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Sign Polar Return-To-Zero Telemetry and Coding Logic

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Preface

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An existing telemetry scheme employs Bipolar Return-to-Zero (BPRZ) logic to encode binary information. The BPRZ provides for trilevel waveform pulse code modulation; however, the current implementation does not use the full capacity of the BPRZ logic. Sign Polar Return-to-Zero encoding exploits the remaining encoding capacity to provide an additional bit transfer per channel word. This implementation transfers the word argument sign information by the polarity encoding of the first nonzero pulse in each telemetry word pulse encoded waveform. Significant increase in data transfer efficiency is provided by this technique.

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FOREWORD

An existing Navy digital time division multiplexing telemetry system employs pulse-code modulation of companded towed array hydrophone channel information. The existing scheme assigns 8 binary data bits per channel word and allocates these bits as follows: 1 bit for the argument sign, 3 bits for its exponent and 4 bits for its mantissa. An improvement in data transfer efficiency is described herein that is a characteristic of the existing scheme and results in the availability of an additional bit per channel word.

The existing scheme employs Bipolar Return-to-Zero (BPRZ) logic to encode binary information for telemetry transfer using a pseudoternary code format. The BPRZ logic provides for trilevel waveform pulse-code modulation: positive voltage pulses, zero voltage (no pulses), and negative voltage pulses. This particular encoding scheme assigns to any BPRZ time division window one binary state to all nonzero levels (all pulses both positive and negative) and the other binary state to all zero voltage levels (no pulse). As can be seen, the binary encoding does not use the full ternary capacity of the BPRZ logic; therefore, this implementation is referred to as pseudoternary encoding.

Pulse polarity encoding, as shown herein, provides an additional bit transfer per channel word. The implementation chosen as an example in this discussion assigns the bit required for the sign of each telemetry channel argument to be transferred by polarity encoding of the existing eight pulse waveform. The first nonzero pulse within each pulse-encoded waveform channel argument transfers the argument sign information by way of its polarity. This technique simply extends the incompletely exploited information capacity of the ternary format, yet retains the BPRZ logic. It is called Sign Polar Return-to-Zero (SPRZ) because of the polarity encoding of argument sign information. Examples used in this description retain the 8 binary pulse-encoded bits per channel word and allocate the additional bit to exponential use, thereby increasing system dynamic range. Similar schemes could assign the additional bit to the mantissa, realizing an increase in quantizing accuracy or simply require only 7 pulse-encoded bits per word to increase the system capacity for channels proportionally. The novel technique described represents an effective and efficient use of existing digital circuit technology to perform a function not being accomplished using a conventional approach.

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Section 1. BACKGROUND

Digital data telemetry systems must efficiently transfer the maximum amount of information possible. An existing time division multiplexing telemetry system employed in U. S. Navy sonar applications utilizes Bipolar Return-to-Zero (BPRZ) logic in a pulse-code-modulation scheme to transmit companded digital data. The use of BPRZ logic provides a trilevel pulse logic capable of supporting a ternary code; however, only binary data are encoded, leaving unused degrees of freedom in the BPRZ logic. Because the tristate (ternary) logic is used only to transfer bistate (binary) data, this application of BPRZ is referred to as a pseudoternary code. The Sign Polar Return-to-Zero (SPRZ) technique improves the data transfer capacity by exploiting an unused degree of freedom available in the BPRZ logic.

The existing telemetry system application of BPRZ logic provides for binary data transfer of 8 bits per channel word using pulse-code modulation. For bit encoding, the binary data requires two states, "a" and "$\bar{a}$." The available trilevels in the BPRZ logic are allocated as follows:

1. BPRZ binary bit-state "a" encoded by transmitting, at that particular bit's time division window, either a positive or negative voltage pulse. The pulse polarity is alternated such that the sequential occurrence of pulse-encoded binary state "a" within any serial bit stream provides a pulse of opposite polarity to the preceding state "a" encoded pulse modulation.

2. BPRZ binary bit-state "$\bar{a}$" encoded by not transmitting any pulse during that bit's time division window, thereby maintaining the zero voltage level.

A typical sequential pair of binary words, J and J+1, 8 bits each, are shown in figure 1, with the corresponding BPRZ pulse-code-modulation waveform. Note that all three voltage levels, +A, 0, and -A, are used to encode binary information because the absence of a pulse during a bit time division window indicates a binary state. Note also that the example given associates BPRZ state "a," as defined above,with the binary value 1_2[1] and BPRZ state "$\bar{a}$" with the binary value 0_2.[1] An equally efficient encoding could reverse the order of association between BPRZ logic states "a" and "$\bar{a}$" and the binary values 0_2 and 1_2. The encoded waveform with this inverted logic would appear as in figure 2, where words J and J+1 contain the same binary values as in figure 1. (Both BPRZ and inverted BPRZ logic pseudoternary encoding are employed in the existing telemetry system.) Lastly, the polarity of the first nonzero pulses in word J+1 in figures 1 and 2 are negative and the polarity of the last nonzero pulses in word J in both figures are positive since polarity alternation is preserved from word to word. In these examples, the pulse waveform for both J words has an odd number of transmitted pulses. Note, however, if a word pulse waveform included a last pulse of negative polarity,

[1]Subscript notation for base 2, binary values.

