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Technology Series

Introduction to E1/2.048 Mbit/s

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1 OVERVIEW

This technology note will introduce you to the basic concepts in 2.048 Mbit/s technology, including sampling a signal, line coding, framing, and basic alarms/errors. This note can be used as an introduction to the technology, as well as a field reference guide for everyday use.

2 PDH STRUCTURE

PDH: Plesiochronous Digital Hierarchy

- Numerous signals, almost synchronous, are received at a mux, where they are multiplexed into a single signal.
- The entire signal must be demultiplexed in order to switch one lower-order signal.
- No standards exist for optical transmission equipment, meaning different manufacturers make equipment to different standards, so the equipment may not interoperate.
- The E1 or 2.048 Mbit/s signal (bitstream) is achieved by multiplexing 32 individual 64 kbit/s bitstreams.

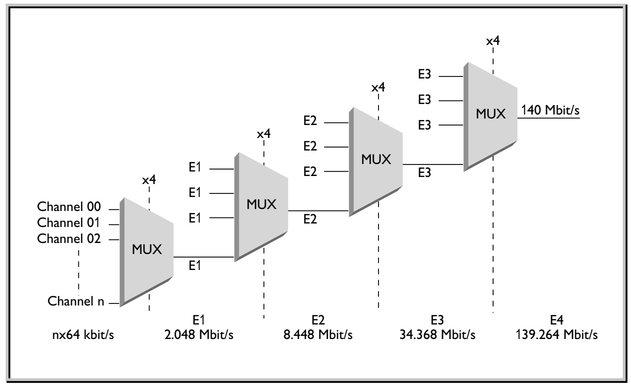

Figure 1 PDH hierarchy

3 DIGITIZING A VOICE SIGNAL

To transmit voice in a digital medium such as a 2.048 Mbit/s line, the analog voice signal needs to be transformed into a binary format, then converted into a bitstream suitable for digital transmission.

3.1 Sampling/Nyquist Theorem

A signal must be sampled at a minimum of twice its maximum frequency in order to be reconstructed in an analog format without major loss of information.

- For voice signals, a maximum frequency of 4000 Hz provides adequate clarity and contains the majority of the information while conserving transmission bandwidth. Thus, a 4000 Hz voice signal must be sampled at at least 8000 samples per second.
- Each amplitude value (sample) is expressed as a 13-bit code "word".
- An 8-bit byte is formed by comparing the sample to a "companding characteristic", which is a non-linear formula.
- Internationally, a companding characteristic known as "A-law" is used, intended to provide optimum signal-to-noise performance over a wide range of signal levels (see Section 3.2).
- In North America, encoding is done according to the "μ-law".
- These 8-bit words occur 8000 times per second for the 64 kbit/s digital bit stream. See Figure 2.

3.2 A-Law Coding (ITU-T G.711)

This is a method used for amplitude compression (companding) that allows higher resolution for lower level signals and lower resolution to high power signals. This helps to assure the quality of the PCM-encoded signal (regardless of the speaker's voice level), by increasing the signal-to-noise ratio. Basically the voice is sampled at 8000 samples per second and converted into a 13-bit word that goes into the compander. The samples are processed using a non-linear formula to transform them into 8-bit words. The compander also inverts all even bits in the word - i.e. 1111111111111 is converted to 11111111 (+127) using compression, resulting in the PCM word 10101010 (AAh).

