



(19) **United States**

(12) **Patent Application Publication**

Duvaut et al.

(10) **Pub. No.: US 2003/0108095 A1**

(43) **Pub. Date: Jun. 12, 2003**

(54) **SYSTEM AND METHOD FOR REDUCING NOISE INDUCED BY DIGITAL SUBSCRIBER LINE (DSL) SYSTEMS INTO SERVICES THAT ARE CONCURRENTLY DEPLOYED ON A COMMUNICATION LINE**

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(21) Appl. No.: **10/316,155**
(22) Filed: **Dec. 10, 2002**

Related U.S. Application Data

(60) Provisional application No. 60/338,939, filed on Dec. 10, 2001. Provisional application No. 60/341,654, filed on Dec. 17, 2001. Provisional application No.

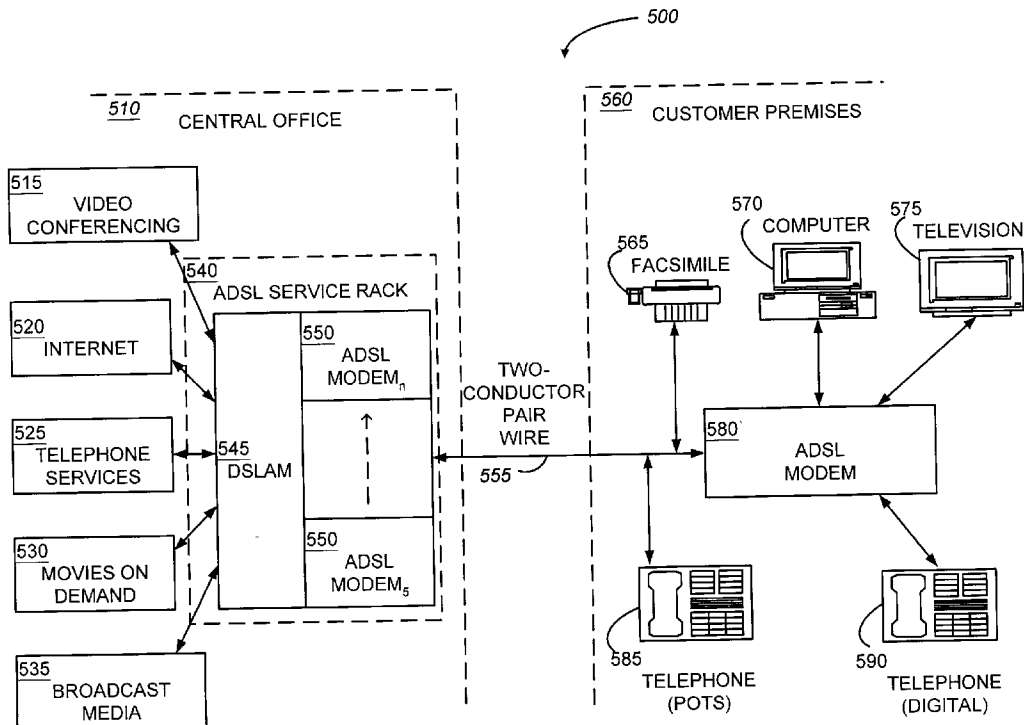
60/346,809, filed on Jan. 7, 2002. Provisional application No. 60/348,575, filed on Jan. 14, 2002. Provisional application No. 60/350,552, filed on Jan. 22, 2002. Provisional application No. 60/353,880, filed on Feb. 2, 2002. Provisional application No. 60/354,888, filed on Feb. 6, 2002. Provisional application No. 60/355,117, filed on Feb. 8, 2002.

Publication Classification

(51) **Int. Cl.⁷** **H04B 1/38; H04L 5/16**
(52) **U.S. Cl.** **375/222**

(57) **ABSTRACT**

Systems and methods are presented for reducing noise induced by digital subscriber line (DSL) systems into services that are concurrently deployed on a communication line. In the disclosed technique, a power level of a discrete multi-tone (DMT) sub-carrier is adaptively calculated from a signal that is received from a communication line. The signal has information indicative of line conditions, which are further indicative of services deployed on the communication line.



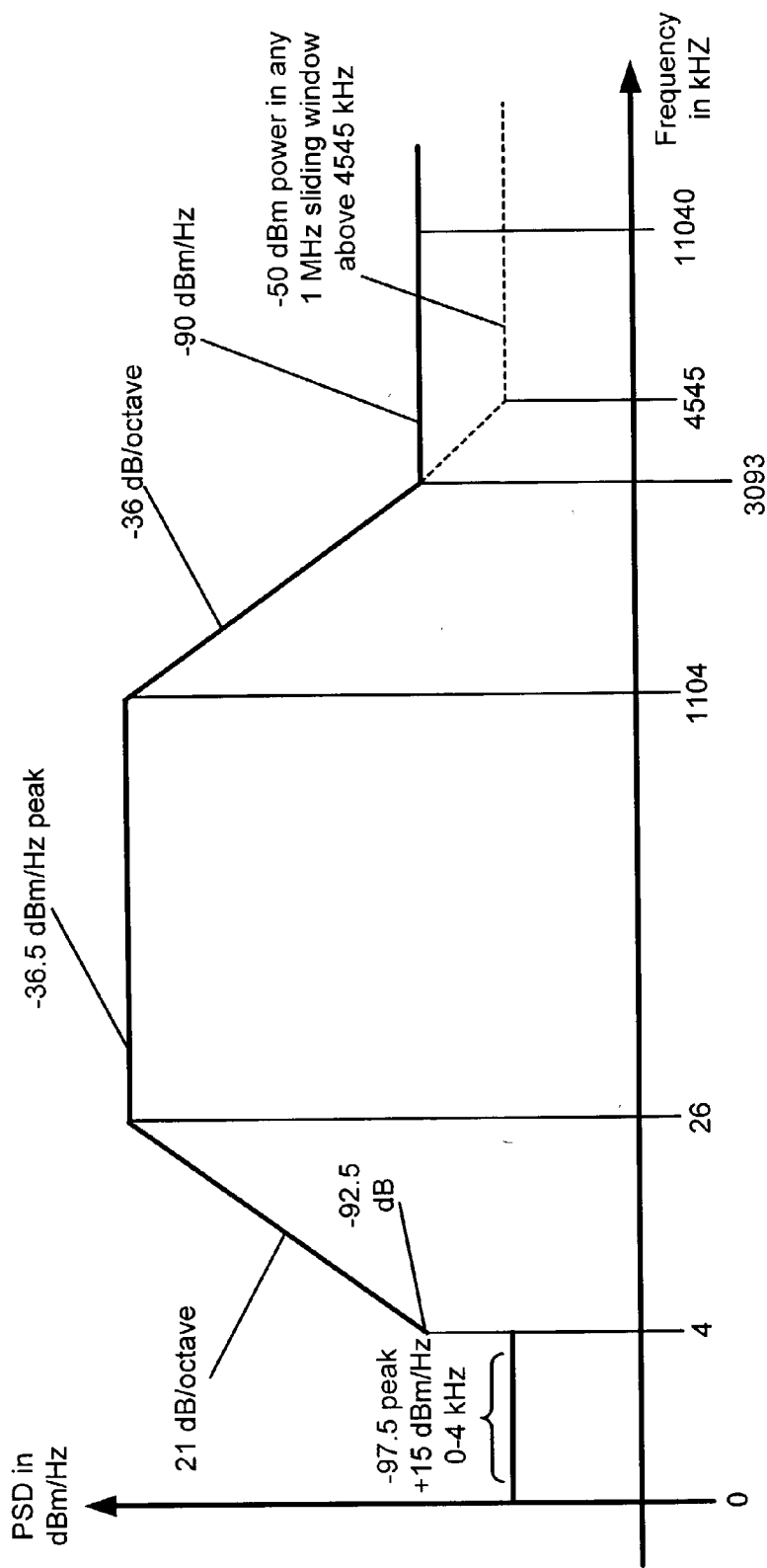


FIG. 1

(Prior Art)

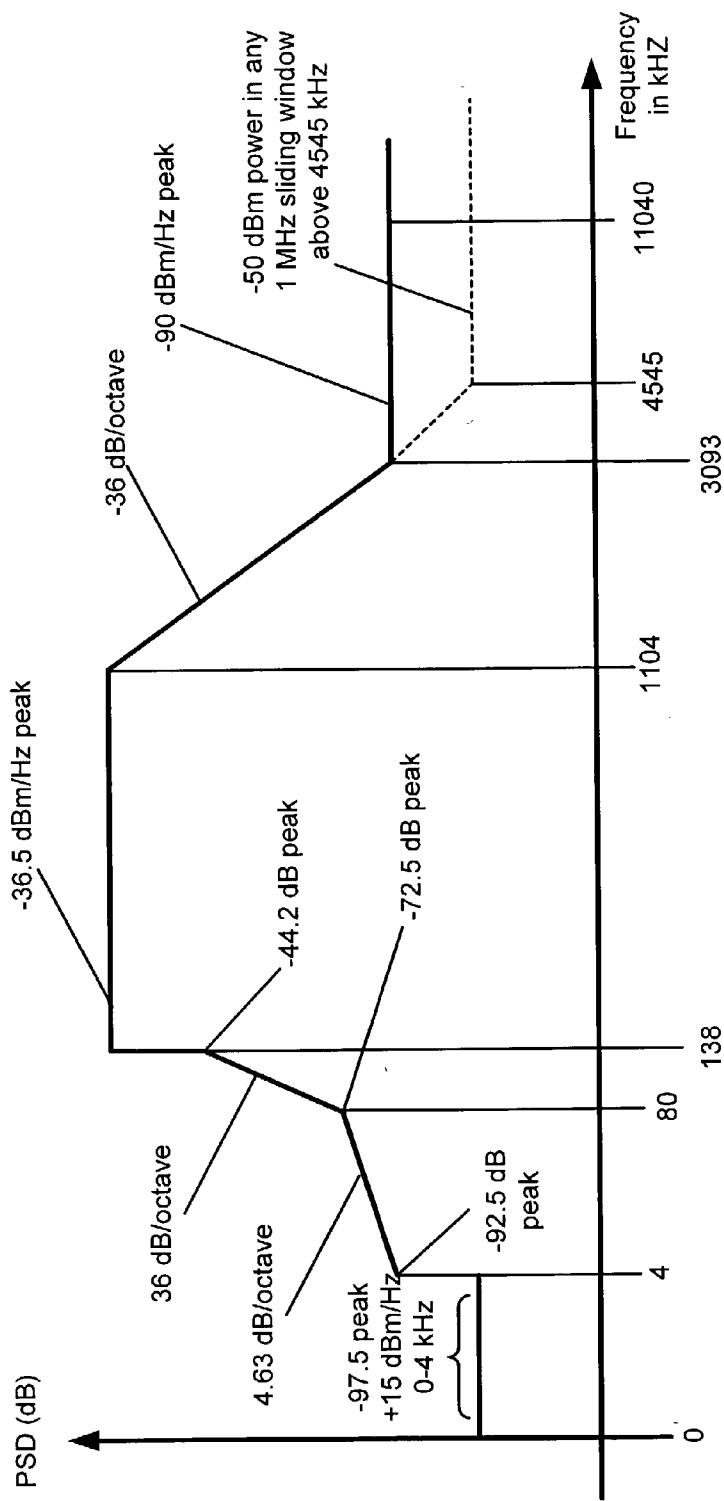


FIG. 2
(Prior Art)

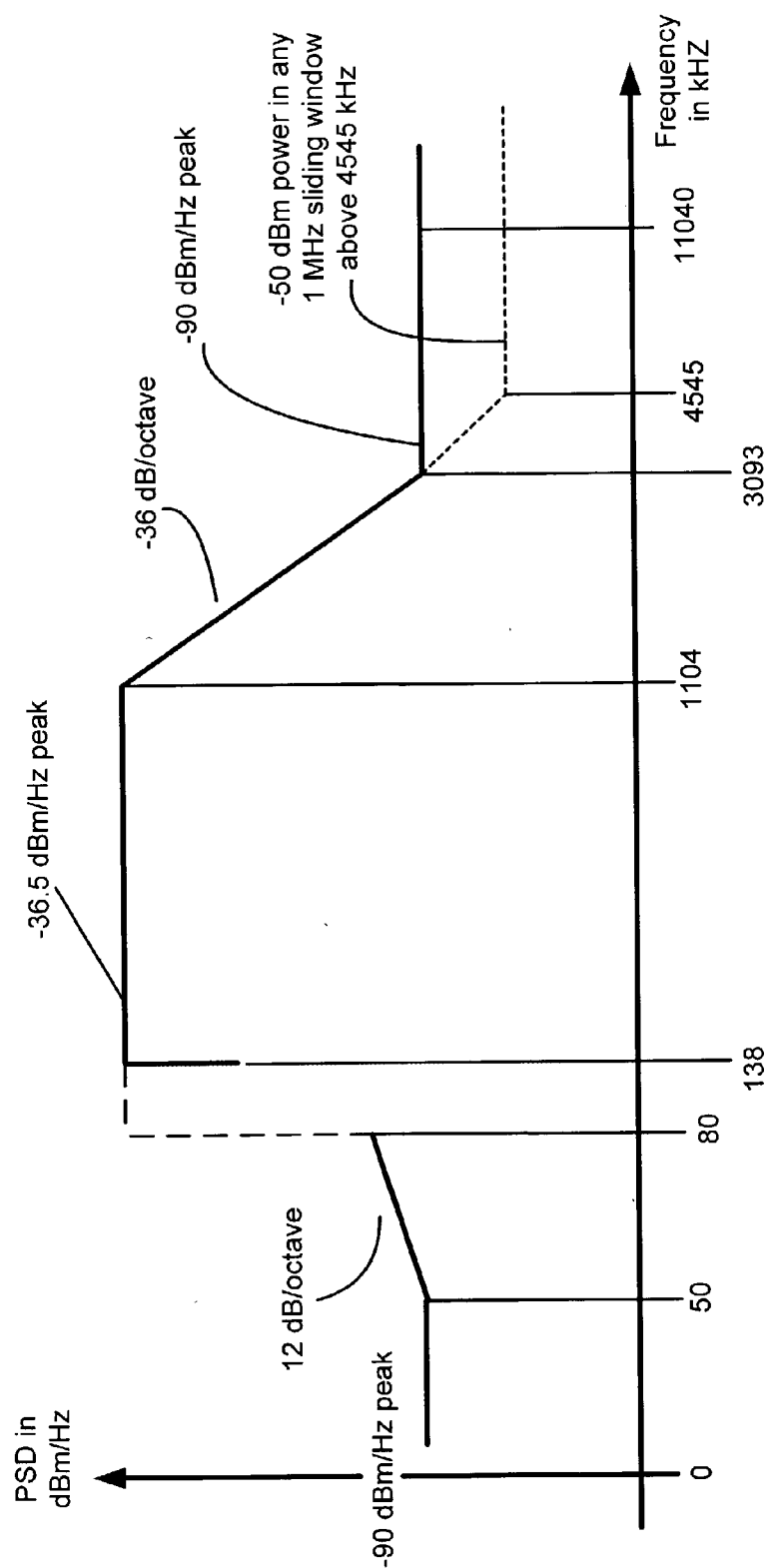


FIG. 3
(Prior Art)

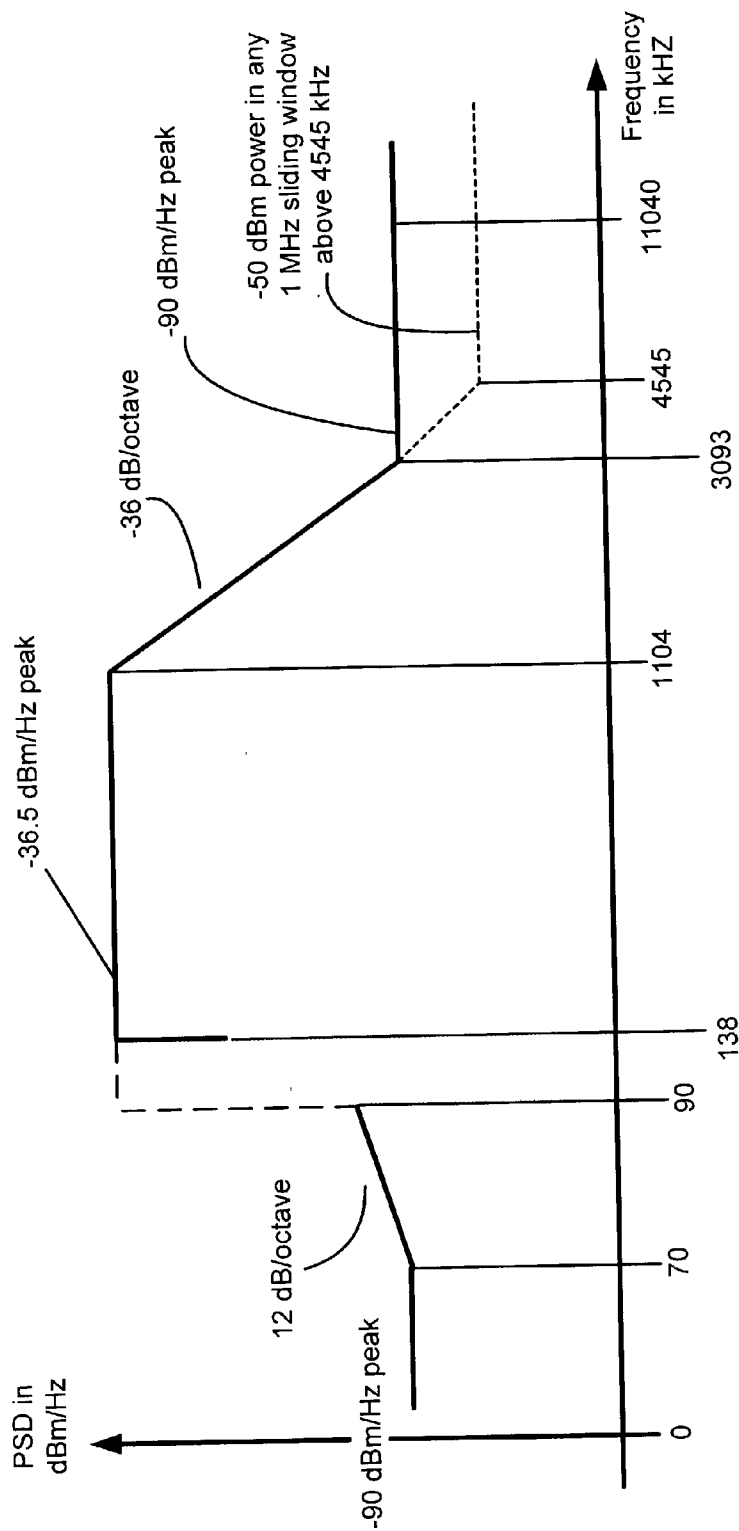


FIG. 4
(Prior Art)

