



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁶ : H04Q 11/00	A2	(11) International Publication Number: WO 98/44757 (43) International Publication Date: 8 October 1998 (08.10.98)
(21) International Application Number: PCT/US98/05711 (22) International Filing Date: 24 March 1998 (24.03.98) (30) Priority Data: 08/827,543 28 March 1997 (28.03.97) US (71) Applicant: DIGI INTERNATIONAL [US/US]; 11001 Bren Road East, Minnetonka, MN 55343 (US). (72) Inventor: SANDERSON, Lelon, W.; 55 Spray Road, Fayetteville, TN 37334 (US). (74) Agent: BRUESS, Steven, C.; Merchant, Gould, Smith, Edell, Welter & Schmidt, P.A., 3100 Norwest Center, 90 South Seventh Street, Minneapolis, MN 55402-4131 (US).		(81) Designated States: AL, AM, AT, AT (Utility model), AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, CZ (Utility model), DE, DE (Utility model), DK, DK (Utility model), EE, EE (Utility model), ES, FI, FI (Utility model), GB, GE, GH, GM, GW, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SK (Utility model), SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG). Published <i>Without international search report and to be republished upon receipt of that report.</i>
(54) Title: SUBSCRIBER LOOP EXTENSION SYSTEM FOR ISDN BASIC RATE INTERFACES (57) Abstract A system and method for reducing signal attenuation of integrated services digital network (ISDN) digital transmissions at the subscriber loop, thereby increasing the available subscriber loop range, is provided. An ISDN digital transmission system is used for transmitting and receiving digital information via a line termination at a central office. Customer premises equipment is coupled to a network termination (NT-1) within the customer premises, which is in turn coupled to interface the line termination at the central office. A plurality of inductive load coils are coupled in series with the two-wire subscriber loop ISDN BRI at predetermined distance intervals, which are calibrated to resonate the two-wire bus.		

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakhstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

SUBSCRIBER LOOP EXTENSION SYSTEM FOR ISDN BASIC RATE INTERFACES

FIELD OF THE INVENTION

5 The present invention relates generally to digital telecommunications, and more particularly, to a system and method for reducing signal attenuation of integrated services digital network (ISDN) digital transmissions at the subscriber loop.

BACKGROUND OF THE INVENTION

10 The introduction of digital communications into the telephone network has greatly increased the available signal bandwidth. A corresponding reduction in the amount of cable required to carry a number of telephone conversations carried by analog telephony methods was also realized. The massive
15 increase in the reliance and demand of telephone systems in today's society has driven the need for this reduction in cable and increased signal bandwidth.

 A number of different technologies have been devised to facilitate the advance of digital communications. Various signaling technologies have used frequency division multiplexing (FDM) to segment the available bandwidth.
20 Separate signals are carried in each segment using digital signaling derived through a digital representation of an analog waveform. Time-division multiplexing (TDM) has been used with T-1 and other transmission facilities, where each of a multiplicity of channels gets an interleaved time segment in order that all of the channels share the transmission medium equally.

25 A relatively newer and emerging field of telecommunications is the integrated services digital network (ISDN), which is a standard established by the International Telecommunications Union-Telecommunications (ITU-T-T) Standardization Sector. ISDN integrates computer and communications technologies to provide a common, worldwide, digital network. ISDN telephone
30 lines use digital communications protocols allowing digital connections at up to 128 Kbps and as many as three separate conversations at the same time through the same line as the twisted-pair copper telephone line that traditionally carried only one voice, or one computer/fax communication.

There are two basic types of ISDN service. Primary rate interface (PRI) is intended for users with large bandwidth capacity requirements and provides up to 23 64-Kbps data channels (B-channels) and 1 64-Kbps signaling channel (D-channel) in the U.S. Basic rate interface (BRI) consists of 2 64-Kbps B-channels and 1 16-Kbps D-channel for a total of 144 Kbps. This basic service is intended to meet the needs of most individual users.

One of the limiting factors in the deployment of the basic rate ISDN digital subscriber line is that the standard physical layer transceivers have a maximum loop reach of 18,000 feet of AWG26 cable. This is due to the attenuation of the signal strength over a distance caused by the electrical properties of the line itself, including the resistance, capacitance, inductance, and leakage conductance. Due to subscriber loop reach limitations, either additional subscriber loops are required to reach more remote subscribers, or repeaters are necessary.

Analog telephony transmission systems faced subscriber loop problems, as it was discovered that voice signals would travel with reduced loss, and with greater fidelity, if the distributed inductance of the line was increased without adversely changing the other distributed circuit coefficients. A practical alternative used in lieu of tackling the difficult process of increasing the uniformly distributed inductance of a line was to insert lumped inductance coils at various intervals along the line. Loop design balanced cost against transmission quality, and loading permitted the economy, in long telephone lines, of using smaller gauge copper wires than would otherwise have been needed to give the same electrical efficiency and quality of transmission.

Digital communications, however, has transmission characteristics different from those of existing analog telephony. This difference has resulted in a generally implemented ISDN communications installation procedure across the existing twisted-pair telephone wires, including removing all load coils from the line as basic rate ISDN service is installed. As previously indicated, BRI ISDN local loops are currently limited to a maximum loop reach of approximately 18,000 feet of AWG26 cable, which results in a large number of subscribers who are not accessible within the normal local subscriber loop.

