

application note

2.048 Mbps Technology Basics and Testing Fundamentals



TTC[™]

OPTIMIZING NETWORK PERFORMANCE

2.048 Mbps Technology Basics and Testing Fundamentals



he demand for high-quality 2.048 Mbps circuits requires thorough installation testing and consistent maintenance and circuit analysis. To provide clean, error-free transmissions, the 2.048 Mbps installation and maintenance personnel who test the performance of these circuits demand reliable equipment for their testing needs.

TTC supplies a range of test sets that are ideal for 2.048 Mbps installation, acceptance testing, routine maintenance, and fault isolation, all of which are integral to providing a quality 2.048 Mbps service.

This Application Note first describes 2.048 Mbps fundamentals and the impairments that can degrade 2.048 Mbps services. It then provides examples of applications for

- In-service monitoring
- Out-of-service testing

Each application section includes guidelines on how to accurately interpret the test results for rapid trouble shooting and fault isolation.

Those familiar with 2.048 Mbps basics may wish to turn immediately to the testing applications beginning on page 9.

2.048 Mbps Basics



2.048 Mbps circuit provides high speed, digital transmission for voice, data, and video signals at 2.048 Mbps.

2.048 Mbps transmission systems are based on the ITU-T specifications G.703, G.732 and G.704, and are predominant in Europe, Australia, Africa, South America, and regions of Asia. Due to an increase in demand for global communications in recent years, 2.048 Mbps installations in North America have risen sharply, and exist alongside the standard T-Carrier systems.

The 2.048 Mbps standards are now firmly established for transmission systems and are used by telecommunications network suppliers, international carriers and end users. The primary use of the 2.048 Mbps is in conjunction with multiplexers for the transmission of multiple low speed voice and data signals over one communication path rather than over multiple paths. *Figure 1* shows a typical system.

The 2.048 Mbps Line Code

The most common line code used to transmit the 2.048 Mbps signal is known as HDB3 (High Density Bipolar 3) which is a bipolar code with a specific zero suppression scheme where no more than three consecutive zeros are allowed to occur. The HDB3 line code is recommended for 2.048 Mbps signals by ITU-T Recommendations G.703, and it is defined in Annex A to Recommendations G.703.

In some instances straightforward bipolar AMI (Alternate Mark Inversion) coding with no zero suppression is also encountered.

In the following paragraphs, we will first review the AMI coding format, which represents the simplest version of bipolar line code. We will then move on to explaining the 2.048 Mbps HDB3 line code, which essentially is a variation of AMI where a high density of pulses is ensured by applying a zero suppression algorithm.

AMI or Bipolar Line Code

In the AMI coding format, a binary one (mark) is represented by a square pulse with a 50% duty cycle and a binary zero (space) is represented by the lack of pulse, i.e., 0 Volts. Since successive pulses (i.e., marks) alternate in polarity the line code is termed AMI (Alternate Mark Inversion).

HDB3 Line Code

Despite its numerous advantages, AMI coding has one very significant shortcoming. Since signal transition are the only way for 2.048 Mbps equipment to recover the timing information, long strings of zeros with no pulse transition in the data stream may cause the equipment to lose timing. Hence AMI coding puts strict limitations on the zero content of the data transmission in the 2.048 Mbps system.

One solution to this problem is to use a coding scheme that suppresses long string of zeros by replacing them with a specific sequence of pulses, which can be recognised and decoded as zeros by 2.048 Mbps equipment. HDB3 is one such coding scheme upon which the 2.048 Mbps industry standardised.

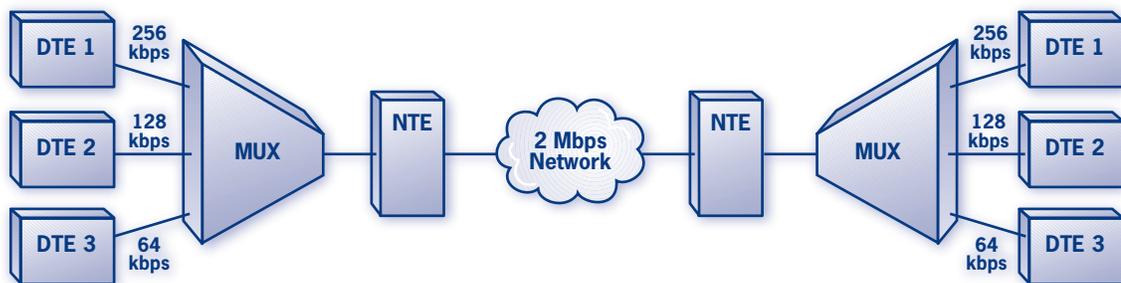


Figure 1:

A typical 2.048 Mbps transmission system

How HDB3 Works

The HDB3 signal is a bipolar signal, where sets of 4 consecutive zeros are replaced by a specific sequence of pulses and the last pulse is coded as a violation. This ensures that the 2.048 Mbps signal has a high density of pulses and no more than 3 consecutive zeros. **Table 1** shows the rules for zero substitution using the HDB3 coding scheme.

An example of how these rules are applied to an AMI signal is shown in **Figure 2**.

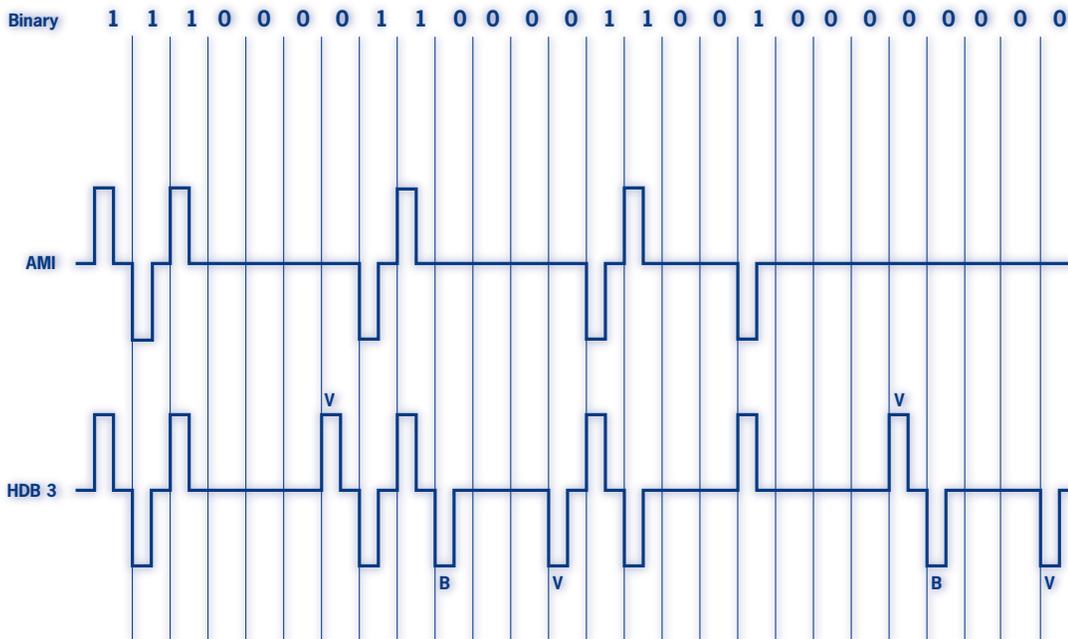
It is important to note that:

