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A Methodology for Broadband Token Passing Bus Interoperability Testing

Robert Rosenthal
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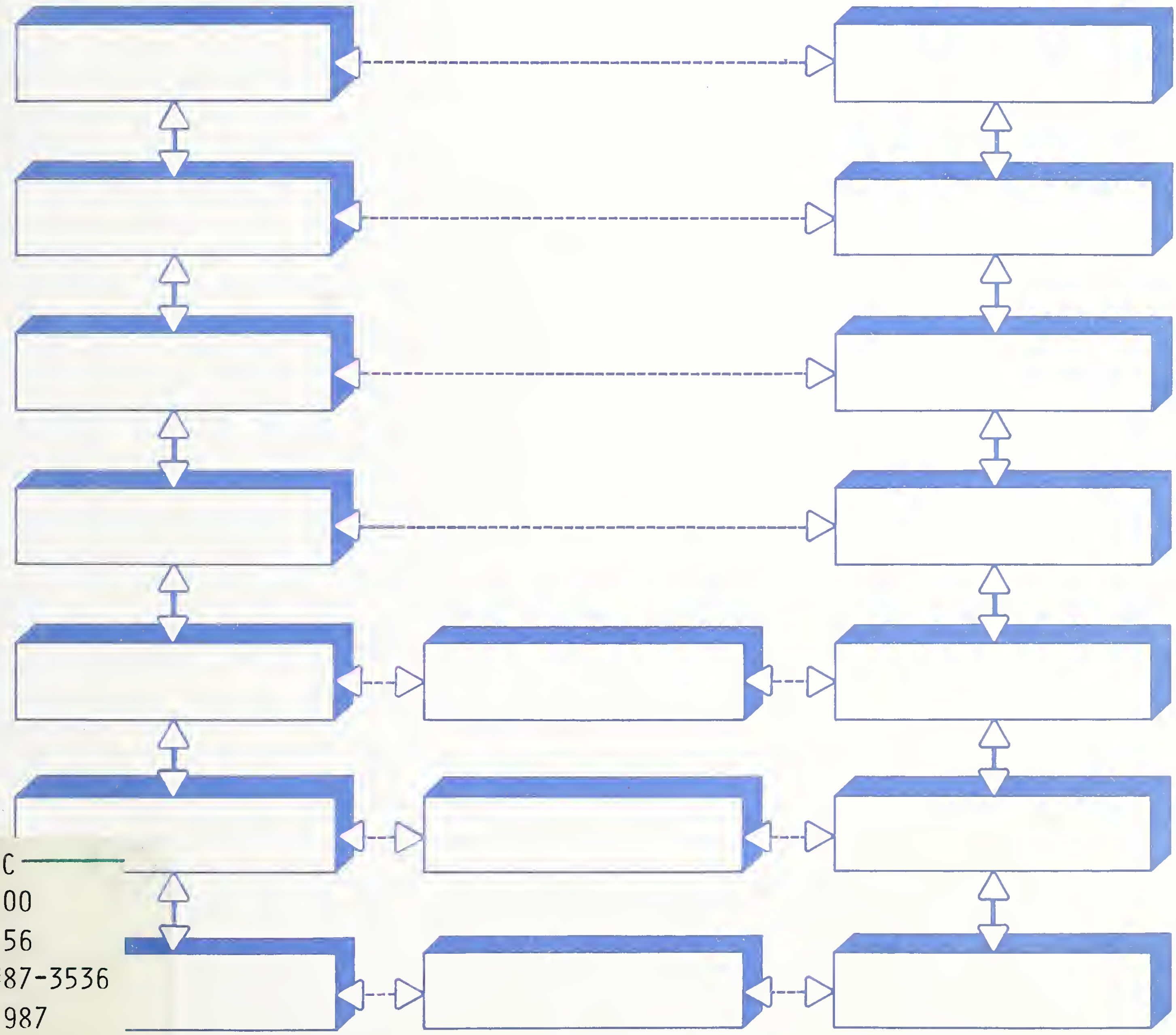

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Ernest Ambler, Director

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A METHODOLOGY FOR BROADBAND TOKEN PASSING BUS INTEROPERABILITY TESTING

Robert Rosenthal and Daniel Stokesberry
National Bureau of Standards.

