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Williams

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(54) **DIGITAL SILENCE FOR A PCM DATA COMMUNICATION SYSTEM**

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(22) Filed: **Jan. 29, 1999**

(57) **ABSTRACT**

Related U.S. Application Data

(60) Provisional application No. 60/073,109, filed on Jan. 30, 1998.

A method of transmitting a quite, or zero, signal in a PCM communication system. The zero signal is specified universally in ordered set terms for either μ -Law or A-Law PCM systems, which has minimal energy in the A-Law system, and contains no energy within the μ -Law system. The signal is preferably specified as a repetition of six intervals (or multiple thereof) because the DTN can modify PCM codes on a six interval period by the robbed-bit signaling mechanism. The zero signal may be used to detect network elements that produce single-signed zero outputs from zero inputs of either sign. In addition, by examination of the zero signal the receiver may determine whether the channel includes an analog link or connection.

(51) **Int. Cl.**⁷ **H04B 14/04**

(52) **U.S. Cl.** **375/242**

(58) **Field of Search** 375/242, 241, 375/243, 254, 285; 370/522, 523, 524

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12 Claims, 6 Drawing Sheets

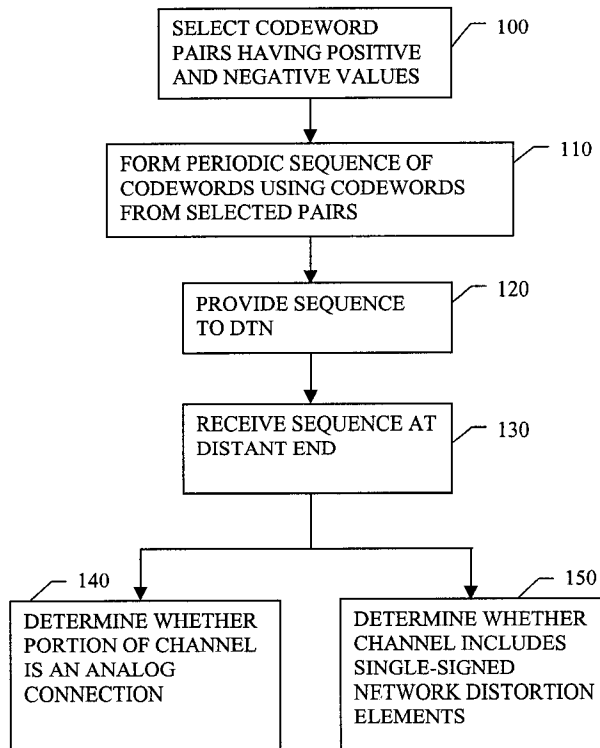


FIG. 1
PRIOR ART

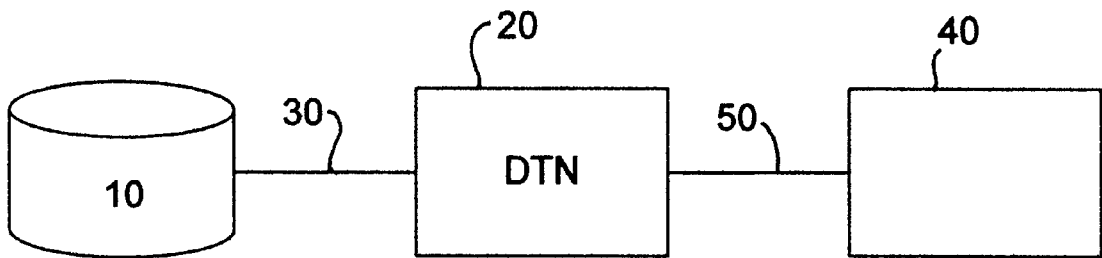


FIG. 4
PRIOR ART

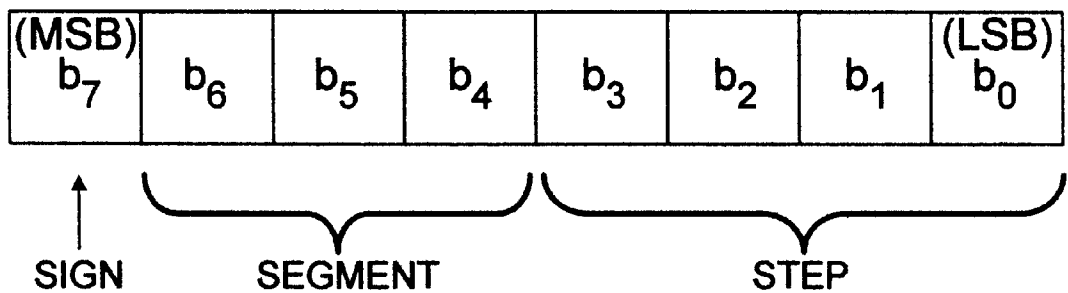


FIG. 2A

PRIOR ART

Ucode	μ -law PCM	μ -law linear	A-law PCM	A-law linear
0	FF	0	D5	8
1	FE	8	D4	24
2	FD	16	D7	40
3	FC	24	D6	56
4	FB	32	D1	72
5	FA	40	D0	88
6	F9	48	D3	104
7	F8	56	D2	120
8	F7	64	DD	136
9	F6	72	DC	152
10	F5	80	DF	168
11	F4	88	DE	184
12	F3	96	D9	200
13	F2	104	D8	216
14	F1	112	DB	232
15	F0	120	DA	248
16	EF	132	C5	264
17	EE	148	C4	280
18	ED	164	C7	296
19	EC	180	C6	312
20	EB	196	C1	328
21	EA	212	C0	344
22	E9	228	C3	360
23	E8	244	C2	376
24	E7	260	CD	392
25	E6	276	CC	408
26	E5	292	CF	424
27	E4	308	CE	440
28	E3	324	C9	456
29	E2	340	C8	472
30	E1	356	CB	488
31	E0	372	CA	504
32	DF	396	F5	528
33	DE	428	F4	560
34	DD	460	F7	592
35	DC	492	F6	624
36	DB	524	F1	656
37	DA	556	F0	688
38	D9	588	F3	720
39	D8	620	F2	752
40	D7	652	FD	784
41	D6	684	FC	816
42	D5	716	FF	848