1. The 4th zero is always coded as a violation pulse.
2. The 1st zero may be coded as a “balancing” pulse to ensure that successive HDB3 violation pulses are of opposite polarity, so that the net DC component of the signal remains zero.

Hence the HDB3 code eliminates all the limitations on the zero content of the signal transmitted in the 2.048 Mbps system, while preserving all the advantages of AMI coding.

Polarity of Preceding Pulse	Number of Bipolar Pulses (Ones) Since Last Substitution	
	Odd	Even
-	000-	+00+
+	000+	-00-

Table 1:
HDB3 substitution rules



V = Pulse violating the AMI sequence
B = Additional pulse ensuring that the consecutive V pulses are of opposite polarity

Figure 2:
Example of a HDB3 signal

The 2.048 Mbps Framing Format

The 2.048 Mbps signal typically consists of multiplexed data and/or voice which requires a framing structure for receiving equipment to properly associate the appropriate bits in the incoming signal with their corresponding channels. **Figure 3** shows the framing for the 2.048 Mbps signal as defined in ITU-T Recommendation G.704.

As can be seen in **Figure 3**, the 2.048 Mbps frame is broken up into 32 timeslots numbered 0-31. Each timeslot contains 8 bits in a frame, and since there are 8000 frames per second, each time slot corresponds to a bandwidth of $8 \times 8000 = 64$ kbps.

Time slot 0 is allocated entirely to the frame alignment signal (FAS) pattern, a remote alarm (FAS Distant Alarm) indication bit, and other spare bits for international and national use. The FAS pattern (0011011) takes up 7 bits (bits 2-8) in timeslot 0 of every other frame. In those frames not containing the FAS pattern, bit 3 is reserved for remote alarm indication (FAS Distant Alarm) which indicates loss of frame alignment when it is set to 1. The remaining bits in timeslot 0 are allocated as shown in **Figure 4**.

If the 2.048 Mbps signal carries no voice channels, there is no need to allocate additional bandwidth to accommodate signalling. Hence, time slot 1-31 are available to transmit data with an aggregate bandwidth of 2.048 Mbps - 64 kbps (TSO) = 1.984 Mbps.

One 2.048 Mbps Frame

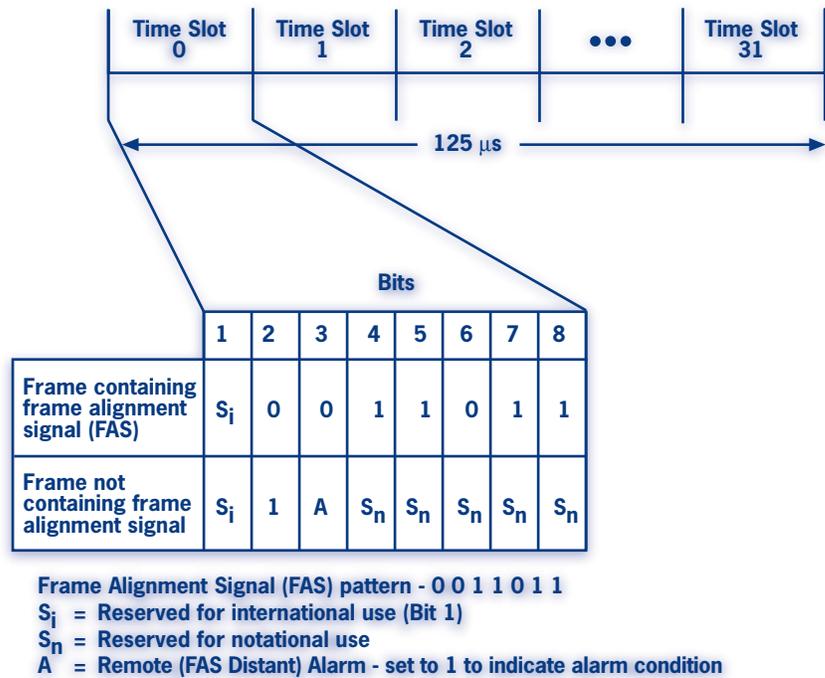
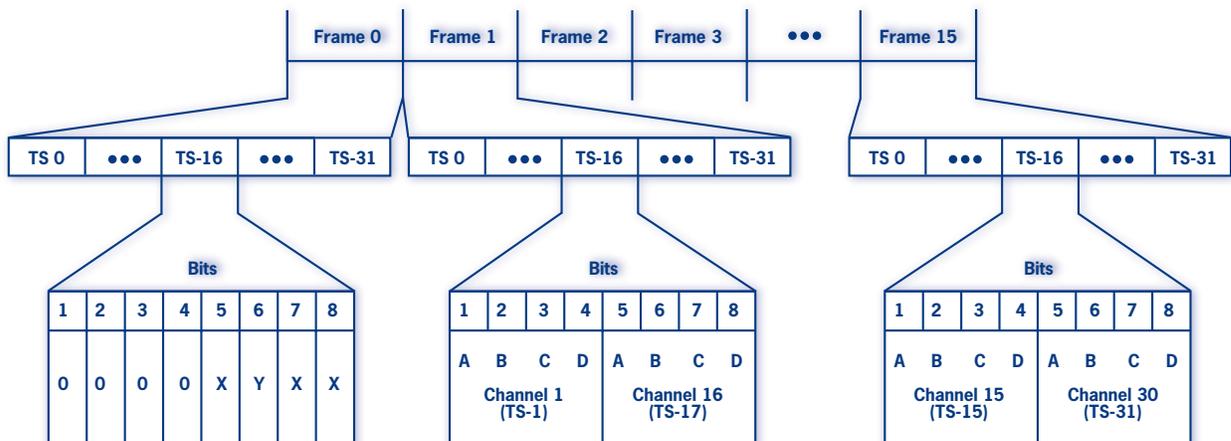


Figure 3:
The 2.048 Mbps framing format



Multiframe Alignment Signal (MFAS) pattern - 0 0 0 0
X = Spare parts (set to 1 if not used)
Y = Remote Alarm (set to 1 to indicate loss of multiframe alignment)
A B C D = Signaling bits

NOTE: Even numbered frames contain the FAS pattern in time slot 0

Figure 4:
The 2.048 Mbps TS-16 multiframe format

If there are voice channels on the 2.048 Mbps signal, it is necessary to take up additional bandwidth to transmit the signalling information. ITU-T Recommendation G.704 allocates time slot 16 for the transmission of the channel-associated signalling information. This is explained in the next section.