One solution currently implemented in digital transmission lines is the use of repeater amplifiers in the long subscriber loops. Repeater amplifiers, however, are implemented at a cost of thousands of dollars per line. Furthermore, repeater amplifiers include active electronic devices, which decreases the field reliability of service and increases the cost of service maintenance. Another approach to lengthen the subscriber loop involves the use of non-standard transceivers at each end of the long loop, resulting in yet another costly installation.

Accordingly, there is a need in the digital communications industry for a transmission arrangement to increase the maximum subscriber loop reach which is inexpensive, easy to implement, and reliable. The present invention provides a system and method for reducing the loop loss on digital subscriber loops having component costs of only tens of dollars per subscriber line. Therefore, the present invention provides a low cost and reliable solution for reaching approximately 95 percent or more of potential digital communications customers without the use of active electronics coupled to the subscriber line. The present invention overcomes the aforementioned problems, and provides these and other advantages over the prior art.

SUMMARY OF THE INVENTION

The present invention is directed to a system and method for reducing signal attenuation of integrated services digital network (ISDN) digital transmissions at the subscriber loop, thereby increasing the available subscriber loop range.

In accordance with one embodiment of the invention, the present invention provides a integrated services digital network (ISDN) digital transmission system for transmitting and receiving digital information via a line termination at a central office. A customer premises having a plurality of terminal equipment devices is coupled to a first interface bus, and a network termination (NT-1) is coupled to the first interface bus within the customer premises. An ISDN interface is coupled to interface the line termination and the network termination (NT-1). The ISDN interface includes a two-wire bus, having a first connection for transmitting B-channel data of the ISDN interface, and a second connection for transmitting D-channel data of the ISDN interface. A plurality of inductive load coils are coupled

in series with the first and second connections at predetermined distance intervals, which are calibrated to resonate the two-wire bus.

In accordance with another embodiment of the invention, a method for reducing signal attenuation on an integrated services digital network (ISDN) connection provided through a basic rate interface (BRI) is provided. Digital information is transmitted across a local loop of the ISDN connection linking a customer premises and a central office. The digital information is passed through one or more localized inductors which together approximate a distributed inductance. The localized inductors are calibrated to provide a distributed inductance which causes the ISDN connection at the local loop to resonate.

The above summary of the present invention is not intended to describe each illustrated embodiment or implementation of the present invention. This is the purpose of the figures and the associated discussion which follows.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of an ISDN environment to which the present invention applies;

FIG. 2 illustrates the basic rate interface (BRI) as defined by the Telecommunications Standards Sector of the International Telecommunications Union;

FIG. 3 is a general diagram of an inductance load coil in accordance with one embodiment of the present invention;

FIG. 4 is a more detailed embodiment of a U-interface in a digital telecommunications subscriber loop;

FIG. 5 is a graphical diagram illustrating the variance of the insertion loss of the cable with respect to frequency for a fixed length of AWG26 cable;

FIG. 6 illustrates another graphical example of the variance of the insertion loss of the cable with respect to frequency for a fixed length of AWG24 cable; and

FIG. 7 is a graphical diagram illustrating the insertion loss versus frequency for a range of inductance load coil values for AWG24 cable in accordance with one embodiment of the present invention.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

Figure 1 is a block diagram of an ISDN environment **100** in which the present invention applies. ISDN lines use digital, rather than analog, communications protocols. Within the customer premises **102** are various ISDN and non-ISDN terminal equipment devices. For example, an analog fax **104** and telephone **106** at the customer premises **102** are examples of communications devices at the customer premises **102** that are not ISDN-compatible. Such devices are coupled to a terminal adapter **108** which provides the ISDN interface at its output and an interface to the non-ISDN equipment at its input side.

ISDN-compatible equipment, referred to as terminal equipment (TE) includes, for example, computing device **110** as well as other ISDN-compatible user devices **112**. The terminal equipment **110**, **112**, and the ISDN-compatible output of the terminal adapter **108**, is provided to the network termination 1 (NT-1) **114** via the S/T interface **116**. ISDN terminal equipment devices, such as computing device **110** and user device **112**, are typically coupled to the network termination NT-1 **114** through a network termination 2 (NT-2) which provides additional services, such as switching or data multiplexing at the customer premises **102**. The S/T interface **116** is a 4-wire ISDN interface which can support multiple devices, and is a full-duplex interface including a pair of wires for received data, and a pair of wires for transmit data.

The NT-1 **114** is basically a termination between the customer and the service provider, which converts the 2-wire U-interface **118** at the local loop **120**. The NT-1 **114** can also provide status as to the condition of the ISDN line connection, as well as network performance and integrity checks. The local loop **120** includes the 2-wire U-interface **118** that interconnects network termination NT-1 **114** and a loop termination (LT) **122** at the central office **124**. The connection to other switches within the network, illustrated as the exchange switching equipment **126**, is referred to as the exchange termination function and occurs via the V-interface **128**.