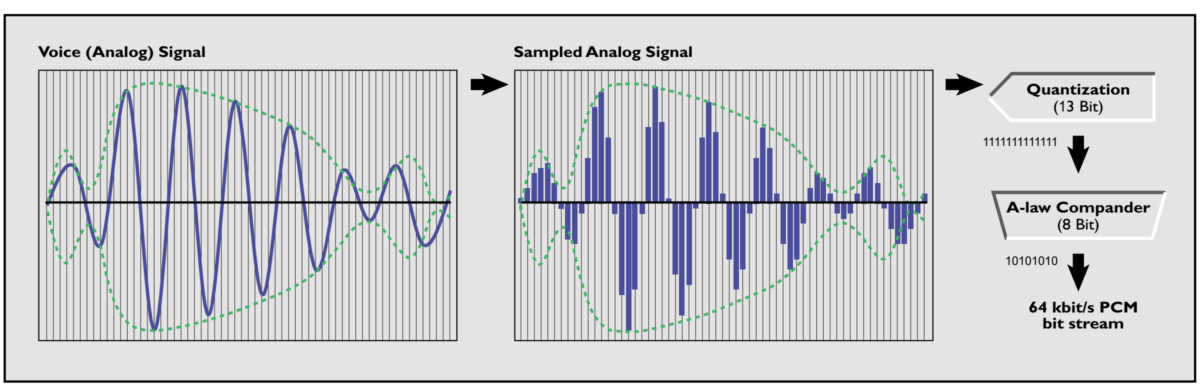

Figure 2 Converting a voice signal (Pulse Code Modulation, PCM)

4 PULSES

The quality of the E1 pulse is an important factor in clear transmission.

- The ITU-T G.703 standard defines the max and min values in the form of a mask. A good pulse shape must fit inside this mask. Refer to Figure 3.
- See Table 1 for the specifications for an E1 pulse, as specified in ITU-T G.703, Table 6.

The 2.048 Mbit/s stream is the basic building block for the transmission of signals in the PCM digital hierarchy. Proper internetworking of equipment along that signal path requires strict compliance with various standards such as ITU-T G.703, G.704 and so on.

Pulse Shape (nominally rectangular)	All marks of a valid signal must conform with the mask (see Figure 15/G.703) irrespective of the sign. The value V corresponds to the nominal peak value.	
Pair(s) in each direction	One coaxial pair (see G.703, 9.4)	One symmetrical pair (see G.703, 9.4)
Test load impedance	74 ohms resistive	120 ohms resistive
Nominal peak voltage of a mark (pulse)	2.37 V	3 V
Peak voltage of a space (no pulse)	0+/-0.237 V	0+/-0.3 V
Nominal pulse width	244 ns	
Ratio of the amplitudes of positive & negative pulses at the center of the pulse interval	0.95 to 1.05	
Ratio of the widths of positive & negative pulses at the normal half amplitude	0.95 to 1.05	
Maximum peak-to-peak jitter at an ouput port	Refer to section 2 of Recommendation G.823	

Table 1 ITU-T G.703/Table 6, 2.048 Mbit/s Pulse Mask specifications

Output signals from such network elements (NE) as multiplexers, regenerators, switches and PBX must be within the defined limits. The input circuitry of the network elements must, further, be able to compensate for any attenuation or distortion caused by the transmission media. Then the logic 1s and 0s will be detected correctly; otherwise, bit/code errors will result.

A portable test instrument can be a useful tool to check the overall health of the transmission system and assist in locating the source of problems or defects. At the physical layer, the parameters of interest are bit rate (and its stability), jitter, wander, level, noise, code errors, and pulse shape distortion. A key test in this area is verification that the signal pulse shape conforms to the ITU-T G.703 recommendation, as illustrated in Figure 3.

The Importance of Pulse Shape Measurement

A G.703-compliant pulse-shaped 2 Mbit/s signal, when transported via metallic cable of correct impedance and prescribed length, will not distort beyond the design limits of the receive ports of the NEs. Otherwise, the resultant errors will lead to degraded service to customers and unnecessary repair costs for service providers (such as PTTs).

