBC laser 500 to produce a dynamically spectrally tailored Raman pump to maintain Raman gain flatness. IBC laser 500 is coupled to controller 62 via cables 501, 502, and 503. Controller 62 controls the output power of emitters 59-1 through 59-N (see FIG. 5) by providing variable current via the lines of cable 501. Additionally, controller 62 receives the power feedback information from cables 502 and 503. Controller 62 is able to determine the output power of each emitter 59-1 through 59-N and the amount of optical power coupled into optical fiber 55. Additionally, optical signal source 11 provides an optical signal to optical fiber 12. The Raman pump generated by IBC laser 500 is provided to optical fiber 12 via multiplexer 15 to generate the desired Raman gain. Multiplexer 15 is coupled to splitter 63. Splitter 63 allows a portion of the amplified optical signal that originated from optical signal source to be provided to spectrum analyzer 61. **Spectrum analyzer 61 analyzes the spectral content of the amplified optical signal. The spectral information is provided to controller 62 via cable 601**. Utilizing the power information from cables 502 and 503 and the spectral information from cable 601, controller 62 varies the drive currents to emitters 59-1 through 59-N as necessary to maintain Raman gain flatness. Controller 62 varies the drive currents according

> to suitable control algorithms as will be discussed in greater detail herein below.

Farmer, 7:4-29.

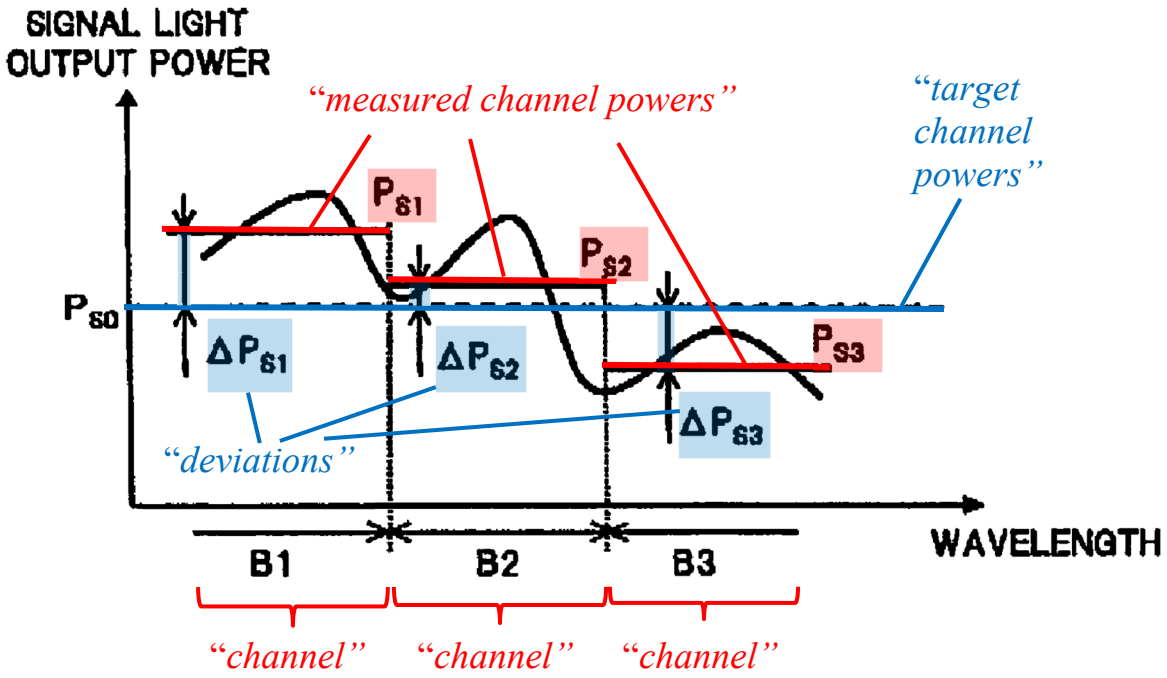
148. Accordingly, it was known to take measurements at each individual signal wavelength ("*channel*"). For the reasons explained above at X.C.2, a POSITA would have found it obvious for Sugaya's technique to apply to individual signal wavelengths. Indeed, Farmer shows that it was known to either measure individual signal wavelengths, or subsets of signal wavelengths: "Additionally, it shall be appreciated that the preceding matrix algorithm does not require measurement of every wavelength associated with communication channels over a given spectrum. Instead, wavelength power information can be gathered for a subset of wavelengths across the given spectrum." Farmer, 10:11-16.