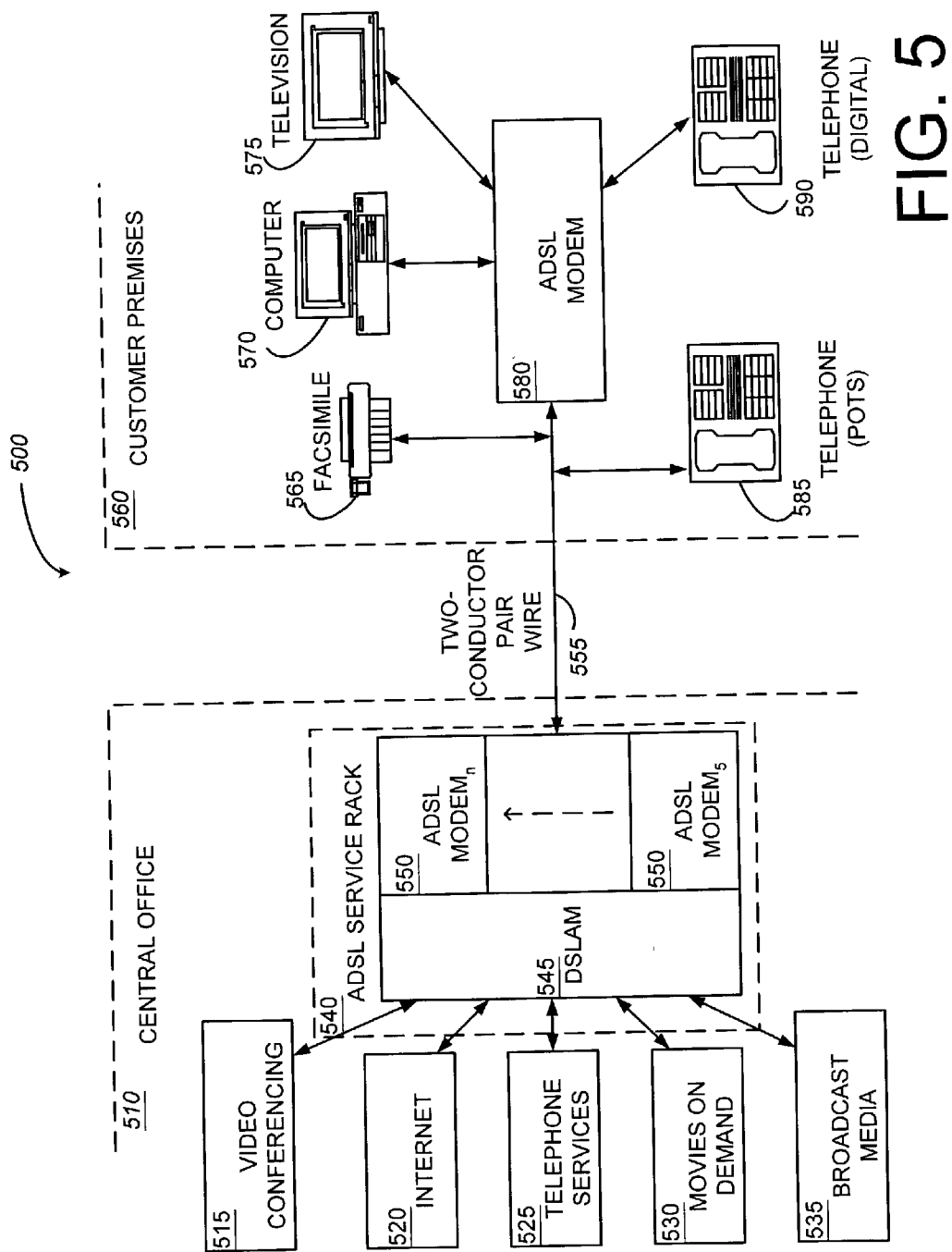


FIG. 5

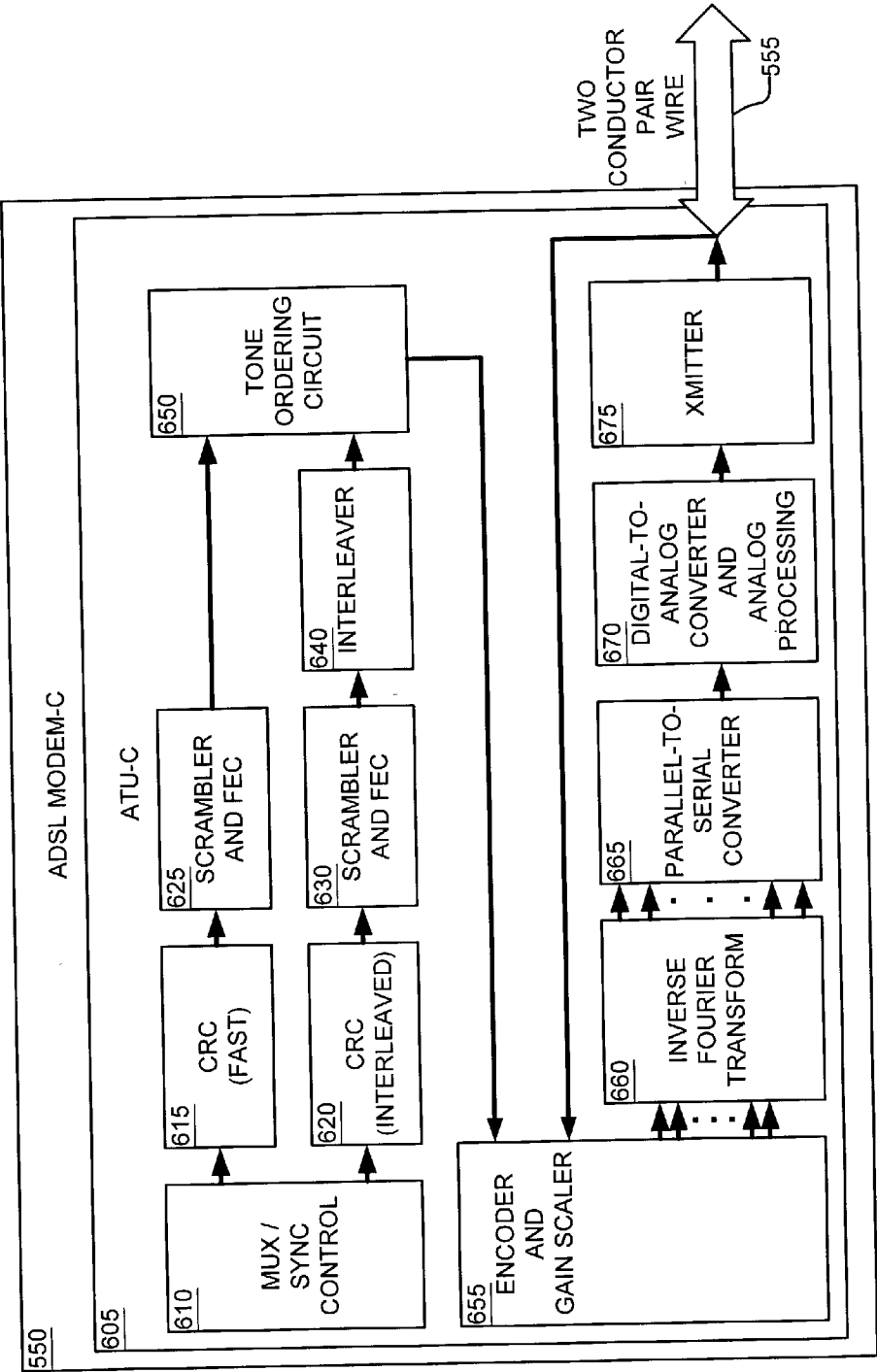
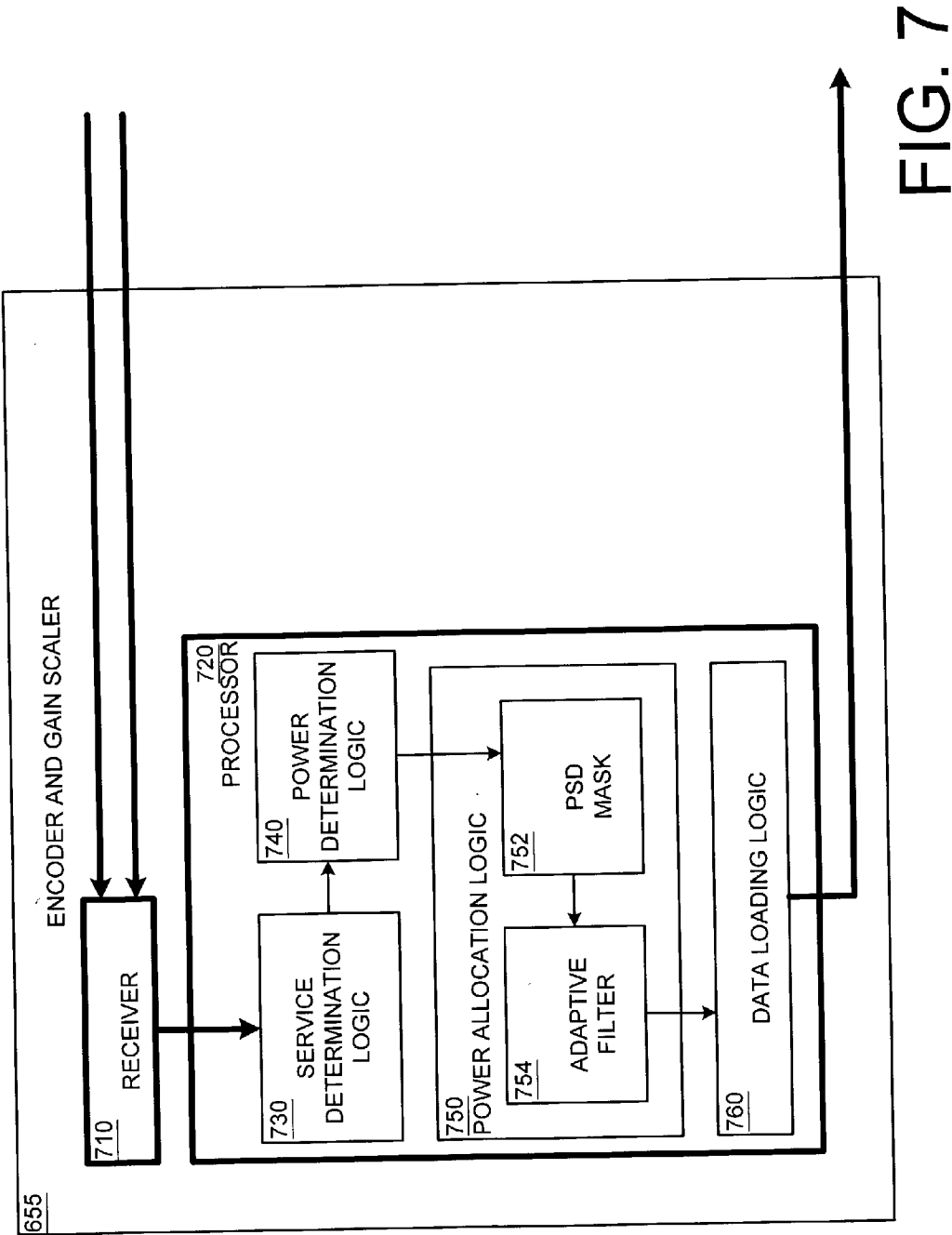