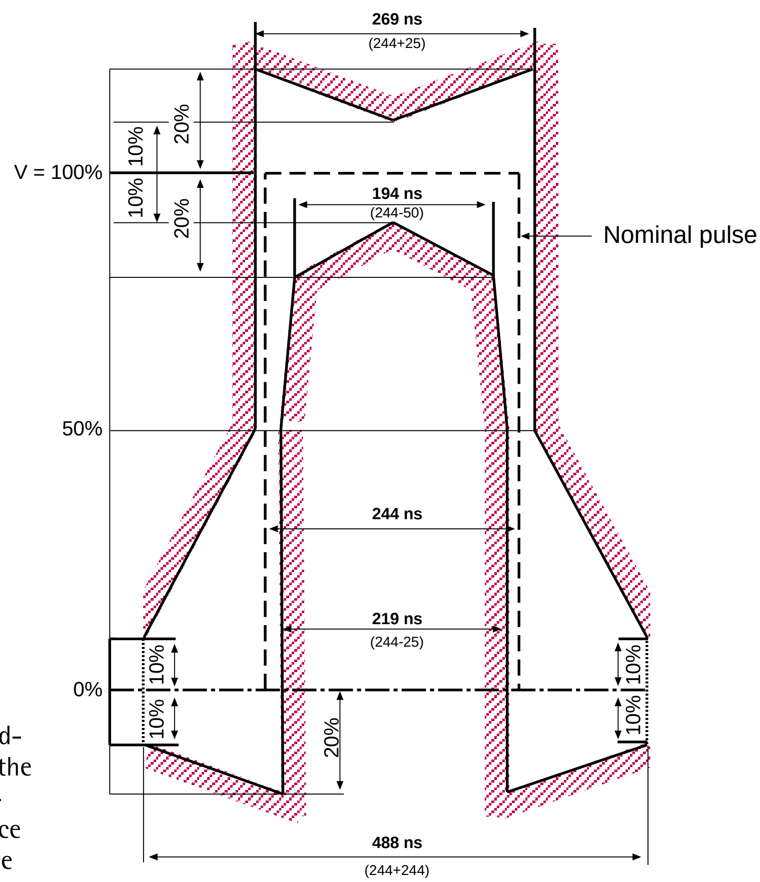

Figure 3 Mask of the pulse at 2.048 Mbps interface

At the time of new installations or recommissioning of service after repair, the importance of pulse shape analysis and level is widely recognized. However, these measurements have nonetheless been frequently omitted because they have been assumed to require the use of an expensive, bulky digital oscilloscope. Current-generation 2 Mbit/s transmission test sets such as the SunSet E-Series, alleviate this problem by incorporating pulse shape measurement, verification, and analysis through a method more practical and appropriate for field use.

The pulse shape can provide an excellent qualitative indication of both noise and jitter. Averaging tends to smooth the noise riding on the signal. If jitter is present, however, the rising and falling edges will be seen as scattered along the time axis. Digital measurement of the pulse width, rise and fall times, and over/undershoot values will give additional information on the possible sources of distortion. The results obtained using this technique (see Figure 4) compare favorably with pulse shape measurements obtained from testing with a digital oscilloscope. One example is shown in Figure 5. The closeness between the two measurement results will depend somewhat on the actual signal under test, but the correlation is generally reliable.

The method used in handheld BER test sets is intended primarily for field verification of the 2 Mbit/s transmission system, in that it provides a quick and easy-to-interpret result and relies on streamlined, hand-held equipment. While the more detailed or precise measurements obtained with a digital oscilloscope continue to be appropriate for other applications, such as design verification or type testing, the use of handheld test sets provides a powerful and efficient way for field service technicians to ensure layer 1 testing of a 2 Mbit/s link. If link quality is not restored to the highest level, other services such as GSM, ISDN PRI, and SS7 – which are also transported on 2 Mbit/s links – will function unreliably. This will lead to levels of downtime and service quality which are unacceptable in today's highly competitive market. Taking the time to perform basic pulse shape analysis plays an important role in both the initial and ongoing quality of any service provider's network.