149. Thus, because Sugaya describes a pumping light power calculating unit that receives measured average output powers P_{S1}, P_{S2}, and P_{S3} for various wavelength blocks, and Farmer shows that it was known to measure at each individual signal wavelength, Sugaya and Farmer render obvious "*receiving measured channel powers*" as claimed.

[1.2] ***determining deviations of respective measured channel powers from respective target channel powers;***

150. **First**, as explained above at [1.2], Ground 1, Sugaya determines the

difference between the measured powers and a target level P_{S0}. These differences ("*deviations*") are expressed in Sugaya as ΔP_{S1}, ΔP_{S2} and ΔP_{S3}. The "differences between the signal light average output powers P_{S1}, P_{S2} and P_{S3} and the target power level P_{S0} are ΔP_{S1}, ΔP_{S2} and ΔP_{S3}." Sugaya, [0181]. Fig. 19 below illustrates the deviations (in blue) between the target channel powers and the measured channel powers (in red).



Sugaya, Fig. 19 (annotated).

151. Second, Farmer describes a similar process for determining deviations from a target power at individual signal wavelengths ("channels"): "[T]he desired change in power for each **signal wavelength** is determined that will result in reasonably flat Raman gain. This can be determined by measuring the deviation of

power of **each signal wavelength** from a desired power." Farmer, 9:13-17. Farmer describes representing the respective deviations for each signal wavelength in a vector: "The desired change in power for each signal wavelength is represented by ΔP_j'. Obtaining reasonably flat Raman gain involves minimization of the vector norm." Farmer, 9:17-20. Again, for the reasons explained above at X.C.2, a POSITA would have found it obvious for Sugaya's technique to apply to individual signal wavelengths. As such, Sugaya's wavelength blocks B1, B2, B3 shown in Fig. 19 would correspond to signal wavelengths.

152. Thus, because Sugaya describes calculating the deviations ΔP_{S1}, ΔP_{S2} and ΔP_{S3} between the measured values P_{S1}, P_{S2} and P_{S3} and a target level P_{S0}, and Farmer similarly describes measuring deviations at individual signal wavelengths, Sugaya and Farmer render obvious "*determining deviations of respective measured channel powers from respective target channel powers*" as claimed.

[1.3] ***projecting the deviations into a space that defines Raman gain profiles achievable with a set of channels and pump lasers whereby projected deviations are formed; and***

153. First, as explained at [1.3], Ground 1, Sugaya describes the same matrix multiplication technique described and claimed in the '721 patent. A measured error vector (ΔP_{S1}, ΔP_{S2} and ΔP_{S3}) ("*deviations*") is multiplied by (projected onto) the gain matrix Bij representing the Raman pump profiles ("*space that defines Raman pump capabilities*") to determine a set of pump power

differences (ΔP_{P1}, ΔP_{P2} and ΔP_{P3}) ("*projected deviations*"). This matrix multiplication is illustrated in equation 2.12 below.

$$\begin{bmatrix} \Delta P_{P1} \\ \Delta P_{P2} \\ \Delta P_{P3} \end{bmatrix} = \begin{bmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{23} \\ B_{31} & B_{32} & B_{33} \end{bmatrix}^{-1} \begin{bmatrix} \Delta P_{S1} \\ \Delta P_{S2} \\ \Delta P_{S3} \end{bmatrix} \quad (2.12)$$

"*projected deviations*" "*space that defines Raman gain profiles*" "*deviations*"

Sugaya, Equation 2.12 (annotated).