FIG. 2B
PRIOR ART

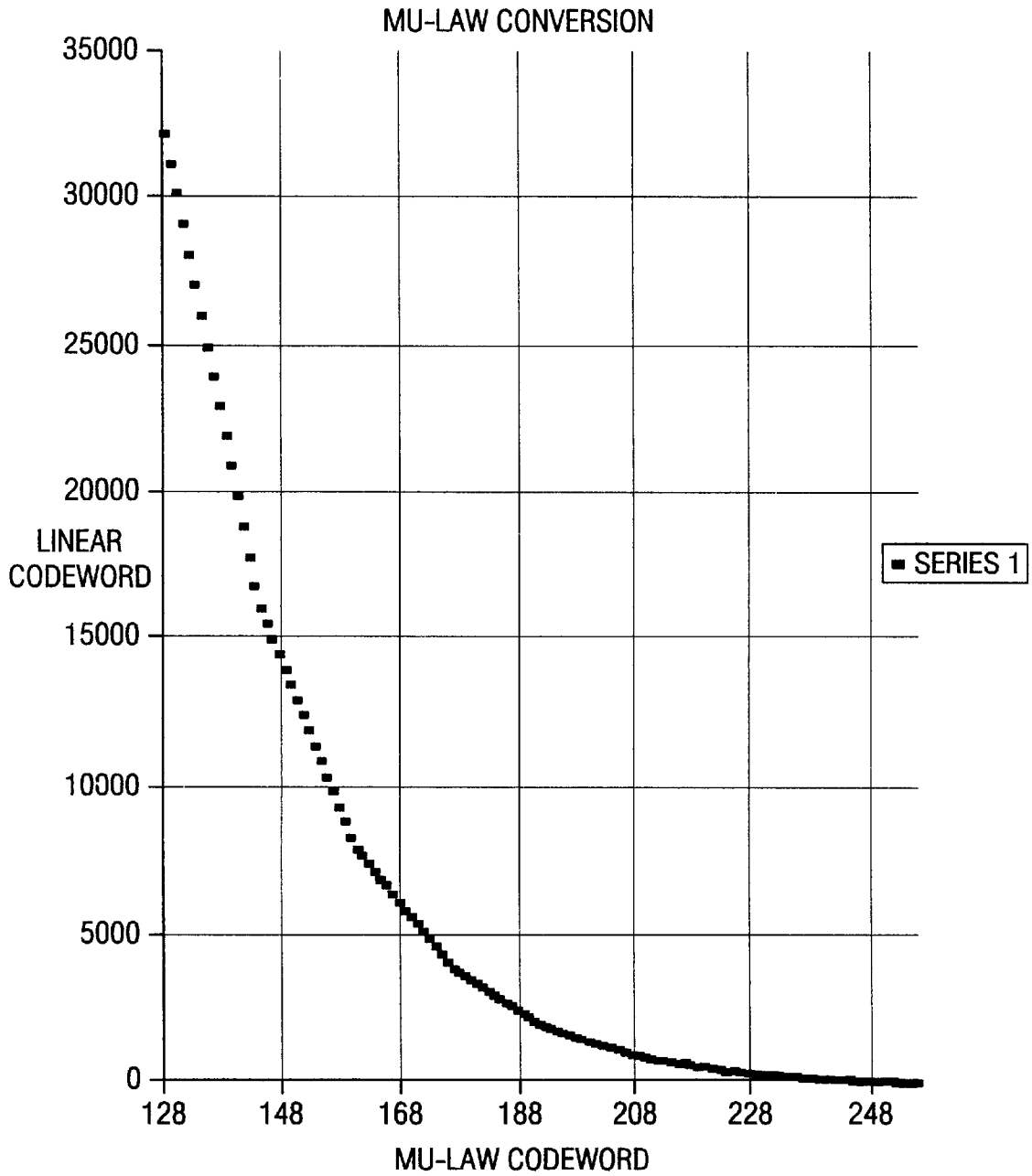
Ucode	μ -law PCM	μ -law linear	A-law PCM	A-law linear
43	D4	748	FE	880
44	D3	780	F9	912
45	D2	812	F8	944
46	D1	844	FB	976
47	D0	876	FA	1008
48	CF	924	E5	1056
49	CE	988	E4	1120
50	CD	1052	E7	1184
51	CC	1116	E6	1248
52	CB	1180	E1	1312
53	CA	1244	E0	1376
54	C9	1308	E3	1440
55	C8	1372	E2	1504
56	C7	1436	ED	1568
57	C6	1500	EC	1632
58	C5	1564	EF	1696
59	C4	1628	EE	1760
60	C3	1692	E9	1824
61	C2	1756	E8	1888
62	C1	1820	EB	1952
63	C0	1884	EA	2016
64	BF	1980	95	2112
65	BE	2108	94	2240
66	BD	2236	97	2368
67	BC	2364	96	2496
68	BB	2492	91	2624
69	BA	2620	90	2752
70	B9	2748	93	2880
71	B8	2876	92	3008
72	B7	3004	9D	3136
73	B6	3132	9C	3264
74	B5	3260	9F	3392
75	B4	3388	9E	3520
76	B3	3516	99	3648
77	B2	3644	98	3776
78	B1	3772	9B	3904
79	B0	3900	9A	4032
80	AF	4092	85	4224
81	AE	4348	84	4480
82	AD	4604	87	4736
83	AC	4860	86	4992
84	AB	5116	81	5248
85	AA	5372	80	5504

FIG. 2C
PRIOR ART