The 2.048 Mbps TS-16 Multiframe Format

The 2.048 Mbps can carry up to thirty 64 kbps voice channels in time slot 1-15 and 17-31.



Voice channels are numbered 1-30; voice channels 16-30 are carried in time slot 17-31.

However, the 8 bits in time slot 16 are not sufficient for all 30 channels to signal in one frame. Therefore, a multiframe structure is required where channels can take turns using time slot 16.

Since two channels can send their ABCD signalling bits in each frame, a total of 15 frames are required to cycle through all of the 30 voice channels. One additional frame is required to transmit the multiframe alignment signal (MFAS) pattern, which allows receiving equipment to align the appropriate ABCD signalling bits with their corresponding voice channels. This results in the TS-16 multiframe structure where each multiframe contains a total of 16 2.048 Mbps, numbered 0-15. **Figure 4** on the previous page shows the TS-16 multiframe format for the 2.048 Mbps signal as defined by the ITU-T Recommendation G.704.

As can be seen in **Figure 4**, time slot 16 of frame 0 contains the 4-bit long multiframe alignment signal (MFAS) pattern (0000) in bits 1-4. The "Y" bit is reserved for the remote alarm (MFAS Distant Alarm) which indicates loss of multiframe alignment when it is set to 1.

Time slot 16 of frames 1-15 contains the ABCD signalling bits of the voice channels. Time slot 16 of the nth frame carries the signalling bits of the nth and (n+15)th voice channels. For example, frame 1 carries the signalling bits of voice channels 1 and 16, frame 2 carries the signalling bits of channels 2 and 17 etc.

It is also important to note that the frame alignment signal (FAS) is transmitted in time slot 0 of the even numbered frames.

We have thus explained how frame alignment and channel associated signalling are achieved in 2.048 Mbps transmission. (Alternatively, time slot 16 may also be used for common channel signalling applications such as primary rate ISDN). It must be noted, however, that the 2.048 Mbps framing and TS-16 multiframing structures discussed so far do not provide any built in error detection capabilities, which could be used to determine the error performance of the 2.048 Mbps system on an in-service basis. This capability is provided by the CRC (Cyclic Redundancy Check) multiframe structure as explained in the next section.

	Sub-multiframe (SMF)	Frame Number	Bits 1 to 8 (TS 0) of the Frame							
			1	2	3	4	5	6	7	8
Multiframe	I	0	C ₁	0	0	1	1	0	1	1
		1	0	1	A	S _n				
		2	C ₂	0	0	0	0	0	0	0
		3	0	1	A	S _n				
		4	C ₃	0	0	1	1	0	1	1
		5	1	1	A	S _n				
		6	C ₄	0	0	1	1	0	1	1
	7	0	1	A	S _n					
	II	8	C ₁	0	0	1	1	0	1	1
		9	1	1	A	S _n				
		10	C ₂	0	0	0	0	0	0	0
		11	1	1	A	S _n				
		12	C ₃	0	0	1	1	0	1	1
		13	S _i	1	A	S _n				
		14	C ₄	0	0	1	1	0	1	1
15		S _i	1	A	S _n					

C₁, C₂, C₃, and C₄ = Cyclic Redundancy Check Bits
 CRC Multiframe Alignment Signal 0 0 1 0 1 1
 S_n = Reserved for notational use
 A = Remote (FAS Distant) Alarm - set to 1 to indicate alarm condition

Figure 5:
The 2.048 Mbps
CRC multiframe format

The 2.048 Mbps CRC Multiframe Format

This section describes the specifics of the 2.048 Mbps CRC Multiframe format. To find out how CRCs provide the enhanced error performance monitoring capabilities mentioned above, refer to the “CRC Error Analysis” section (page 9) under Application #1, In-Service Analysis of Live Traffic.

The 2.048 Mbps CRC Multiframe structure as defined by ITU-T Recommen-

ation G.704 is shown in **Figure 5** on the previous page.

The CRC Multiframe consists of 16 frames (numbered 0-15) which are divided into two sub-multiframes (SMF-1 and SMF-11) of 8 frames each. The 4-bit long CRC word associated with each sub-multiframe, SMF(N) is inserted into the next sub-multiframe, SMF(N+1). The CRC bits take up the 1st bit of time slot 0s containing the 7-bit FAS (Frame Alignment Signal) pattern. The CRC Multiframe

alignment signal uses the 1st bit of time slot 0s not containing the FAS pattern. (See **Figure 5**).

Combining the TS-16 and CRC Multiframe Structures

A 2.048 Mbps signal may come in a number of different formats, depending on which of the above frame and multiframe structures are implemented in the 2.048 Mbps system. **Table 2** gives a comparison of the possible variations of a 2.048 Mbps signal.

Framing Format	Total Bandwidth Available for Data/Voice	Notes/Limitations
No Framing	2.048 Mbps (32 time slots)	Cannot use the publicly switched network.
No Multiframe	1.984 Mbps (31 time slots)	No voice transmission with TS-16 signalling possible.
TS-16 Multiframe No CRC Multiframe	1.920 Mbps (30 time slots)	No error performance monitoring via CRCs.
CRC Multiframe No TS-16 Multiframe	1.984 Mbps (31 time slots)	No voice transmission with TS-16 signalling possible.
TS-16 Multiframe and CRC Multiframe*	1.920 Mbps (30 time slots)	Voice transmission with TS-16 signalling and error monitoring possible.

***Note:**

The two multiframe structures are not related, and need not be aligned with each other in any way.