The U-interface **118** provides the interface between the central office **124** and the various customer premises **102**. This connection typically runs under

streets, or on telephone poles, into homes and businesses along the local subscriber loop **120**. The U-interface has been implemented to be operable on the existing twisted-pair telephone network lines, and is designed to reach over relatively long distances between the central office **124** and the customer premises **102**. All ISDN voice and data communications are coded into a single binary stream including pairs of bits expressed as 1 of 4 voltage levels, referred to as the 2B1Q line coding scheme. This scheme allows the interface to perform relatively well over distances up to approximately 18,000 feet. The present invention, however, allows the reach of the U-interface **118** at the local loop **120** to be increased, while maintaining the integrity of the information traversing the line.

Figure 2 illustrates the basic rate interface (BRI) as defined by the Telecommunications Standards Sector of the International Telecommunications Union. BRI is defined as 2 64-Kbps bearer (B) channels **200**, and 1 16-Kbps data (D) channel **202**, often referred to as a 2B+D connection. The B channels **200** transmit user information such as voice and data information, while the D channel **202** provides control and signaling information such as the ISDN exchange with the number of the party to call. Therefore, a single BRI can carry two simultaneous voice or data conversations to the same or different locations, or can be combined for transmitting information at double the bandwidth.

In order to increase the distance at which the U-interface **118** can reach from the central office **124**, the present invention reduces the attenuation on the U-interface **118** at the local loop **120** by providing circuitry which resonates the line at an approximate center of the spectrum for the BRI standard transceivers, which is approximately 40 KHz. The resonate frequency can be realized through the use of a circuit which balances the inductive and capacitive reactance components of the line, resulting in an input impedance of the network which is purely resistive, and the voltage and current at the network input terminals are in phase. The present invention enables the existing BRI ISDN equipment to communicate at up to 30,000 feet using AWG24 cable. Analogously, communication is greatly increased for other cable gauges as well.

Referring now to FIG. 3, an inductance load coil **300** in accordance with one embodiment of the present invention is illustrated. The load coil **300**

represents a lumped inductance, shown as a toroidal inductor formed by providing conductor windings on an conductive core, which simulates a distributed inductance over the U-interface **118**. The load coil **300** is interleaved into the U-interface **118** in order to resonate the line thereby reducing the attenuation on the U-interface **118**.

- 5 As will be described below, this allows the local subscriber loop **120** to be increased while maintaining the integrity of the transmitted digital information.

Referring now to FIG. 4, a more specific embodiment of a U-interface **400** is provided. The U-interface **400** is a 2-wire interface including lines **400a** and **400b**. A plurality of load coils **402**, **404**, and **406** on line **400a**, and a
 10 plurality of load coils **408**, **410** and **412** on line **400b** comprise the inductance loading of the ISDN interface **400** illustrated in FIG. 4. The load coils on each line are in series, separated by a distance *d* represented by dimension lines **414** and **416**. It should be recognized that a greater or lesser number of inductance load coils can be used on lines **400a** and **400b**, as will become readily apparent in accordance with
 15 the following description.

The twisted-pair U-interface **400** has inherent distributed transmission line parameters for wires having certain physical and electrical characteristics. For example, the standard copper wire used for the U-interface **400** can be calculated depending on the diameter of the wire used. This is based on the
 20 resistance, inductance, capacitance and conductance per mile for each of the standard wire gages at various temperatures and frequencies. The load coils **402-412** act to resonate with the distributed capacitance on the transmission line to provide a low pass filter effect. The resonant frequency is inversely proportional to the square root of the inductance times the capacitance as shown in equation 1 below:

25

$$f_R = \frac{1}{2\pi \sqrt{(L \times C)}} \quad [\text{Eq. 1}]$$

where f_R is the resonant frequency;

L is the inductance of the line; and

C is the capacitance of the line.

30

The approximate center of the frequency spectrum for a 2B1Q signal for BRI standard transceivers is approximately 40 KHz. Other modulated signaling schemes, such as Quadrature Amplitude Modulation (QAM), which occupy a similar signal spectrum may be similarly benefited by the digital signal inductance loading scheme as described herein.

Using Equation 1 above, and targeting a 40 KHz resonant frequency, a resulting inductance of approximately 820 microhenries for the load coils **402-412**, separated by a distance d of 3,000 feet, is calculated. The capacitive effect is generated by the cable pairs themselves, which act as large capacitors that attenuate signals as the frequency rises. Transmission line equations and computer simulations were used in connection with Equation 1 to determine a preferable range of inductance values particularly suited for the desired ISDN local loop extensions. In one embodiment of the invention, a range of preferable inductances for an approximate 40 KHz resonant frequency for load coils separated by approximately 3,000 feet is 680 microhenries to 1000 microhenries, as will be illustrated in the following diagrams.