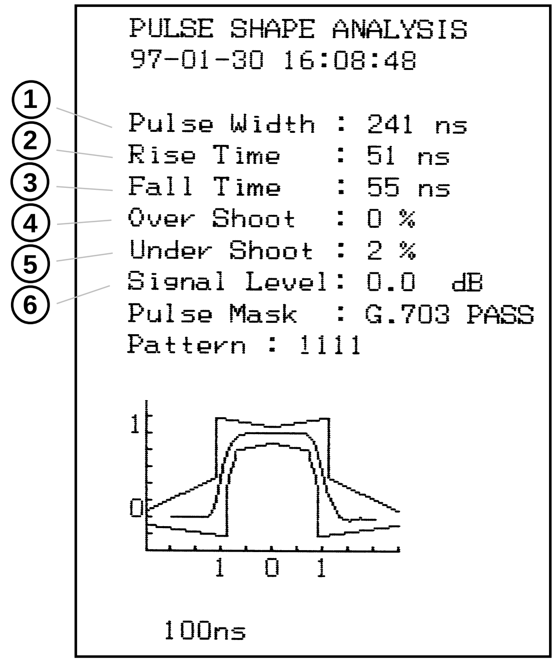

Figure 4 Example of pulse shape measurement screen

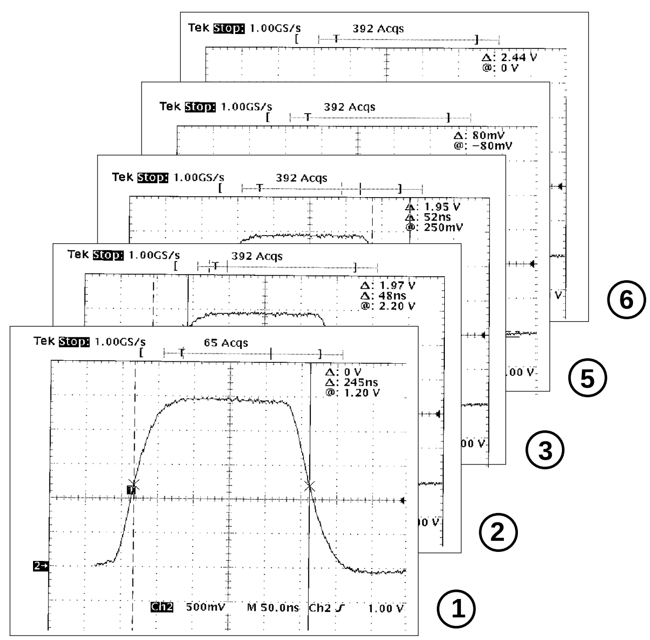

Figure 5 Comparable displays from a digital oscilloscope

5 LINE CODING

Two types of line coding are used in a typical E1 2.048 Mbit/s network: AMI (top of Figure 6) and HDB3 (bottom of Figure 6). HDB3 is the coding used most commonly for 2M, 8M, and 34M.

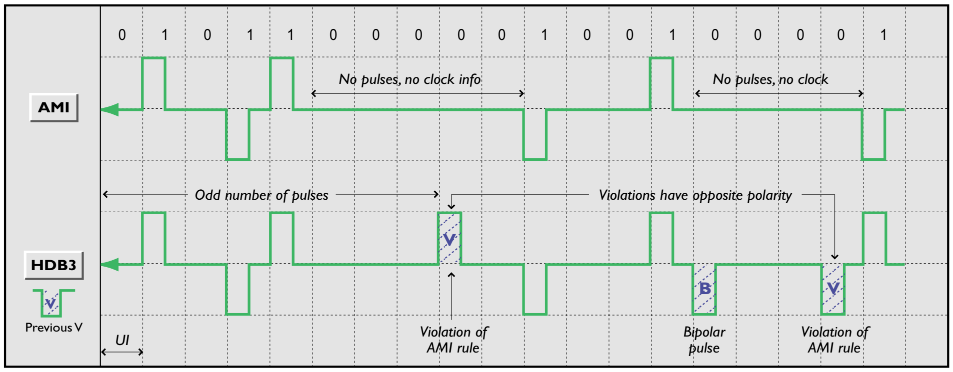

Figure 6 AMI and HDB3 line coding

5.1 AMI

- AMI: Alternate Mark Inversion
- AMI is used to represent successive 1s' values in a bitstream with alternating positive and negative pulses to eliminate any DC offset.
- AMI is not used in most 2.048 Mbit/s transmission because synchronization loss may occur during long strings of zeros as there are no pulses.

5.2 HDB3

High Density Bipolar 3 (HDB3) line coding is used for transmission of 2 Mbps for two key reasons:

- The HDB3 coded signal is DC-free. Therefore, the signal can be transmitted through balanced transformers' coupled circuits.
- The clock recovery circuits of the receivers can operate well, even though the data contains long strings of zeros.

5.2.1 Basic Encoding Principles

No more than three consecutive zeroes are permitted. The AMI (Alternate Mark Inversion) rule is violated intentionally whenever 4 or more zeros are encountered. The 4 zeros are substituted in one of the two ways described and illustrated below. Which method is used is governed by the polarity of the last inserted violation pulse (V) and whether the number of pulses between the previous violation pulse and the next one is odd or even.