ABSTRACT

A method for testing broadband token passing bus interoperability is described. The method was tested in a controlled laboratory environment at the National Bureau of Standards with four modem manufacturers' and three headend remodulator manufacturers' equipment. The tested equipment implemented specific token passing bus options found in commercially available products.

The methodology specifies seven environmental and electrical parameters; for the first set of tests, nominal parameter settings were selected. The methodology uses specific test frames developed for their unique bit patterns. These frames were transmitted, received and counted to exercise the broadband modems and headend remodulators. The methodology organizes the frame transmissions into five test definitions. Each test definition is repeated for each headend remodulator.

Keywords: Local area Networks; physical layer testing; protocol testing; test methodology; token bus.

1. INTRODUCTION

The manufacturing automation community is developing a Manufacturing Automation Protocol (MAP) specification [1] derived from specific International Standards Organization (ISO) data communication protocols. These protocols, developed in a layered framework or model known as the ISO Open Systems Interconnection (OSI) Basic Reference Model [2], include contributions from the American National Standards Institute (ANSI). ANSI accredits the Institute of Electrical and Electronic Engineers (IEEE) to develop technical standards. The IEEE has developed a family of local area networking standards for use in office, factory and process control applications. These standards are published with both an ANSI/IEEE reference and an ISO reference. The MAP specification includes "ANSI/IEEE 802.4-1985 ISO/DIS 8804 Token Passing Bus," [3] a document often referred to simply as 802.4.

802.4 specifies protocols and interfaces at the lowest layers of the OSI Basic Reference Model -- the physical layer and a portion of the link layer called the media access control sublayer or MAC. The physical layer and MAC sublayer, like most protocol specifications, identify many options for the myriad of applications envisioned. With these standards in place, user and vendor communities are able to select appropriate options for specific applications.

The manufacturing automation community has not only identified 802.4 for use in the MAP specifications, it has worked closely with the National Bureau of Standards' Implementors Workshop to develop a set of options for use in products that implement OSI protocols. An "agreements" document [4] defines the specific options selected for 802.4 as well as the specific options for other OSI protocols selected for use in the upper layers. These workshops are expected to expedite the development of OSI protocols and promote interoperability of independently manufactured data communications equipment.

End users and original equipment manufacturers or OEM users expect this equipment to interoperate. Larger automated machinery and smaller mini and micro systems and controllers from different manufactures must work together on the factory floor providing the user with cost effective, off-the-shelf solutions for distributed computer applications. To demonstrate token passing bus interoperability, a test methodology has been designed and tested by 802.4 equipment vendors working closely with the National Bureau of Standards.

The test methodology demonstrates token passing bus physical layer interoperability by systematically testing the modem's capabilities to transmit and receive data frames through different headend remodulator equipment and by systematically testing the remodulator's capability to respond appropriately to noise bursts and other media specific phenomena and physical layer protocols.

This methodology describes a set of five tests designed to demonstrate the electrical and functional compatibility of different 802.4 broadband implementations. In test 1, a baseline cable plant facility that meets or exceeds the 802.4 broadband cable plant specification is established. Each remodulator is switched, one at a time, into the cable plant facility where the assigned forward channel is checked for the presence of pseudo silence -- the normal remodulator output when no input signal is present. Test 2 demonstrates the transmission and reception of short frames. Good and bad frames are counted and recorded; in test 3, long test frames are transmitted and received. In test 4, frame fragments and other combinations of simulated contentions are sent to the remodulator. Finally, in test 5, a ring is established and link protocol data units are sent between token passing bus stations.

The methodology is not complete. An interoperability test of all MAP physical layer products in every network configuration is impossible. Rather, the methodology demonstrates with reasonable assurance that MAP specifications for IEEE 802.4 broadband physical layer protocols are adequate to insure interoperability among modem and headend equipment.