Referring now to FIG. 5, a graphical diagram illustrating the variance of the insertion loss of the cable with respect to frequency for a fixed length of cable is provided. Figure 5 represents a plot of the insertion loss (IL) of the cable in dBs versus the frequency for a fixed length of cable, namely, an AWG26 cable in this example. Inductance load coils **300** having an approximate value of 820 microhenries were placed at approximately 3,000 feet spacings, which resulted in characteristics depicted by FIG. 5. Figure 5 illustrates how the gain versus frequency is increased near 40 KHz when load coils of the appropriate values are applied to the cable. As can be seen by the distance depicted on line **500** between the original waveform **502** and the loaded waveform **504**, for 18,000 feet of AWG26 cable, loop attenuation is decreased by approximately 9 dB near the 40 kHz range.

Figure 6 illustrates another graphical example of the variance of the insertion loss of the cable with respect to frequency for a fixed length of cable. Figure 6 represents a plot of the insertion loss (IL) of the cable versus the frequency for a fixed length of AWG24 cable. The local loop reach in this example is extended from approximately 22,000 feet to approximately 30,000 feet, resulting from a

decrease in loop attenuation of approximately 15dB near 40 Khz. This decrease can be seen by the distance depicted on line **600** between the original waveform **602** and the loaded waveform **604**.

Figure 7 is a graphical diagram illustrating the insertion loss versus frequency for a range of inductance load coil values for AWG24 cable in accordance with one embodiment of the present invention. Waveform **700** represents the signal corresponding to a line loaded with 820 microhenries of inductance at 3,000 feet spacings. Waveform **702** illustrates how the resonant frequency is decreased as the load inductance increases, as waveform **702** corresponds to a line loaded with 1000 microhenries of inductance at 3,000 feet spacings. Analogously, waveform **704** illustrates how the resonant frequency increases as the load inductance decreases, as waveform **704** corresponds to a line loaded with 680 microhenries of inductance at 3,000 feet spacings. This illustrates the variance of insertion loss using different inductance loading values.

It will, of course, be understood that various modifications and additions can be made to the preferred embodiments discussed hereinabove without departing from the scope or spirit of the present invention. Accordingly, the scope of the present invention should not be limited by the particular embodiments discussed above, but should be defined only by the claims set forth below and equivalents thereof.

CLAIMS

What is claimed is:

1. An integrated services digital network (ISDN) digital transmission system for transmitting and receiving digital information via a line termination at a central office, comprising:
 - (a) a customer premises having a plurality of terminal equipment devices coupled to a first interface bus;
 - (b) a network termination (NT-1), coupled to the first interface bus within the customer premises;
 - (c) an ISDN interface coupled to interface the line termination and the network termination (NT-1), comprising:
 - (1) a two-wire bus, having a first connection for transmitting B-channel data of the ISDN interface, and a second connection for transmitting D-channel data of the ISDN interface; and
 - (2) a plurality of inductive load coils coupled in series with the first and second connections at predetermined distance intervals.
2. The ISDN digital information transmission system as in Claim 1, wherein the inductive load coils comprise toroidal inductors formed via conductor windings on a conductive core.
3. The ISDN digital information transmission system as in Claim 1, wherein the inductive load coils comprise inductors having a value in the approximate range of 680 microhenries to 1000 microhenries.
4. The ISDN digital information transmission system as in Claim 1, wherein the predetermined distance intervals are each approximately 3000 feet.
5. The ISDN digital information transmission system as in Claim 1, wherein all of the predetermined distance intervals include distances of approximately the same value.

6. The ISDN digital information transmission system as in Claim 1, wherein the inductive load coils comprise inductors having a value of approximately 820 microhenries, and wherein the predetermined distance intervals are each approximately 3000 feet.

7. The ISDN digital information transmission system as in Claim 1, wherein an inductance value of the inductance load coils and the predetermined distance intervals are selected so as to resonate the two-wire bus at a frequency approximately centered on a frequency spectrum for 2B1Q signaling for an ISDN basic rate interface.

8. The ISDN digital information transmission system as in Claim 1, wherein an inductance value of the inductance load coils and the predetermined distance intervals are selected so as to resonate the two-wire bus at a frequency of approximately 40,000 Hz.

9. The ISDN digital information transmission system as in Claim 1, wherein the plurality of inductive load coils comprises:

- (a) first inductive load coils coupled in series to the first connection at predetermined distance intervals; and
- (b) second inductive load coils coupled in series to the second connection at the predetermined distance intervals.

10. The ISDN digital information transmission system as in Claim 1, wherein the plurality of inductive load coils comprises a plurality of dual-input/dual-output load coils each coupled to both of the first and second connections at common locations along the two-wire bus.

11. The ISDN digital information transmission system as in Claim 1, wherein the customer premises further comprises:

- (a) a plurality of analog communication devices;

(b) a terminal adapter, coupled to receive analog communications signals from the analog communication devices and to provide digital signals to the first interface bus in response thereto.

12. The ISDN digital information transmission system as in Claim 1, wherein the first interface bus comprises a four-wire S/T interface.

13. The ISDN digital information transmission system as in Claim 1, wherein the first and second connections of the two-wire bus comprise twisted pair copper conductors selected from the group comprising: 26-gauge wire, 24-gauge wire, 22-gauge wire, 20-gauge wire, and 19-gauge wire.

14. The ISDN digital information transmission system as in Claim 1, wherein the ISDN interface comprises a basic rate interface (BRI) having two B-channels of data and one D-channel of data.