FIG. 6



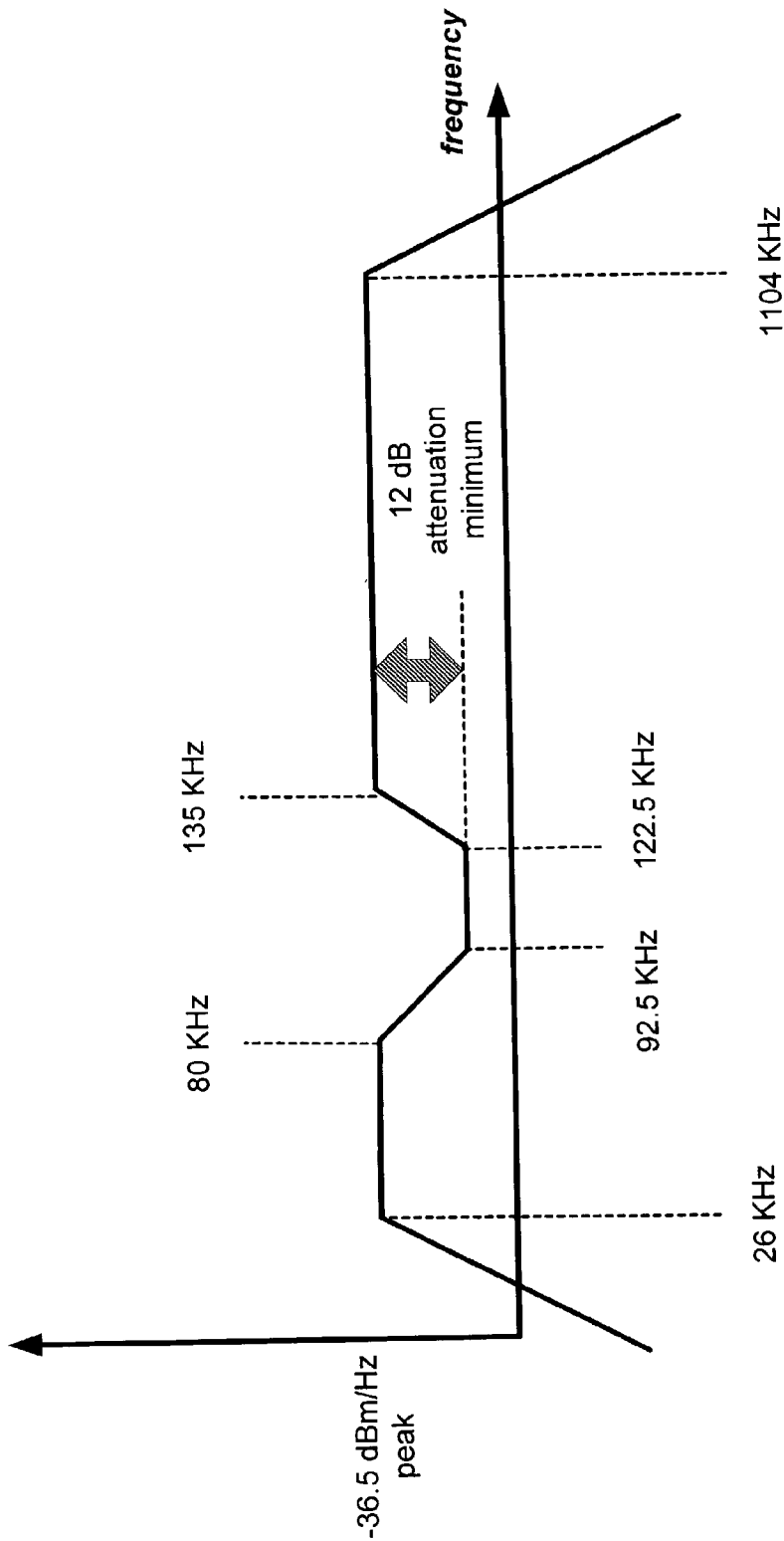


FIG. 8

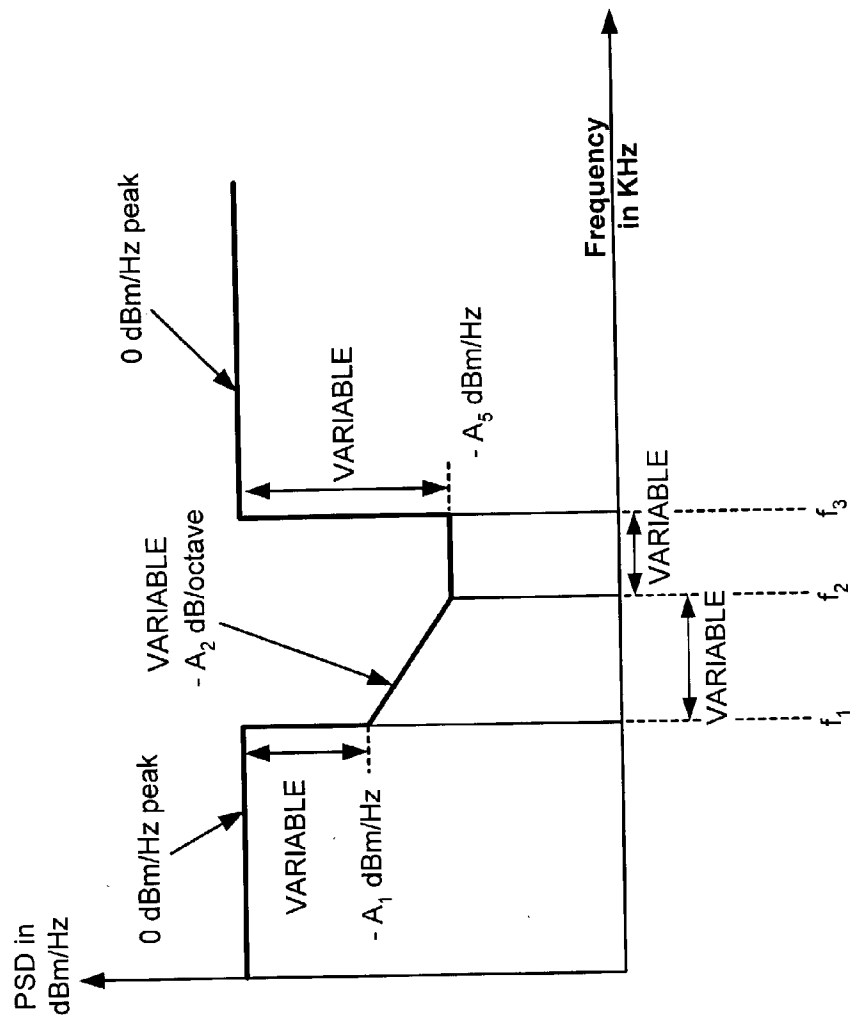


FIG. 9A

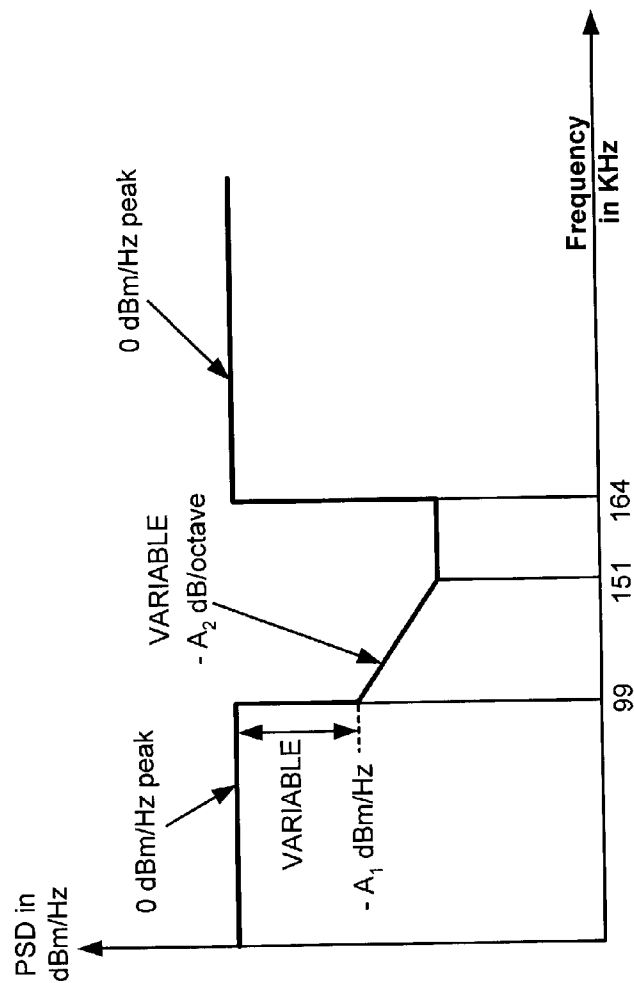


FIG. 9B

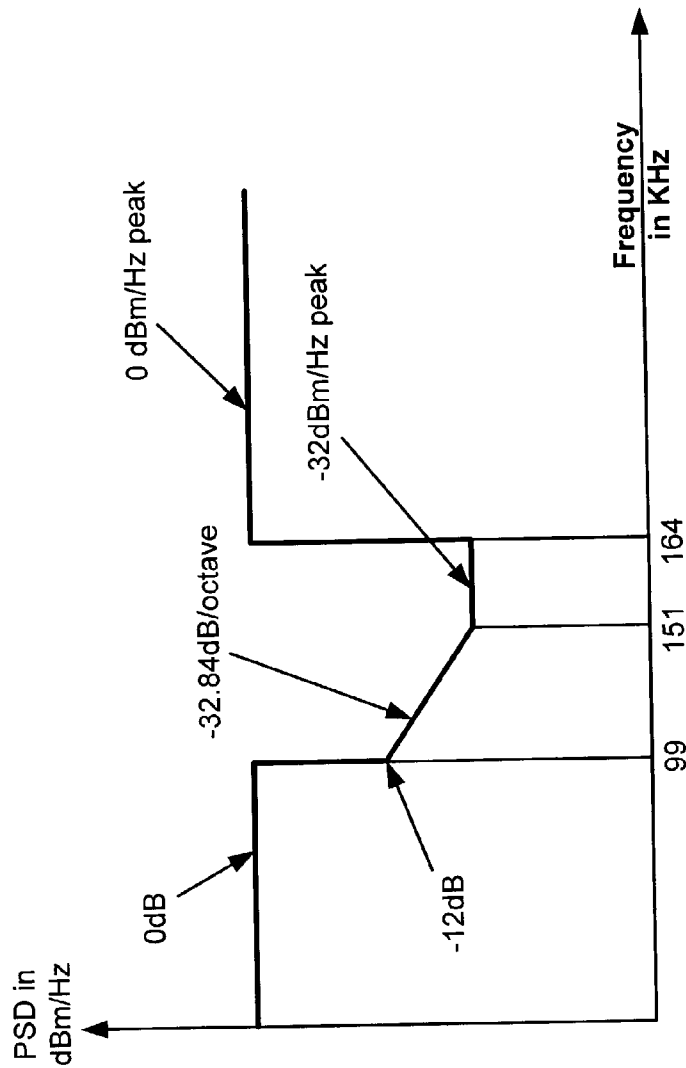


FIG. 9C

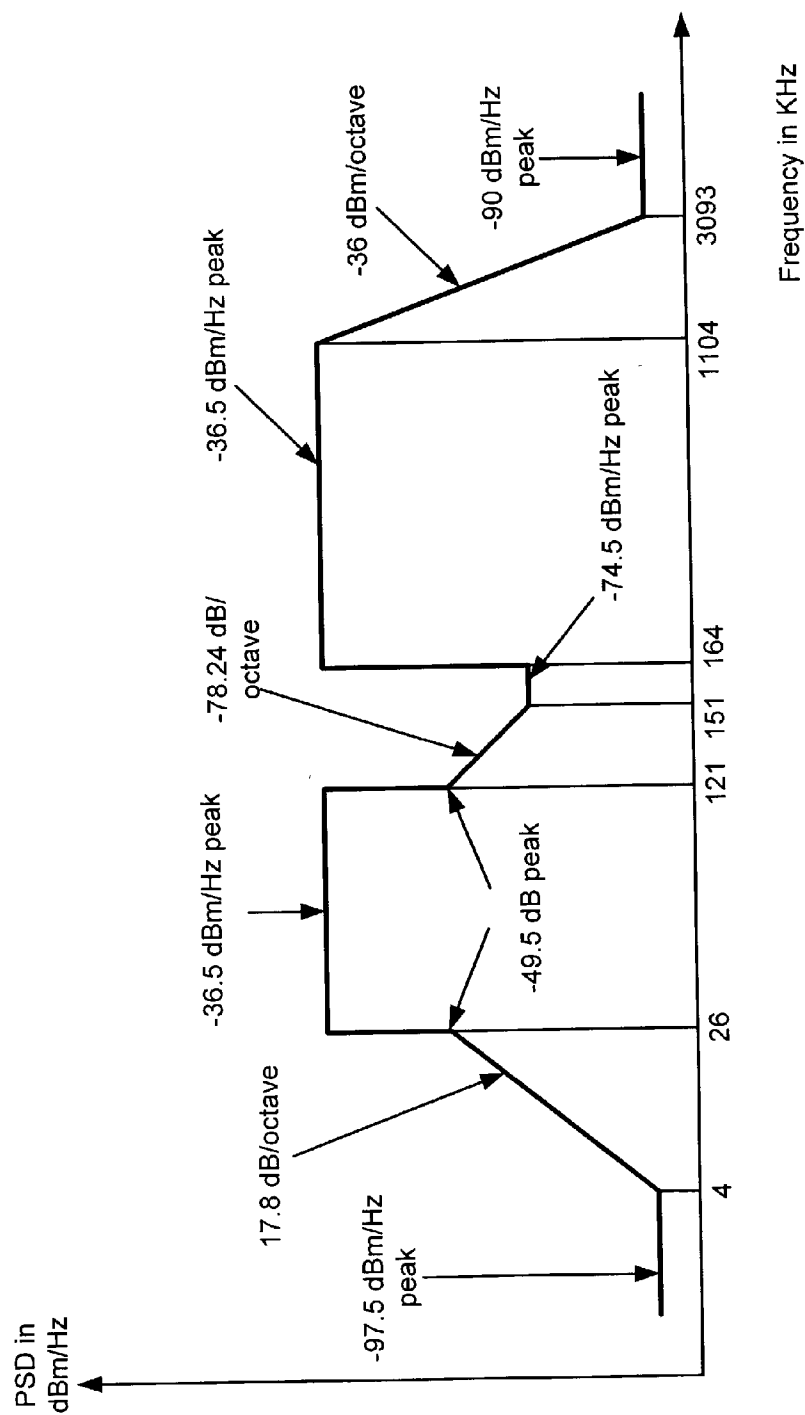


FIG. 10

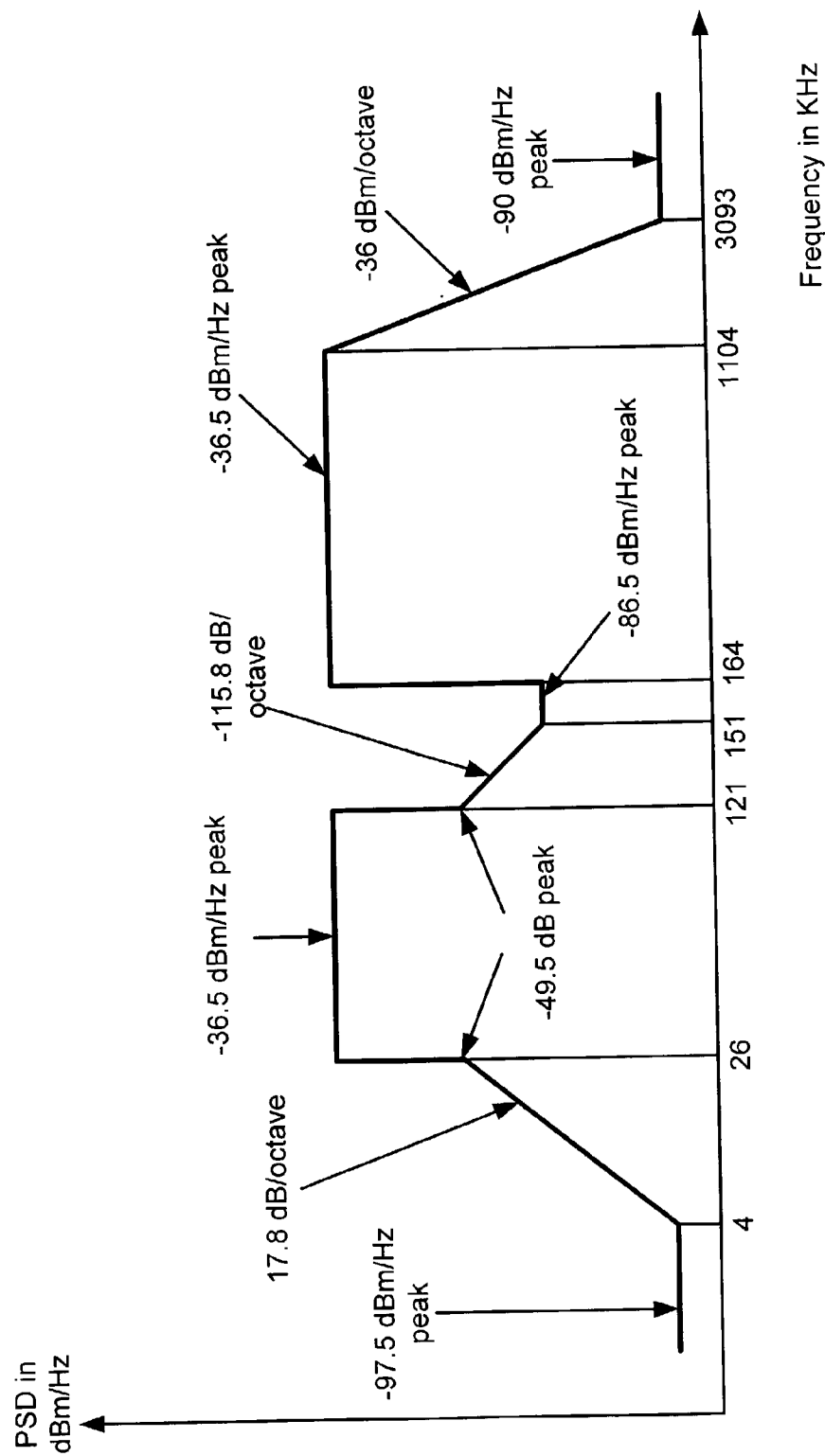


FIG. 11

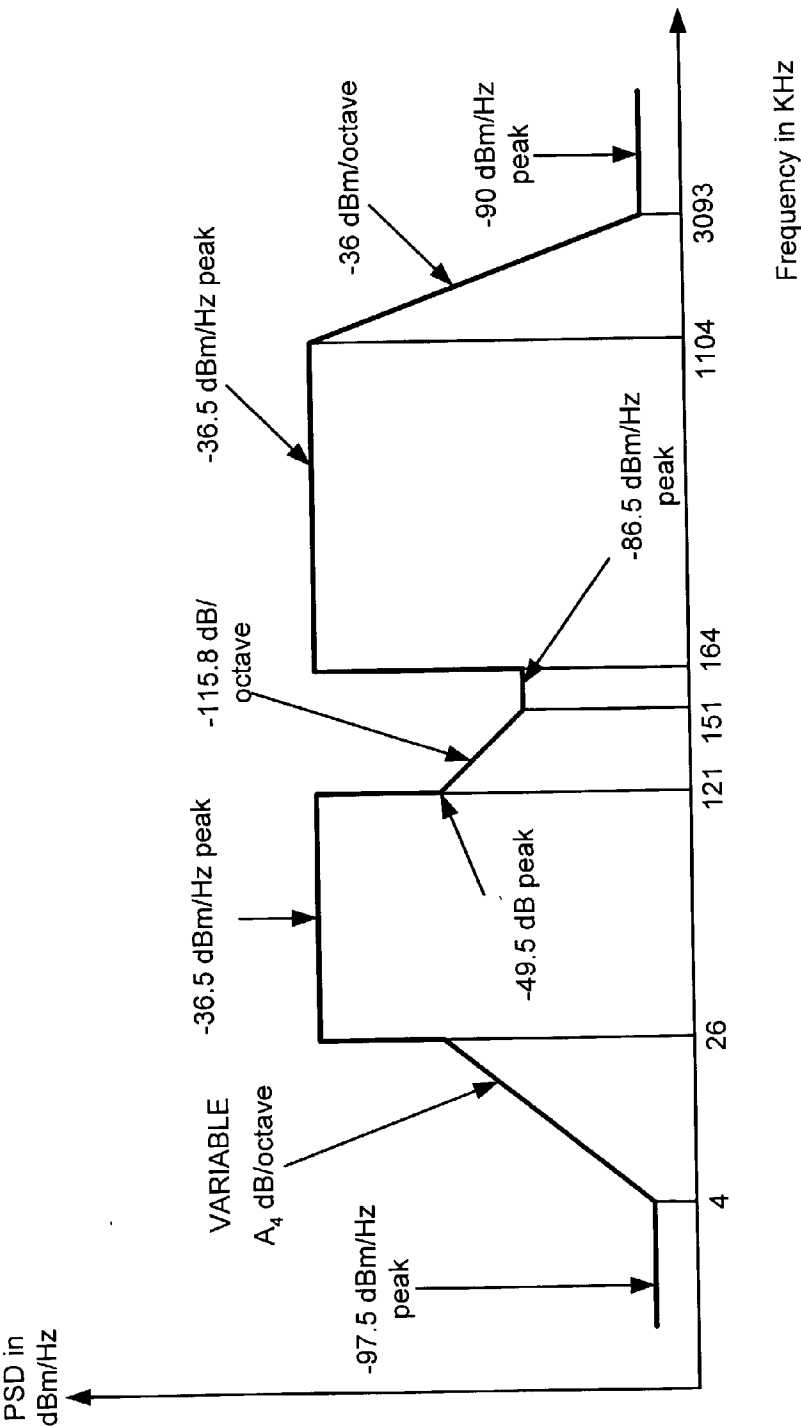


FIG. 12

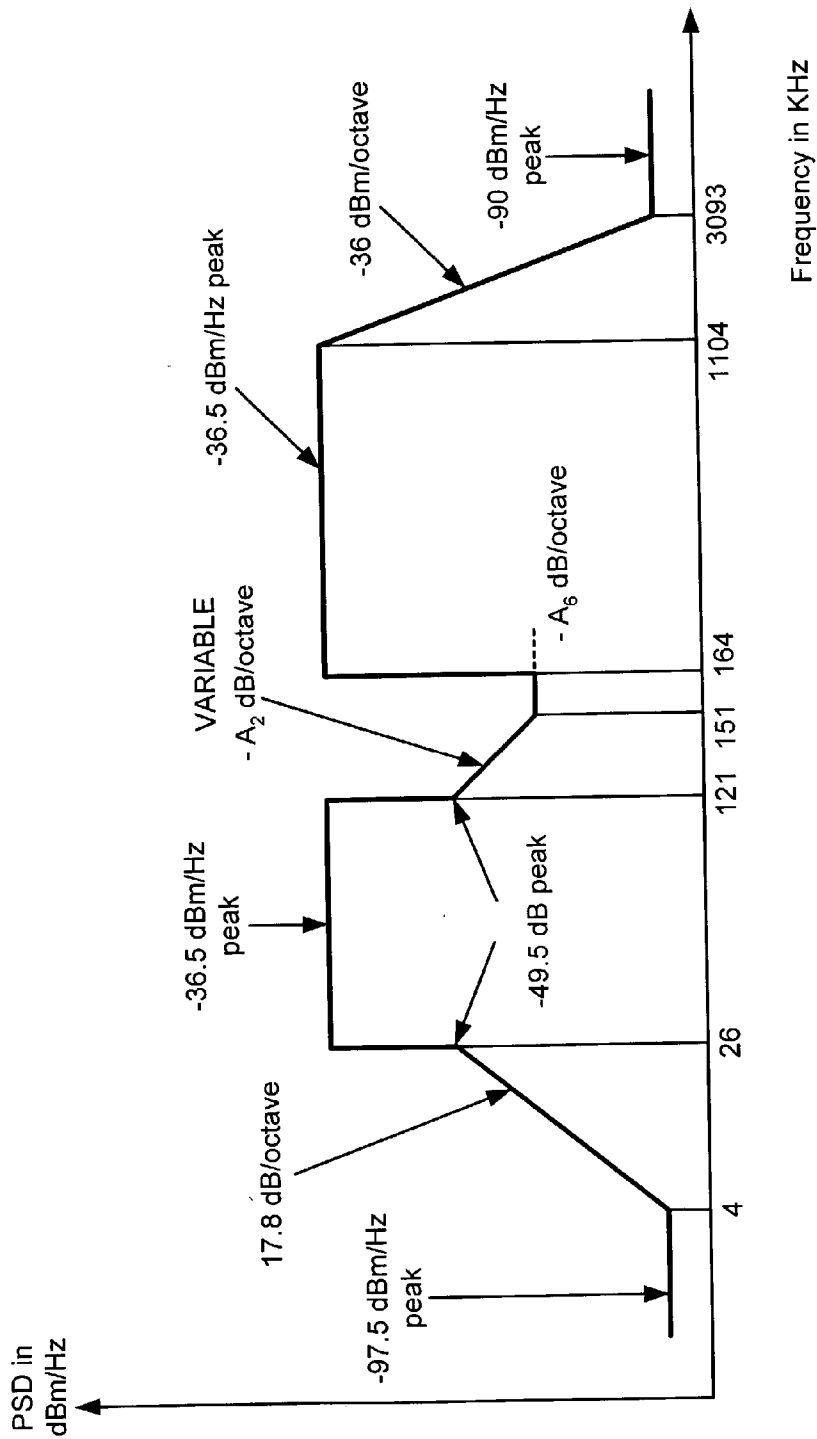


FIG. 13

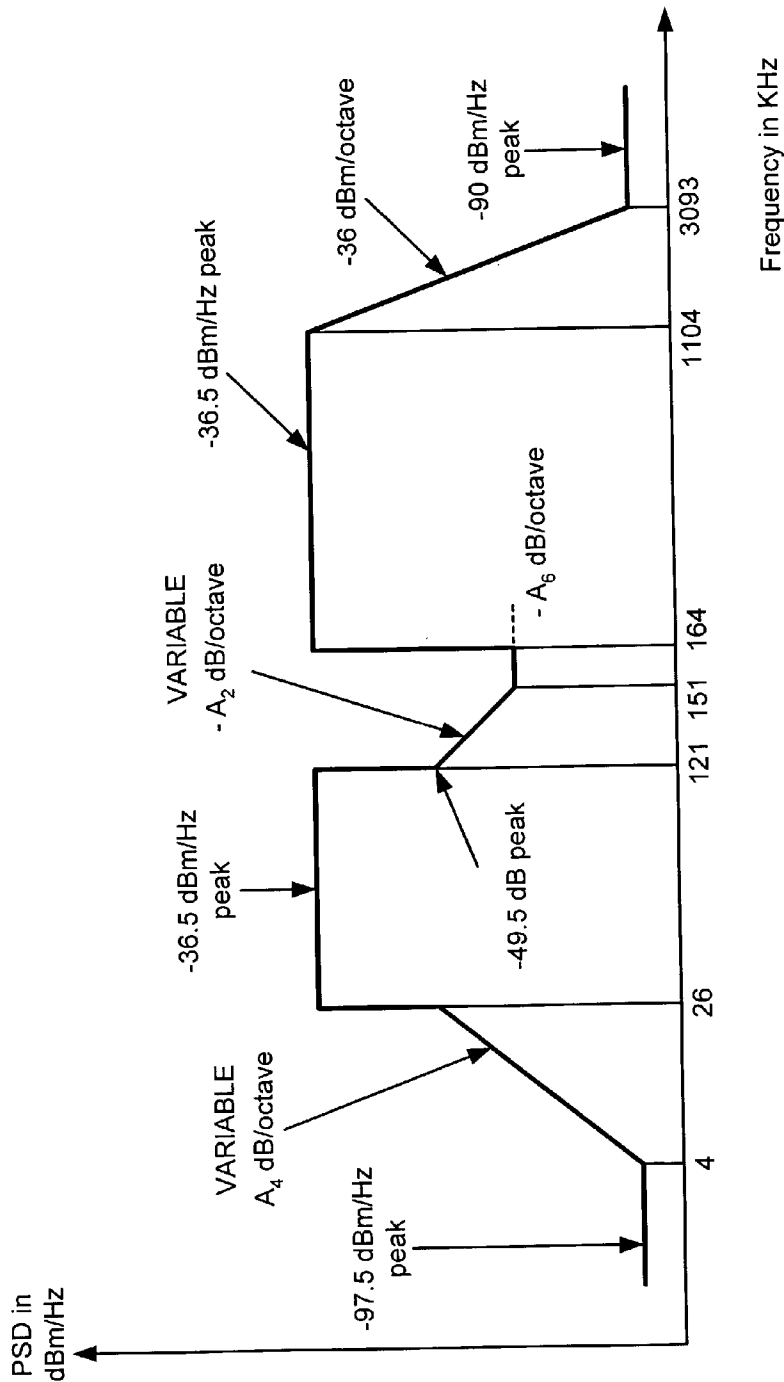


FIG. 14

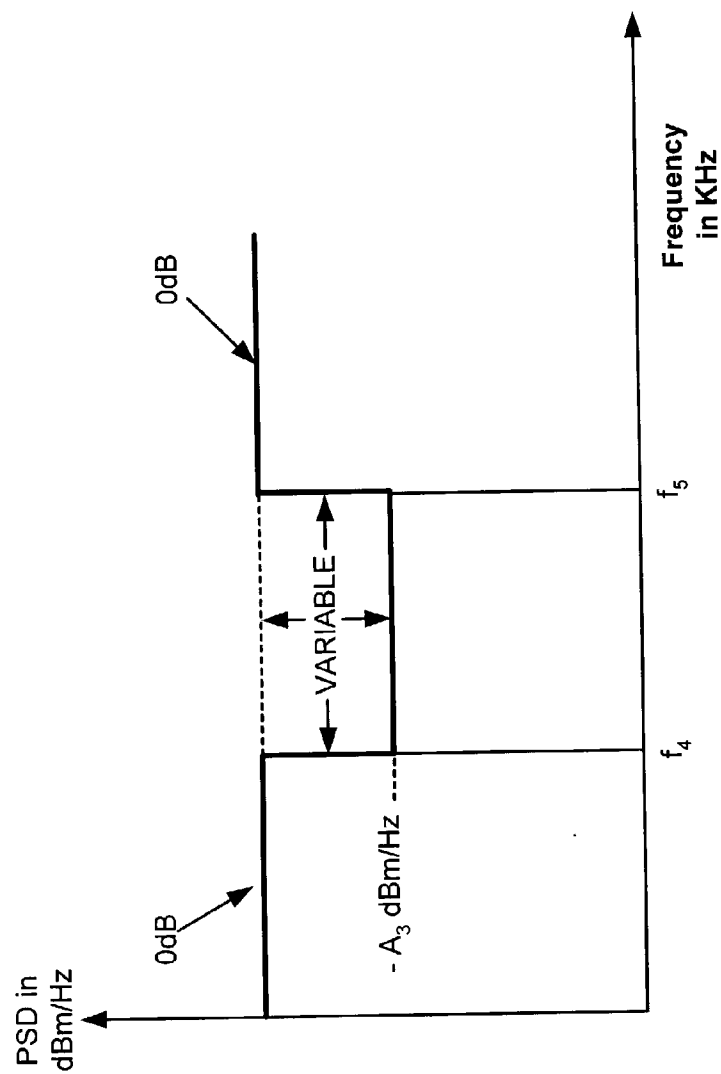


FIG. 15A

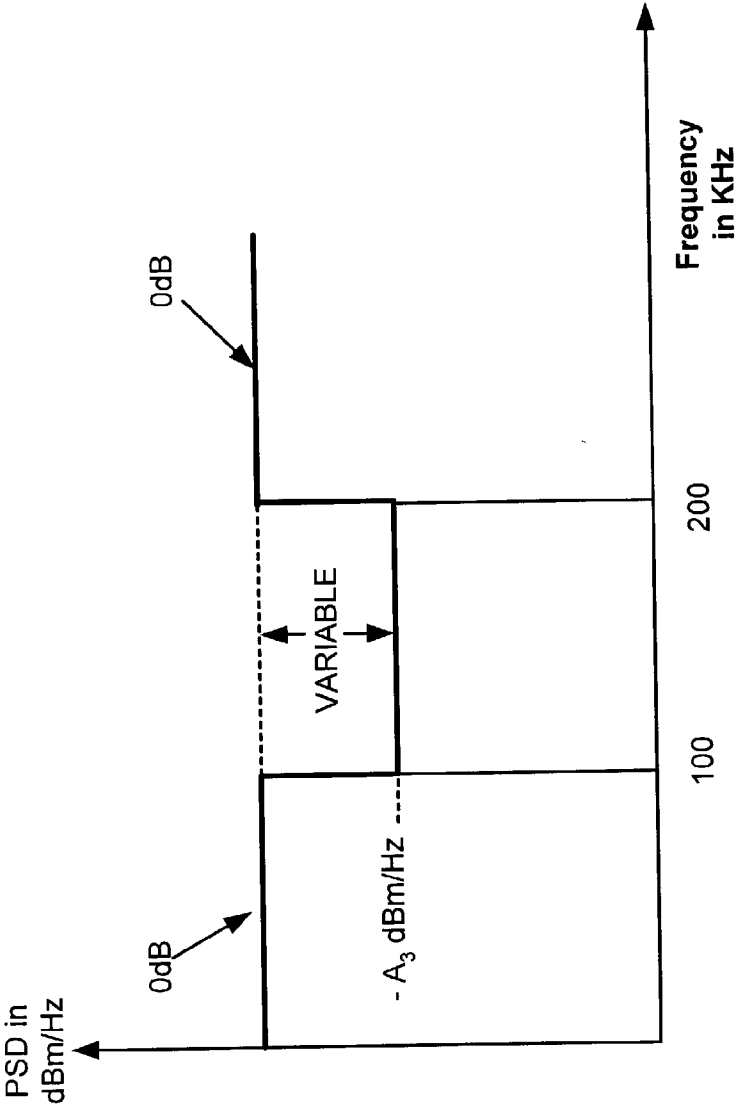


FIG. 15B

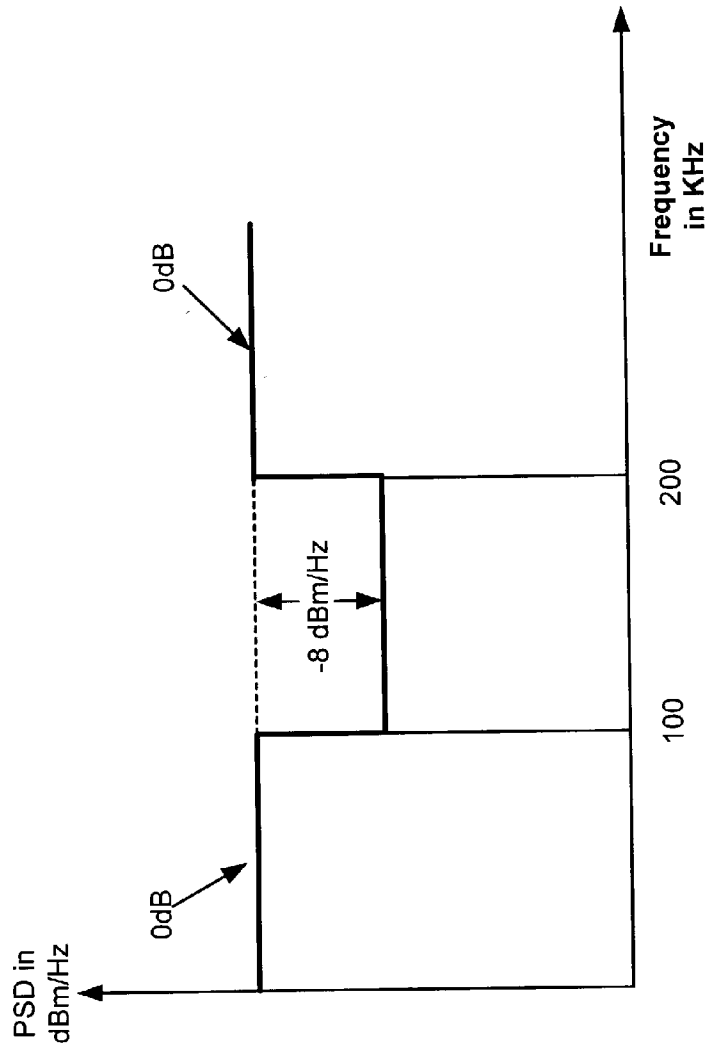


FIG. 15C

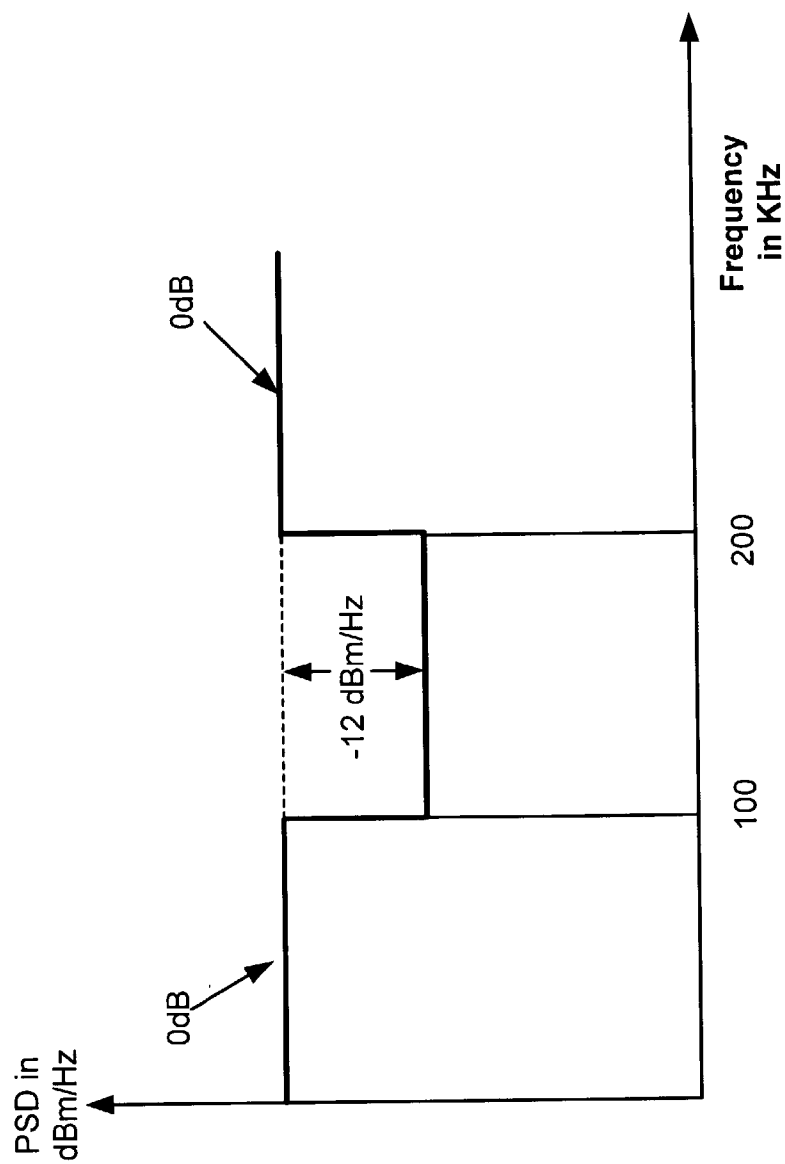


FIG. 15D

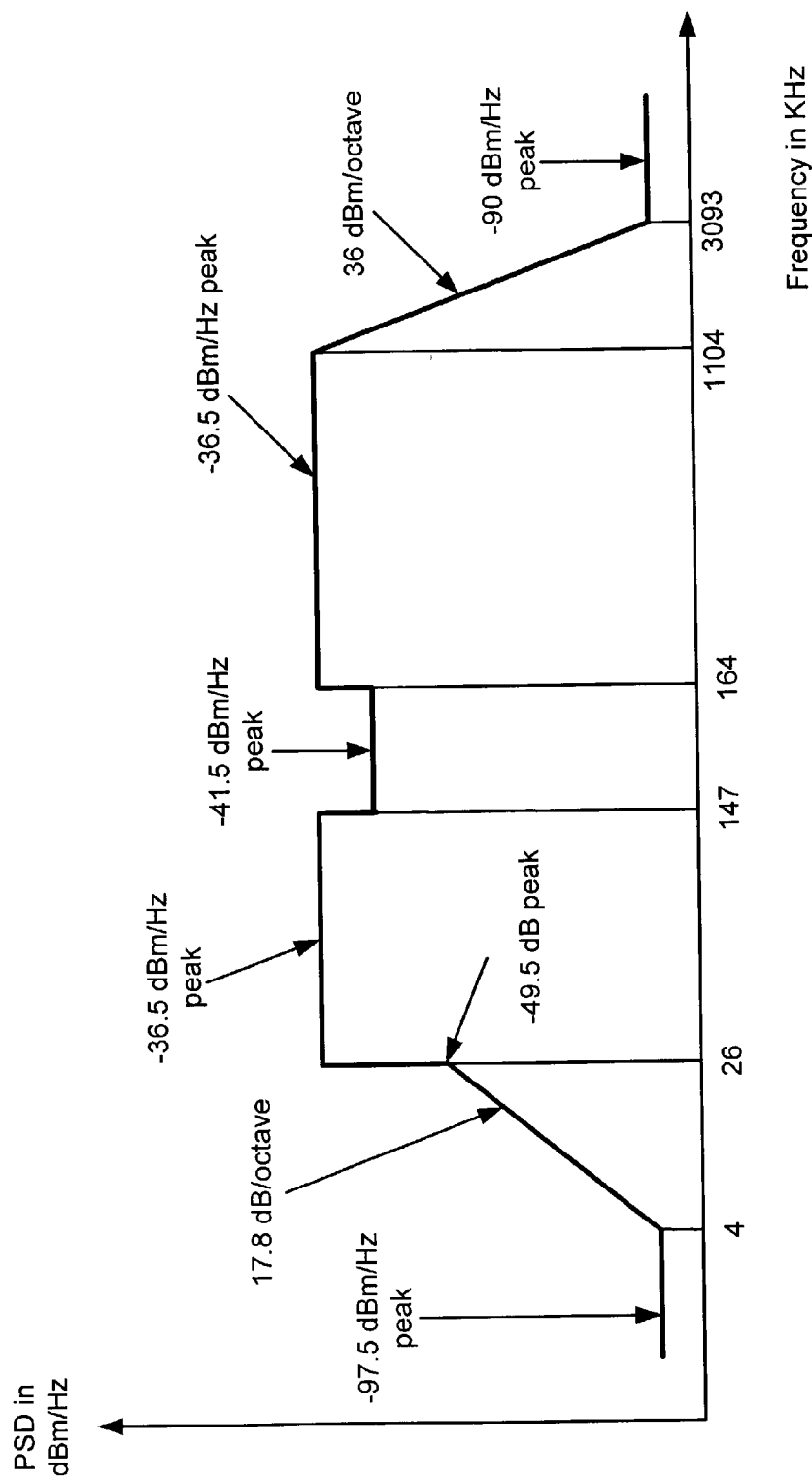


FIG. 16

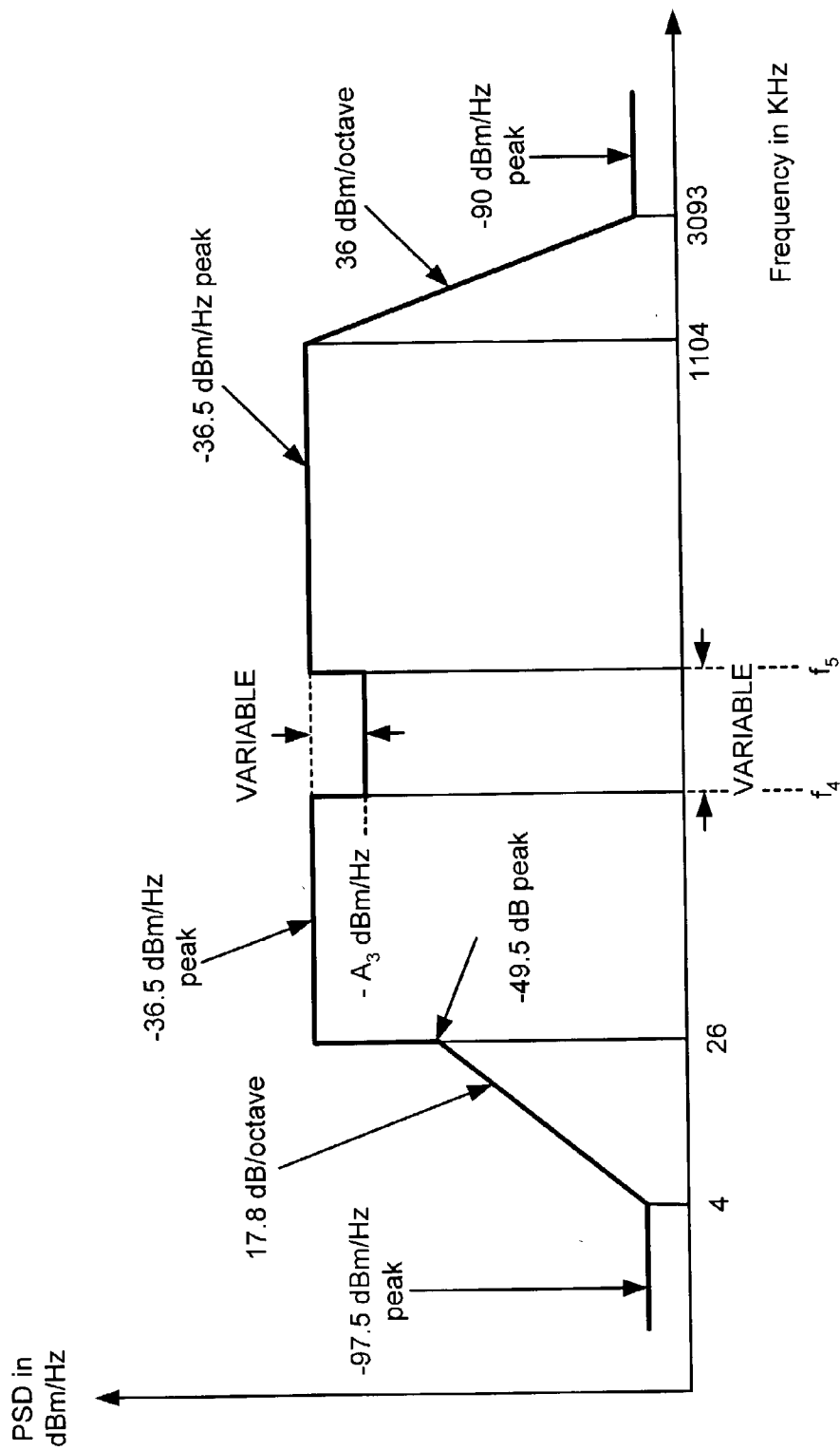


FIG. 17

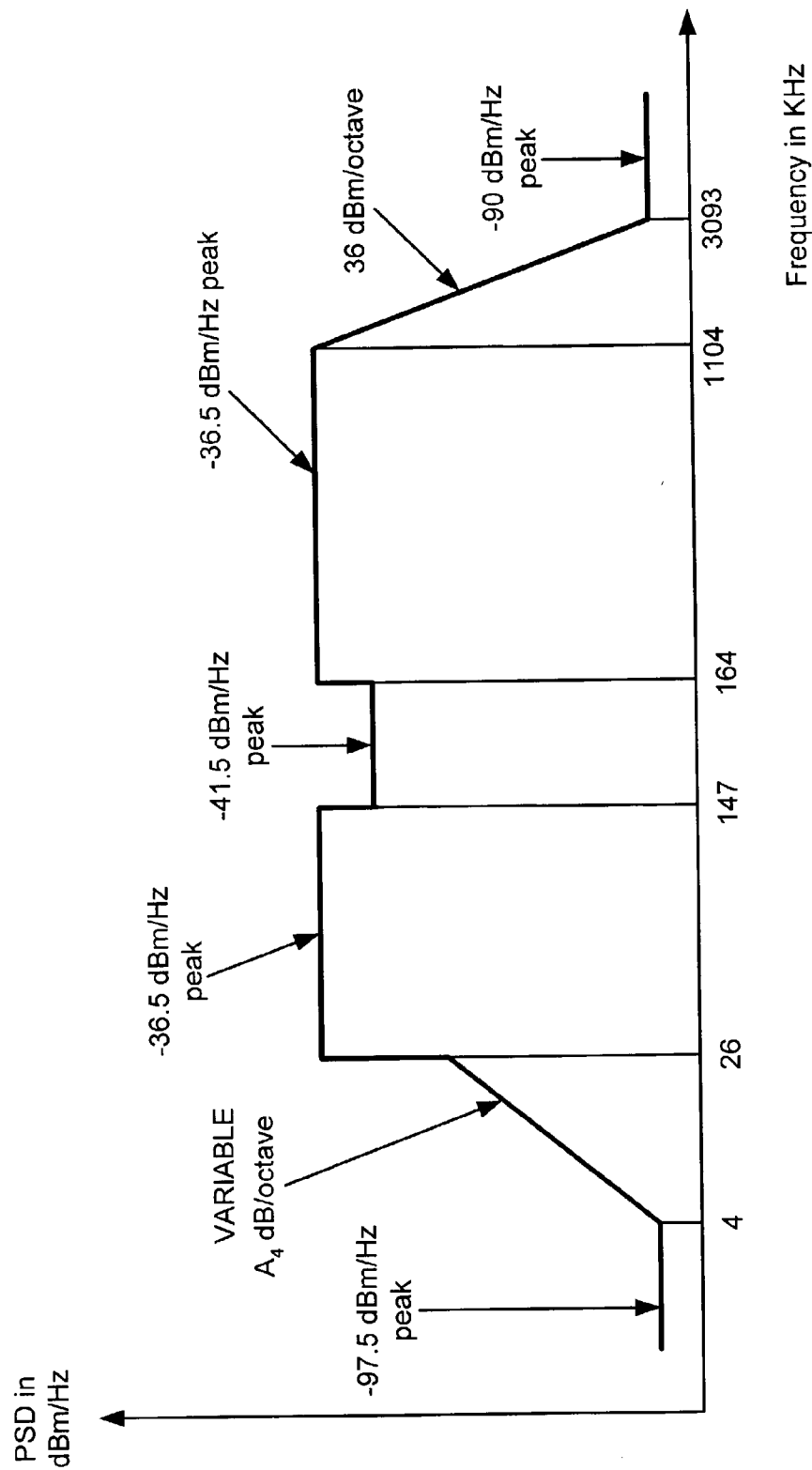


FIG. 18

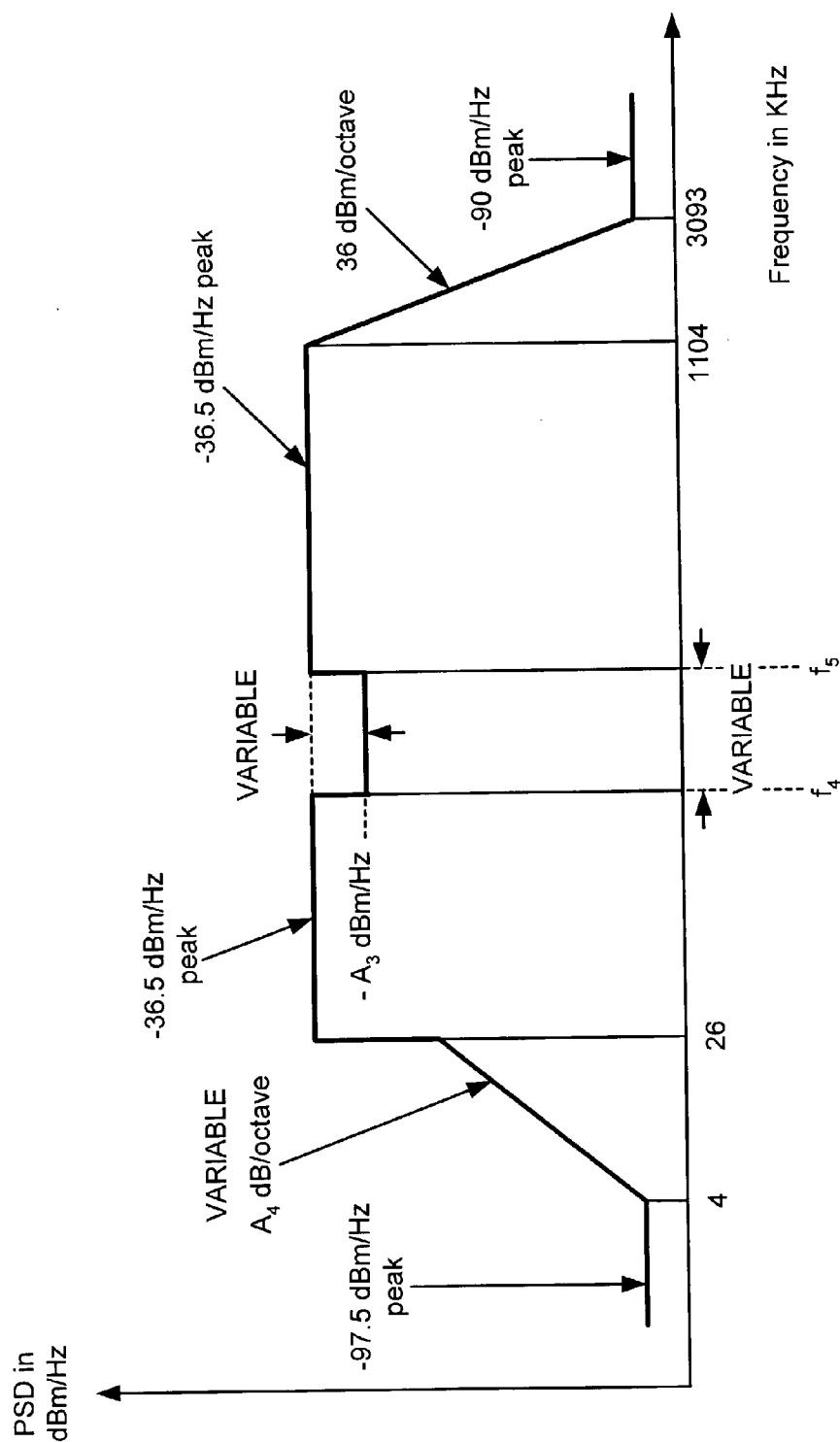


FIG. 19

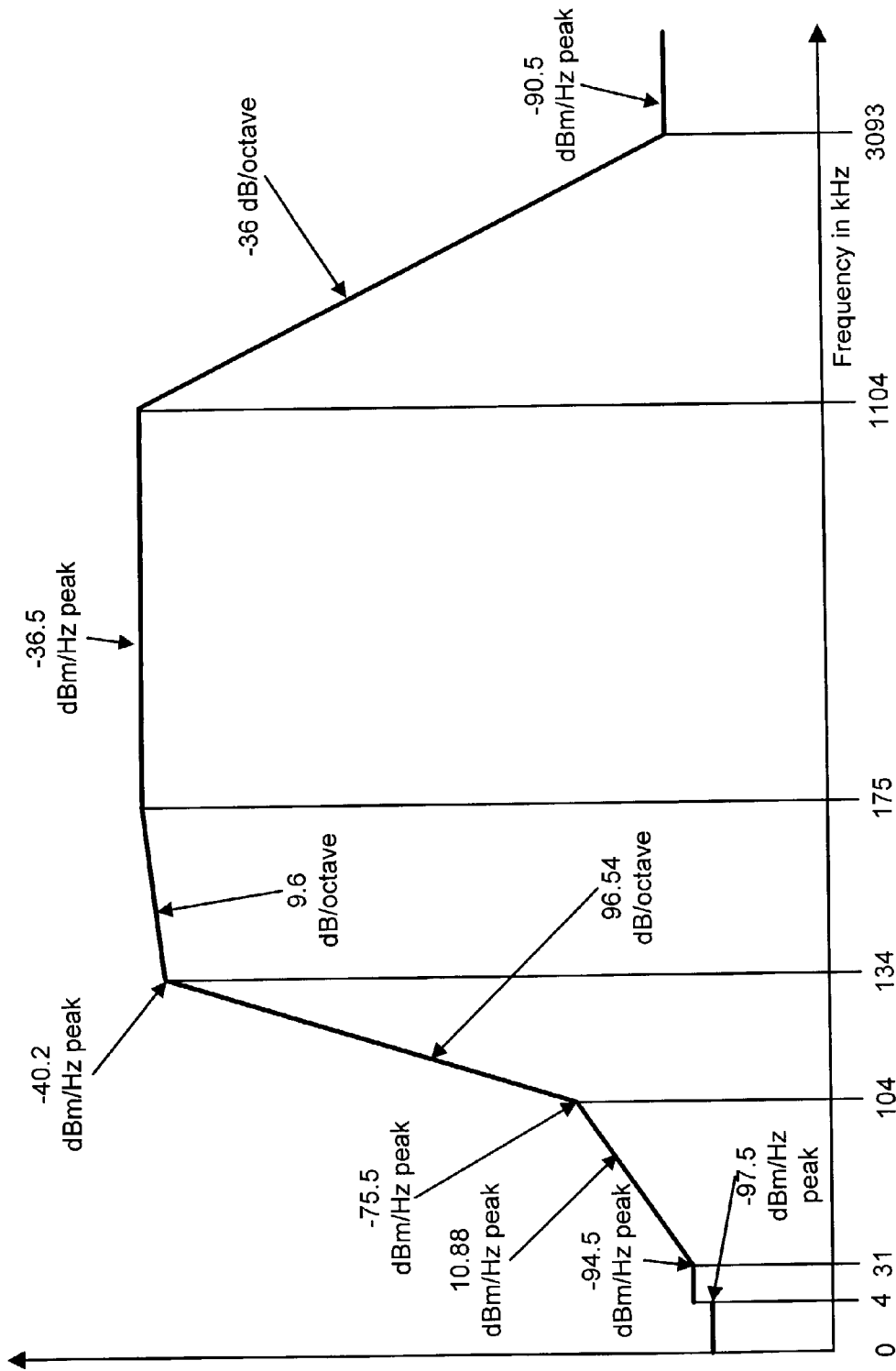


FIG. 20

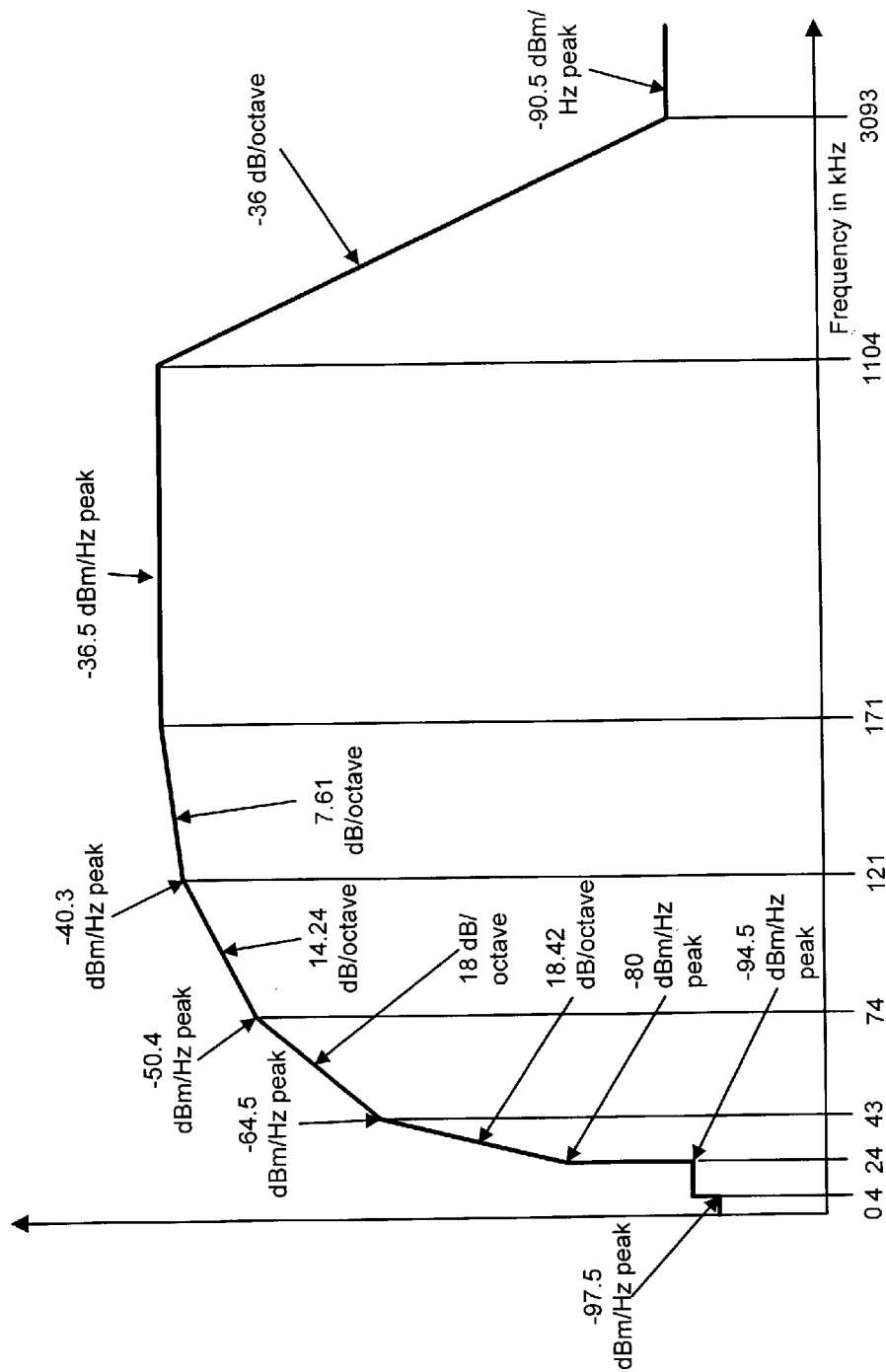
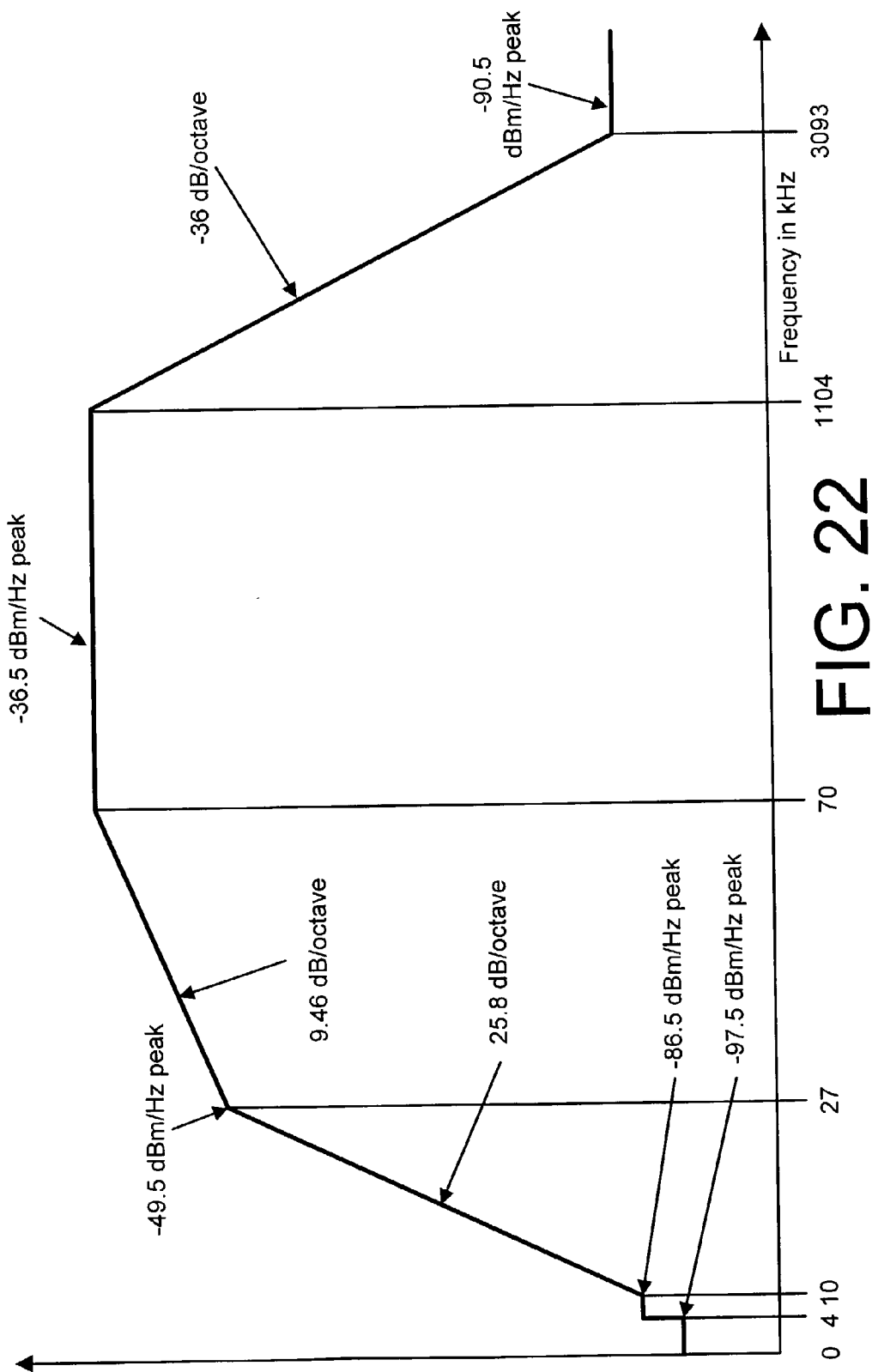