2. IEEE 802.4 OPTIONS

While the test methodology developed at the National Bureau of Standards is based on ANSI/IEEE Std 802.4-1985 ISO/DIS 8802/4, it reflects recent changes made and approved by the IEEE 802.4 working committee. A new "change document," developed by the working committee, has neither been approved by the IEEE Standards Board nor considered by the ISO. This change document corrects known errors in the 802.4 Standard and these changes are reflected in all known emerging vendor implementations. These changes most likely will be reflected in future approved ANSI/IEEE and ISO 802.4 standards.

The IEEE 802.4-1985 ISO/DIS 8802/4 document specifies three physical layer technologies: 1) Phase Continuous-FSK, 2) Phase Coherent-FSK, and 3) Broadband Bus AM/PSK. Phase Continuous FSK has been deleted from the change document and Phase Coherent FSK has undergone considerable technical change. Minor technical changes and clarifications to the Broadband Bus AM/PSK documentation are reflected in the change document. Figure 1 identifies Broadband Bus as an option selected for MAP and the focus of this interoperability test methodology.

	Phase Continuous FSK	Phase Coherent FSK	Broadband Bus AM/PSK
OPTION			*

Figure 1. IEEE 802.4 TEST METHODOLOGY

Broadband Bus AM/PSK is defined in chapters 8, 9, 14 and 15 of the IEEE specification. Chapter 8 describes the media access control (MAC) to physical layer interface. Chapter 9 describes generic station management of the physical layer. Chapter 14 is the broadband bus physical layer specification and chapter 15 is the specification for the broadband medium which includes the regenerative headend specification. These chapters enumerate the various options for broadband bus. The options are summarized in Figure 2 where an asterisk indicates options selected for use in this test methodology.

REPEATERS			ENCODING	
active regenerative		*	duobinary	*
MEDIUM			DATA RATE	
single coaxial cable		*	1 MBit/s	
dual coaxial cable			5 MBit/s	
			10 MBit/s	*
CHANNEL ASSIGNMENTS			TRUNK CABLE	
Forward	Reverse		RG-6	*
			RG-11	
P	3'	*	Semi Rigid	
Q	4'	*		
R	4A			
S	5'			
T	6'			
U	FM1'			

Figure 2. BROADBAND BUS OPTION SELECTION

3. TESTBED PARAMETRIC ASSUMPTIONS

A wide variety of environmental and electrical parameters are possible in a token bus network. Seven factors identified in Figure 3 characterize the network being tested. The values selected were used during the first set of tests conducted at the National Bureau of Standards.

FACTOR	LOW	LEVEL MEDIUM	HIGH
noise	> 46 dB S/N	NONE	30 dB S/N
transmit level	NONE	+43 dBmV	NONE
receive level	-7 dBmV	+ 3 dBmV	+13 dBmV
temperature	NONE	ambient	NONE
humidity	NONE	ambient	NONE
channel	EVERY CHANNEL OF INTEREST		
cable length	EVERY LENGTH OF INTEREST		

Figure 3. PARAMETER VALUES FOR INTEROPERABILITY TESTS

The levels chosen seem a reasonable choice. The noise level specified is easily achieved with short 50 foot RG-6 cable. Transmit and receive levels are also easily obtained without additional amplification. While temperature and humidity level changes may impact performance, ambient level settings seem adequate to test the test methodology.

4. CHARACTERISTICS TO BE TESTED

IEEE 802.4 physical layer implementations may differ considerably from vendor to vendor; yet each implementation must exhibit similar electrical and functional characteristics. The approach is to first identify and categorize these characteristics. Then, an appropriate stimulus is defined to test the characteristic. For example, the characteristic of a modem to scramble and descramble data is tested using test frames A and A'. Figure 4 associates a stimulus with each characteristic considered.