15. A method for reducing signal attenuation on an integrated services digital network (ISDN) connection provided through a basic rate interface (BRI), comprising:

transmitting digital information across a local loop of the ISDN connection linking a customer premises and a central office;

passing the digital information through one or more localized inductors together approximating a distributed inductance; and

calibrating the localized inductors to provide a distributed inductance to cause the ISDN connection at the local loop to resonate.

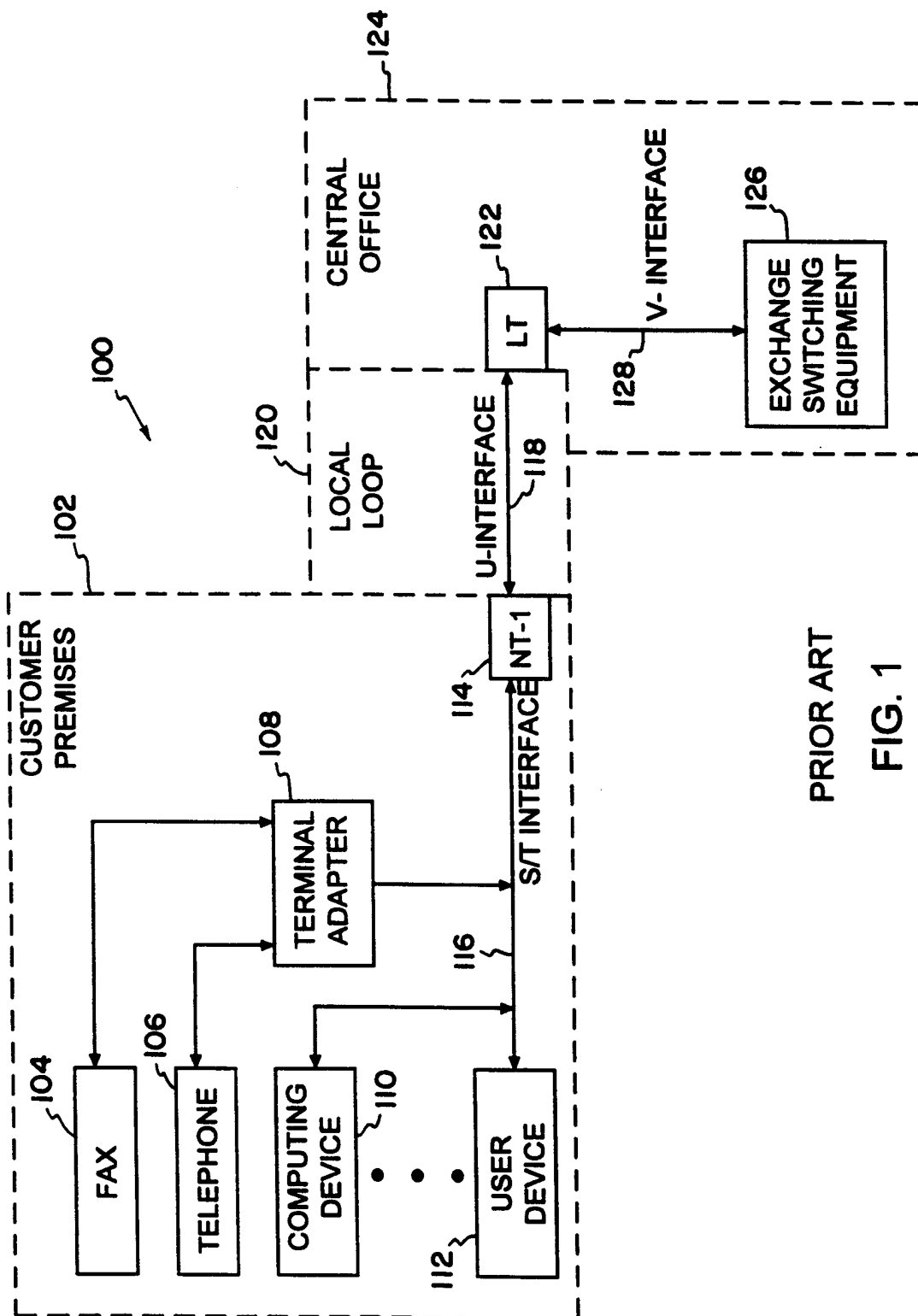
16. A method for reducing signal attenuation on a digital network architecture, comprising:

transmitting digital information across a local loop of the digital network architecture linking a customer premises and a central telephony office;

modulating the digital information at a frequency substantially equivalent to a center of a frequency spectrum for digital transmitters/receivers communicating the digital information;