Ucode	μ -law PCM	μ -law linear	A-law PCM	A-law linear
86	A9	5628	83	5760
87	A8	5884	82	6016
88	A7	6140	8D	6272
89	A6	6396	8C	6528
90	A5	6652	8F	6784
91	A4	6908	8E	7040
92	A3	7164	89	7296
93	A2	7420	88	7552
94	A1	7676	8B	7808
95	A0	7932	8A	8064
96	9F	8316	B5	8448
97	9E	8828	B4	8960
98	9D	9340	B7	9472
99	9C	9852	B6	9984
100	9B	10364	B1	10496
101	9A	10876	B0	11008
102	99	11388	B3	11520
103	98	11900	B2	12032
104	97	12412	BD	12544
105	96	12924	BC	13056
106	95	13436	BF	13568
107	95	13948	BE	14080
108	93	14460	B9	14592
109	92	14972	B8	15104
110	91	15484	BB	15616
111	90	15996	BA	16128
112	8F	16764	A5	16896
113	8E	17788	A4	17920
114	8D	18812	A7	18944
115	8C	19836	A6	19968
116	8B	20860	A1	20992
117	8A	21884	A0	22016
118	89	22908	A3	23040
119	88	23932	A2	24064
120	87	24956	AD	25088
121	86	25980	AC	26112
122	85	27004	AF	27136
123	84	28028	AE	28160
124	83	29052	A9	29184
125	82	30076	A8	30208
126	81	31100	AB	31232
127	80	32124	AA	32256