Table 2:

Various 2.048 Mbps frame and multiframe formats

Causes of 2.048 Mbps Impairments



here are four main causes of 2.048 Mbps impairments:

1. **Faulty Equipment:** Any piece of 2.048 Mbps equipment can cause errors when the components fail or operate outside of specifications. Errors, which can signal faulty equipment, include code errors, bit errors, FAS (frame) errors, excessive jitter, and slips. For instance, code errors can occur due to faulty clock recovery circuitry in span repeaters. These errors occur as the equipment becomes older and begins to drift out of specifications.
2. **Improper Connections:** Transmission errors are created by improper connections or configurations. For example,

intermittent errors can occur when component or cable connections are loose, and timing errors can occur when improper or conflicting timing sources are connected together. Dribbling errors are often caused by loose or unconnected shield ground cables and by bridge taps. Further, upon installation, the circuit may not work at all due to mislabelled pin-outs on terminating cable blocks and to flip-flopped wires: transmit-to-transmit as opposed to transmit-to-receive. These errors are typically discovered upon circuit installation and possibly during circuit acceptance when tests are performed end-to-end.

3. **Environmental:** Electrical storms, power lines, electrical noise, interference, and crosstalk between transmission links can cause logic errors, FAS (frame) errors, CRC errors in addition to code errors. Typically, these conditions cause intermittent, bursty errors, which are some of the most difficult to locate.
4. **Data Specific:** Data characteristics, such as repetitive patterns, can force equipment to create pattern-dependant jitter and code errors. These errors may not exist when testing the transmission path with standard pseudorandom patterns.

Analyzing 2.048 Mbps Impairments

Techniques and Measurements



To analyse a 2.048 Mbps circuit's performance and to isolate the causes of degraded services, the test set must perform many measurements in different scenarios.

There are four typical scenarios where 2.048 Mbps testing is required:

1. **Installation:** When installing a 2.048 Mbps circuit, out-of-service testing is very useful in verifying equipment operations and end-to-end transmission quality. One starts by testing the equipment (such as NTE's, channel banks, multiplexers), and then verifying cable connections, timing source selections, and frequency outputs.

Application #2 covers this test scenario.

2. **Acceptance Testing:** In addition to the test performed during installation, two other tests—stress tests and timed tests—should be performed to ensure that the 2.048 Mbps circuit is operating properly with respect to the relevant 2.048 Mbps circuit specifications and tariff. The equipment may be stressed by verifying the transmission frequency around 2.048 Mbps equipment. The same procedure may be performed end-to-end to stress the entire 2.048 Mbps circuit. Timed tests with printouts should be performed over a 24- or 48-hour period using standard pseudorandom patterns, which simulate live data.

Application #2 is useful for this scenario.

3. **Routine Preventive Measure:** Routine maintenance test are strongly recommended once live data is transmitted across the 2.048 Mbps circuit. Routine maintenance can alert technicians to degrading service before it disrupts normal operations. In most instances, this involves monitoring the live data for alarms, code errors, FAS (frame) errors,

CRC errors, and signal frequency measurements which provide information about the performance of the 2.048 Mbps circuit. These tests should be performed with printouts over a 24- or 48-hour period to detect time specific or intermittent errors.

Application #1 covers this scenario.

4. **Fault Isolation:** Fault isolation is required once service is disrupted due to excessive error rates. This can be performed using both in-service and out-of-service tests. In-service monitoring provides general information and can be used before out-of-service analysis to localise problems and minimise circuit downtime. By monitoring the circuit at various points, technicians are able to analyse the results and determine where problems are originating. By performing standard out-of-service tests, such as loopback and end-to-end tests, technicians are able to stress the equipment, find sources of errors, and verify proper operation once the trouble is repaired.

Application #1 and Application #2 are relevant for fault isolation.

Application #1: In-Service Analysis of Live Traffic



The following sections explain how to evaluate the performance of a 2.048 Mbps system using customer data. It is useful:

- When performing periodic maintenance and when looking for transmission degradation before it effects service.
- When analysing the span for intermittent errors, which are caused by faulty equipment or environmental influences.
- For analysis of 2.048 Mbps circuits which cannot be taken out-of-service.

- Before out-of-service analysis, to localise the problem and minimise circuit downtime.

To achieve all these benefits, the TTC test set may be configured to monitor the 2.048 Mbps circuit from practically any 2.048 Mbps access point. **Figure 6** shows a typical circuit and possible monitoring locations.

Analysis of Alarm and Error Indications (In-Service Testing)

Testing and troubleshooting of a 2.048 Mbps signal requires regular monitoring for alarms and errors. The monitoring for alarms and errors allows the user to detect and sectionalize transmission lines or equipment problems in a 2 Mbps signal. Errors can also be intentionally injected to see the response of the system.

Table 3 highlights some of the important alarm and error indications along with possible reasons and solutions.

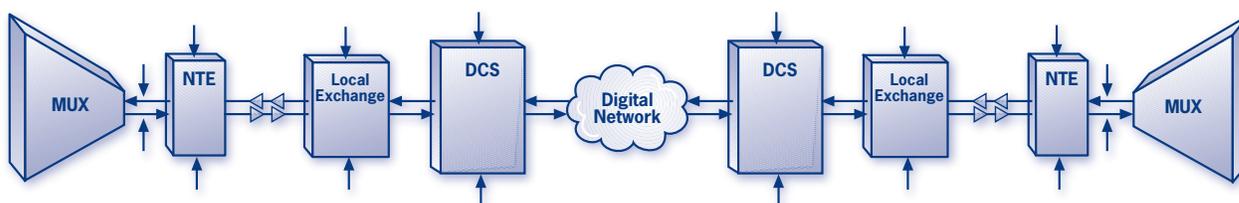


Figure 6:
Possible 2.048 Mbps circuit monitoring locations

Result	Reason	Possible Solution
SIGNAL LOSS	Indicates history of receiver signal loss	Check cabling and connections. Check network equipment.
FRAME LOSS	Indicates history of frame synchronisation loss	Check SIGNAL LOSS and POWER LOSS LEDs. If these LEDs are not on, check FAS Distant alarm and AIS alarm.
FRAME SYNC	Signal is unframed, or synchronisation to the specified framing has not been achieved	Verify all settings and connections.
FAS Distant Alarm	Indicates remote (FAS Distant) alarm	Check span equipment downstream from present location. Check local Tx.
AIS Alarm	Indicates AIS alarm (Unframed All Ones)	Check span equipment upstream from present location.

Table 3:
Common alarm and error indications (in-service testing)

The AIS and FAS Distant Alarms

This section gives a detailed explanation of the 2.048 Mbps AIS and FAS Distant alarms.

The AIS Alarm

An AIS alarm is an unframed continuous stream of binary ones. However, a signal with all bits except the frame alignment in the 1 state is not mistaken as an AIS.

If the network equipment shown in **Figure 7** suffers a signal or frame synchronisation loss, or receives an AIS alarm at input #1 (2), it transmits the AIS alarm at output #1 (2). Hence, the AIS alarm indicates the presence of an alarm indication to the equipment farther downstream (away from the source of the trouble).