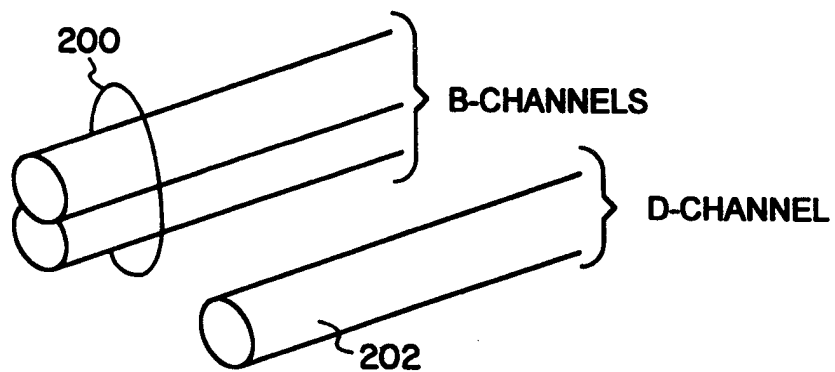
transferring the digital information through one or more localized inductors which together approximate a distributed inductance; and

calibrating the localized inductors to provide a distributed inductance to resonate lines on a local loop between the customer premises and the central telephony office at the frequency corresponding to the center of a frequency spectrum.