FIG. 3

PRIOR ART



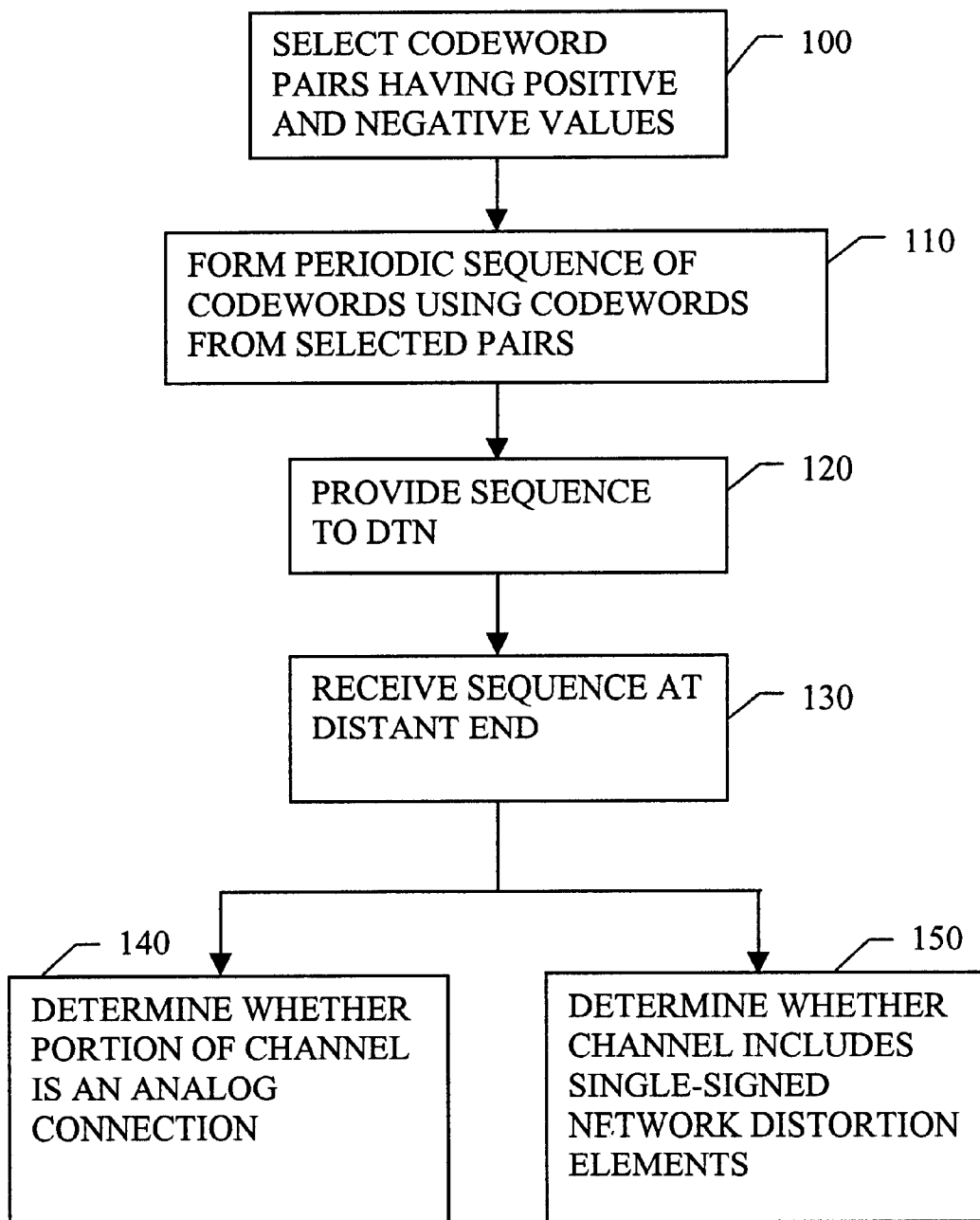


Fig. 5

DIGITAL SILENCE FOR A PCM DATA COMMUNICATION SYSTEM

RELATED APPLICATION

This application claims the benefit under 35 U.S.C. §119 (e) of U.S. Provisional Patent Application Serial No. 60/073,109, filed Jan. 30, 1998, entitled "Digital Silence for a PCM Data Communication System" for all common subject matter disclosed therein.