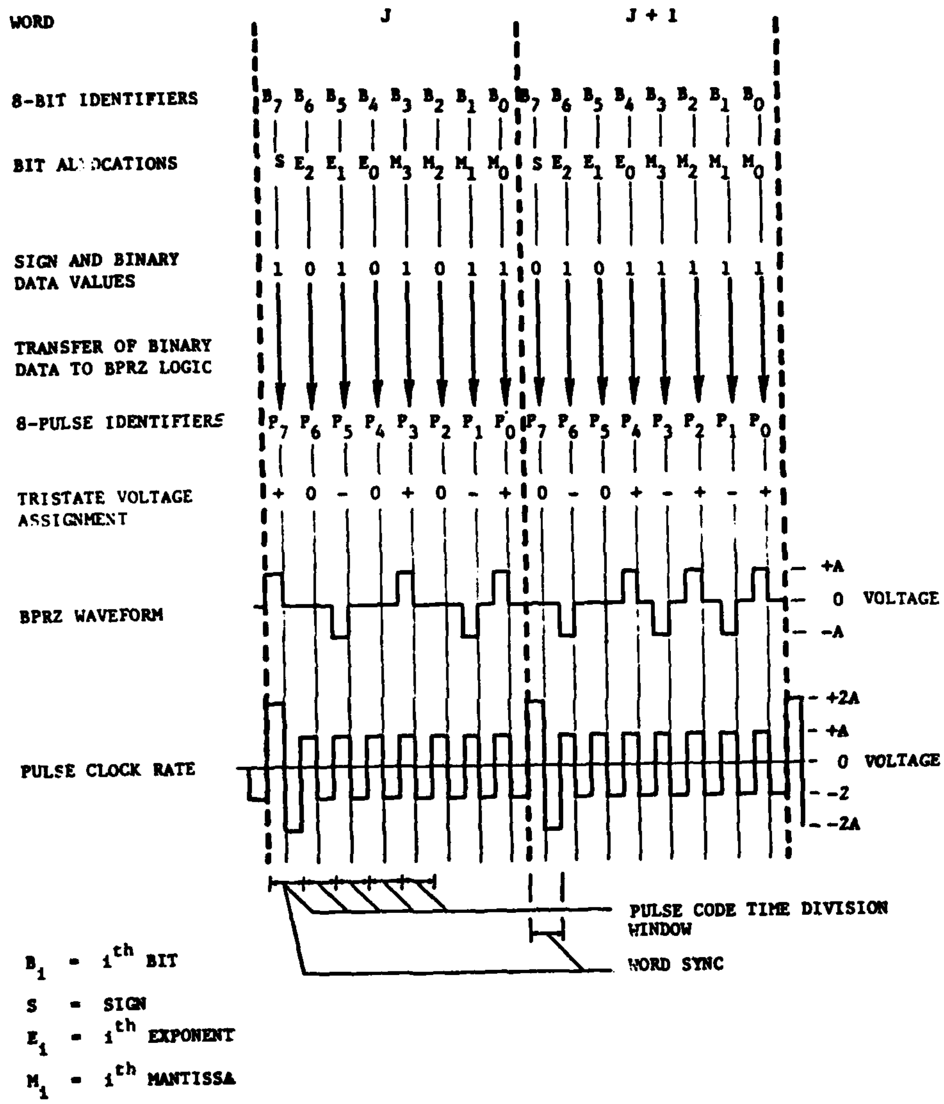

Figure 1. BPRZ Logic Pseudoternary
Waveform Encoding

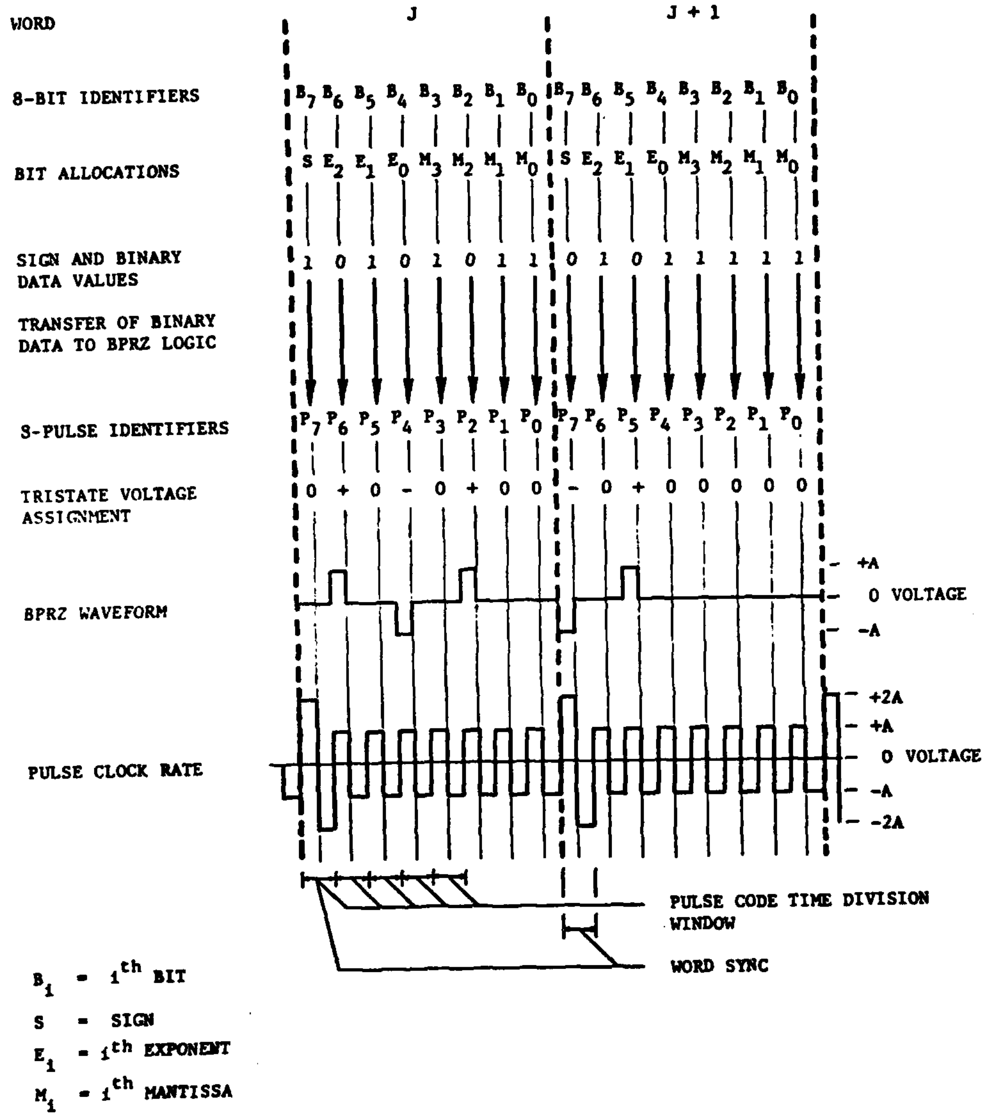

Figure 2. Inverted BPRZ Logic Pseudoternary Waveform Encoding

the first pulse of the next word waveform would be positive, again preserving polarity alternation from word to word.

BPRZ logic transmitting and receiving codes have been employed for a number of years. These transmitting schemes normally employ word formats consisting of 4, 8, 12, or 16 bits. The existing Navy telemetry system uses a BPRZ 8-bit word code to transfer data input from companding analog-to-digital (A/D) converter electronics.

Analog signals are input to a linear 12-bit A/D converter that provides an output of 1 sign bit and 11 magnitude bits. A compander reduces the 11 bits of magnitude to the following 7 bits: 3 bits for exponential values that identify the value of the most significant bit (MSB) and 4 bits of mantissa value to further define the analog signal amplitude at the sacrifice of precision because of lost least significant bits (LSB's). The sign bit is transferred by an 8th bit through the companded circuitry. The decompanded value at an expander output provides a linear value to 5 most significant bits: 1 bit transferred by the exponential set of 3 companded bits and 4 bits transferred by the mantissa set of 4 companded bits. Note, by design the exponential set of 3 companded bits identify the position and binary value of the most significant bit of the 11-bit magnitude value at the output of the 12-bit A/D converter. The system functional details are shown in figure 3, and the specifics of companded encoding are shown in figure 4. The expander output reformats the binary word into a 12-bit value: 1 bit sign and 11 bits magnitude. However, the expander output only contains 5 significant bits of information. The block diagram of the companding shown in figure 3 indicates the bit transfers between functions. The BPRZ logic pseudoternary encoding is used to transfer the 8 data bits between the digital compander and the digital expander.

The transfer characteristics for the 12-bit A/D converter code and the resultant companded 8-bit code are shown in figure 4. The top of the figure shows the enumerated 12 bits from the A/D converter: bits number 0 through 10 for magnitude and bit number 11 for sign encoding. The bottom of the figure demonstrates the allocation of companded bits: bits 0_c[2] through 3_c identify mantissa, bits 4_c through 6_c are for exponent encoding transferring the MSB, and bit 7_c is for sign encoding. Figure 4 presents three regions:

1. Region of No Data — a region of no error, since it carries no information and all bits are zero.

2. Region of Lost Data — a region of 1_2's and 0_2's, but is not carried through the system and can represent a maximum quantizing error of 3.125 percent.