- If there is an odd number of pulses between the last violation pulse V and the next V to be inserted, the 0000 is substituted with 000V. The polarity of the inserted V bit is the same as that of the pulse immediately preceding it. The polarity of this V is opposite to that of the previous V (Figure 7).
- If there is an even number of pulses between the last violation V and the next V, the 0000 is substituted with B00V. B (Bipolar pulse) is inserted in the place of the first zero and its polarity is opposite to that of the pulse immediately preceding it. The polarity of the inserted V is the same as that of B and opposite to that of the previous V.

5.2.2 Detection of Errors in HDB3 Coded Signals

In practice, the transmitted signal encounters a variety of distortions and impairments such as attentuation and noise. This leads to improper detection of the received signal – a zero, for instance, may be detected as a positive or negative one, or vice versa. Depending upon the pattern and the actual bit position errored, the receiver may declare code and/or bit error, as illustrated in the following example:

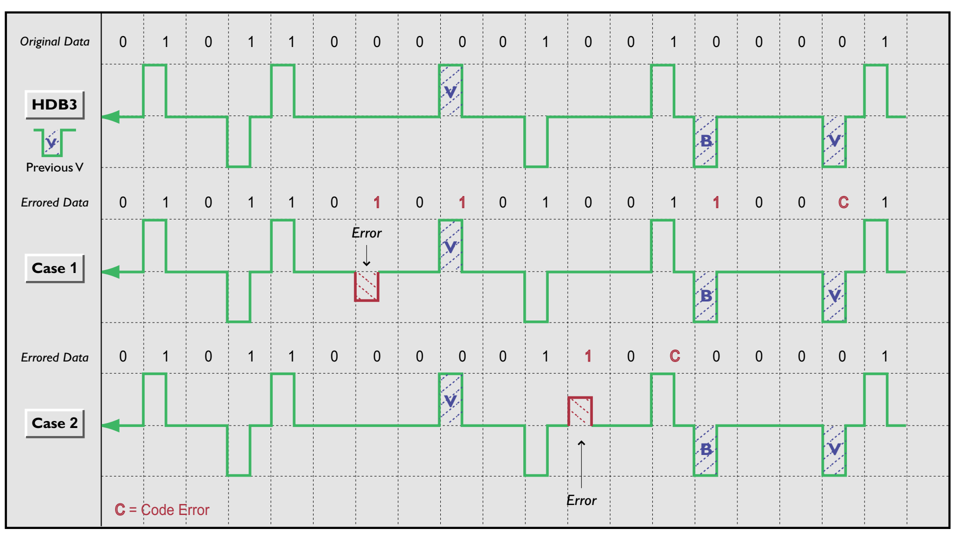

Figure 7 HDB3 error detection

6 FRAMING

- Framing is necessary so any equipment receiving the E1 signal can synchronize, identify, and extract the individual channels.
- 2M transmission utilizes two main types of framing:
  - Frame Alignment Signal (FAS)
  - MultiFrame Alignment Signal (MFAS)
- PCM-30 transmission systems use MFAS framing along with FAS framing
  - In PCM-30 timeslots 1 through 15 correspond to channels 1 through 15, and timeslots 17 through 31 correspond to channels 16 through 30.
  - Timeslot 16 is used for the multiframe alignment and Channel Associated Signaling (CAS)
- PCM-31 transmission systems use only FAS framing
  - In PCM-31 framing, timeslots 1 through 31 correspond to channels 1 through 31.
- Fractional E1 is not offered with unframed signals, because framing is required to determine the location of timeslots.

6.1 Frame Alignment Signal (FAS)

- The 2.048 Mbit/s frame consists of 32 individual timeslots (numbered 0-31). Each timeslot consists of individual 64 kbit/s channels of data.
- Timeslot 0 of every even frame is reserved for the FAS. See Figure 8.
- Odd frames have the NFAS (Non FAS) word that contains the Distant Alarm indication bit and other bits reserved for national and International use.
- 31 timeslots remain for bearer channels, into which customer data can be placed.