154. Farmer describes a similar matrix multiplication technique using individual signal wavelengths ("*set of channels*"). "By finding the inverse of the differential gain matrix, δ_{ji}, the required change in emitter currents that results in the desired change in signal wavelength power can be determined. The solution can be obtained by finding the generalized (or pseudo) inverse, δ_{ji}^{-1}." Farmer's matrix multiplication is shown below.

$$\Delta I_i = \delta_{ij}^{-1} \Delta P'_j,$$

pump setting changes gain matrix Measured differences

Farmer, 9:30-35 (annotated).

155. Again, a POSITA would have understood that this process is not limited to case where the number of measurements is equal to the number of Raman pumps. *See e.g.,* Farmer, 9:8-11 ("It shall be appreciated that the differential gain matrix, δ_{ji} is not typically a square matrix, since the number of emitters 59-i does not necessarily equal the number of signal wavelengths."). For example, if the number of measured wavelength blocks is greater than the number of Raman pumps, then the matrix multiplication technique will result in a smaller vector than the measured error vector.

156. Thus, because Sugaya describes a multiplication technique that projects the measured pump power deviations from a target power onto a gain matrix that defines the capabilities of the Raman pumps, and Farmer describes a similar technique that optimizes for individual signal wavelengths, Sugaya and Farmer renders obvious "*projecting the deviations into a space that defines Raman gain profiles achievable with a set of channels and pump lasers whereby projected deviations are formed*" as claimed.

[1.4] ***determining power setting values for the pump lasers based on the projected deviations.***

157. **First**, as described above at [1.4], Ground 1, Sugaya describes using the result ("*projected deviations*") of the matrix multiplication to change the Raman pump settings. Indeed, the purpose of the method described in Fig. 18 is to determine the power setting values for the Raman pumps. "Here, **a specific setting**

method of the pumping light power will be described referring to a flowchart of FIG. 18." Sugaya, [0172]. "By performing the series of processing shown in step 211 to step 217, based on the measurement result using the optical transmission path 202 to be actually used, the setting values of the pumping light powers for obtaining the output signal light L_S having the desired wavelength characteristic are obtained." Sugaya, [0183].

158. Farmer, which performs a similar technique using individual signal wavelengths, similarly describes using the results to determine the power settings. The results of Farmer's matrix multiplication "provide[] the change in emitter currents that will result in the desired change in signal wavelength power." Farmer, 9:36:37.

159. Thus, because Sugaya uses the result of the matrix multiplication technique to determine the power settings for the Raman pumps, Sugaya renders obvious "*determining power setting values for the pump lasers based on the projected deviations*" as claimed.

4. Claim 2

[2.1] ***The method of claim 1 further comprising: applying the power setting values determined to the pump lasers.***

160. *See* [2.1], Ground 1.

5. Claim 4

[4.1] ***The method of claim 1 further comprising: compensating the deviations for***

fiber propagation loss.

161. *See* [4.1], Ground 1.

6. Claim 6

[6.1] ***The method of claim 1 further comprising: measuring channel power for a plurality of channels.***

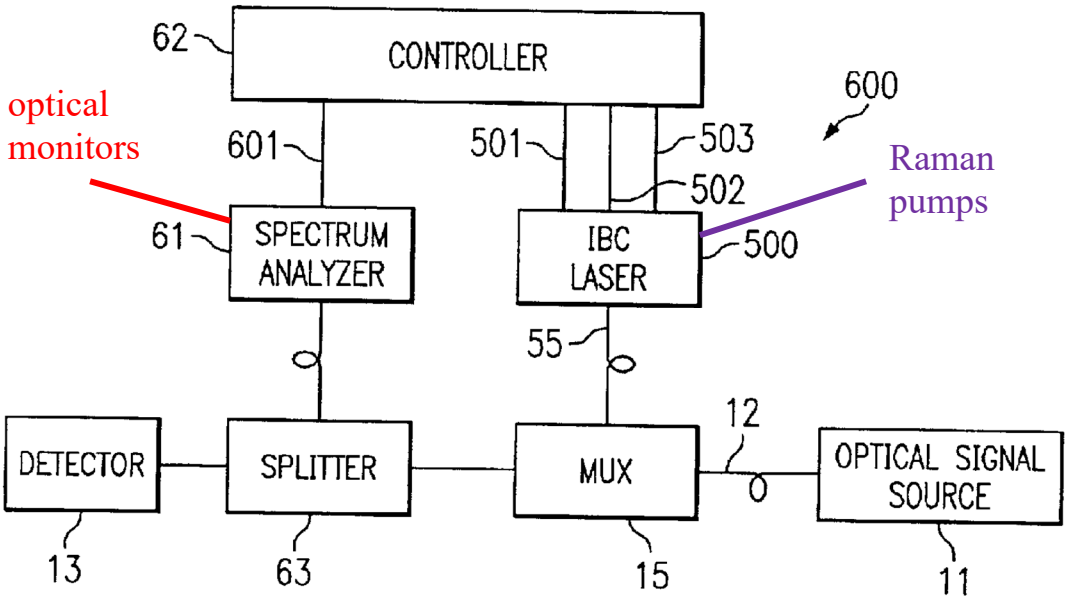
162. See [6.1], Ground 1.