Therefore if the TTC test set receives an AIS alarm, this indicates that the trouble must lie somewhere farther upstream in the network. This is illustrated in **Figure 8**.

The FAS Distant Alarm

The FAS Distant alarm is indicated by setting bit 3 equal to 1 in time slot 0 of the frames not containing the FAS pattern. (See **Figure 3** on page 4).

If the network equipment shown in **Figure 9** suffers a signal or frame synchronisation loss, or receives an AIS alarm at input #1 (2), it transmits the FAS Distant Alarm at output #2 (1). Hence, the FAS Distant alarm indicates the presence of an alarm condition to the equipment farther upstream (back towards the source of the trouble).

Therefore if the test set receives a FAS Distant alarm, this indicates that the trouble must lie somewhere farther downstream in the network. This is illustrated in **Figure 8**.

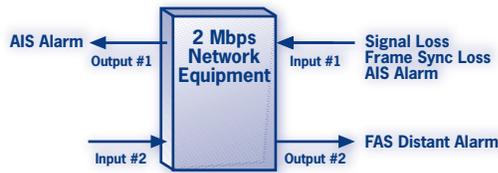


Figure 7:
2.048 Mbps network alarms

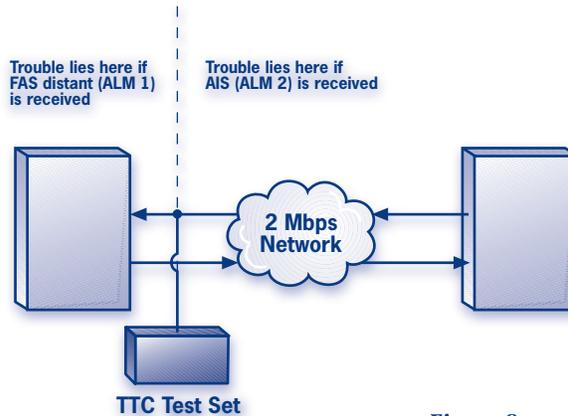


Figure 8:
Detection of 2.048 Mbps network alarms

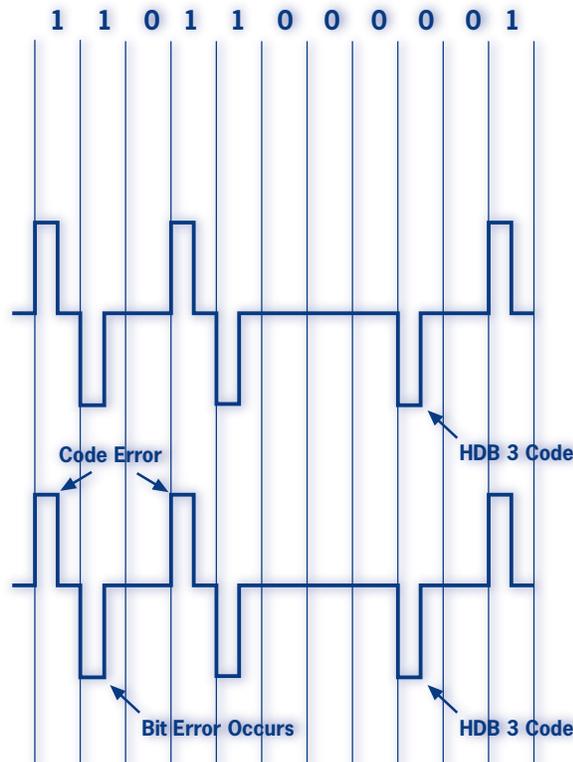


Figure 9:
Code errors

- A. Code violation due to HDB 3 (no code errors counted)
- B. The bit error on the 2nd bit causes a code error (the HDB 3 code is recognized and 1 code error is counted)

Code Error Analysis

The bipolar nature of the AMI signal allows the detection of single (isolated) errors since single errors on the line cause a pulse to be either incorrectly added or omitted, which in turn results in two successive pulses of the same polarity. This constitutes a violation of the bipolar coding scheme.

Recall that due to the zero suppression scheme used in HDB3, the signal may also contain *intentional* bipolar code violations representing strings of 4 consecutive zeros. These intentional code violations due to HDB3 must be distinguishing from code violations due to the errors occurring on the 2.048 Mbps line.

Since bipolar code violations due to HDB3 follow specific rules, they can be recognised as such by the TTC test set. This constitutes the basis for the code error analysis performed by the test set.

A *code error* is defined as any violation of the bipolar code, which is not a code violation due to HDB3's zero substitution algorithm. For comparison, an illustration of a code error along side an HDB3 substitution code is shown in **Figure 9**.

It is not necessary to receive and transmit a known pattern to recognise code errors. Hence the TTC test set can perform code error analysis on an in-service basis without disrupting the traffic on the 2 Mbps line. To do this analysis, the TTC test set provides the following key result:

Code Errors (CODE ERR)	Number of code errors detected since beginning of test.
Code Error Rate (CER)	Ratio of number of code errors in last test interval to number of bits examined in last test interval.

Advantages/Limitations of Code Error Analysis

Code errors provide an approximate indication of the error performance on a *metallic* 2.048 Mbps line without the need to disrupt live traffic. Furthermore, they can generally be used to sectionalise problems to the local span in the 2.048 Mbps network. (This will be discussed further under “Correlation of Results and Problem Causes”).

It must be noted, however, that code error analysis has certain limitations. Code errors are useful in identifying local (near end) metallic span and repeater problems. However they are not a good indication of end-to-end performance since network equipment beyond the local span or non-metallic transmission media (e.g. microwave and fibre) will correct code errors in the far end 2.048 Mbps span.

FAS (Frame Alignment Signal) Error Analysis

As we explained in our discussion of the 2.048 Mbps Framing Format, time slot 0 of every other 2.048 Mbps frame contains a *fixed* 7-bit long FAS pattern (See **Figure 3** on page 4). When doing in-service FAS error analysis, the TTC test set takes advantage of the fact that even though the data portion of the 2.048 Mbps frame is unknown, the FAS bits contain a *known* pattern such that the errors occurring on these bits can be detected without disrupting the traffic.

Hence the TTC test set counts a FAS error each time one or more bits in the FAS pattern are received in error.

Upon synchronisation with the frame alignment signal, the TTC test set automatically provides the following result:

FAS Errors (FAS ERR)	Number of FAS errors received since beginning of test.
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Advantages/Limitations of FAS Error Analysis

FAS errors allow in-service error performance analysis of the 2.048 Mbps circuit. Under random (Gaussian) error conditions, the FAS error rate will closely approximate the actual error rate if the test is performed over a significantly long period of time.