PRIOR ART
FIG. 1

BASIC RATE INTERFACE



PRIOR ART

FIG. 2

3/6

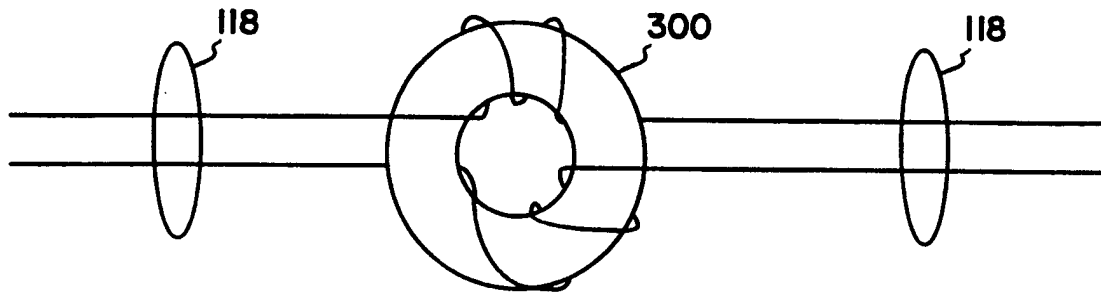


FIG. 3

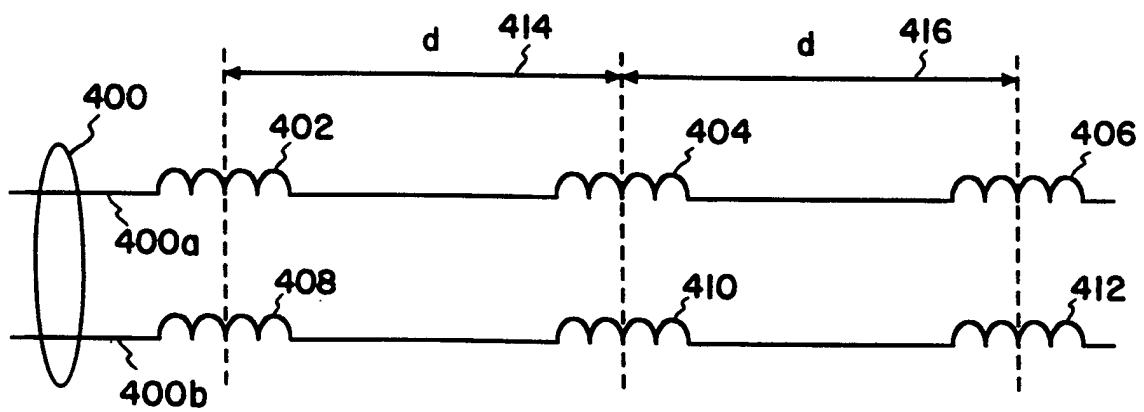
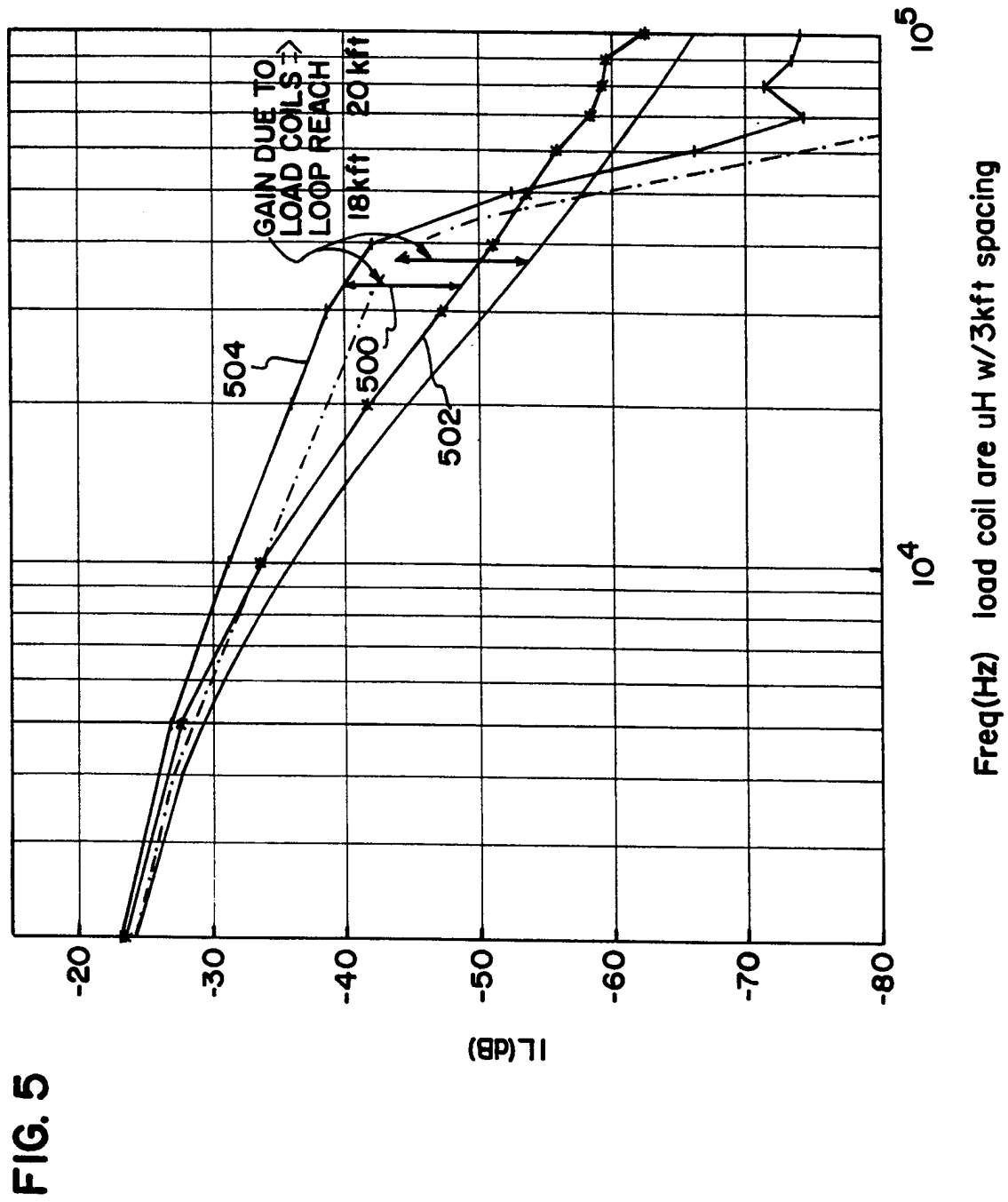
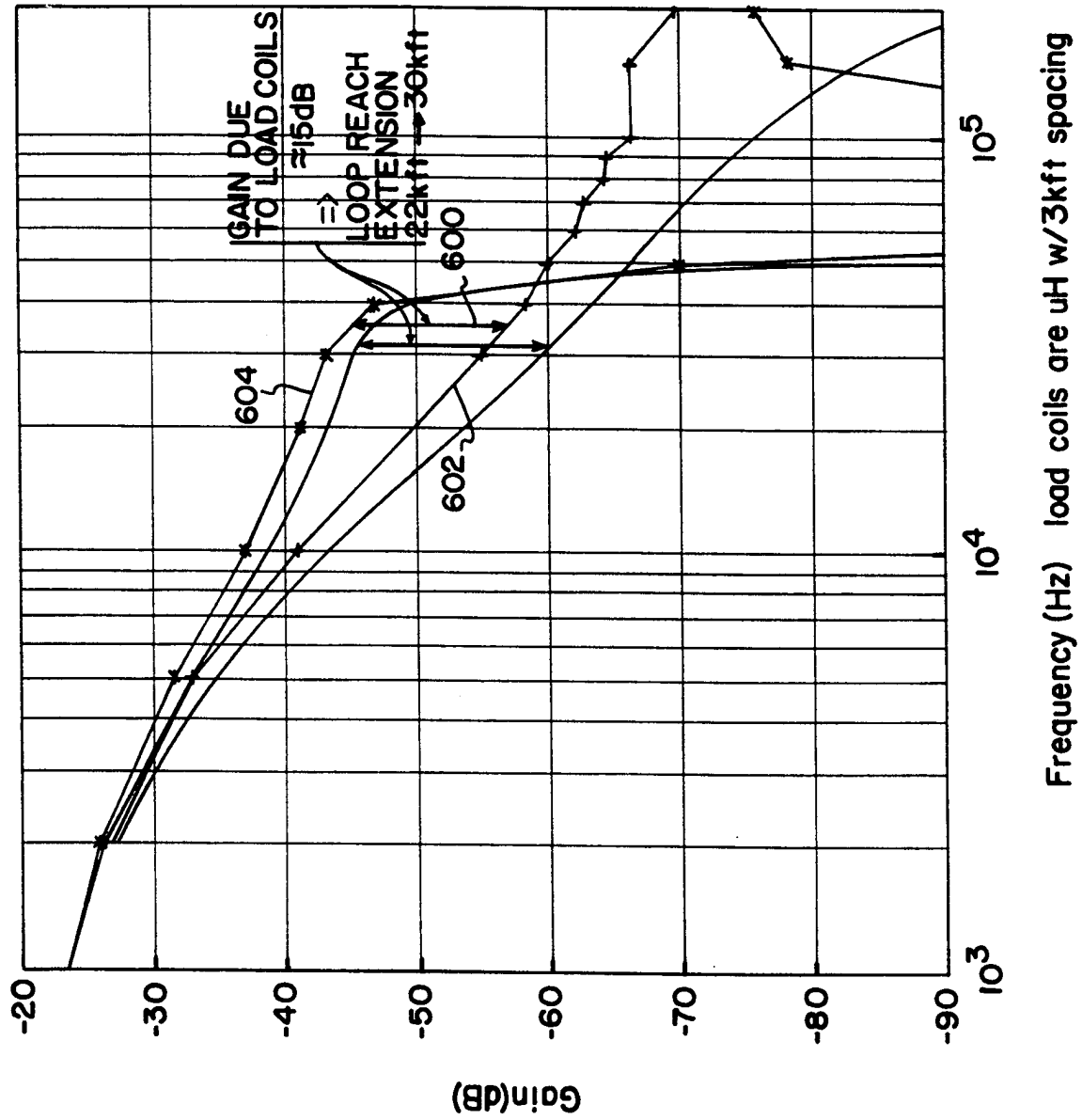