3. Region of Mantissa — a region occurring between the Regions of No Data and Lost Data that presents the highest energized bits (MSB of the mantissa) and the following 4 lower significant bits. This region presents a linear measure of the data, but is limited to 5 significant bits of precision.

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[2] i_c denotes the i^{th} companded form binary bit.

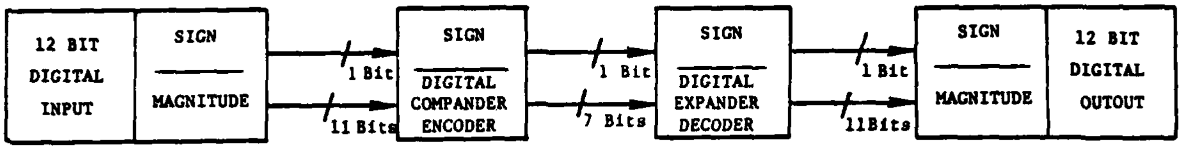

Figure 3. Companding Block Diagram

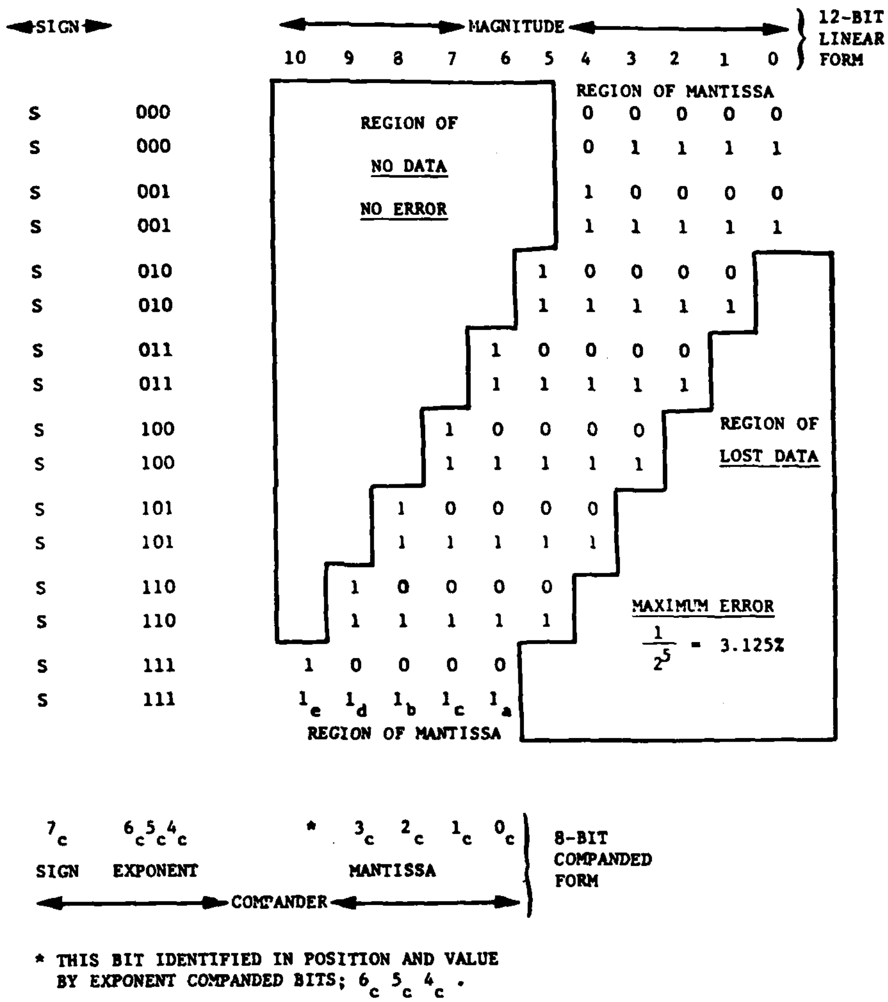

Figure 4. Companding A/D Converter
Bit Identification

The BPRZ pseudoternary code allocation for the 8 companded bits can be shown as follows:

7_c[3]	6_c	5_c	4_c	3_c	2_c	1_c	0_c
S	E_2	E_1	E_0	M_3	M_2	M_1	M_0,

where

S Sign $\pm$

E_n Exponent (Identifies the location of the highest order binary value, 1_2, of the 11 magnitude bits from a 12-bit (sign + 11 magnitude) A/D conversion for the noncompanded telemetry receiver output.

M_n Mantissa (carries the magnitude to 4 additional binary places).