Moreover FAS errors can be used to isolate problems to network equipment (such as digital cross connect systems and higher order multiplexers) which frame (or reframe) the 2.048 Mbps data.

The limitations of FAS error analysis are threefold.

1. Since the FAS pattern takes up only 7 bits for every 512 bits transmitted (2 frames x 32 time slots/frame x 8 bits/time slot = 512 bits), the analysis is performed on a relatively small number of the received bits (about 1.4%). As a result, errors not occurring on the FAS bits will be missed.
2. Bursty error condition are far more common than random (Gaussian) error condition.
3. FAS errors are corrected by multiplexers and digital cross-connected systems. Hence, FAS error analysis cannot be used to determine end-to-end error performance in networks where this type of equipment is installed.

CRC Error Analysis

When the 2.048 Mbps signal has the CRC Multiframe format implemented, the TTC test equipment will automatically perform CRC error analysis as explained in **Table 4**.

At the Transmitter:	
Step 1	The 4-bit CRC is calculated for a 2.048 Mbps SMF (submultiframe = 8 frames).
Step 2	The CRC is inserted in the CRC bits of the next SMF.
At the Receiver:	
Step 1	The TTC test set recalculates the CRC for the SMF.
Step 2	The TTC test set compares the calculated CRC to the CRC it receives in the CRC bits of the next SMF.
Step 3	The TTC test set declares a CRC error if the received CRC and the calculated CRC do not match indicating the occurrence of one or more bit errors in the SMF.
For CRC error analysis, the TTC test set provides the following results:	
CRC Errors (CRC ERR)	Number of CRC errors counted since beginning of test.
CRC Error Rate (AVG CRC)	Ratio of number of CRC errors counted to number of CRCs received.

Note:

To derive the approximate bit error rate (BER) from the average CRC error rate use the following formula:

$$\begin{aligned} \text{Approximate BER} &= \text{AVG CRC} / (\# \text{ of bits in SMF} - \text{CRC bits in SMF}) \\ &= \text{AVG CRC} / (2048 - 4) = \text{AVG CRC} / 2044 \end{aligned}$$

This formula will give a fairly accurate approximation to the actual BER, as long as there is no more than one bit error per submultiframe (i.e., average BER < 1E-6).

Table 4:
CRC error analysis procedure

Advantages/Limitations of CRC Error Analysis

Most data sequences generate a CRC word which can be uniquely associated with that particular data sequence. Therefore, CRC errors can detect the presence of one or more bit errors in a submultiframe to a very high degree of accuracy (93.75%) without the need to take the 2.048 Mbps circuit out-of-service.

However, the following limitation of CRC error analysis must be kept in mind.

1. A CRC error indicates the *occurrence* of one or more errors, but not the *total number* of errors in a submultiframe. Hence, the BER obtained using the formula above will be somewhat lower than the actual error rate if the error rate is so high that there are several errors in the submultiframe.



1 error per submultiframe corresponds to an average error rate of 4.9E-4.

2. CRCs may be recalculated by network equipment such as digital cross connect systems. Therefore, CRC error analysis cannot be used to determine end-to-end performance in networks where this type of equipment is installed.

Correlation of In-Service Results

To find possible problem causes, use **Figure 10** to find your location along the 2.048 Mbps span, and cross-reference your location with **Table 5**, which shows various combinations of the results discussed in the previous sections.

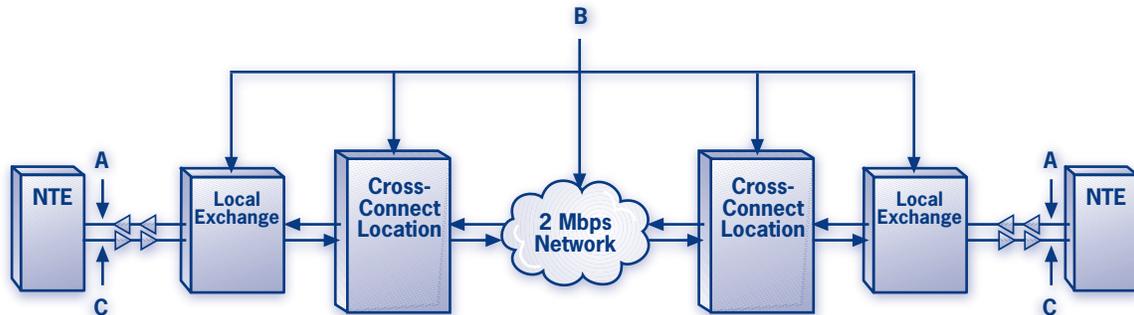


Figure 10:
Possible problem locations

Location for Figure 10	Results	Problem/Location
A	Code Errors	Local problem. Possibly bad cabling connections between test set and circuit, corroded “dirty” cable plugs, or defective NTE.
A, B, or C	Received Frequency Offset	Frequencies which are out of range may affect jitter tolerance and noise margins, in addition to causing error bursts and slips.
B or C	Code Errors, FAS Errors, or CRC Errors	Local 2.048 Mbps span problem. Possible faulty repeater, span line noise, crosstalk, poor cabling, or defective monitor jacks.
C	Code Errors, No FAS Errors, or CRC Errors	Local 2.048 Mbps span problem.
C	No Code Errors, FAS Errors, or CRC Errors	Typically far-end span line problem. Sectionalise further. Potential for light guide, radio, or Violation Monitor Removal (VMR) equipment in network.

Table 5:
Correlation of results and problem causes

Application #2: Out-of-Service Testing of 2.048 Mbps Circuits



The following sections explain how the TTC test set is used to evaluate the performance of a 2.048 Mbps system using pseudorandom

data. It is useful:

- When installing 2.048 Mbps circuits and verifying end-to-end continuity.
- When isolating 2.048 Mbps circuit faults and verifying end-to-end continuity.
- When performing acceptance testing which includes timed and stress tests.

Errors found via this analysis may be caused by faulty equipment, improper connections, environmental influences, or data content. To find these errors, use results such as bit errors, bit error rate (BER), FAS errors, pattern slips, received frequency, error free seconds (EFS), percentage error free seconds (%EFS), etc, which are all measured simultaneously. These results will help in isolating the cause of the problem.

There are basically two methods of performing out-of-service testing: loopback testing and end-to-end testing. These methods are addressed in the following sections.