BACKGROUND OF THE INVENTION

The present invention relates to a method for generating and transmitting "silence" for use in a Pulse Code Modulation (PCM) data communication system. The communication system of particular interest herein uses the public digital telephone network (DTN) to transmit data directly from a digital source to a remote unit, where the remote unit is connected to the DTN either digitally or via an analog local loop. Within this PCM data communication system it is desirable to utilize a "zero" signal. The signaling method described herein a method of forming and transmitting a zero signal, and is compatible with both the μ -Law and A-Law PCM coding, and minimizes the impact of coding differences between the two PCM coding systems.

Presently, typical modems used to communicate over the public telephone system represent binary data by an analog waveform that is modulated in response to the binary data. As an example, one such standard for modem communications is detailed in the International Telecommunication Union, Telecommunication Standardization Sector ("ITU-T") Recommendation V.34 (1994). The waveform is in turn analyzed at a receiving modem to recover the binary data. For modem signals transmitted over the public telephone system, the analog waveforms are treated by central office facilities in the same manner as if the waveforms were analog voice signals. In other words, the waveforms are digitized into eight bit octets by an analog to digital converter (ADC) codec at the central office, and the octets are transmitted in digital format between central offices until they are converted back to an analog signal by a digital to analog converter (DAC) codec at the central office that is connected to the receiving subscriber loop. The public switched telephone network has operated in this manner for many years.

The data rate attainable by a modem operating in such an environment is limited by numerous factors including, in particular, the codec sample rate and the number and spacing of quantization levels of the codec converters at the central office switches. The effect on an analog signal associated with sampling the signal amplitude and representing the sample by one of a finite number of discrete (digital) values is generally referred to as quantization noise. Most telephone switches utilize voice codecs that perform nonlinear A/D and D/A conversions known as μ -law or A-law conversion. In these conversion formats, the 8-bit codec codewords, also referred to as octets, represent analog voltages that are nonlinearly spaced. This type of conversion performs well for voice signals intended for a human listener (especially when transmitted over a noisy line), but have a negative impact on modulated analog waveforms associated with modems. Specifically, codecs that adhere to these standard nonlinear conversion formats use nonlinearly spaced quantization levels, and have the effect of increasing quantization noise which is detrimental to modulated analog waveforms.

Until recently, it was thought that the maximum attainable data rate for signals passing through the DTN was limited by

the quantization noise associated with the codecs. However, it has been recognized that a data distribution system can overcome certain aspects of the aforesaid limitations by providing a digital data source connected directly to the DTN, without any intervening ADC or DAC. In such a system, the telephone network routes digital signals from the data source to the client's local subscriber loop without any intermediary analog facilities, such that the only analog portion of the link from server to client is the client's local loop (plus the associated analog electronics at both ends of the loop). The only DAC in the transmission path is the one at the Telephone Company's end of the client's subscriber loop. In such a system digital data can be converted into PCM codes, and fed to the DTN as 8-bit bytes (octets) at the network's clock rate of 8 kHz. At the distant end, the DTN's DAC converts each byte to one of 255 analog voltage levels in a system utilizing μ -law encoding (or 256 levels in an A-law system), which is sent over the client's subscriber loop and received by a subscriber device (i.e., a modem) at the client's location.

FIG. 1 shows a block diagram of a PCM data distribution system. The system includes a data source **10**, or server, having a direct digital connection **30** to a digital telephone network (DTN) **20**. A client **40** is connected to the DTN **30** by a subscriber loop **50** that is typically a two-wire, or twisted-pair, cable. The DTN routes digital signals from the data source **10** to the client's local subscriber loop without any intermediary analog facilities such that the only analog portion of the link from the server to the client is the client's local loop **50**. The analog portion thus includes the channel characteristics of the local loop transmission line plus the associated analog electronics at both ends of the line. This typically includes a subscriber line interface card at the central office that includes a codec, as well as circuitry used to generate and interpret call progress signals (ring voltage, on-hook and off-hook detection, etc.). The only D/A converter in the transmission path from the server to the client is the one at the DTN end of the client's subscriber loop. It is understood that the client-side, or subscriber-side, equipment may incorporate an A/D and D/A for its internal signal processing, as is typical of present day modem devices. For the reverse channel, the only A/D converter in the path from the client to the server is also at the Telephone Company's end of the client's subscriber loop.