It became necessary to increase the dynamic range of the A/D converter system. One such system to accomplish this is described in NUSC TD 6317.[4] This system requires data transfer capacity for 4 bits of mantissa information, 4 bits of exponential information, and 1 bit of sign information. The existing BPRZ pseudoternary telemetry system has no space for the required additional exponential bit per word. SPRZ logic digital encoding was developed to accommodate this extension of dynamic range. This method outputs at the transmitter a conventional BPRZ waveform polarized for sign identification to present a 9-bit code at the telemetry receiver expander input.

As indicated above, recently developed underwater acoustic arrays that use BPRZ digital logic to transfer data over coaxial cable are not being utilized as efficiently as possible. By using an inexpensive encoding/decoding technique, we can take advantage of a BPRZ logic polarity modulation characteristic to transfer the information content of an additional bit in the transmitted digital word. The example presented demonstrates the extraction of the sign ($\pm$) information of an electrical (acoustic) signal without transferring this information by using a conventional pulse-encoded bit in the transmitted digital word.

The purpose of the SPRZ digital encoder/decoder is to present a conventional N-pulse logic, enhanced by polarity sign encoding, to a BPRZ transmitter and, thereby, extract an N+1-bit code at the receiver. The SPRZ logic described increases the telemetry system's information capacity for data transmission; however, the same number of time division windows for binary pulse encoded modulation is used. Because BPRZ logic is being employed in existing Navy digital transmission systems, any cost effective improvement in information transfer efficiency is of great interest.

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[3] i_c denotes the i^{th} companded form binary bit.

[4] G. L. Assard, A Gain Step Companding (COMpressing ExPANDING) Analog-to-Digital Converter, NUSC Technical Document 6317, Naval Underwater Systems Center, New London, CT, 30 March 1981.

Section 2. TECHNICAL DESCRIPTION

The block diagram in figure 5 presents the functional blocks required to transform an N+1-bit binary word into a sign polar enhanced conventional N-bit format that can be reconstructed into the original N+1-bit word at a corresponding telemetry receiver. In this specific case,

$$N = 8.$$

The timing block (1) in figure 5 consists of binary circuitry that will generate the required timing functions to format the N+1-bit word stored in the transmit register (2) through the SPRZ codes (3) into the N-bit transmitter similar to the existing BPRZ format.

The N+1-bit word transmit register stores the N+1-bit word and presents the bits serially into the SPRZ encoder (3).

The SPRZ encoder (3) polarizes the bit stream to be transmitted so that the first nonzero voltage pulse encoded bit of each word contains two pieces of binary information: first, its own bit identity and, second, the polarization (a second degree of freedom) that identifies the additional bit state. Thereafter, the SPRZ encoder (3) alternates the polarization of the remaining bits of the word to produce a pulse-encoded waveform entirely similar to the existing BPRZ format.

For example, two typical 9-bit words, K and K+1, can be used to demonstrate waveform pulse encoding. These words are shown in figure 6, where the bit allocation per word is as follows: 1 bit for sign state identification, 4 bits for exponential precision, and 4 bits for mantissa precision. Note that the first nonzero pulse in words K and K+1 transfers sign information as well as binary state. This sign information is carried in the first pulse-time-division window, i. e., pulse P_7 in word K. In word K+1, where the 9-bit word binary value $+00000001_2$ is similarly encoded, its sign is transferred by the polarity of the last word pulse, P_0. It also should be observed that while positive and negative pulse encoding alternates within the 8-pulse train of a word, the particular data now may require two consecutive identical polarity pulses occurring in the last nonzero pulse of word K and the first nonzero pulse of word K+1. Moreover, figure 7 demonstrates the possibility of inverse SPRZ logic application, as was demonstrated for BPRZ logic in figure 2. As mentioned earlier, certain telemetry system electronic areas use this inverting flexibility to enhance performance.

The N-bit transmitter (4) in figure 5 is a conventional BPRZ transmitter with polarization under the control of the SPRZ encoder (3). The transmitter (4) drives the transmission line (5) with the SPRZ N-bit code. The bits are extracted from the transmission line (5) at the receiver N-bit detector (6). The detector (6) provides the receiver timing (7) block with the conventional synchronizing pulses to maintain synchronization with the transmitted digital bit stream. The second function of the detector is to present the SPRZ decoder (8) with the polarity of the first nonzero voltage encoded bit along with the