FIG. 21



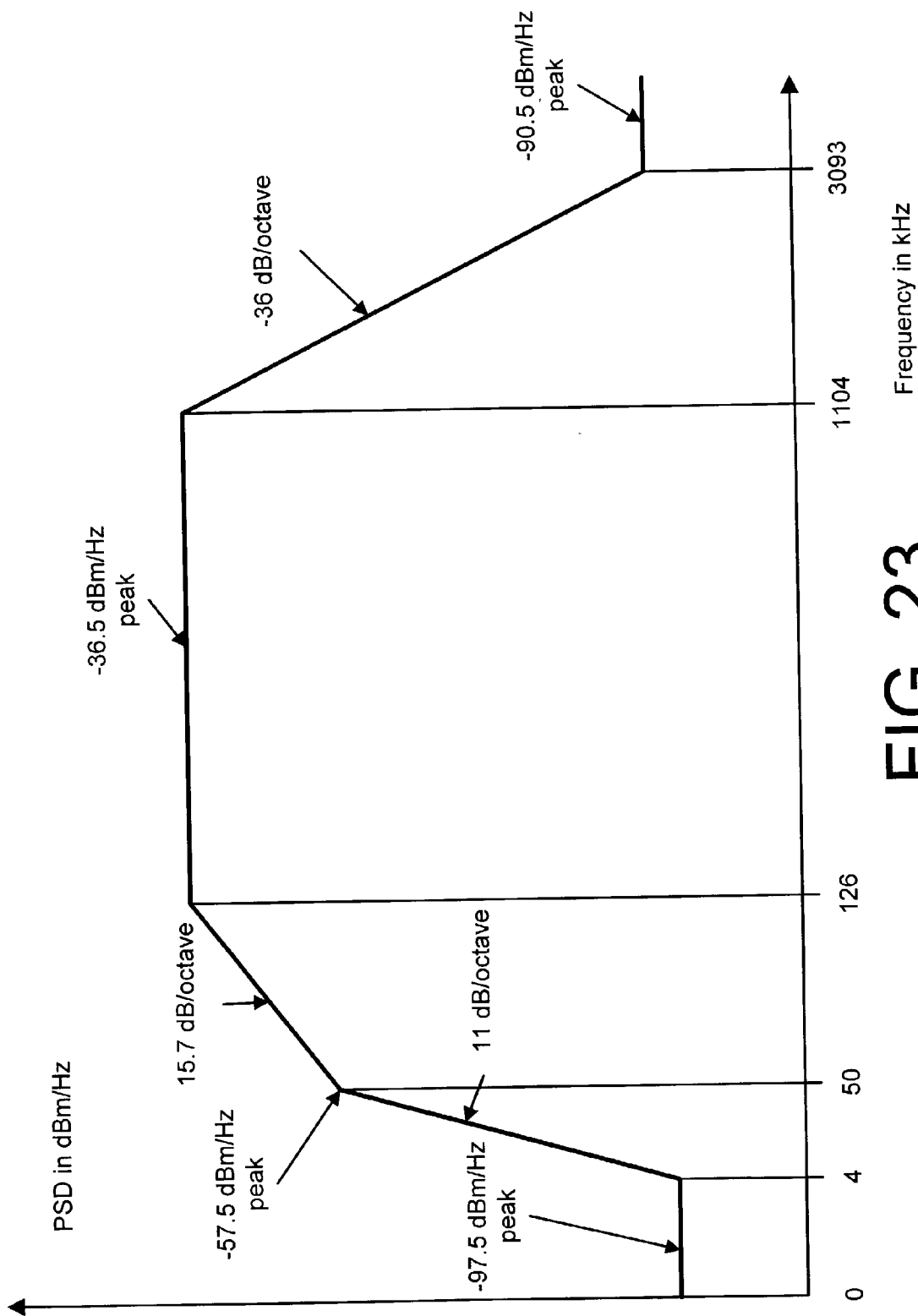


FIG. 23

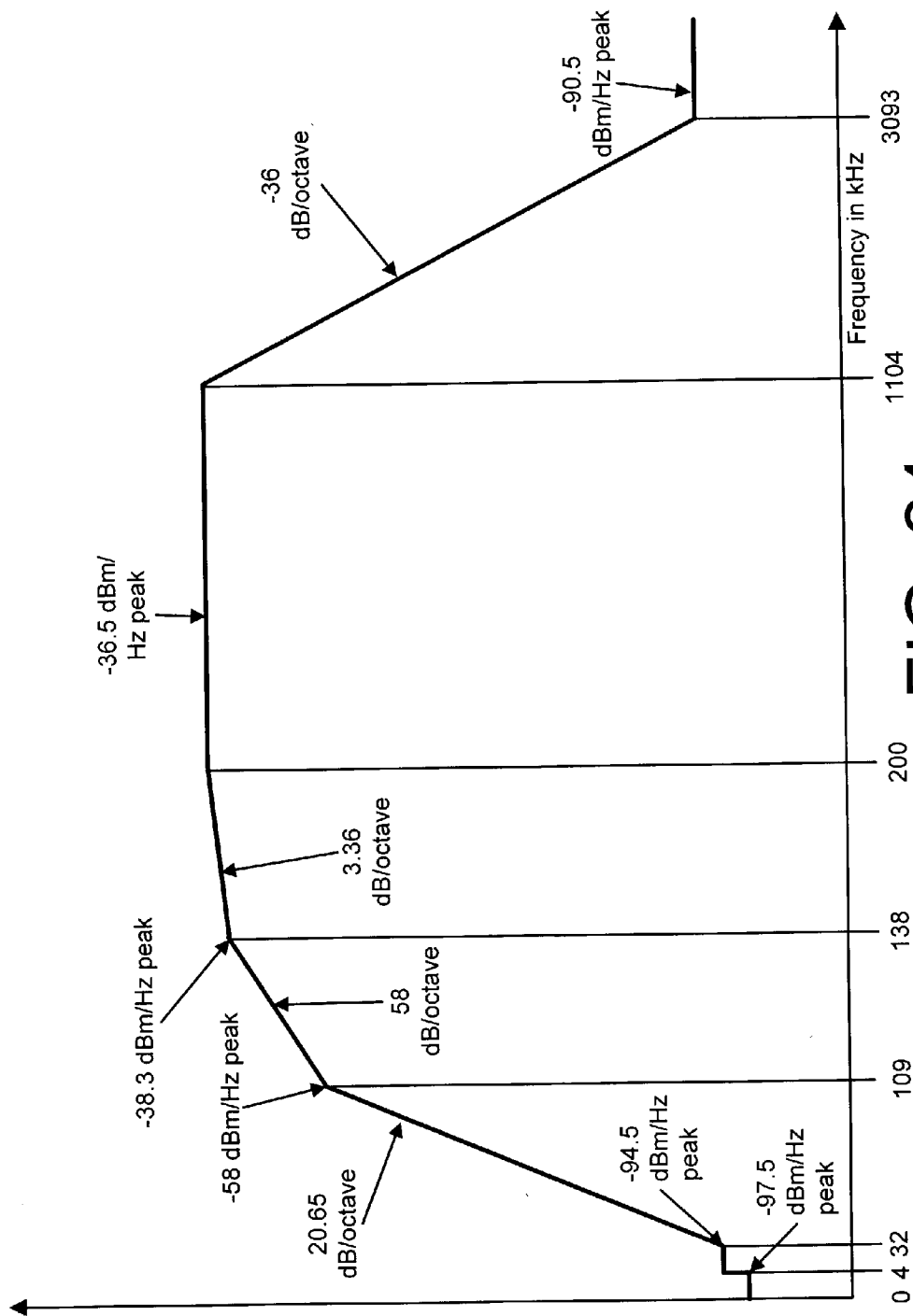


FIG. 24

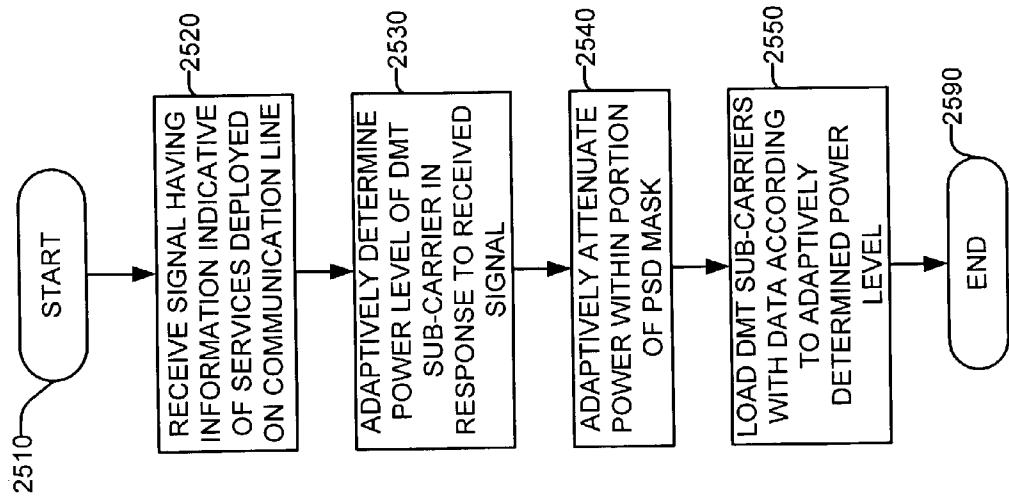


FIG. 25

**SYSTEM AND METHOD FOR REDUCING NOISE
INDUCED BY DIGITAL SUBSCRIBER LINE (DSL)
SYSTEMS INTO SERVICES THAT ARE
CONCURRENTLY DEPLOYED ON A
COMMUNICATION LINE**

**CROSS REFERENCE TO RELATED
APPLICATIONS**

[0001] This application claims the benefit of U.S. provisional patent application serial Nos. 60/338,939, dated Dec. 10, 2001; 60/341,654, dated Dec. 16, 2001; 60/346,809, dated Jan. 7, 2002; 60/348,575, dated Jan. 14, 2002; 60/350,552, dated Jan. 22, 2002; 60/353,880, dated Feb. 2, 2002; 60/354,888, dated Feb. 6, 2002; and 60/355,117, dated Feb. 8, 2002. These U. S. provisional patent applications are incorporated herein by reference as if set forth in their entireties.

[0002] Co-pending U.S. patent application Ser. Nos. 060706-1550 (EL 891429200 US) and 060706-1680 (EL 891429227 US), both mailed on Dec. 10, 2002, are also incorporated herein by reference as if set forth in their entireties.

FIELD OF INVENTION

[0003] The present invention relates generally to data communication and, more particularly, to systems and methods for reducing noise induced by digital subscriber line (DSL) systems into services that are concurrently deployed on a communication line.

BACKGROUND

[0004] Industries related to modern communication systems have experienced a tremendous growth due to the increasing popularity of the Internet. Digital subscriber line (DSL) technology is one technology that has developed in recent years in response to the demand for high-speed Internet access. DSL technology uses a communication line of a pre-existing telephone system as the backbone for the DSL lines. Thus, both plain old telephone systems (POTS) and DSL systems share a common line for DSL-compatible customer premises. Similarly, other services such as time compression multiplexing (TCM) integrated services digital network (ISDN) can also share a common line with DSL and POTS.