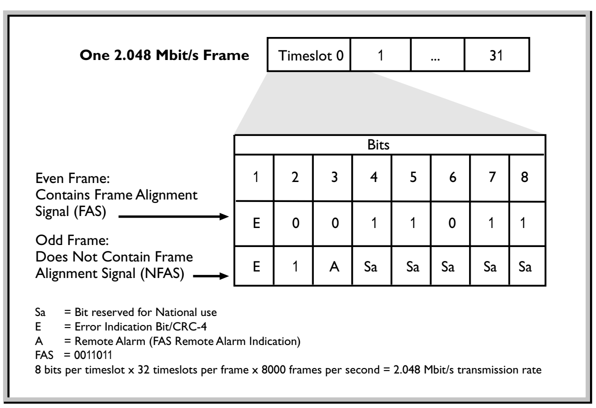

Figure 8 FAS framing format

6.2 MultiFrame Alignment Signal (MFAS)

- MFAS framing is used for Channel Associated Signaling (CAS) to transmit A/B/C/D bit information for each of the 30 channels (Refer to Figure 9).
  - This method uses the 32 timeslot frame format with timeslot 0 for the FAS and timeslot 16 for the MFAS and CAS.
- 16 frames make up a MultiFrame
- When a PCM-30 multiframe is transmitted, 16 FAS frames are assembled together. Timeslot 16 of the first frame is dedicated to MFAS bits, then timeslot 16 of the remaining 15 frames is dedicated to A/B/C/D bits.
- Frame 0, timeslot 16: 8-bit MFAS signal

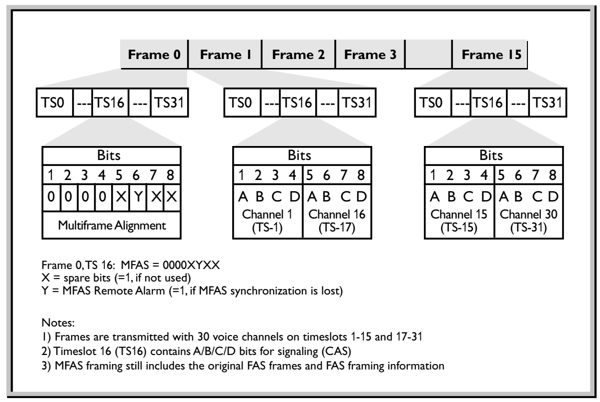

Figure 9 MFAS framing format

6.3 CRC Error Checking

A Cyclic Redundancy Check-4 (CRC-4) is often used in 2M transmission to identify possible bit errors during in-service error monitoring.

- CRC-4 is a checksum calculation which allows for the detection of errors within the 2.048 Mbit/s signal while it is in service. A discrepancy indicates at least one bit error in the received signal.
- The equipment which originates the 2M data calculates the CRC-4 bits for one sub-multiframe. It inserts the CRC-4 bits in the CRC-4 positions in the next sub-multiframe.
- The receiving equipment performs the reverse mathematical computation on the sub-multiframe. It examines the CRC-4 bits which were transmitted in the next sub-multiframe, then it compares the transmitted CRC-4 bits to the calculated value. If there is a discrepancy in the two values, a CRC-4 error is reported via E-bits indication.
- Each individual CRC-4 error does not necessarily correspond to a single bit error, which is a drawback. Multiple bit errors within the same sub-multiframe will lead to only one CRC-4 error for the block.

- Errors could occur such that the new CRC-4 bits are calculated to be the same as the original CRC-4 bits.
- CRC-4 error checking provides a most convenient method of identifying bit errors within an in-service system, but provides only an approximate measure (93.75% accuracy) of the circuit's true performance.

Consider the MFAS framing, illustrated in Figure 10. Each MFAS frame can be divided into "sub-multiframes". These are labeled SMF#1 and SMF#2 and consist of 8 frames apiece. We associate 4 bits of CRC information with each sub-multiframe.

The CRC-4 bits are calculated for each sub-multiframe, buffered, then inserted into the following sub-multiframe to be transmitted.