CHARACTERISTIC	STIMULUS
scrambler/descrambler encoding headend capture timing recovery minimum preamble {0} and {4} kickers	Test Frame A and A'
AGC stability phase recovery	Test Frame B and B'
abort sequence contention	Contention Generator
headend AGC/phase dynamic variation turnoff level variable length frames turn off time	Establish a Token Ring using MAC Protocols

Figure 4. EQUIPMENT CHARACTERISTICS

5. TEST FRAMES

The test methodology requires equipment capable of sending, receiving and counting the four test stimuli identified in figure 4 above. Figure 5 below indicates the capabilities required of each modem. An "x" indicates that all modems (or controllers) must exhibit the capability while an "o" indicates specialized equipment. In particular, test frame generator A and A' must be available in each modem (or controller) while test frame generator B and B' and a contention generator are specialized equipment not required by each vendor; but, each vendor must be capable of receiving, and counting these generated frames. All vendor modems or MAC controllers connected to these modems must be capable of forming and maintaining a logical ring by executing portions of the media access control protocol.

CAPABILITY	A	A'	B	B'	CONTENTION	RING
	STIMULUS					
Send Test Frame	x	x	o	o	o	x
Count Total Sent	x	x	o	o		x
Receive Test Frame	x	x	x	x	x	x
Count Total Received	x	x	x	x	x	x
Count Total Received in Error	x	x	x	x	x	x

Figure 5. TESTING CAPABILITY OF VENDOR EQUIPMENT

5.1. TEST FRAME TRANSMITTERS AND RECEIVERS

The IEEE 802.4 physical layer specification requires scrambling the output data bits at the transmitter and descrambling at the receiver, providing a pseudo random distribution of energy on the coaxial cable during packet transmission. When long strings of similar scrambled symbols are transmitted, they are modified or "kicked" to provide suitable energy levels for the receiver detectors.

Three symbols are used during packet transmission: {0}, {2} and {4}. The {0} represents a zero bit; the {4} represents a one bit; and, the {2} represents a code violation used in start delimiters, stop delimiters, abort sequences and kickers. The rules for scrambling and kicking are found in the 802.4 standard.

The register used to hold the scrambler output data is said to be seeded when it is set to all ones and deseeded when set to all zeros. Each transmitted frame includes a 32 bit frame check sequence (FCS) derived from a cyclic redundance check (CRC) calculation. The register used in this calculation is also said to be seeded when set to all ones and deseed when set to all zeros.

5.2. TEST FRAME A and A' (PRIME)

Each modem has the capability to transmit test frame A and A' and to count the total frames sent. The interframe time for test frame A and A' was set at 500 microseconds. Test frame A and A' are defined in figure 6a and 6b below. The IEEE 802.4 frame format descriptor is above the hexadecimal digits. The frame control is abbreviated "FC," the destination address is abbreviated "DA," the source address is abbreviated "SA," and the frame control sequence is abbreviated "FCS."

Test frame A is a well formed token consisting of four octets of preamble, a valid start delimiter, the FC, DA, SA and FCS fields defined in figure 6a and an end delimiter.

FC	DA	SA	FCS
10	0a 00 00 00 00 00	12 bb 3f af b1 00	ff ff ff ff

Figure 6a. TEST FRAME A DATA

The bit pattern in the destination address (DA) was chosen to cycle the scrambler to zero, exercising the {0} kicker mechanism. The source address (SA) zeros or deseeds the CRC shift register forcing each CRC bit to zero. The resultant FCS (the negation of the CRC) is thus all ones (ff ff ff ff).

Test frame A' is an IEEE 802.2 [5] Logical Link Control data frame consisting of four octets of preamble, a valid start delimiter, the FC, DA, SA DATA and FCS fields defined in figure 6b below, and a valid end delimiter.

FC	DA	SA	DATA	FCS
02	12 00 00 00 00 00	22 00 00 00 00 00	68 db 90 3a 00 00 00 00	ff ff ff ff

Figure 6b. TEST FRAME A' (PRIME) DATA

The data portion is used to zero or deseed the CRC at the same time the scrambler is seeded or set to all ones. The scrambler seeds before an octet alignment providing a check for octet aligned kicker action just before the FCS. The seeded scrambler results in an FCS of all ones with a scrambler of all ones thus checking {4} kickers at the very end of the frame. This last kicker results in a {0} {2} {2} just before the end delimiter. The first two symbols of the end delimiter are {2} {2} providing four {2} symbols in a row -- the only way four {2} symbols can ever be generated in a legal 802.4 frame.