[0005] POTS services and DSL services are deployed on non-overlapping portions of available bandwidth on the communication line. Thus, there is very little concern of cross-talk or other interference between POTS services and DSL services. However, DSL and TCM-ISDN often share a portion of the available bandwidth, thereby making DSL services susceptible to cross-talk from TCM-ISDN services, and vice versa.

[0006] To compound problems even further, system requirements (e.g., the degree of permissible disruption of TCM-ISDN service caused by DSL service) may vary greatly from country to country. For example, Japan may have a greater limitation than the United States on how much disruption is tolerable between concurrently-deployed services on the same line. Thus, acceptable power levels for signal transmission in the United States may be unacceptable for signal transmission in Japan.

[0007] Certain standards committees, such as the International Telecommunication Union-Telecommunication Standardization Sector (ITU-T), have provided standards documents for deployment of DSL, such as G.992.2, "Splitterless Asymmetric Digital Subscriber Line (ADSL) Transceivers" (hereinafter "ITU-T G.992.2"), published in June of 1999. These standards documents provide static power spectral density (PSD) masks that limit the amount of power allocated to the DSL bandwidth, thereby limiting the amount of cross-talk induced by the DSL system on other services concurrently deployed on the same line. For example, **FIGS. 1 through 4** show several static PSD masks defined by the ITU.

[0008] **FIG. 1** is a diagram showing a static PSD mask for an asymmetric digital subscriber line transceiver unit at a central office (ATU-C) as defined by the ITU-T in Annex A of G.992.1 "Asymmetric Digital Subscriber Line (ADSL) Transceivers" (hereinafter "ITU-T G.992.1") and G.992.2. As shown in **FIG. 1**, the static PSD mask is defined by a -97.5 dBm/Hz peak power in the POTS bandwidth; approximately

$$\left(-92.5 + 21 \times \log_2\left(\frac{f}{4}\right)\right)$$

[0009] dBm/Hz between approximately 4 kHz and approximately 26 kHz; approximately -36.5 dBm/Hz between approximately 26 kHz and approximately 1104 kHz; approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

[0010] between approximately 1104 kHz and approximately 3093 kHz; and approximately -90 dBm/Hz above approximately 3093 kHz.

[0011] **FIG. 2** is a diagram showing a static PSD mask for reduced near-end cross talk (NEXT) for an ATU-C as defined by Annex A of G.992.1 and G.992.2. As shown in **FIG. 2**, the static PSD mask is defined by approximately -97.5 dBm/Hz below approximately 4 kHz; approximately

$$\left(-92.5 + 4.63 \times \log_2\left(\frac{f}{4}\right)\right)$$

[0012] dBm/Hz between approximately 4 kHz and approximately 80 kHz; approximately

$$\left(-72.5 + 36 \times \log_2\left(\frac{f}{80}\right)\right)$$

[0013] dBm/Hz between approximately 80 kHz and approximately 138 kHz; approximately -36.5 dBm/Hz

between approximately 138 kHz and approximately 1104 kHz; approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

[0014] between approximately 1104 kHz and approximately 3093 kHz; approximately -90 dBm/Hz between approximately 3093 kHz and approximately 4545 kHz; and approximately -50 dBm/Hz power in any 1 MHz sliding window between approximately 4545 kHz and approximately 11040 kHz.

[0015] FIG. 3 is a diagram showing a static PSD mask for ADSL/Integrated Service Digital Network (ISDN) with 2-Binary-1-Quaternary (2B1Q) line coding as defined by Annex B of G.992.1 and G.992.2. As shown in FIG. 3, the static PSD mask is defined by a power level of approximately -90 dBm/Hz below approximately 50 kHz; approximately

$$\left(-90 + 12 \times \log_2\left(\frac{f}{70}\right)\right)$$

[0016] dBm/Hz between approximately 50 kHz and approximately 80 kHz; low-pass and high-pass filter-design-dependent power level between approximately 80 kHz and approximately 138 kHz; approximately -36.5 dBm/Hz between approximately 138 kHz and approximately 1104 kHz; approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

[0017] between approximately 1104 kHz and approximately 3093 kHz; approximately -90 dBm/Hz between approximately 3093 kHz and approximately 4545 kHz; and approximately -50 dBm/Hz power in any 1 MHz sliding window between approximately 4545 kHz and approximately 11040 kHz.

[0018] FIG. 4 is a diagram showing a static PSD mask for ADSL/ISDN with 4B3T line coding as defined by Annex B of G.992.1 and G.992.2. As shown in FIG. 4, the static PSD mask is defined by a power level of approximately -90 dBm/Hz below approximately 70 kHz; approximately

$$\left(-90 + 12 \times \log_2\left(\frac{f}{70}\right)\right)$$

[0019] dBm/Hz between approximately 70 kHz and approximately 90 kHz; low-pass and high-pass filter-design-dependent power level between approximately 90 kHz and approximately 138 kHz; approximately -36.5 dBm/Hz between approximately 138 kHz and approximately 1104 kHz; approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

[0020] between approximately 1104 kHz and approximately 3093 kHz; approximately -90 dBm/Hz between approximately 3093 kHz and approximately 4545 kHz; and approximately -50 dBm/Hz power in any 1 MHz sliding window between approximately 4545 kHz and approximately 11040 kHz.

[0021] The various static PSD masks of FIGS. 1 through 4 are configured for certain fixed line conditions. Thus, while the static PSD masks shown in FIGS. 1 through 4 may result in acceptable disruptions to TCM-ISDN services by the DSL services in one environment, these static PSD masks may result in unacceptable disruptions in other environments. Consequently, communication devices that are standards-compliant in one environment may not necessarily be standards-compliant in other environments.

[0022] Given the potential incompatibility of communication devices in various environments, heretofore-unaddressed needs exist in the industry.

SUMMARY

[0023] The present invention provides systems and methods for reducing noise induced by digital subscriber line (DSL) systems into services that are concurrently deployed on a communication line.

[0024] Briefly described, in architecture, one embodiment of the system comprises a receiver and logic configured to adaptively calculate a power level of a discrete multi-tone (DMT) sub-carrier. The receiver is configured to receive signals from a communication line. The signals are indicative of line conditions, which may be indicative of services deployed on the communication line. The power level of the DMT sub-carrier may be adaptively calculated from the signals received from the communication line.

[0025] Another embodiment of the system comprises an adaptively-filtered power spectral density (PSD) mask and logic configured to load DMT sub-carriers with data. The adaptively-filtered PSD mask has an attenuated portion that adaptively changes in response to line characteristics. The DMT sub-carriers may be loaded in accordance with the adaptively-filtered PSD-mask.

[0026] Yet another embodiment of the system comprises an adaptive filter and logic configured to allocate power to sub-carriers in a discrete multi-tone (DMT) modulated communication system. The adaptive filter is configured to adaptively attenuate power within a portion of a power spectral density (PSD) mask to generate an adaptively-filtered PSD mask. The power allocated to the sub-carriers may be allocated in accordance with the adaptively-filtered PSD mask.

[0027] The present invention can also be embodied as methods for reducing noise induced into services that are concurrently deployed on a communication line. In this regard, one embodiment of the method comprises the steps of receiving a signal from a communication line and adaptively determining a power level of a discrete multi-tone

(DMT) sub-carrier in response to receiving the signal from the communication line. In one embodiment, the signal has information indicative of services deployed on the communication line.

[0028] Other systems, methods, features, and advantages of the present invention will be or become apparent to one with skill in the art upon examination of the following drawings and detailed description. It is intended that all such additional systems, methods, features, and advantages be included within this description, be within the scope of the present invention, and be protected by the accompanying claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] Many aspects of the invention can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating the principles of the present invention. Moreover, in the drawings, like reference numerals designate corresponding parts throughout the several views.

[0030] FIG. 1 is a diagram showing a static power spectral density (PSD) mask for an asymmetric digital subscriber line transceiver unit at a central office (ATU-C) as defined by the Telecommunication Standardization Sector (ITU-T) of the International Telecommunication Union (ITU) in Annex A of G.992.1 "Asymmetric Digital Subscriber Line (ADSL) Transceivers" (hereinafter "G.992.1 ") and G.992.2 "Splitterless Asymmetric Digital Subscriber Line (ADSL) Transceivers" (hereinafter "G.992.2").

[0031] FIG. 2 is a diagram showing a static PSD mask for reduced near-end cross talk (NEXT) for an ATU-C as defined by Annex A of G.992.1 and G.992.2.

[0032] FIG. 3 is a diagram showing a static PSD mask for ADSL/Integrated Service Digital Network (ISDN) with 2-Binary-1-Quaternary (2B1Q) line coding as defined by Annex B of G.992.1 and G.992.2.

[0033] FIG. 4 is a diagram showing a static PSD mask for ADSL/ISDN with 4B3T line coding as defined by Annex B of G.992.1 and G.992.2.

[0034] FIG. 5 is a block diagram showing an example ADSL environment employing adaptively-filtered PSD masks.

[0035] FIG. 6 is a block diagram showing the ADSL modem of FIG. 5 in greater detail.

[0036] FIG. 7 is a block diagram showing logic components in the ATU-C of FIG. 6, which are configured to generate the adaptively-filtered PSD masks.

[0037] FIG. 8 is a diagram showing one embodiment of an adaptively-filtered PSD mask generated by the system of FIG. 7.

[0038] FIG. 9A is a diagram showing a transfer function associated with one embodiment of the adaptive filter of FIG. 7, which has a variable attenuation over a variable frequency range.

[0039] FIG. 9B is a diagram showing a transfer function associated with one embodiment of the adaptive filter of FIG. 7, which has a variable attenuation over a fixed frequency range.

[0040] FIG. 9C is a diagram showing a transfer function associated with one embodiment of the adaptive filter of FIG. 7, which has a specific attenuation over a fixed frequency range.

[0041] FIG. 10 is a diagram showing another embodiment of an adaptively-filtered PSD mask generated by the system of FIG. 7.

[0042] FIG. 11 is a diagram showing yet another embodiment of an adaptively-filtered PSD mask generated by the system of FIG. 7.

[0043] FIG. 12 is a diagram showing one embodiment of an adaptively-filtered PSD mask having a variable attenuation immediately above the plain old telephone system (POTS) bandwidth.

[0044] FIG. 13 is a diagram showing one embodiment of an adaptively-filtered PSD mask having a variable attenuation in a frequency bandwidth affected by integrated services digital network (ISDN) services.

[0045] FIG. 14 is a diagram showing one embodiment of an adaptively-filtered PSD mask having a variable attenuation over a variable frequency range.

[0046] FIG. 15A is a diagram showing a transfer function associated with another embodiment of the adaptive filter of FIG. 7, which has a variable attenuation over a variable frequency range.

[0047] FIG. 15B is a diagram showing a transfer function associated with another embodiment of the adaptive filter of FIG. 7, which has a variable attenuation over a fixed frequency range.

[0048] FIG. 15C is a diagram showing a transfer function associated with another embodiment of the adaptive filter of FIG. 7, which has a specific attenuation over a fixed frequency range.

[0049] FIG. 15D is a diagram showing a transfer function associated with another embodiment of the adaptive filter of FIG. 7, which has a specific attenuation over a fixed frequency range.

[0050] FIG. 16 is a diagram showing yet another embodiment of an adaptively-filtered PSD mask generated by the system of FIG. 7.

[0051] FIG. 17 is a diagram showing one embodiment of an adaptively-filtered PSD mask having a variable attenuation in a frequency bandwidth affected by integrated services digital network (ISDN) services.

[0052] FIG. 18 is a diagram showing another embodiment of an adaptively-filtered PSD mask having a variable attenuation immediately above the POTS bandwidth.

[0053] FIG. 19 is a diagram showing another embodiment of an adaptively-filtered PSD mask having a variable attenuation in several non-adjacent bandwidths.

[0054] FIG. 20 is a diagram showing yet another embodiment of an adaptively-filtered PSD mask generated by the system of FIG. 7.

[0055] FIG. 21 is a diagram showing yet another embodiment of an adaptively-filtered PSD mask generated by the system of FIG. 7.

[0056] FIG. 22 is a diagram showing yet another embodiment of an adaptively-filtered PSD mask generated by the system of FIG. 7.

[0057] FIG. 23 is a diagram showing yet another embodiment of an adaptively-filtered PSD mask generated by the system of FIG. 7.

[0058] FIG. 24 is a diagram showing yet another embodiment of an adaptively-filtered PSD mask generated by the system of FIG. 7.

[0059] FIG. 25 is a flowchart showing one embodiment of a method employing adaptively-filtered PSD masks.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0060] Having summarized various aspects of the present invention, reference is now made in detail to the description of the embodiments as illustrated in the drawings. While several embodiments are described in connection with these drawings, there is no intent to limit the invention to the embodiment or embodiments disclosed herein. On the contrary, the intent is to cover all alternatives, modifications, and equivalents included within the spirit and scope of the invention as defined by the appended claims.

[0061] In Japan, for example, feeder cables that radiate out of a central office to various customer premises are predominantly pulp-insulated. Each feeder cable typically has approximately 400 two-conductor pair wires, and a large portion of the pulp-insulated two-conductor pair wires are used to service integrated services digital network (ISDN) subscribers. Thus, when ADSL signals are present, the pulp insulation causes ADSL signal attenuation at higher frequencies, and adjacent ISDN signals cause significant levels of cross-talk interference. The combination of attenuation and cross-talk reduces ADSL performance. While Annex C of the G.992.1 standard was developed to reduce adverse effects (e.g., attenuation and cross-talk), the static power spectral density (PSD) masks often provide for sub-optimal data transmission.

[0062] FIGS. 5 through 25 illustrate various systems, methods, and power spectral density (PSD) masks, which are configured to reduce cross-talk between ADSL and ISDN while optimizing ADSL performance for systems similar to those found in Japan. Each of the embodiments maximizes downstream performance, balances upstream and downstream signal ratios, and provides spectral compatibility between ADSL and concurrently-deployed services (e.g., integrated services digital network (ISDN), plain old telephone systems (POTS), etc.). In maximizing downstream performance, the systems and methods are configured to determine the optimum data capacity given certain line conditions (e.g., signal-to-noise ratio (SNR), line attenuation, etc.). The line conditions further provide information that permit the allocation of bandwidths and time slots for upstream and downstream signals, thereby balancing the upstream and downstream signal ratios. Additionally, since the line conditions provide information related to other concurrently-deployed services on the line, the systems and methods of FIGS. 5 through 25 also provide spectral compatibility between ADSL and other concurrently-deployed services. The optimum conditions are predetermined as a function of government regulations, known or measured

physical parameters, and other factors that are well known in the art. The data transmission parameters are then adjusted according to the predetermined optimum conditions.

[0063] FIG. 5 is a block diagram showing an example asymmetric digital subscriber line (ADSL) communication system 500 employing adaptively-filtered PSD masks. Generally, the ADSL system is implemented between a central office 510 and a customer premise 560. Communication between the two sites 510, 560 takes place over a communication line 555 (also referred to as a local loop, twisted-pair cable, two-conductor pair wire, or channel). The central office 510 end of the communication line 555 is configured to provide broadband services (e.g., video conferencing 515, Internet 520, telephone services 525, movies on demand 530, broadcast media 535, etc.), which are assembled via central office ADSL modems 550 for transmission over the communication line 555. The central office 510 assembles the signals from the broadband services at an ADSL service rack 540, which comprises a digital subscriber line access multiplexer (DSLAM) 545 and ADSL modems 550. The central office 510 assembles the broadband services via the DSLAM 545 for appropriate transformation and transmission by one or more ADSL modems 550. Each of the ADSL modems 550 may be in communication via a dedicated communication line 555 with a suitably configured ADSL modem 580 at a customer premise 560.

[0064] As illustrated in FIG. 5, the DSLAM 545 and each of a plurality of ADSL modems 550 may be assembled within an ADSL service rack 540 within the central office 510. For simplicity of illustration and explanation, the ADSL communication system 500 presented in FIG. 5 is shown with a single ADSL service rack 540 for communicating each of the broadband services to a plurality of ADSL modems 550. The ADSL service rack 540 may be configured to supply conditioned resources necessary to support the operation of the a plurality of ADSL modems 550. Those skilled in the art will appreciate the scalability of the ADSL communication system 500 generally presented in FIG. 5. For example, the central office 510 may be configured with a plurality of Transmission Control Protocol/Internet Protocol (TCP/IP) routers and Asynchronous Transfer Mode (ATM) switches (not shown) that may distribute one or more broadband service signals to a plurality of DSLAMs 545. In turn, the plurality of DSLAMs 545 may further distribute the broadband service signals to a plurality of remotely located ADSL modems 580.

[0065] At the opposite end of the communication line 555, the customer premise 560 may be configured with a compatible ADSL modem 580, which may be configured to process and distribute the multiple broadband services to appropriate destination devices such as a computer 570, a television 575, and digital telephones 590 as illustrated. It is significant to note that the customer premise 560 may have plain old telephone systems (POTS) devices such as a facsimile machine 565 and an analog (POTS) telephone 585 integrated on the communication line 555 along with the ADSL modem 580. It is also feasible that the customer premise 560 may be replaced in some applications by another central office 510 or an ADSL repeater, where the POTS service may not be available or needed.

[0066] FIG. 6 is a block diagram showing the ADSL modem 550 of FIG. 5 in greater detail. While FIG. 6 shows

only one ADSL modem 550, it should be appreciated that each of the ADSL modems 550 of FIG. 5 may have similar components. As shown in FIG. 6, the ADSL modem 550 at the central office 510 comprises an ADSL transceiver unit (ATU-C) 605 configured to assemble data for transmission on the communication line 155. In this regard, the ATU-C 605 comprises both a fast path and an interleaved path between a multiplexer (MUX) and synchronization (sync) control block 610 and a tone ordering circuit 650. The fast path, which provides low latency, comprises a fast cyclic redundancy checking (CRC) block 615 and a scrambling and forward error correcting (FEC) block 625. The interleaved path, which provides a lower error rate at a greater latency, comprises an interleaved CRC block 620, a scrambling and FEC block 630, and an interleaver 640. Since MUX/sync control blocks 610, CRC blocks 615, 620, scrambling and FEC blocks 625, 630, interleavers 640, and tone ordering circuits 650 are known in the art, further discussion of these components is omitted here. However, it should be appreciated that the signal, upon traversing either the fast path or the interleaved path, enters an encoding and gain scaling block 655, which encodes the data into a constellation and also scales the data for transmission. The encoding and gain scaling block 655 is discussed in greater detail with reference to FIG. 7.

[0067] Once the data has been encoded and gain-scaled, the data is relayed in parallel blocks to an inverse Fourier transform (IFT) block 660, which performs a IFT on the parallel data blocks. The IFT data is conveyed to a parallel-to-serial (P/S) converter 665, which converts the data into a serial data stream. The serial data stream is conveyed to a digital-to-analog (D/A) converter and analog processor 670, which produces an analog signal for data transmission. Since IFT blocks 660, P/S converters 665, D/A converters and analog processors 670 are known in the art, further discussion of these components is omitted here. The analog signal is transmitted through the communication line 555 by a transmitter 675 in the ATU-C 605.

[0068] FIG. 7 is a block diagram showing logic components in the encoding and gain scaling block 655 of FIG. 6, which is configured to encode and gain scale data according to adaptively-filtered PSD masks. As shown in FIG. 7, the encoder and gain scaler 655 comprises a receiver 710 and a processor 720. The receiver 710 is configured to receive data from the tone-ordering circuit 650 as well as signals from the communication line 555. The signals contain information related to line conditions, which, in turn, are indicative of services deployed on the communication line 555. The signals from the communication line 555 comprise signal-to-noise ratio (SNR) information of the communication line 555, line attenuation information of the communication line 555, and information related to usable sub-carriers in the DMT modulated system. The signals from the communication line 555 are updated for each data frame being encoded and gain scaled. Thus, the encoder and gain scaler 655 is continuously updated with information on concurrently deployed services on the communication line 555.

[0069] The processor 720 is configured to adaptively calculate a power level of the DMT sub-carriers in response to the signals received from the communication line 555. In this regard, the processor 720 comprises service determination logic 730, which adaptively determines services concurrently deployed on the communication line 555. In, other

words, if the received signal characteristics change and indicate that line conditions have changed, then the service determination logic 730 adaptively determines which services are deployed on the communication line 555 from the changes in line condition.

[0070] Additionally, the processor 720 comprises power determination logic 740, which adaptively calculates an appropriate power level for each sub-carrier (or bin) once the services have been adaptively determined. In this regard, the power determination logic calculates sub-carrier power levels for each sub-carrier of each frame, which permits an optimization of power levels as a function of the determined services deployed on the communication line 555.

[0071] The processor 720 further comprises power allocation logic 750, which allocates the power to each sub-carrier as determined by the power determination logic 740. The power allocation logic 750 comprises a power spectral density (PSD) mask 752 and an adaptive filter 754. Since the sub-carrier power levels may change from frame to frame due to potential changes in line conditions, a static PSD mask may not provide optimum sub-carrier power levels. The adaptive filter 754 adaptively alters the PSD mask 752 as a function of changing line conditions, thereby generating an adaptively-filtered PSD mask, which permits optimization of sub-carrier power levels as a function of changing line conditions.

[0072] In one embodiment, the adaptive filter 754 is configured to selectively provide a fixed attenuation over a fixed frequency range. Thus, if all possible services concurrently deployed on the communication line 555 are known, then the adaptive filter 754 may selectively filter or not filter the PSD mask 752 as a function of the line conditions.