An alternative system is one where connection **50**, like connection **30**, is a digital connection to subscriber unit **40**. In such a system there are preferably no analog transmission links, that is, the digital PCM codewords are not converted to one of a plurality of an analog voltage levels, but transmitted directly to unit **40** in binary form. Of course, at the physical layer, the transmission of the binary signals or codewords is performed by transmitting voltage levels representing logic signals having values of "1" and "0".

The conversion from octet to analog voltage is well known, and is based on a system called μ -law coding in North America. In Europe, a format known as A-law coding is used. Theoretically, there are 256 points represented by the 256 possible octets, or μ -law/A-law codewords. FIGS. 2A-C show the positive values of the μ -law and A-law codewords. There are one hundred twenty eight values, and a total of two hundred fifty six values including the negatives. The codewords are given in hexadecimal format, and are ordered according to the corresponding analog voltage level. Note that the analog level is calibrated in integers from 0 to 32,124. These numbers correspond to a linear 16-bit A/D converter. As is known to those of ordinary skill in the art, the sixteenth bit is a sign bit which provides integers

from 0 to -32124 which correspond to the first 128 octets (hexadecimal 0 to 7F), not shown in FIG. 2 or 3.

FIG. 3 plots the μ -law codewords versus the analog voltage level. FIG. 3 can be viewed as a conversion between the logarithmic binary data and the corresponding linear 16-bit binary data. It can also be seen in FIG. 3 that the logarithmic function of the standard μ -law conversion format is approximated by a series of 8 linear segments.

The format of the μ -law codewords is shown in FIG. 4, where the most significant bit b_7 indicates the sign, the three bits b_6 - b_4 represent the linear segment, and the four bits, b_3 - b_0 indicate the step along the particular linear segment. These points are symmetric about zero; i.e., there are 128 positive and 128 negative levels, including two encodings of zero. Since there are 254 points not including zero, the maximum number of bits that can be sent per signaling interval in a system having an analog link in the channel (symbol) is just under 8 bits. In an all digital system, all 256 octets may be utilized, resulting in eight bits per signaling interval. Other factors, such as noise, digital attenuation (pads), channel distortion introduced by the subscriber loop, and the crowding of points at the smaller voltage amplitudes and the associated difficulty in distinguishing between them at the decoder/receiver, may reduce the maximum attainable bit rate. Note that the A-law format, however, has no codewords corresponding to an analog voltage level of zero volts. As seen in FIG. 2A, the codeword D5 represents a linear value of 8, the smallest linear value. The corresponding negative codeword having a linear value of -8 is obtained by changing the sign bit, and is hexadecimal 55.

In the system shown in FIG. 1, digital data can be input to the DTN as 8-bit bytes (octets) at the DTN's clock rate of 8 kHz. This is commonly referred to as a DS-0 signal format. In the system having an analog subscriber loop, the DTN's interface to the subscriber loop includes a codec that converts each byte to one of 256 analog voltage levels (although two of these are zero volts in the μ -law system). These voltage levels are sent over the client's subscriber loop and received by a decoder at the client's location. As shown in FIG. 3, the analog voltages, or points, corresponding to the quantization levels are non-uniformly spaced and follow a generally logarithmic curve. As can be seen in FIG. 3, the increment in the analog voltage levels produced from one codeword to the next is not linear, but depends on the mapping as shown.

Certain network connections utilize a supervisory signaling technique called Robbed Bit Signaling (RBS). On RBS links, the least significant bit (LSB) of the PCM code is usurped, or "robbed", by the network periodically and used to convey control information. The PCM codes from different channels are grouped together and multiplexed into frames, typically 24 DS-0 channels plus a framing bit, to create a DS-1 signal that may be sent over a T-1 carrier system. In typical robbed bit signaling, the T-1 carrier system uses the LSB of every channel, every sixth frame, for sending control and status information between network equipment. Thus, each DS-0 user loses the use of the LSB every sixth octet (once per every sixth DS-1 frame). Ordinarily, these channels are used for voice communications, and the bit robbing merely increases quantization noise of the effected time slots. The effect of robbed bit signaling on voice quality is barely perceptible to the human ear.