Multiframe	Sub-multiframe	Frame#	Timeslot 0 Bits bit1	bit2	bit3	bit4	bit5	bit6	bit7	bit8
	SMF #1	0	c1	0	0	1	1	0	1	1
		1	0	1	A	Sa4	Sa5	Sa6	Sa7	Sa8
		2	c2	0	0	1	1	0	1	1
		3	0	1	A	Sa4	Sa5	Sa6	Sa7	Sa8
		4	c3	0	0	1	1	0	1	1
		5	1	1	A	Sa4	Sa5	Sa6	Sa7	Sa8
		6	c4	0	0	1	1	0	1	1
		7	0	1	A	Sa4	Sa5	Sa6	Sa7	Sa8
	SMF #2	8	c1	0	0	1	1	0	1	1
		9	1	1	A	Sa4	Sa5	Sa6	Sa7	Sa8
		10	c2	0	0	1	1	0	1	1
		11	1	1	A	Sa4	Sa5	Sa6	Sa7	Sa8
		12	c3	0	0	1	1	0	1	1
		13	E	1	A	Sa4	Sa5	Sa6	Sa7	Sa8
		14	c4	0	0	1	1	0	1	1
		15	E	1	A	Sa4	Sa5	Sa6	Sa7	Sa8

SMF#1: Sub-multiframe #1
Sa: Spare bit reserved for National use
A: Remote Alarm (FAS Remote Alarm Indication)
Frame Alignment Signal Pattern: 0011011
CRC-4 Frame Alignment Signal: 001011
CRC multiframe is not aligned with MFAS timeslot 16 multiframe

SMF#2: Sub-multiframe #2
E: E-bit indicator
c1, c2, c3, c4: CRC bits

Figure 10 CRC-4 multiframe format

6.4 E-bit Performance Monitoring

When a 2.048 Mbit/s circuit's terminal equipment is optioned for CRC-4 transmission, E-bit transmission may also be enabled and E-bit performance monitoring of the circuit is possible. Check the specifications of your network equipment. Refer to Figure 11.

- When this type of terminal equipment detects an incoming CRC-4 error, it will respond by transmitting an E-bit error toward the other terminal.
  - Test set 2, shown in the diagram, will be able to see the E-bits by plugging into a protected monitoring point.
  - Note that the test set cannot see the actual code errors, framing bit errors, and CRC errors introduced at the trouble point. The test set can only see the E-bits transmitted by Terminal B.
- Without E-bits transmission, only a complete circuit failure can be reliably determined at any point on the circuit.
  - With a complete circuit failure, the test set will see either loss of signal, alarm indication signal, or remote alarm indication.
- E-bits indication has two bits; this notifies CRC-4 errors in sub-multiframe 1 and/or 2.

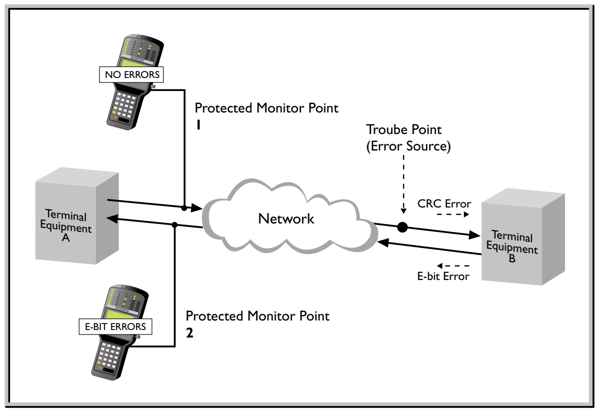

Figure 11 E-bit performance monitoring

7 ERRORS AND ALARMS

Troubleshooting an E1 line often involves monitoring for errors or alarms, or intentionally injecting errors or a particular stress test pattern to see how the system responds.

- Specifications covering error conditions include ITU-T G.821 and G.826. The requirements also depend on the grade of the line.
- A key concept for the measurements is availability. A circuit is available for use only when the bit error rate is low enough that the signal can get through and be understood.
- A circuit is said to be unavailable at the beginning of 10 consecutive severely errored seconds. Errors, errored seconds, and severely errored seconds are not counted when the circuit is unavailable.
- Once a circuit is unavailable, it becomes available only after 10 consecutive seconds without severe errors.

Below are the definitions of some important errors & alarms.

AIS: Alarm Indication Signal is an unframed, all 1s signal.