[0073] In another embodiment, the adaptive filter 754 is configured to provide a variable attenuation over a fixed frequency range of between approximately 90 kHz and approximately 200 kHz. Thus, if the frequency range of concurrently deployed services is known to be between approximately 90 kHz and approximately 200 kHz, but the fluctuations in power level are not known, then the adaptive filter may variably attenuate the PSD mask 752 within the fixed frequency range as a function of the line conditions. In an example embodiment, the variable attenuation may range from approximately 0 dB to approximately -12 dB. More specifically, in another embodiment, the variable attenuation may vary in a smaller range from approximately 0 dB to approximately -8 dB.

[0074] In yet another embodiment the adaptive filter 754 is configured to provide a variable attenuation over a different fixed frequency range. In an example embodiment, the fixed frequency range is between approximately 4 kHz and approximately 26 kHz.

[0075] The adaptive filter 754, in another embodiment, is configured to provide a variable attenuation over a variable frequency range. Thus, if neither the frequency range nor the fluctuations in power level due to other services is known with particularity, then the adaptive filter may variably attenuate the PSD mask 752 over a variable frequency range as a function of the line conditions. In an example embodiment, the variable frequency range may vary anywhere in the range of between approximately 90 kHz and approximately 200 kHz to accommodate services operating within

that bandwidth. More specifically, in another embodiment, the variable frequency range may vary in a narrower frequency range of, for example, between approximately 121 kHz and approximately 164 kHz. The 164 kHz frequency is the location of the peak of the first lobe of the TCM ISDN bandwidth, and the 121 kHz frequency is the frequency at which downstream performance is optimized, upstream and downstream signals are balanced, and spectral compatibility between ADSL and concurrently-deployed TCM ISDN services is optimized according to predefined conditions. The variable frequency range may also be between approximately 4 kHz and approximately 200 kHz, which is the range immediately above the POTS bandwidth and the upper operating frequencies of ISDN.

[0076] The processor 720 also comprises data loading logic 760, which loads each of the sub-carriers. In an example embodiment, once the line conditions have been determined and the optimum adaptively-filtered PSD mask has been generated or selected, the data loading logic 760 loads the sub-carriers with data according to the adaptively-filtered PSD mask. Thus, the data is loaded to each sub-carrier using an optimized power level as defined by the adaptively-filtered PSD mask.

[0077] Having described several embodiments of systems configured to generate adaptively-filtered PSD masks and load sub-carriers with data according to the adaptively-filtered PSD masks, attention is turned to FIGS. 8 through 24, which show several transfer functions of adaptive filters 754 and several embodiments of adaptively-filtered PSD masks.

[0078] FIG. 8 is a diagram showing one embodiment of an adaptively-filtered PSD mask generated by the system of FIG. 7. Specifically, FIG. 8 shows a portion of the G.992.1 Annex A PSD mask having, approximately -12 dB attenuation between approximately 92.5 kHz and approximately 122.5 kHz. Thus, rather than having a uniform peak power of approximately -36.5 dBm/Hz between approximately 26 kHz and approximately 1104 kHz like the prior-art Annex A PSD mask of FIG. 1, the adaptively-filtered PSD mask of FIG. 8 has an approximately -12 dB attenuation "notch" between approximately 92.5 kHz and approximately 122.5 kHz. The "notch" reduces the power allocated to the frequency range defined by the "notch," thereby concomitantly reducing any cross-talk that the DSL service may induce into other services deployed on the communication line 555 within that frequency range.

[0079] FIG. 9A is a diagram showing a transfer function associated with one embodiment of the adaptive filter 754 of FIG. 7, which has a variable attenuation over a variable frequency range. In this regard, FIG. 9A shows a general adaptive filter 754 in which the attenuation bandwidth may be adaptively changed in response to detected line conditions. As shown in FIG. 9A, one embodiment of the adaptive filter 754 is configured as a piece-wise linear function defined by 0 dBm/Hz attenuation below a frequency of

$$\left(-A_1 - A_2 \times \left(\frac{f}{f_1}\right)\right)$$

[0080] attenuation between f_1 and f_2 ; $-A_5$ dBm/Hz attenuation between f_2 and f_3 ; and 0 dBm/Hz attenuation above f_3 , where $-A_1$, $-A_2$, and $-A_5$ are attenuation values that are adaptively set in response to detected line conditions, and f_1 , f_2 , and f_3 are frequencies that are adaptively set in response to detected line conditions.

[0081] FIG. 9B is a diagram showing a transfer function associated with one embodiment of the adaptive filter 754 of FIG. 7, which has a variable attenuation over a fixed frequency range. As shown in FIG. 9B, this embodiment of the adaptive filter 754 is configured as a piece-wise linear function defined by 0 dBm/Hz attenuation below a frequency of approximately

$$99 \text{ kHz}; \left(-A_1 - A_2 \times \left(\frac{f}{99}\right)\right)$$

[0082] attenuation between approximately 99 kHz and approximately 151 kHz; $-A_5$ dBm/Hz attenuation between approximately 151 kHz and approximately 164 kHz; and 0 dBm/Hz attenuation above approximately 164 kHz, where $-A_1$, $-A_2$, and $-A_5$ are attenuation values that are adaptively set in response to detected line conditions.

[0083] FIG. 9C is a diagram showing a transfer function associated with one embodiment of the adaptive filter 754 of FIG. 7, which has a specific attenuation over a fixed frequency range. As shown in FIG. 9C, this embodiment of the adaptive filter 754 is configured as a piece-wise linear function defined by 0 dBm/Hz attenuation below a frequency of approximately 99 kHz; approximately

$$\left(-12 - 32.84 \times \left(\frac{f}{99}\right)\right)$$

[0084] attenuation between approximately 99 kHz and approximately 151 kHz; approximately -32 dBm/Hz attenuation between (approximately 151 kHz and approximately 164 kHz; and 0 dBm/Hz attenuation above approximately 164 kHz. For a fixed adaptive filter 754 similar to that shown in FIG. 9C, the processor 720 may selectively apply or not apply the notch filter to a PSD mask depending on the presence or absence of other services on the communication line 555, as indicated by the detected line conditions.

[0085] FIG. 10 is a diagram showing another embodiment of an adaptively-filtered PSD mask generated by the system of FIG. 7. As shown in FIG. 10, the adaptively-filtered PSD mask is defined by power levels of approximately -97.5 dBm/Hz below approximately 4 kHz; approximately

$$\left(-97.5 + 17.8 \times \log_2 \left(\frac{f}{4}\right)\right)$$

[0086] dBm/Hz between approximately 4 kHz and approximately 26 kHz; approximately -36.5 dBm/Hz between approximately 26 kHz and approximately 121 kHz; approximately

$$\left(-49.5 - 78.24 \times \log_2\left(\frac{f}{121}\right)\right)$$

[0087] between approximately 121 kHz and approximately 151 kHz; approximately -74.5 dBm/Hz between approximately 151 kHz and approximately 164 kHz; approximately -36.5 dBm/Hz between approximately 164 kHz and approximately 1104 kHz; approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

[0088] between approximately 1104 kHz and approximately 3093 kHz; and approximately -90 dBm/Hz above approximately 3093 kHz. Specifically, the PSD mask shown in FIG. 10 is configured to optimize downstream performance, balance downstream and upstream signal ratios, and provide spectral compatibility in Annex A and Annex C far-end cross-talk (FEXT) bit-mapped (FBM) systems. Since Annex A and Annex C are well known and, also, are described in the G.992.1 standard, further discussion of Annex A and Annex C is omitted here.

[0089] FIG. 11 is a diagram showing yet another embodiment of an adaptively-filtered PSD mask generated by the system of FIG. 7. As shown in FIG. 11, the adaptively-filtered PSD mask is defined by power levels of approximately -97.5 dBm/Hz below approximately 4 kHz; approximately

$$\left(-97.5 + 17.8 \times \log_2\left(\frac{f}{4}\right)\right)$$

[0090] dBm/Hz between approximately 4 kHz and approximately 26 kHz; approximately -36.5 dBm/Hz between approximately 26 kHz and approximately 121 kHz; approximately

$$\left(-49.5 - 115.8 \times \log_2\left(\frac{f}{121}\right)\right)$$

[0091] between approximately 121 kHz and approximately 151 kHz; approximately -86.5 dBm/Hz between approximately 151 kHz and approximately 164 kHz; approximately -36.5 dBm/Hz between approximately 164 kHz and approximately 1104 kHz; approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

[0092] between approximately 1104 kHz and approximately 3093 kHz; and approximately -90 dBm/Hz above approximately 3093 kHz. Specifically, the PSD mask shown in FIG. 11 is configured to optimize downstream performance,

balance downstream and upstream signal ratios, and provide spectral compatibility in Annex A FBM systems.

[0093] FIG. 12 is a diagram showing one embodiment of an adaptively-filtered PSD mask having a variable attenuation immediately above the plain old telephone system (POTS) bandwidth. As shown in FIG. 12, the adaptively-filtered PSD mask is defined by power levels of approximately -97.5 dBm/Hz below approximately 4 kHz; a variable attenuation of

$$\left(-97.5 + A_1 \times \left(\frac{f}{4}\right)\right)$$

[0094] between approximately 4 kHz and approximately 26 kHz, where A_1 is adaptively set in response to detected line conditions; approximately -36.5 dBm/Hz between approximately 26 kHz and approximately 121 kHz; approximately

$$\left(-49.5 - 115.8 \times \log_2\left(\frac{f}{121}\right)\right)$$

[0095] between approximately 121 kHz and approximately 151 kHz; approximately -86.5 dBm/Hz between approximately 151 kHz and approximately 164 kHz; approximately -36.5 dBm/Hz between approximately 164 kHz and approximately 1104 kHz; approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

[0096] between approximately 1104 kHz and approximately 3093 kHz; and approximately -90 dBm/Hz above approximately 3093 kHz.

[0097] FIG. 13 is a diagram showing yet another embodiment of an adaptively-filtered PSD mask having a variable attenuation between approximately 121 kHz and 164 kHz. As shown in FIG. 13, the adaptively-filtered PSD mask is defined by power levels of approximately -97.5 dBm/Hz below approximately 4 kHz; approximately

$$\left(-97.5 + 17.8 \times \log_2\left(\frac{f}{4}\right)\right)$$

[0098] dBm/Hz between approximately 4 kHz and approximately 26 kHz; approximately -36.5 dBm/Hz between approximately 26 kHz and approximately 121 kHz; a variable attenuation of approximately

$$\left(-49.5 - A_2 \times \log_2\left(\frac{f}{121}\right)\right)$$

[0099] between approximately 121 kHz and approximately 151 kHz; a variable attenuation of $-A_6$ dBm/Hz

between approximately 151 kHz and approximately 164 kHz; approximately -36.5 dBm/Hz between approximately 164 kHz and approximately 1104 kHz; approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

[0100] between approximately 1104 kHz and approximately 3093 kHz; and approximately -90 dBm/Hz above approximately 3093 kHz, where $-A_2$ and $-A_6$ are adaptively set in response to detected line conditions.

[0101] FIG. 14 is a diagram showing one embodiment of an adaptively-filtered PSD mask having a variable attenuation over a plurality of different frequency ranges. As shown in FIG. 14, the adaptively-filtered PSD mask is defined by power levels of approximately -97.5 dBm/Hz below approximately 4 kHz; a variable attenuation of

$$\left(-97.5 + A_4 \times \log_2\left(\frac{f}{4}\right)\right)$$

[0102] between approximately 4 kHz and approximately 26 kHz; approximately -36.5 dBm/Hz between approximately 26 kHz and approximately 121 kHz; a variable attenuation of approximately

$$\left(-49.5 - A_2 \times \log_2\left(\frac{f}{121}\right)\right)$$

[0103] between approximately 121 kHz and approximately 151 kHz; a variable attenuation of $-A_6$ dBm/Hz between approximately 151 kHz and approximately 164 kHz; approximately -36.5 dBm/Hz between approximately 164 kHz and approximately 1104 kHz; approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

[0104] between approximately 1104 kHz and approximately 3093 kHz; and approximately -90 dBm/Hz above approximately 3093 kHz, where $-A_2$, $-A_4$, and $-A_6$ are adaptively set in response to detected line conditions.

[0105] FIG. 15A is a diagram showing a transfer function associated with another embodiment of the adaptive filter 754 of FIG. 7, which has a variable attenuation over a variable frequency range. In this regard, FIG. 15A shows a general adaptive filter 754 in which the attenuation bandwidth may be adaptively changed in response to detected line conditions. As shown in FIG. 15A, one embodiment of the adaptive filter 754 is configured as a piece-wise linear function defined by 0 dBm/Hz attenuation below a frequency of f_4 ; $-A_3$ dBm/Hz attenuation between f_4 and f_5 ; and 0 dBm/Hz attenuation above f_5 where $-A_3$ is an attenuation value that is adaptively set in response to detected line conditions, and f_4 and f_5 are frequencies that are adaptively set in response to detected line conditions.

[0106] FIG. 15B is a diagram showing a transfer function associated with another embodiment of the adaptive filter 754 of FIG. 7, which has a variable attenuation over a fixed frequency range. As shown in FIG. 15B, this embodiment of the adaptive filter 754 is configured as a piece-wise linear function defined by 0 dBm/Hz attenuation below a frequency of approximately 100 kHz; $-A_3$ dBm/Hz attenuation between approximately 100 kHz and approximately 200 kHz; and 0 dBm/Hz attenuation above approximately 200 kHz, where $-A_3$ is an attenuation value that is adaptively set in response to detected line conditions.

[0107] FIG. 15C is a diagram showing a transfer function associated with another embodiment of the adaptive filter 754 of FIG. 7, which has a specific attenuation over a fixed frequency range. As shown in FIG. 15C, this embodiment of the adaptive filter 754 is configured as a piece-wise linear function defined by 0 dBm/Hz attenuation below a frequency of approximately 100 kHz; approximately -8 dBm/Hz attenuation between approximately 100 kHz and approximately 200 kHz; and 0 dBm/Hz attenuation above approximately 200 kHz.

[0108] FIG. 15D is a diagram showing a transfer function associated with another embodiment of the adaptive filter 754 of FIG. 7, which has a specific attenuation over a fixed frequency range. As shown in FIG. 15D, this embodiment of the adaptive filter 754 is configured as a piece-wise linear function defined by 0 dBm/Hz attenuation below a frequency of approximately 100 kHz; approximately -12 dBm/Hz attenuation between approximately 100 kHz and approximately 200 kHz; and 0 dBm/Hz attenuation above approximately 200 kHz.

[0109] FIG. 16 is a diagram showing yet another embodiment of an adaptively-filtered PSD mask generated by the system of FIG. 7. As shown in FIG. 16, the adaptively-filtered PSD mask is defined by power levels of approximately -97.5 dBm/Hz below approximately 4 kHz; a variable attenuation of

$$\left(-97.5 + 17.8 \times \left(\frac{f}{4}\right)\right)$$

[0110] between approximately 4 kHz and approximately 26 kHz; approximately -36.5 dBm/Hz between approximately 26 kHz and approximately 147 kHz; approximately -41.5 dBm/Hz between approximately 147 kHz and approximately 164 kHz; approximately -36.5 dBm/Hz between approximately 164 kHz and approximately 1104 kHz; approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

[0111] between approximately 1104 kHz and approximately 3093 kHz; and approximately -90 dBm/Hz above approximately 3093 kHz, where $-A_2$, $-A_4$, and $-A_6$ are adaptively set in response to detected line conditions.

[0112] FIG. 17 is a diagram showing another embodiment of an adaptively-filtered PSD mask having a variable attenu-

ation within a variable frequency range. As shown in **FIG. 17**, the adaptively-filtered PSD mask is defined by power levels of approximately -97.5 dBm/Hz below approximately 4 kHz; a variable attenuation of

$$\left(-97.5 + 17.8 \times \left(\frac{f}{4}\right)\right)$$

[0113] between approximately 4 kHz and approximately 26 kHz; approximately -36.5 dBm/Hz between approximately 26 kHz and f_4 kHz; a variable attenuation of approximately $(-36.5 - A_3)$ dBm/Hz between f_4 kHz and f_5 kHz; approximately -36.5 dBm/Hz between f_5 kHz and approximately 1104 kHz; approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

[0114] between approximately 1104 kHz and approximately 3093 kHz; and approximately -90 dBm/Hz above approximately 3093 kHz, where $-A_3$, f_4 , and f_5 are adaptively set in response to detected line conditions.

[0115] **FIG. 18** is a diagram showing another embodiment of an adaptively-filtered PSD mask having a variable attenuation immediately above the POTS bandwidth. As shown in **FIG. 17**, the adaptively-filtered PSD mask is defined by power levels of approximately -97.5 dBm/Hz below approximately 4 kHz; a variable attenuation of

$$\left(-97.5 + A_4 \times \left(\frac{f}{4}\right)\right)$$

[0116] between approximately 4 kHz and approximately 26 kHz; approximately -36.5 dBm/Hz between approximately 26 kHz and approximately 147 kHz; approximately -41.5 dBm/Hz between approximately 147 kHz and approximately 164 kHz; approximately -36.5 dBm/Hz between approximately 164 kHz and approximately 1104 kHz; approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

[0117] between approximately 1104 kHz and approximately 3093 kHz; and approximately -90 dBm/Hz above approximately 3093 kHz, where $-A_4$ is adaptively set in response to detected line conditions.

[0118] **FIG. 19** is a diagram showing another embodiment of an adaptively-filtered PSD mask having a variable attenuation in several non-adjacent bandwidths. As shown in **FIG. 19**, the adaptively-filtered PSD mask is defined by power levels of approximately -97.5 dBm/Hz below approximately 4 kHz; a variable attenuation of

$$\left(-97.5 + A_4 \times \left(\frac{f}{4}\right)\right)$$

[0119] between approximately 4 kHz and approximately 26 kHz; approximately -36.5 dBm/Hz between approximately 26 kHz and f_4 kHz; a variable attenuation of approximately $(-36.5 - A_3)$ dBm/Hz between f_4 kHz and f_5 kHz; approximately -36.5 dBm/Hz between f_5 kHz and approximately 1104 kHz; approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

[0120] between approximately 1104 kHz and approximately 3093 kHz; and approximately -90 dBm/Hz above approximately 3093 kHz, where $-A_3$, $-A_4$, f_4 , and f_5 are adaptively set in response to detected line conditions.

[0121] **FIG. 20** is a diagram showing yet another embodiment of an adaptively-filtered PSD mask generated by the system of **FIG. 7**. As shown in **FIG. 20**, the adaptively-filtered PSD mask is defined by power levels of approximately -97.5 dBm/Hz below approximately 4 kHz; approximately -94.5 dBm/Hz between approximately 4 kHz and approximately 31 kHz; approximately

$$\left(-94.5 + 10.88 \times \log_2\left(\frac{f}{31}\right)\right)$$

[0122] dBm/Hz between approximately 31 kHz and approximately 104 kHz; approximately

$$\left(-75.5 + 96.54 \times \log_2\left(\frac{f}{104}\right)\right)$$

[0123] dBm/Hz between approximately 104 kHz and approximately 134 kHz; approximately

$$\left(-40.2 + 9.6 \times \log_2\left(\frac{f}{134}\right)\right)$$

[0124] dBm/Hz between approximately 134 kHz and approximately 175 kHz; approximately -36.5 dBm/Hz between approximately 175 kHz and approximately 1104 kHz; approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

[0125] between approximately 1104 kHz and approximately 3093 kHz; and approximately -90.5 dBm/Hz above approximately 3093 kHz. Specifically, the PSD mask shown

in **FIG. 20** is configured to optimize downstream performance, balance downstream and upstream signal ratios, and provide spectral compatibility during a near-end cross-talk (NEXT) period in extended reach Annex C systems adapted for time-frequency division duplexing. Since Annex C systems are known in the art and, also, are described in G.992.1, further discussion of Annex C systems and their requirements is omitted here.

[0126] **FIG. 21** is a diagram showing yet another embodiment of an adaptively-filtered PSD mask generated by the system of **FIG. 7**. As shown in **FIG. 21**, the adaptively-filtered PSD mask is defined by power levels of approximately -97.5 dBm/Hz below approximately 4 kHz; approximately -94.5 dBm/Hz between approximately 4 kHz and approximately 24 kHz; approximately

$$\left(-80 + 18.42 \times \log_2\left(\frac{f}{24}\right)\right)$$

[0127] dBm/Hz between approximately 24 kHz and approximately 43 kHz; approximately

$$\left(-64.5 + 18 \times \log_2\left(\frac{f}{43}\right)\right)$$

[0128] dBm/Hz between approximately 43 kHz and approximately 74 kHz; approximately

$$\left(-50.4 + 1424 \times \log_2\left(\frac{f}{74}\right)\right)$$

[0129] dBm/Hz between approximately 74 kHz and approximately 121 kHz; approximately

$$\left(-40.3 + 7.61 \times \log_2\left(\frac{f}{121}\right)\right)$$

[0130] dBm/Hz between approximately 121 kHz and approximately 171 kHz; approximately -36.5 dBm/Hz between approximately 171 kHz and approximately 1104 kHz; approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

[0131] between approximately 1104 kHz and approximately 3093 kHz; and approximately -90.5 dBm/Hz above approximately 3093 kHz. Specifically, the PSD mask shown in **FIG. 21** is configured to optimize downstream performance, balance downstream and upstream signal ratios, and provide spectral compatibility during a flu-end cross-talk (FEXT) period in extended reach Annex C systems adapted for time-frequency division duplexing.