To control power levels, some networks impose digital attenuators. Unlike analog attenuators, a network digital attenuator (NDA) is not linear. Because there are a finite

number of digital levels to choose from, the NDA will be unable to divide each codeword exactly. This causes distortion of the analog level ultimately transmitted by the DAC over the subscriber loop. For example, if the NDA is designed to reduce voltage levels by $\frac{1}{2}$ (6 dB), then PCM code 130 will attenuate to code 146, and the corresponding analog levels will not be related exactly by a factor of $\frac{1}{2}$. Also, NDAs can produce code ambiguities, which happens more frequently with codes corresponding to small absolute linear values. Specifically, more than one codeword may be reduced to the same attenuated codeword, resulting in an ambiguity. Another type of ambiguity may be introduced when low-amplitude codewords of positive and negative values pass through an NDA and are transformed to a codeword having the smallest magnitude, but perhaps having a positive value. That is, e.g., in a μ -law format, both negative and positive zeroes (hex values 7F and FF) are converted to the same codeword.

At certain points in data transmission, it is desirable for the devices used at each end of the above-described data transmission system to transmit silence, or the equivalent of an analog zero voltage level. The silence is often transmitted before the nature of the channel is fully determined. That is, the device may attempt to transmit a zero signal over a channel that may include NDAs or RBS signaling, or may be fully digital end-to-end, or may have analog portions of the channel. These impairments will interfere with the transmission of the desired zero signal.

SUMMARY OF THE INVENTION

A method of transmitting a quite, or zero, signal in a PCM communication system is provided. The zero signal is specified universally in ordered set terms for either μ -Law or A-Law PCM systems, which has minimal energy in the A-Law system, and contains no energy within the μ -Law system. The signal is preferably specified as a repetition of six intervals (or multiple thereof) because the DTN can modify PCM codes on a six interval period by the robbed-bit signaling mechanism. The zero signal may be used to detect network elements that produce single-signed zero outputs from zero inputs of either sign. In addition, by examination of the zero signal the receiver may determine whether the channel includes an analog link or connection.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features and advantages of the present invention will be more readily appreciated upon reference to the following disclosure when considered in conjunction with the accompanying drawings, in which:

FIG. 1 depicts a communications network with a data source having direct digital access to the DTN;

FIGS. 2A-C show a table of PCM codewords in the μ -law, A-law and analog values;

FIG. 3 shows a μ -law to linear conversion graph;

FIG. 4 shows the elements of a μ -law codeword; and

FIG. 5 shows a flow diagram of the method of transmitting a zero signal.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The Table of FIGS. 2A-C shows the values commonly accepted for conversion between the μ -Law and A-Law PCM systems. The column labeled Ucode are an ordering, of smallest to largest of the codewords in each PCM standard as set forth in Recommendation V.90, published by

the International Telecommunications Union (ITU). The μ -Law PCM and A-Law PCM columns are the eight bit hexadecimal codeword value within the coding system. The two columns marked " μ -law linear" and "A-law linear" contain linear representations of the PCM codewords corresponding to the two encoding schemes. The linear values are scaled to correspond to a range of $\pm 32,768$. This scale is selected for convenience, as it represents the decimal equivalent of a sixteen bit binary number. Negative values are not shown, but can be created by making the most significant bit of the codeword zero, rather than one, with a corresponding negation of the linear table entries. Thus Ucode 0 corresponds to A-law codeword D5, representing a linear value of 8. The negative of this is A-law codeword 55, representing a linear value of -8. The Ucode 0 corresponds to codeword FF in a μ -law system. FF represents a linear zero value. The negative of this corresponds to 7F, which, in this case, also represents a linear zero value. This is because the μ -law encoding has two separate values for zero.

Note the differences between the linear values corresponding to Ucode 0. Within the A-Law system this corresponds to a linear value of 8, and within the μ -Law system, this has a linear value of zero. Thus, within an A-law system, it is not possible to send a "zero" signal. It is possible to send a constant DC level in such a system, however, it is preferable to send a signal that has a small amount of energy, but no DC bias. This is in part because of the transient response of DTN transmission elements.

The preferred zero signal is periodic over a single 6 octet frame, or periodic over a plurality of frames. Generally, a periodic low-amplitude (linear value) sequence is preferred. One preferred signal is repetition of the sequence FF,FF,FF, 7F,7F,7F within the μ -Law system, and the corresponding D5,D5,D5,55,55,55 within the A-Law system. Another preferred signal is the μ -Law FF,7F,FF,7F,FF,7F and the corresponding D5,55,D5,55,D5,55 in A-Law. Note that the signals set forth above are periodic over a six codeword cycle. The preferred signals are transmitted over the communication channel when the transmission of a zero signal is desired.