BBE: A Background Block Error is an errored block (a block is a set of consecutive bits associated with a path) not occurring as part of an SES.

Bit Errors: Bit errors are bits which are in error. Bit errors are not counted during unavailable time.

Bit Slip: A bit slip occurs when the synchronized pattern either loses a bit or has an extra bit stuffed into it.

Clock Slips: Clock slips occur when the measured frequency deviates from the reference frequency by one unit interval.

Code Errors: A Code Error is a violation of the coding rules: two successive pulses with the same polarity. In HDB3 coding, a Code Error is a bipolar violation that is not part of a valid HDB3 substitution.

CRC Errors: CRC-4 block errors. This measurement applies to signals containing a CRC-4 check sequence.

Degraded Minutes: A Degraded Minute (DM) occurs when there is a 10-6 or worse bit error rate during 60 available, non-severely bit errored seconds.

Errored Block: A block in which one or more bits are in error.

E-bit Indication: An E-bit is transmitted by the receiving equipment after detecting a CRC-4 error.

ES: An errored second is any second in which one or more bits are in error. An errored second is not counted during an Unavailable Second. For G.826, an errored second contains one or more blocks with at least one defect.

FALM: Frame Alarm seconds is a count of seconds that have had far end frame alarm (FAS Remote Alarm Indication, RAI), which is when a 1 is transmitted in every third bit of each timeslot 0 frame that does not contain the frame alignment signal.

FASE: A count of the bit errors in the Frame Alignment Signal words received. It applies to both PCM-30 & PCM-31 framing.

Frequency: Any variance from 2.048 Mbit/s in the received frequency is recorded in hertz or parts per million.

LOFS: Loss of Frame Seconds is a count of seconds since the beginning of the test that have experienced a loss of frame.

LOSS: Loss Of Signal Seconds is a count of the number of seconds during which the signal has been lost during the test.

MFAL: MultiFrame ALarm seconds is a count of seconds that have had far end multiframe alarm (MFAS Remote Alarm Indication, RAI).

MFAS Distant Alarm: In this alarm, a 1 is transmitted in every sixth bit of each timeslot 16 in the zero frame.

SES: A Severely Errored Second has an error rate of 10^{-3} or higher. Severely errored seconds are not counted during unavailable time. For G.826 block measurements, a SES is a one second period containing 30% or greater errored blocks.

Timeslot 16 AIS: In this alarm all 1s are transmitted in timeslot 16 of all frames.

UAS: Unavailable time begins at the onset of 10 consecutive severely errored seconds. Unavailable Seconds also begins at a loss of signal or loss of frame.

Wander: This is the total positive or negative phase difference between the measured frequency and the reference frequency. The +Wander value increases whenever the measured frequency is one UI larger than the reference frequency. The -Wander increases whenever the measured frequency is one UI less than the reference frequency.

8 64 KBIT/S INTERFACES

Data is generally transmitted at a rate of 64 kbit/s. Recommendation G.703 provides requirements for different interfaces. For each direction of transmission, three signals can be carried across the interface: 64 kbit/s information, 64 kHz timing, and 8 kHz timing. The 8 kHz timing signal is not mandatory.

8.1 Codirectional Interface

A codirectional interface is an interface across which the data and its timing signal are transmitted in the same direction. This interface is used for synchronized networks, or in pleisochronous networks with sufficiently stable network clocks. It has a maximum tolerance of ±100 ppm for transmitted signals. A balanced pair is required for each direction of transmission.

8.2 Contradirectional Interface

A contradirectional interface is an interface across which the timing for both directions is directed towards the subordinate equipment. It has a maximum tolerance of ±100 ppm for transmitted signals. Each direction should have two symmetrical pairs of wires: one pair carrying the data, the other pair carrying the timing.

9 ITU-T RECOMMENDATIONS

The following Recommendations are commonly used:

G.703	Physical/electrical characteristics of hierarchical digital interfaces.
G.704	Synchronous frame structures used at 1544, 6312, 2048, 8488, and 44,736 kbit/s.
G.706	Frame alignment and cyclic redundancy check (CRC) procedures relating to basic frame structures defined in Recommendation G.704.
G.711	Pulse code modulation (PCM) of voice frequencies.