[0132] **FIG. 22** is a diagram showing yet another embodiment of an adaptively-filtered PSD mask generated by the

system of **FIG. 7**. As shown in **FIG. 22**, the adaptively-filtered PSD mask is defined by power levels of approximately -97.5 dBm/Hz below approximately 4 kHz; approximately -86.5 dBm/Hz between approximately 4 kHz and approximately 10 kHz; approximately

$$\left(-86.5 + 25.8 \times \log_2\left(\frac{f}{10}\right)\right)$$

[0133] dBm/Hz between approximately 10 kHz and approximately 27 kHz; approximately

$$\left(-49.5 + 9.46 \times \log_2\left(\frac{f}{27}\right)\right)$$

[0134] dBm/Hz between approximately 27 kHz and approximately 70 kHz; approximately -36.5 dBm/Hz between approximately 70 kHz and approximately 1104 kHz; approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

[0135] between approximately 1104 kHz and approximately 3093 kHz; and approximately -90.5 dBm/Hz above approximately 3093 kHz. Specifically, the PSD mask shown in **FIG. 22** is configured to optimize downstream performance, balance downstream and upstream signal ratios, and provide spectral compatibility during a far-end cross-talk (FEXT) period in FEXT bit-mapped (FBM) Annex C systems.

[0136] **FIG. 23** is a diagram showing yet another embodiment of an adaptively-filtered PSD mask generated by the system of **FIG. 7**. As shown, in **FIG. 23**, the adaptively-filtered PSD mask is defined by power levels of approximately -97.5 dBm/Hz below approximately 4 kHz; approximately

$$\left(-97.5 + 11 \times \log_2\left(\frac{f}{4}\right)\right)$$

[0137] dBm/Hz between approximately 4 kHz and approximately 50 kHz; approximately

$$\left(-57.5 + 15.7 \times \log_2\left(\frac{f}{50}\right)\right)$$

[0138] dBm/Hz between approximately 50 kHz and approximately 126 kHz; approximately -36.5 dBm/Hz between approximately 126 kHz and approximately 1104 kHz; approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

[0139] between approximately 1104 kHz and (approximately 3093 kHz; and approximately -90.5 dBm/Hz above approximately 3093 kHz. Specifically, the PSD mask shown in FIG. 23 is configured to optimize downstream performance, balance downstream and upstream signal ratios, and provide spectral compatibility during a far-end cross-talk (FEXT) period in Annex C systems adapted for time-frequency division duplexing.

[0140] FIG. 24 is a diagram showing yet another embodiment of an adaptively-filtered PSD mask generated by the system of FIG. 7. As shown in FIG. 24, the adaptively-filtered PSD mask is defined by power levels of approximately -97.5 dBm/Hz below approximately 4 kHz; approximately -94.5 dBm/Hz between approximately 4 kHz and approximately 32 kHz; approximately

$$\left(-94.5 + 20.65 \times \log_2\left(\frac{f}{32}\right)\right)$$

[0141] dBm/Hz between approximately 32 kHz and approximately 109 kHz; approximately

$$\left(-58 + 58 \times \log_2\left(\frac{f}{109}\right)\right)$$

[0142] dBm/Hz between approximately 109 kHz and approximately 138 kHz; approximately

$$\left(-38.3 + 3.36 \times \log_2\left(\frac{f}{138}\right)\right)$$

[0143] dBm/Hz between approximately 138 kHz and approximately 200 kHz; approximately -36.5 dBm/Hz between approximately 200 kHz and approximately 1104 kHz; approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

[0144] between approximately 1104 kHz and approximately 3093 kHz; and approximately -90.5 dBm/Hz above approximately 3093 kHz. Specifically, the PSD mask shown in FIG. 24 is configured to optimize downstream performance, balance downstream and upstream signal ratios, and provide spectral compatibility during a near-end cross-talk (NEXT) period in Annex C systems adapted for time-frequency division duplexing.

[0145] FIG. 25 is a flowchart showing one embodiment of a method employing adaptively-filtered PSD masks. As shown in FIG. 25, one embodiment of the method begins

when a DMT-modulated communication system receives (2520) a signal from a communication line 555. The received (2520) signal has information indicative of services deployed on the communication line 555. In this regard, the received (2520) signal contains information related to line conditions. Upon receiving (2520) the signal, the DMT-modulated communications system adaptively determines (2530) a power level of a DMT sub-carrier. Additionally, the DMT-modulated communication system adaptively attenuates (2540) power within a portion of a PSD mask using the adaptively determined (2530) power level of the DMT sub-carrier. Thereafter, the DMT sub-carrier is loaded (2550) with data according to the adaptively determined (2530) power level.

[0146] In an example embodiment, the method of FIG. 25 may be performed by the systems described with reference to FIGS. 5 through 24. However, it should be understood that other communication systems employing DMT modulation might also perform the steps described with reference to FIG. 25.

[0147] The service determination logic 730, the power determination logic 740, the power allocation logic 750, and the data loading logic 760 of the present invention can be implemented in hardware, software, firmware, or a combination thereof. In the preferred embodiment(s), the service determination logic 730, the power determination logic 740, the power allocation logic 750, and the data loading logic 760 is implemented in hardware using any or a combination of the following technologies, which are all well known in the art: a discrete logic circuit(s) having logic gates for implementing logic functions upon data signals, an application specific integrated circuit (ASIC) having appropriate combinational logic gates, a programmable gate array(s) (PGA), a field programmable (late array (FPGA), etc. In an alternative embodiment, the service determination logic 730, the power determination logic 740, the power allocation logic 750, and the data loading logic 760 is implemented in software or firmware that is stored in a memory and that is executed by a suitable instruction execution system.

[0148] Any process descriptions or blocks in flow charts should be understood as representing modules, segments, or portions of code which include one or more executable instructions for implementing specific logical functions or steps in the process, and alternate implementations are included within the scope of the preferred embodiment of the present invention in which functions may be executed out of order from that shown or discussed, including substantially concurrently or in reverse order, depending on the functionality involved, as would be understood by those reasonably skilled in the art of the present invention.

[0149] Although an exemplary embodiment of the present invention has been shown and described, it will be apparent to those of ordinary skill in the art that a number of changes, modifications, or alterations to the invention as described may be made, none of which depart from the spirit of the present invention. For example, while the processor and logic configured to adaptively calculate the DMT sub-carrier power level are shown within the encoding and gain scaling block, it should be appreciated that the processor and logic configured to adaptively calculate the DMT sub-carrier power level may also be located as a separate unit outside of

the encoding and gain scaling block. Also, while exemplary embodiments of the present invention have been described with reference to a digital subscriber line (DSL) system, it should be understood that the systems and methods presented herein may be implemented in other digital communication systems that employ sub-carriers for data transmission. Additionally, while specific examples of PSD masks have been shown with reference to FIGS. 8, 10-14, and 16-24, it should be appreciated that the various cutoff frequencies and attenuation values shown as fixed values may be adjusted to maximize downstream performance, balance upstream and downstream signals, and provide greater spectral compatibility with concurrently deployed services, such as ISDN services. All such changes, modifications, and alterations should therefore be seen as within the scope of the present invention.

The claims are:

1. A discrete multi-tone (DMT) modulated communication system comprising:

a receiver configured to receive signals from a communication line, the signals having information indicative of line conditions; and

logic configured to adaptively calculate a power level of a DMT sub-carrier in response to received signals from the communication line.

2. The system of claim 1, wherein the logic configured to adaptively calculate the power level of the DMT sub-carrier comprises logic configured to determine a signal-to-noise ratio (SNR) of the communication line.

3. The system of claim 1 wherein the logic configured to adaptively calculate the power level of the DMT sub-carrier comprises logic configured to determine line attenuation information of the communication line.

4. The system of claim 1, wherein the logic configured to adaptively calculate the power level of the DMT sub-carrier comprises logic configured to determine information related to usable sub-carriers in the DMT modulated system.

5. The system of claim 1, further comprising logic configured to load the DMT sub-carrier with data, the DMT sub-carrier being loaded as a function of the adaptively-determined power level.

6. A discrete multi-tone (DMT) modulated digital subscriber line (DSL) system comprising:

an adaptively-filtered power spectral density (PSD) mask having an attenuated portion, the attenuated portion configured to adaptively change in response to line characteristics; and

logic configured to load DMT sub-carriers with data, the DMT sub-carriers, being loaded according to the adaptively-filtered PSD mask.

7. The system of claim 6, further comprising:

a receiver configured to receive signals from a communication line, the signals having information indicative of line conditions; and

logic configured to adaptively determine the services deployed on the communication line from the received signals.

8. The system of claim 7, wherein the attenuated portion is further configured to change in response to the adaptively determined services deployed on the communication line.

9. The system of claim 6, wherein the attenuated portion has a variable power over a fixed frequency range.

10. The system of claim 6, wherein the attenuated portion has a variable power over a variable frequency range.

11. A system comprising:

an adaptive filter having an attenuation bandwidth, the adaptive filter configured to adaptively attenuate power within a portion of a power spectral density (PSD) mask to generate an adaptively-filtered PSD mask; and

logic configured to allocate power to sub-carriers in a discrete multi-tone (DMT) modulated communication system, the power being allocated according to the adaptively-filtered PSD mask.

12. The system of claim 11, wherein the adaptive filter is configured to selectively provide a fixed attenuation over a fixed frequency range.

13. The system of claim 12, wherein the fixed attenuation over the fixed frequency range is approximately -8 dB between approximately 100 kHz and approximately 200 kHz.

14. The system of claim 12, wherein the adaptively-filtered PSD mask is defined by power levels of:

approximately -97.5 dBm/Hz below approximately 4 kHz;

approximately

$$\left(-97.5 + 17.8 \times \log_2\left(\frac{f}{4}\right)\right)$$

dBm/Hz between approximately 4 kHz and approximately 26 kHz;

approximately -36.5 dBm/Hz between approximately 26 kHz and approximately 147 kHz;

approximately -41.5 dBm/Hz between approximately 147 kHz and approximately 164 kHz;

approximately -36.5 dBm/Hz between approximately 164 kHz and approximately 1104 kHz;

approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

between approximately 1104 kHz and approximately 3093 kHz; and

approximately -90 dBm/Hz above approximately 3093 kHz.

15. The system of claim 12, wherein the fixed attenuation over the fixed frequency range is:

approximately

$$\left(-12 - 32.84 \times \log_2\left(\frac{f}{99}\right)\right)$$

between approximately 99 kHz and approximately 151 kHz; and

approximately -32 dBm/Hz between approximately 151 kHz and approximately 164 kHz.

16. The system of claim 12, wherein the adaptively-filtered PSD mask is defined by power levels of:

approximately -97.5 dBm/Hz below approximately 4 kHz;

approximately

$$\left(-97.5 + 17.8 \times \log_2\left(\frac{f}{4}\right)\right)$$

dBm/Hz between approximately 4 kHz and approximately 26 kHz;

approximately -36.5 dBm/Hz between approximately 26 kHz and approximately 121 kHz;

approximately

$$\left(-49.5 - 115.8 \times \log_2\left(\frac{f}{121}\right)\right)$$

dBm/Hz between approximately 121 kHz and approximately 151 kHz;

approximately -86.5 dBm/Hz between approximately 151 kHz and approximately 164 kHz;

approximately -36.5 dBm/Hz between approximately 164 kHz and approximately 1104 kHz;

approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

between approximately 1104 kHz and approximately 3093 kHz; and

approximately -90 dBm/Hz above approximately 3093 kHz.

17. The system of claim 12, wherein the adaptively-filtered PSD mask is defined by power levels of:

approximately -97.5 dBm/Hz below approximately 4 kHz;

approximately

$$\left(-97.5 + 17.8 \times \log_2\left(\frac{f}{4}\right)\right)$$

dBm/Hz between approximately 4 kHz and approximately 26 kHz;

approximately -36.5 dBm/Hz between approximately 26 kHz and approximately 121 kHz;

approximately

$$\left(-49.5 - 78.24 \times \log_2\left(\frac{f}{121}\right)\right)$$

dBm/Hz between approximately 121 kHz and approximately 151 kHz;

approximately -74.5 dBm/Hz between approximately 151 kHz and approximately 164 kHz;

approximately -36.5 dBm/Hz between approximately 164 kHz and approximately 1104 kHz;

approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

between approximately 1104 kHz and approximately 3093 kHz; and

approximately -90 dBm/Hz above approximately 3093 kHz.

18. The system of claim 12, wherein the adaptively-filtered PSD mask is defined by power levels of:

approximately -97.5 dBm/Hz below approximately 4 kHz;

approximately -94.5 dBm/Hz between approximately 4 kHz and approximately 31 kHz;

approximately

$$\left(-94.5 + 10.88 \times \log_2\left(\frac{f}{31}\right)\right)$$

dBm/Hz between approximately 31 kHz and approximately 104 kHz;

approximately

$$\left(-75.5 + 96.54 \times \log_2\left(\frac{f}{104}\right)\right)$$

dBm/Hz between approximately 104 kHz and approximately 134 kHz;

approximately

$$\left(-40.2 + 9.6 \times \log_2\left(\frac{f}{134}\right)\right)$$

dBm/Hz between approximately 134 kHz and approximately 175 kHz;

approximately -36.5 dBm/Hz between approximately 175 kHz and approximately 1104 kHz; approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

between approximately 1104 kHz and approximately 3093 kHz; and

approximately -90.5 dBm/Hz above approximately 3093 kHz.

19. The system of claim 12, wherein the adaptively-filtered PSD mask is defined by power levels of:

approximately -97.5 dBm/Hz below approximately 4 kHz;

approximately -94.5 dBm/Hz between approximately 4 kHz and approximately 24 kHz;

approximately

$$\left(-80 + 18.42 \times \log_2\left(\frac{f}{24}\right)\right)$$

dBm/Hz between approximately 24 kHz and approximately 43 kHz;

approximately

$$\left(-64.5 + 18 \times \log_2\left(\frac{f}{43}\right)\right)$$

dBm/Hz between approximately 43 kHz and approximately 74 kHz;

approximately

$$\left(-50.4 + 14.24 \times \log_2\left(\frac{f}{74}\right)\right)$$

dBm/Hz between approximately 74 kHz and approximately 121 kHz;

approximately

$$\left(-403 + 761 \times \log_2\left(\frac{f}{121}\right)\right)$$

dBm/Hz between approximately 121 kHz and approximately 171 kHz;

approximately -36.5 dBm/Hz between approximately 171 kHz and approximately 1104 kHz;

approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

between approximately 1104 kHz and approximately 3093 kHz; and

approximately -90.5 dBm/Hz above approximately 3093 kHz.

20. The system of claim 12, wherein the adaptively-filtered PSD mask is defined by power levels of:

approximately -97.5 dBm/Hz below approximately 4 kHz;

approximately -86.5 dBm/Hz between approximately 4 kHz and approximately 10 kHz;

approximately

$$\left(-86.5 + 258 \times \log_2\left(\frac{f}{10}\right)\right)$$

dBm/Hz between approximately 10 kHz and approximately 27 kHz;

approximately

$$\left(-495 + 946 \times \log_2\left(\frac{f}{27}\right)\right)$$

dBm/Hz between approximately 27 kHz and approximately 70 kHz

approximately -36.5 dBm/Hz between approximately 70 kHz and approximately 1104 kHz;

approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

between approximately 1104 kHz and approximately 3093 kHz; and

approximately -90.5 dBm/Hz above approximately 3093 kHz.

21. The system of claim 12, wherein the adaptively-filtered PSD mask is defined by power levels of:

approximately -97.5 dBm/Hz belongs approximately 4 kHz;

approximately

$$\left(-97.5 + 11 \times \log_2\left(\frac{f}{4}\right)\right)$$

dBm/Hz between approximately 4 kHz and approximately 50 kHz;

approximately

$$\left(-57.5 + 157 \times \log_2\left(\frac{f}{50}\right)\right)$$

dBm/Hz between approximately 50 kHz and approximately 126 kHz;

approximately -36.5 dBm/Hz between approximately 164 kHz and approximately 1104 kHz;

approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

between approximately 1104 kHz and approximately 3093 kHz; and

approximately -90.5 dBm/Hz above approximately 3093 kHz.

22. The system of claim 12, wherein the adaptively-filtered PSD mask is defined by power levels of:

approximately -97.5 dBm/Hz below approximately 4 kHz;

approximately -94.5 dBm/Hz between approximately 4 kHz and approximately 32 kHz;

approximately

$$\left(-94.5 + 2065 \times \log_2\left(\frac{f}{32}\right)\right)$$

dBm/Hz between approximately 32 kHz and approximately 109 kHz;

approximately

$$\left(-58 + 58 \times \log_2\left(\frac{f}{109}\right)\right)$$

dBm/Hz between approximately 109 kHz and approximately 138 kHz;

approximately

$$\left(-38.3 + 3.36 \times \log_2\left(\frac{f}{138}\right)\right)$$

dBm/Hz between approximately 138 kHz and approximately 200 kHz;

approximately -36.5 dBm/Hz between approximately 200 kHz and approximately 1104 kHz;

approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

between approximately 1104 kHz and approximately 3093 kHz; and

approximately -90.5 dBm/Hz above approximately 3093 kHz.

23. The system of claim 11, wherein the adaptive filter is configured to provide a variable attenuation over a fixed frequency range.

24. The system of claim 23, wherein the adaptively-filtered PSD mask is defined by power levels of:

approximately -97.5 dBm/Hz below approximately 4 kHz;

approximately

$$\left(-97.5 + 17.8 \times \log_2\left(\frac{f}{4}\right)\right)$$

dBm/Hz between approximately 4 kHz and approximately 26 kHz;

approximately -36.5 dBm/Hz between approximately 26 kHz and approximately 147 kHz;

an adaptively varying, power level between approximately 147 kHz and approximately 164 kHz;

approximately -36.5 dBm/Hz between approximately 164 kHz and approximately 1104 kHz;

approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

between approximately 1104 kHz and approximately 3093 kHz; and

approximately -90 dBm/Hz above approximately 3093 kHz.

25. The system of claim 23, wherein the adaptively-filtered PSD mask is defined by power levels of:

approximately 97.5 dBm/Hz below approximately 4 kHz;

an adaptively varying power level between approximately 4 kHz and approximately 26 kHz;

approximately -36.5 dBm/Hz between approximately 26 kHz and approximately 147 kHz;

approximately -41.5 dBm/Hz between approximately 147 kHz and approximately 164 kHz;

approximately -36.5 dBm/Hz between approximately 164 kHz and approximately 1104 kHz;

approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

between approximately 1104 kHz and approximately 3093 kHz; and

approximately -90 dBm/Hz above approximately 3093 kHz.

26. The system of claim 23, wherein the adaptively-filtered PSD mask is defined by power levels of:

approximately -97.5 dBm/Hz below approximately 4 kHz;

an adaptively varying power level between approximately 4 kHz and approximately 26 kHz;

approximately -36.5 dBm/Hz between approximately 26 kHz and approximately 147 kHz;

an adaptively varying power level between approximately 147 kHz and approximately 164 kHz;

approximately -36.5 dBm/Hz between approximately 164 kHz and approximately 1104 kHz;

approximately

$$\left(-36.5 - 36 \times \log_2\left(\frac{f}{1104}\right)\right)$$

between approximately 1104 kHz and approximately 3093 kHz; and

approximately -90 dBm/Hz above approximately 3093 kHz.

27. The system of claim 24, wherein the adaptively varying power level ranges from approximately 0 dBm/Hz to approximately -12 dBm/Hz.

28. The system of claim 11, wherein the adaptive filter is configured to provide a fixed attenuation over a variable frequency range.

29. The system of claim 28, wherein the fixed attenuation is approximately -8 dBm/Hz.

30. The system of claim 28, wherein the fixed attenuation is approximately -12 dBm/Hz.

31. The system of claim 11, wherein the adaptive filter is configured to provide a variable attenuation over a variable frequency range.

32. In a discrete multi-tone (DMT) modulated communication system, a method comprising:

receiving a signal from a communication line, the signal having information indicative of line conditions; and

adaptively determining a power level of a DMT sub-carrier in response to receiving the signal from the communication line.

33. The method of claim 32, further comprising:

loading the DMT sub-carrier with data, the DMT sub-carrier being loaded according to the adaptively determined power level.

34. The method of claim 32, further comprising:

adaptively attenuating power within a portion of a power spectral density (PSD) mask.

35. The method of claim 34, wherein the adaptively attenuating power within the portion of the PSD mask comprises:

variably attenuating a fixed bandwidth.

36. The method of claim 35, wherein the variably attenuating a fixed bandwidth comprises:

variably attenuating DMT sub-carriers between approximately 100 kHz and approximately 200 kHz

37. The method of claim 35, wherein the variably attenuating a fixed bandwidth comprises:

variably attenuating DMT sub-carriers between approximately 4 kHz and approximately 26 kHz

38. The method of claim 35, wherein the variably attenuating a fixed bandwidth comprises:

variably attenuating DMT sub-carriers between approximately 121 kHz and approximately 164 kHz

39. The method of claim 34, wherein the adaptively attenuating power within the portion of the PSD mask comprises:

variably attenuating a variable bandwidth.

40. In a discrete multi-tone (DMT) modulated communication system, a system comprising:

means for receiving a signal from a communication line, the signal having information indicative of line conditions; and

means for adaptively determining a power level of a DMT sub-carrier in response to receiving the signal from the communication line.

41. The system of claim 40, further comprising:

means for loading the DMT sub-carrier with data, the DMT sub-carrier being loaded according to the adaptively determined power level.

42. The system of claim 40, further comprising:

means for adaptively attenuation power within a portion of a power spectral density (PSD) mask.

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