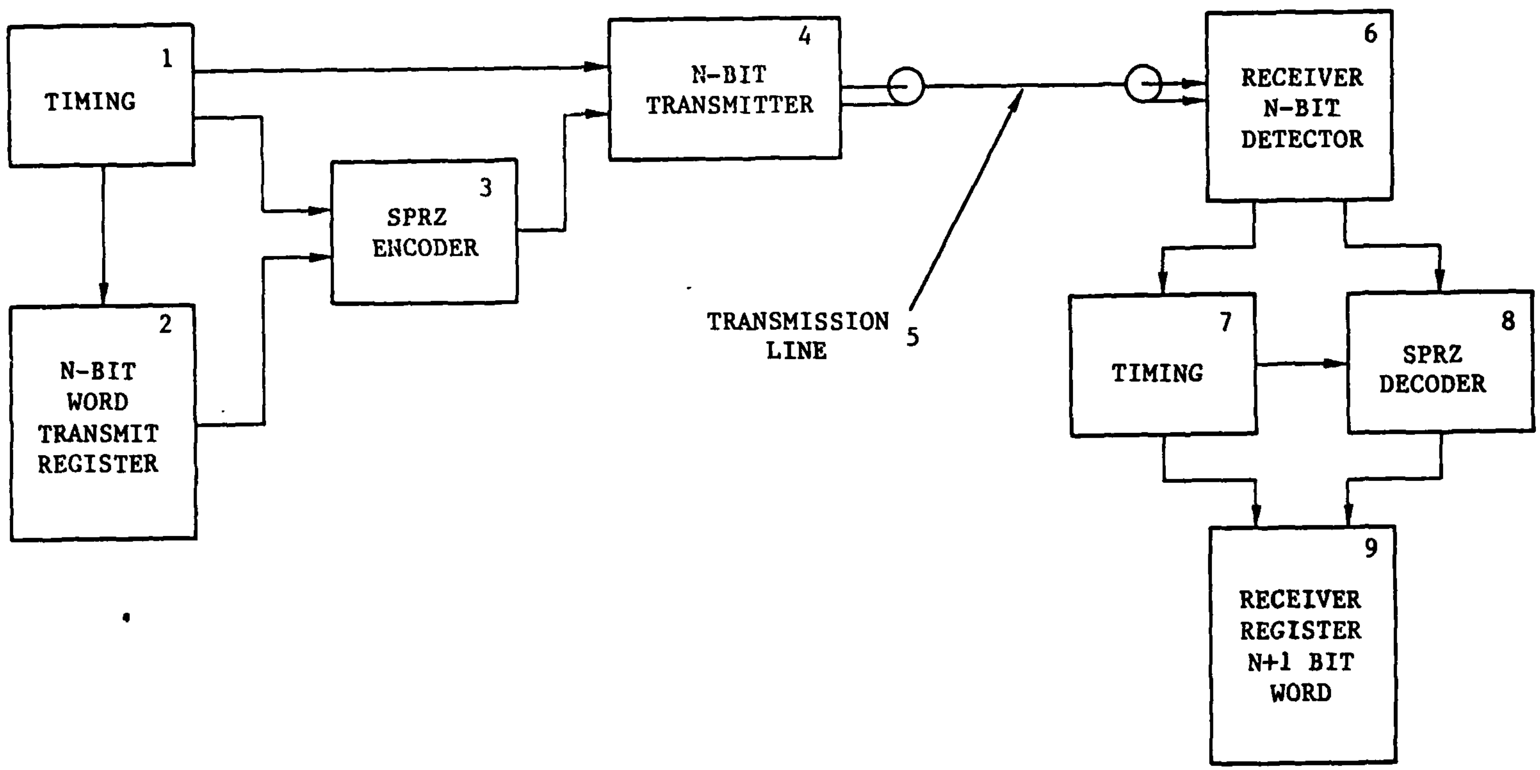
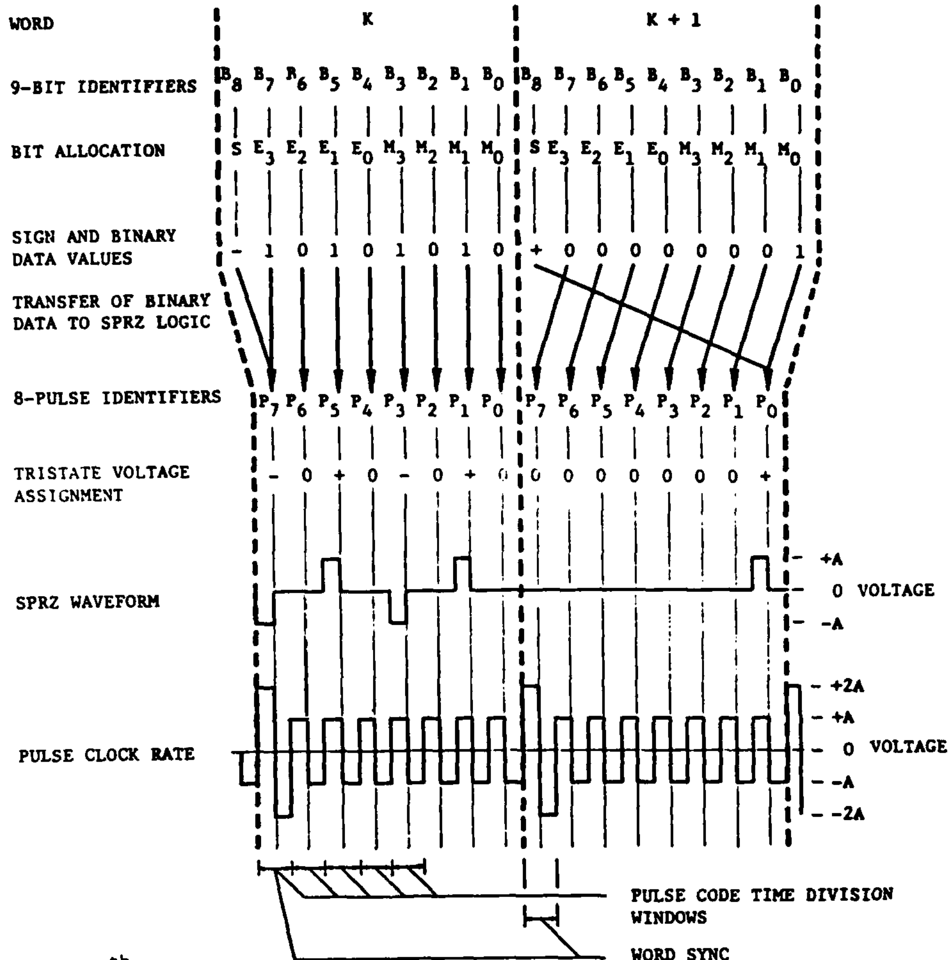