5.3. TEST FRAME B AND B' (PRIME)

Test frames B and B' are IEEE 802.2 Logical Link Control data frames. They consist of four octets of preamble, a valid start delimiter, the fields defined in figures 7a and 7b below, and a valid end delimiter. The data field contains repeating octets of 00 or ff to fill the frames. The frames are 4000 total octets each.

FC	DA	SA	DATA	FCS
02	67 00 00 00 00 00	00 00 00 00 00 00	00 ... 00	0c d1 e9 ef

Figure 7a. TEST FRAME B DATA

FC	DA	SA	DATA	FCS
02	d8 ff ff ff ff ff	ff ff ff ff ff ff	ff ... ff	ed ed 5c a4

Figure 7b. TEST FRAME B' (PRIME) DATA

A specialized generator is required for test frame B and B'. This generator has the capability to transmit a sequence of these test frames with an interframe gap of 500 microseconds and to count the total frames sent. Test frame B and B' tests the automatic gain control (AGC) stability and phase recovery of the modems and the remodulator while checking proper insertion and removal of zero {0} and one {4} kickers.

5.4. CONTENTION GENERATOR

The contention generator is a specialized transmitter capable of transmitting:

1. pseudo silence on the uplink to the headend,
2. a frame fragment on the uplink,
3. pad-idle then continuous {4} symbols,
4. continuous {4} symbols followed by silence,
5. test frame A with an invalid end delimiter, an invalid FCS, or with octet misalignment.

5.5. ESTABLISH A LOGICAL RING

Establishing a logical ring requires a Media Access Control (MAC) capability not strictly required for physical layer testing. However, in developing this interoperability methodology, all participants felt strongly that establishing a ring, passing the token and sending data frames is crucial to interoperability testing. The MAC implementation requires initialization of 13 MAC parameters. Figure 8 identifies the MAC options chosen for these parameters. (reference: section 6.4 page 79 ANSI/IEEE 802.4-1985)

(1) TS (station address)	individually assigned
(2) address_length	6 octets
(3) slot_time (octet_times)	300 and 2000
(4) hi_pri_token_hold_time	> 25 ms
(5) mac_ac_4_rotation_time	> 250 ms
(6) max_ac_2_rotation_time	> 250 ms
(7) max_ax_0_rotation_time	> 250 ms
(8) max_ring_maintenance_rotation_time	off, >250 ms
(9) ring_maintenance_timer_initial_value	solicit immediately
(10) max_inter_solicit_count	255
(11) min_post_silence_preamble_length	4 bytes
(12) in_ring_desired	true
(13) max_retry_limit	not applicable

Figure 8. MAC PARAMETERS

6. TEST DEFINITIONS

Five test definitions exercise the IEEE 802.4 broadband physical layer. Each definition is described below. Three vendor headend remodulator and four vendor modem equipments were used during the testing.

6.1. BASELINE

The BASELINE test provides each vendor with assurance that the cable plant facility is operational and capable of use. The vendor performs a visual inspection, conducts an independent "proof-of-performance" test, conducts a self test or any initialization required and verifies that the headend remodulator connected to the cable plant facility transmits pseudo silence.

The cable plant system schematic is shown in figure 9a. Figure 9b shows the headend rack, patch panel arrangement, switchable attenuators, splitters and diplex filter. Figure 10a is a sweep of the cable plant system from 10 MHz to 500 MHz at 50 MHz per division. Attenuation is 10 dB per division. The sweep was obtained by injecting the low frequencies into the reverse channel attenuator; then the high frequencies into the forward channel. The spectrum analyzer, connected to the output of one four way splitter was set to display the max value. This provides the "notch" display of the diplex filter as well as the slope of the cable plant. It is down 10 dB at 500 MHz. The reference line at 0 dB is the direct output of the sweep generator.