FIG. 4





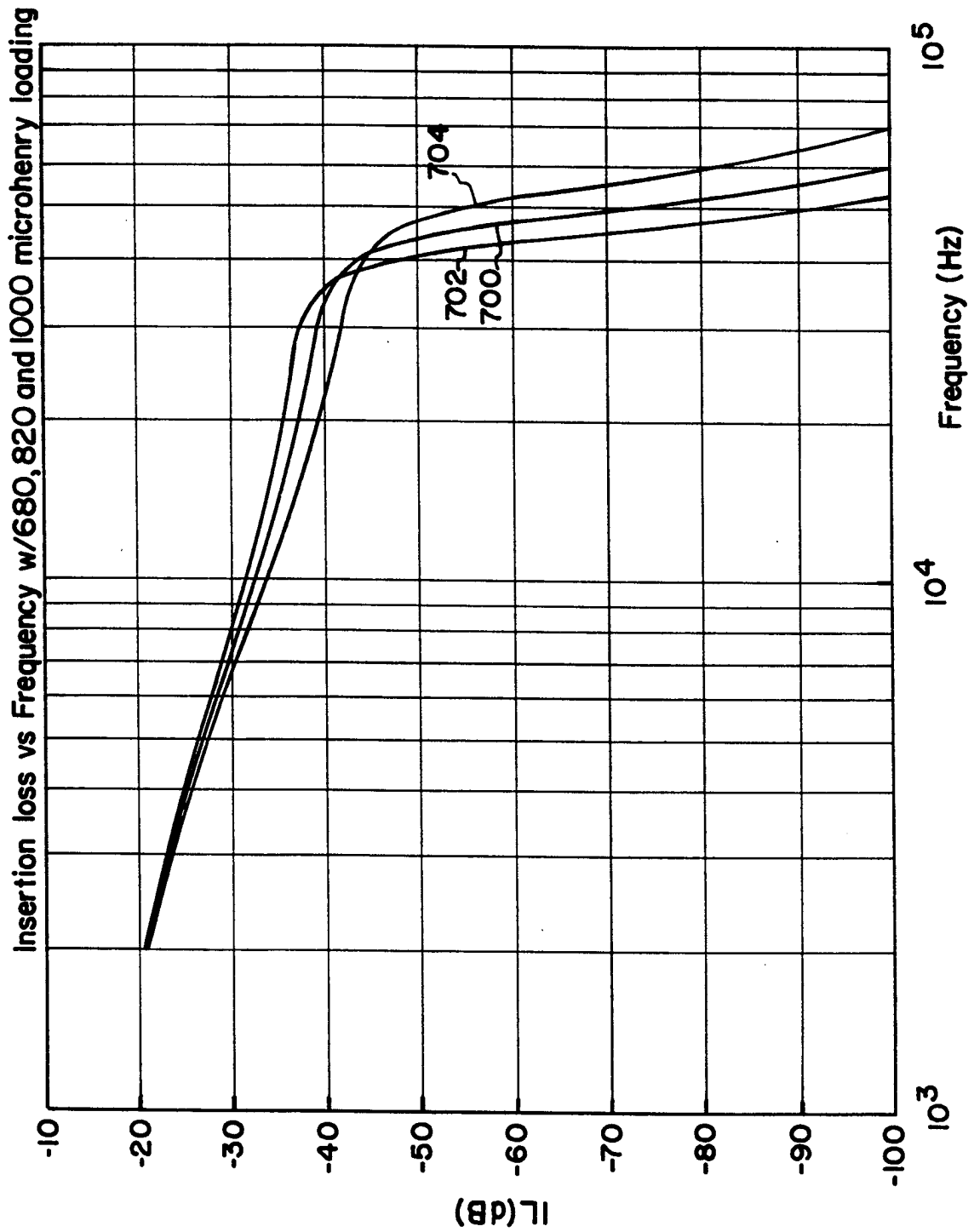


FIG. 7