Figure 5. SPRZ Block Diagram



B_i = i^{th} BIT

S = SIGN

E_i = i^{th} EXPONENT

M_i = i^{th} MANTISSA

Figure 6. SPRZ Logic Pseudoternary Waveform Encoding

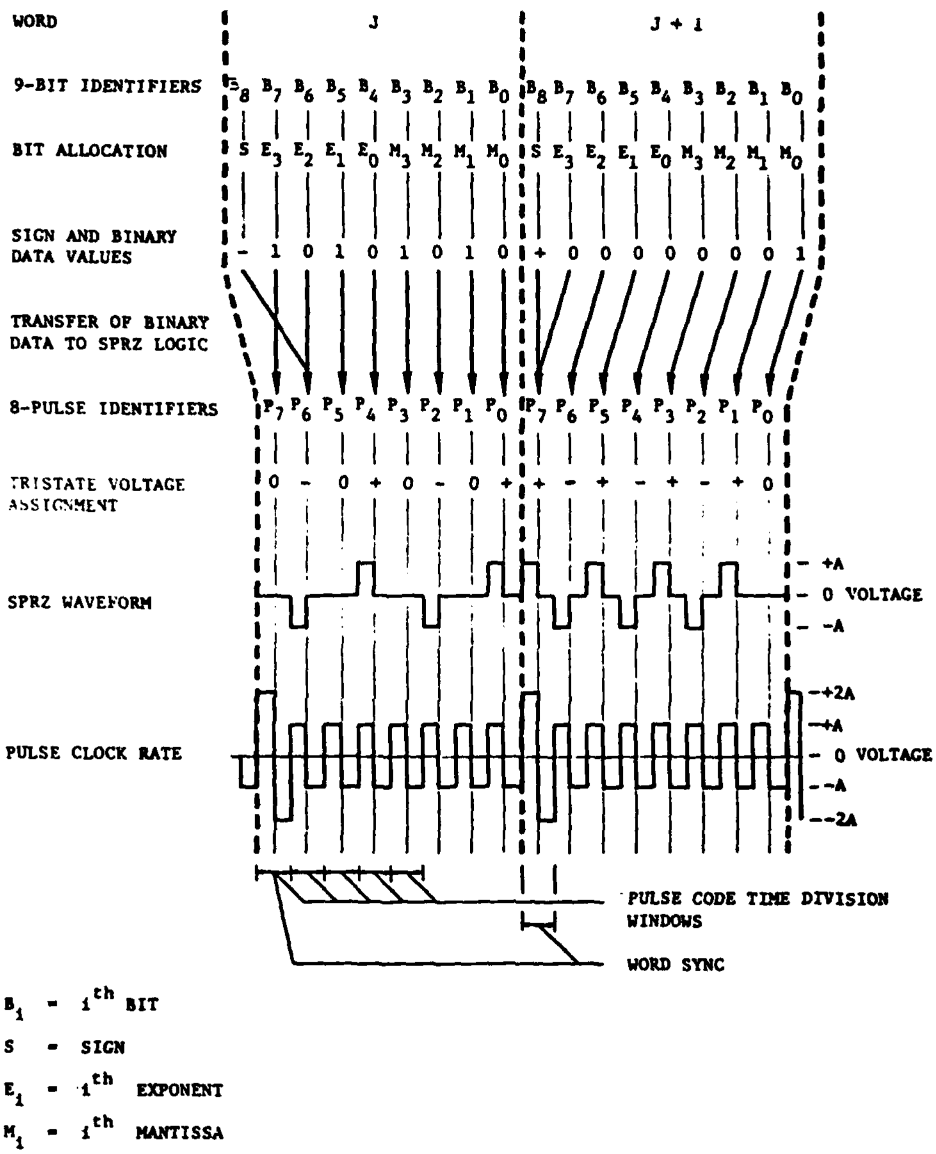


Figure 7. Inverted SPRZ Pseudoternary Waveform Encoding

transmitted N-bit serial binary word. The polarity of the first nonzero voltage encoded bit is processed within the SPRZ decoder (8) to identify the additional transmitted bit state and reconstruct the original N+1-bit word. While the word is being decoded (8), it is being clocked (7) into the N+1-bit word receiver register (9) where it can be transferred to its intended destination, thereby clearing the receiver for accepting the next serial word.

Figure 8 presents two simulated 9-bit words and their pulse-encoded waveform as they appear at various points in the system block diagram, (figure 5). The simulated 9-bit word is first seen at the functional block (2) in figure 5. The B_8 bit is encoded as the polarity of first nonzero pulse in the 8-pulse waveform at blocks 4, 5, or 6. The B_8 bit has been decoded from the polarity of the first nonzero voltage encoded bit to complete the original 9-bit word and is again available at block (9) in figure 5.

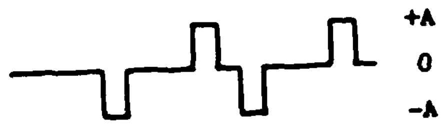
In figure 5, the SPRZ decoder (6) must also provide for decoding the B_8 bit, (word argument sign) for the case when no pulses are transmitted; i.e., B_0 through B_7 are all zero-pulse encoded. The all-zero pulse transmitted word can accommodate only one sign state of the B_8 bit, as in the conventional 2's complement format that would transfer to the receiver a decoded +0 word state. However, an alternative would be to never transmit the B_0 through B_7 all-zero pulse-encoded state. This can easily be accomplished by forcing the all-zero pulse-encoded state to be modified by including a B_0 pulse polarized to preserve the word argument sign information. This is a hard clipped sign implementation.

9-BIT WORD (POSITIVE)

										OBSERVED AT