The transmission of the zero signal is performed by first selecting minimum energy codewords and their opposites. For example, in μ -law, the opposite of FF is 7F, and in A-law, the opposite of D5 is 55. Other codeword pairs corresponding to low energy linear values may alternatively be used, or may be combined with those above. The selected codewords of both signs (codewords corresponding to positive and negative linear values) are then formed into a cyclic pattern having a period of a multiple of six codewords. The period may be exactly 6 codewords, 12 codewords, 18 codewords, etc. Slight aperiodicity of the codewords of the zero signal may be tolerated, but is not preferred. The codewords are then supplied to the digital telephone network.

With reference to FIG. 5, the method described above includes the step 100 of selecting codeword pairs having positive and negative values. The codeword pair FF and 7F is one such pair. Step 110 involves forming a periodic sequence of codewords using codewords from the pairs selected in step 100. In step 120, the sequence is provided to the DTN. In step 130, the sequence is received at the distant end.

The communications receiver may utilize the zero signal to detect network elements that produce single-signed zero outputs from zero inputs of either sign. Specifically, the zero signal having minimum energy codewords of both signs as described above will be converted by some network ele-

ments into minimum energy codewords of a single sign. Step 150 of FIG. 5 depicts this step taken by the receiver to determine whether channel includes single-signed network distortion elements

In addition, the receiver may determine if the channel includes an analog link or connection. If an analog portion exists, for example if the system has an inter-switch analog trunk line, the codewords will be converted to an analog waveform for transmission over the trunk line, and then re-converted back to a PCM codeword. The noise inherent in analog transmission systems will be added to the analog voltage level, and when the level is re-converted back to a PCM codeword, distortion in the quantization will result in corrupted codewords. Step 140 of FIG. 5 is to determine if the connection includes an analog link by analyzing the received codewords for distortion.

A preferred embodiment of the present invention has been described herein. It is to be understood, of course, that changes and modifications may be made in the embodiment without departing from the true scope of the present invention, as defined by the appended claims.

I claim:

1. A method of transmitting a minimal energy signal comprising the steps of:

selecting at least one pair of minimal energy codewords comprising a minimal energy codeword and a corresponding opposite codeword;

forming a frame comprising a sequence of codewords selected from said at least one pair of codewords; and, providing said sequence to a digital telephone network (DTN).

2. The method of claim 1 wherein said sequence is periodic, having a period equal to a multiple of six codewords.

3. The method of claim 1 wherein said at least one pair of minimal energy codewords comprises hexadecimal values FF and 7F.

4. The method of claim 1 wherein said at least one pair of minimal energy codewords comprises hexadecimal values D5 and 55.

5. The method of claim 1 further comprising the step of determining the presence of network elements that produce single-signed zero outputs from zero inputs of either sign.

6. The method of claim 1 further comprising the step of determining whether a channel includes an analog link or connection.

7. A method for transmitting a Pulse-Code-Modulation (PCM) signal through a digital telephone network (DTN), the method comprising the steps of:

selecting a zero signal codeword pair, the zero signal codeword pair comprising a minimum energy codeword and an opposite codeword, where the minimum energy codeword corresponds to a zero signal for a channel of the DTN;

forming a transmission frame comprising a sequence of codewords selected from the zero signal codeword pair; and

when transmission of the zero signal is desired, transmitting the transmission frame over the channel.

8. The method of claim 7, where the step of forming a transmission frame includes selecting the sequence of codewords to be periodic having a period equal to a multiple of six codewords.

9. The method of claim 7, where the channel further comprises a μ -law PCM channel and the step of selecting a zero signal codeword pair further comprises selecting a

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hexadecimal value of FF for the minimum energy codeword and a hexadecimal value of 7F for the opposite codeword.

10. The method of claim 7, where the channel further comprises an A-law PCM channel and the step of selecting a zero signal codeword pair further comprises selecting a hexadecimal value of D5 for the minimum energy codeword and a hexadecimal value of 55 for the opposite codeword.

11. The method of claim 7, the method further including the steps of:

receiving the transmission frame over the channel of the DTN; and

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determining a presence of DTN elements that produce single-signed zero outputs from zero inputs of either sign.

12. The method of claim 7, the method further including the steps of:

receiving the transmission frame over the channel of the DTN; and

analyzing codewords of the received transmission frame for distortion in order to determine whether the channel of the DTN includes an analog link.

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