Analysis of Alarm and Error Indications (Out-of-Service Testing)

Testing and troubleshooting of a 2.048 Mbps signal requires regular monitoring for alarms and errors. The monitoring for alarms and errors allows the user to detect and sectionalize transmission lines or equipment problems in a 2 Mbps signal. Errors can also be intentionally injected to see the response of the system.

Table 6 highlights some of the important alarm and error indications along with possible reasons and solutions.

Result	Reason	Solution
PATTERN SYNC	Test set is not synchronised to the incoming pseudorandom pattern	Check BERT pattern selection and FRM SYNC status. If test set in self loop is operating properly, this indicates 2.048 Mbps circuit problem.
FRAME SYNC	Signal is unframed, or synchronisation to specified framing has not been achieved	Verify all settings and connections.
FAS Distant	Indicates remote (FAS Distant) alarm	Check span equipment downstream from present location.
AIS Alarm	Indicates AIS alarm	Check span equipment upstream from present location.

Table 6:
Common alarm and error indications

End-to-End Testing

End-to-end testing is performed with two TTC test sets so that both directions of the 2.048 Mbps circuit may be analysed simultaneously. **Figure 11** shows the set-up of an end-to-end test. This test method is better than the loopback test since the direction of errors can be found more quickly.

Loopback Testing

Loopback testing is performed with one TTC test set. **Figure 12** shows the set-up of the loopback test. If NTE loopbacks are

established to perform the test, it is important to realise that the far end NTE in loopback will affect the result. By design, most NTE's remove received code errors before transmitting the data. This will affect the analysis result, because the near end technician will be unaware of code errors occurring on the far end metallic loop and may draw inconclusive results. Furthermore loopback tests cannot identify incorrect timing configurations where the customer premises equipment (connected to the NTE) may not be loop-timed to the network.



The appropriate pseudorandom pattern recommended for out-of-service testing at 2.048 Mbps is the $2^{15} - 1$ pattern as specified by ITU-T Recommendation O.151.

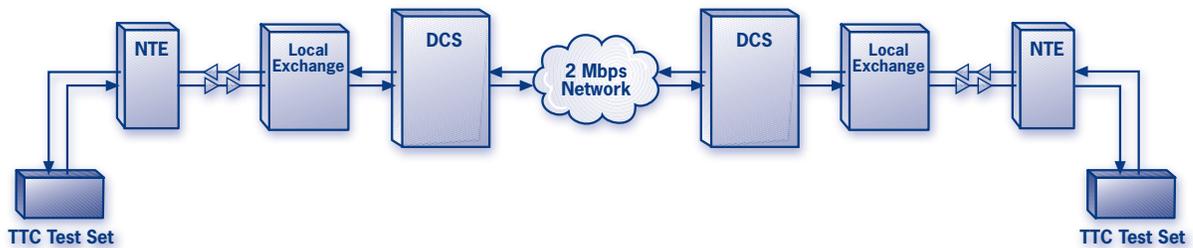


Figure 11:
Basic setup—end-to-end testing

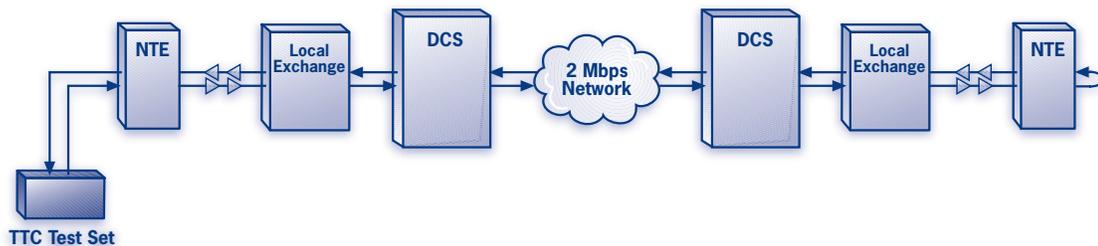


Figure 12:
Basic setup—loopback testing

Analysis of Slips

Slips and Their Causes

A pattern slip is the insertion of data bits into or from the data stream. Based on the source of the slip and its effect on the network, all slips can be placed on any of the following categories.

1. **Controlled Slips:** Controlled Slips are bit additions or deletions which do not disrupt frame synchronisation.

These slips are typically caused by synchronisation impairments in digital cross-connect (DCS) equipment. DCS equipment handles buffer overflows or underflows by deleting or repeating entire frames of data. Since data is added or deleted by entire frames, frame synchronisation is not disrupted.

2. **Uncontrolled Slips:** Uncontrolled slips are bit additions or deletions that cause both data and framing bits to be displaced. The misalignment of framing bits typically results in frame synchronisation loss.

Uncontrolled slips are typically from synchronisation problems in equipment which buffer the entire bit stream such as

satellite down link receivers. Since the buffer in this equipment does not distinguish between framing and data bits, buffer underflows or overflows result in the addition and deletion of arbitrary blocks of data.

It should be noted that slips can also result from impairments unrelated to network synchronisation. Low signal level, noise, and excessive jitter can also cause slips.

Examples of controlled and uncontrolled slips are illustrated in *Figure 13*.

Measuring the Slips

The TTC test sets pattern slip measurements count the number of times data is inserted into or deleted from the pattern.



This measurement is not a count of the actual number of bits added or deleted, but rather a count of the number of instances where a group of bits were added or deleted from the bit stream.

Interpreting the Results

To troubleshoot a problem, which causes slips, pattern slip results must be compared to other test results.

If an occurrence of a pattern slip is associated with a frame loss, it can be assumed that the frame loss is caused by an uncontrolled slip. If a pattern slip occurs without disrupting framing, it can be assumed that a controlled slip has occurred. Categorisation of slips can help identify the cause of the problem.

A better understanding of the underlying problems can also be obtained by considering the frequency at which pattern slips occur.