BIT ASSIGNMENT	S	E_3	E_2	E_1	E_0	M_3	M_2	M_1	M_0	
BIT IDENTIFICATION	B_8	B_7	B_6	B_5	B_4	B_3	B_2	B_1	B_0	
SIGN VALUE	+									
COMPANDED BINARY DATA	1	0	0	1	0	1	1	0	1	BLOCKS 2 and 9 *
TRISTATE LEVELS FOR 8-PULSE TRAIN		0	0	+	0	-	+	0	-	
WAVEFORM										BLOCKS 4, 5, and 6 *

9-BIT WORD (NEGATIVE)

BIT ASSIGNMENT	S	E_3	E_2	E_1	E_0	M_3	M_2	M_1	M_0	
BIT IDENTIFICATION	B_8	B_7	B_6	B_5	B_4	B_3	B_2	B_1	B_0	
SIGN VALUE	-									
COMPANDING BINARY DATA	0	0	0	1	0	1	1	0	1	BLOCKS 2 and 9 *
TRISTATE LEVELS FOR 8-PULSE TRAIN		0	0	-	0	+	-	0	+	
WAVEFORM										BLOCKS 4, 5, and 6 *



* AS SHOWN IN THE FUNCTIONAL BLOCK DIAGRAM IN FIGURE 5.

Figure 8. Two Simulated 9-Bit Words and Their Pulse Encoded Waveforms

Section 3. SUMMARY

The Sign Polar Return-to-Zero (SPRZ) telemetry digital formatter employs an inherent additional degree of freedom of the serial N-bit BPRZ transmitter. Use of this degree of freedom, previously unencoded, results in an advantage because the telemetry receiver is able to extract N+1 bits of digital code from an otherwise conventional N-bit transmitted code. The polarization of the N-bit per word BPRZ logic has been employed to present an N+1 bit per word code at the telemetry output.

In summary the SPRZ utilizes an encoded tristate voltage waveform to transmit binary information over a telemetric link. It is more efficient than the conventional Bipolar Return-to-Zero (BPRZ) format because the SPRZ does not require a separate waveform state solely dedicated to transfer word argument sign information. The sign information for each word is transferred by the polarity of the first nonzero waveform pulse in each word as described herein. The SPRZ format reduces an N+1 bit format by one bit to an N-bit code for waveform transfer because this coding has eliminated the requirement of the conventional BPRZ transmitted sign bit. This increase in telemetry efficiency is significant to multichannel digital telemetry circuit technology.

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