7. Claim 19

[19.0] ***An apparatus comprising:***

163. As explained above at [19.0] in Ground 1, Sugaya describes a Raman amplification unit 201 ("*apparatus*").

164. In addition, Farmer describes a similar apparatus. Farmer describes a Raman pump system. As shown in Fig. 6, an optical system 600 includes an "IBC laser 500 which can be adapted to produce a tailored Raman pump spectrum." Ex.1012, 5:25-26. The system 600 also includes a "Spectrum analyzer 61 [that] analyzes the spectral content of the amplified optical signal," thus serving as an optical monitor. Farmer, 7:32-33.



Farmer, Fig. 6 (annotated).

[19.1] ***a processor configured to receive measured channel powers and,***

165. *See* [19.1], Ground 1.

166. As explained above at [19.1], Ground 1, Sugaya's Raman amplification unit 201 includes pumping light power calculating circuity 238 ("*a processor*"). In addition, Farmer similarly describes a controller with a processor. The "processor 91 of controller 62 actuates changes in current supplied to emitters 59-1 through 59-N through cable 501 to **measure accompanying changes in the power of signal wavelengths** through input cable 601." Farmer, 8:46-49. Thus, Farmer further renders obvious a "*processor*" as claimed.

167. For the reasons explained above at [1.1], Ground 1, a POSITA would have found it obvious for Sugaya's system to receive measured powers at

individual signal wavelengths ("*receive measured channel powers*") as taught by Farmer.

[19.2] ***to determine deviations of respective measured channel powers from respective target channel powers,***

168. See [19.2], Ground 1.

169. Additionally, for the reasons explained above at [1.2] Ground 2, it would have been obvious for Sugaya's pumping light power calculating circuit 238 to determine deviations at individual signal wavelengths, as evidenced by Farmer.

[19.3] ***wherein the processor is further configured to project the deviations into a space that defines Raman gain profiles achievable with a set of channels and pump lasers whereby projected deviations are formed, and***

170. For the reasons explained above at [1.3], Sugaya and Farmer render obvious "*wherein the processor is further configured to project the deviations into a space that defines Raman gain profiles achievable with a set of channels and pump lasers whereby projected deviations are formed*" as claimed.

[19.4] ***wherein the processor is further configured to determine power setting values for the pump lasers based on the projected deviations.***

171. For the reasons explained above at [1.4], Sugaya and Farmer render obvious "*wherein the processor is further configured to determine power setting values for the pump lasers based on the projected deviations*" as claimed.

8. Claim 21

[21.1] ***The apparatus of claim 19 wherein the processor is configured to compensate the deviations for fiber propagation loss.***

172. For the reasons explained above at [4.1], Ground 2 and [21.1], Ground 1, Sugaya's pumping light power calculating circuit 238 is "*wherein the processor is further to compensate the deviations for fiber propagation loss*" as claimed.

IX. CONCLUSION

173. This declaration and my opinions herein are made to the best of my knowledge and understanding, and based on the material available to me, at the time of signing this declaration. I declare that all statements made herein on my own knowledge are true and that all statements made on information and belief are believed to be true, and further, 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 or Title 18 of the United States Code.

Date: _November 30, 2024_

Daniel Blumenthal