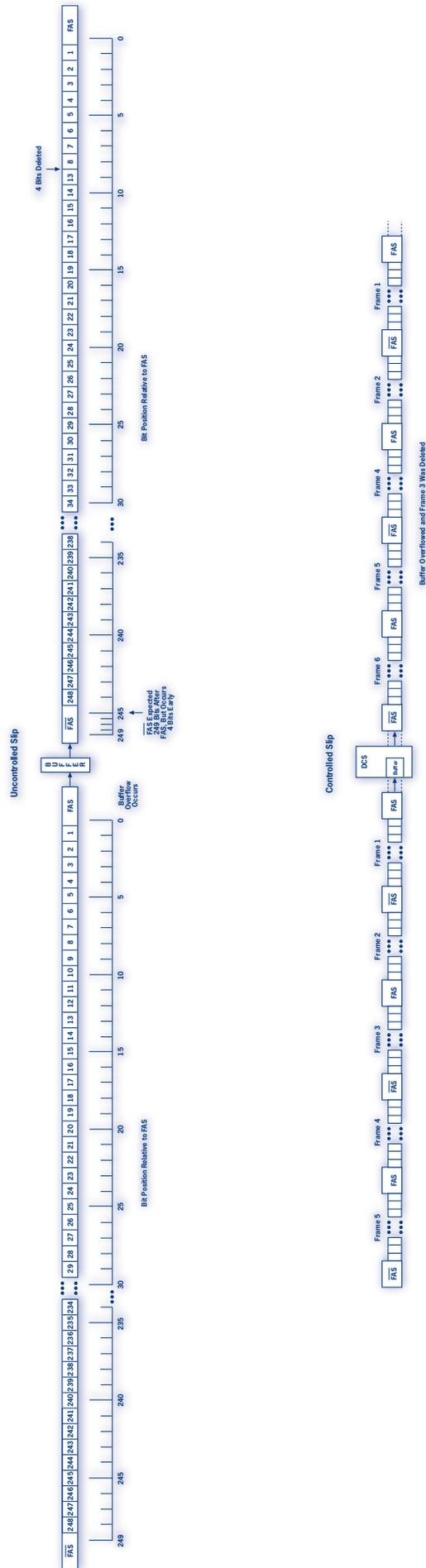


Figure 13:
Controlled and uncontrolled slips

Transmission Delay Analysis

Using the TTC test set's DELAY can help in troubleshooting specific problems such as protocol errors due to timeouts.

As an example consider the 2.048 Mbps circuit shown in **Figure 14**. In this figure, transmission path #1 has a roundtrip delay of 30 ms, whereas transmission path #2 has a round trip delay of 75 ms. If we assume a protocol timeout threshold of 50 ms, switching the

2.048 Mbps circuit from transmission path #1 to transmission path #2 would cause protocol timeouts not experienced when path #1 was in use. TTC test set's DELAY measurements can identify this problem by determining such changes in the transmission path of a 2.048 Mbps circuit.

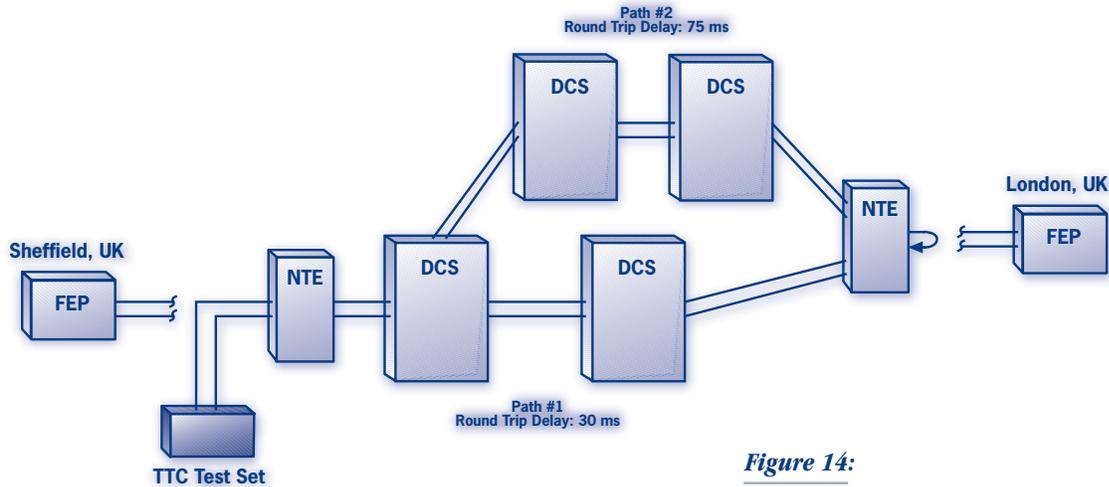


Figure 14:
Roundtrip delay measurements

ITU-T Performance Analysis

Performance Analysis results as specified by ITU-T Recommendations G.821 provide statistical information about the performance of the equipment or system under test. These results are used to check the compliance of equipment or circuits with the specified performance objectives.

available time. When the bit error rate (BER) is worse than 10^{-3} for 10 consecutive seconds, a transition is made to unavailable time, and these 10 seconds are considered to be unavailable time. When the BER is better than 10^{-3} for 10 consecutive seconds, the period of unavailable time terminates, and these 10 seconds are counted as available seconds. Hence, a sliding window, 10 seconds in length, is used to detect transitions from available time to unavailable time and vice versa.

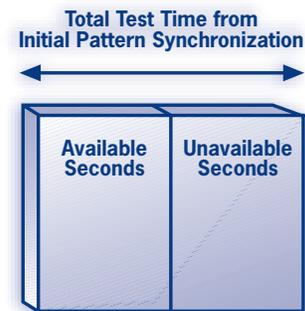


Figure 15:
G.821 available time and unavailable time

Available Time vs. Unavailable Time

According to ITU-T Recommendation G.821, the total test time after the initial pattern synchronisation is broken up into available and unavailable seconds. Every test second belongs to either one of these categories. This is illustrated in **Figure 15**.

After initial synchronisation is achieved, seconds are considered to be

Any second in which a signal loss or pattern synchronisation loss occurs, is also considered to be a second with BER worse than 10^{-3} .

Available Time

As shown in Figure 16, available time (or available seconds) is broken up into further categories. These categories are explained below.

Error Free Seconds (EFS)	Available seconds in which no bit errors occurred.
Errored Seconds (ERR SEC)	Available seconds in which at least one bit error occurred.
Severely Errored Seconds (SES)	Available seconds in which the BER was worse than 10^{-3} .

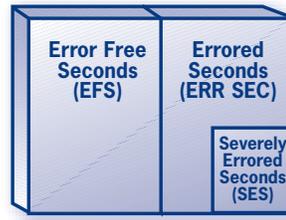


Figure 16:
Available time



Severely errored seconds are defined to be part of available time. Therefore, severely errored seconds are likely to account for short error bursts with a BER worse than 10^{-3} , whereas longer error bursts with a BER worse than 10^{-3} are likely to be counted as part of unavailable time.

Degraded Minutes

Degraded minutes is a count of the number of minutes during which an average BER of 10^{-6} or worse occurs. The one-minute intervals are derived by removing unavailable seconds and severely errored seconds from the total test time, and then consecutively grouping the remaining seconds into blocks of 60. The average BER is calculated for the block of 60 seconds, and if it is 10^{-6} or worse, the block is counted as a degraded minute.

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