Figure 10b shows a sweep of the forward channel. The center frequency is 258 MHz; the span is 18 MHz. The straight line is the reference output from the sweep generator. Vertical gain is 1 dB per division. Figure 10c shows a sweep of the reverse channel. The center frequency is 65.75 MHz; the span is 18 MHz. The positively sloped line is the reference output from the sweep generator. Vertical gain is 1 dB per division. The cable plant system falls within the 802.4 specifications.

Figures 11a, 11b, and 11c show the RF output at a four way splitter from each headend remodulator transmitting pseudo silence. Slight differences in the levels were noted.

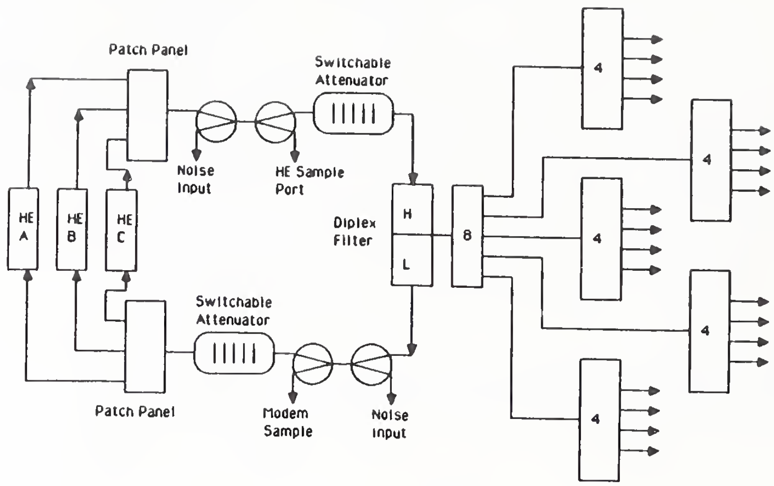


Figure 9a SCHEMATIC DIAGRAM OF CABLE PLANT

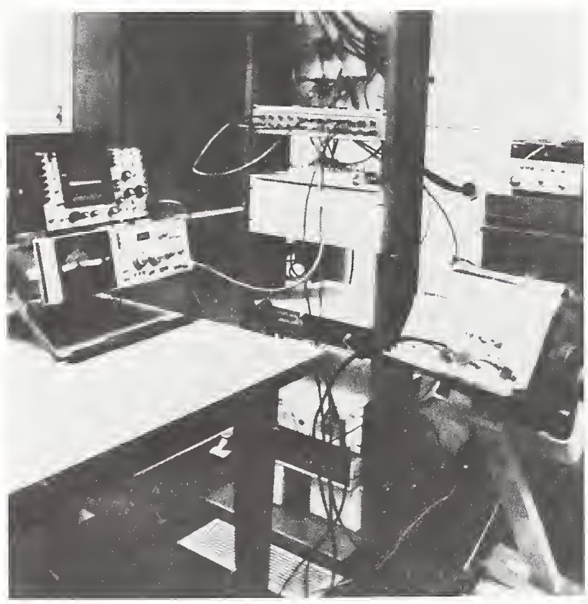
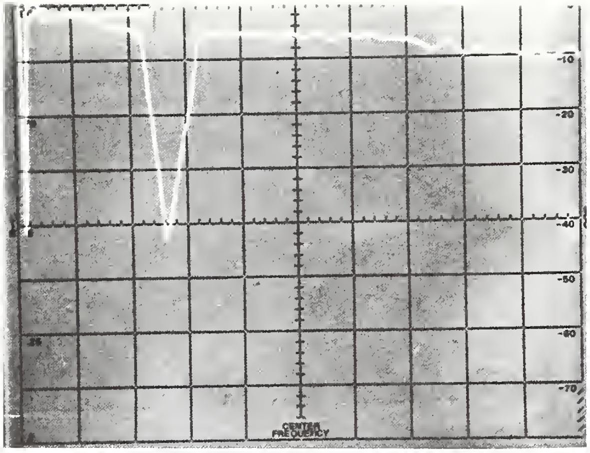
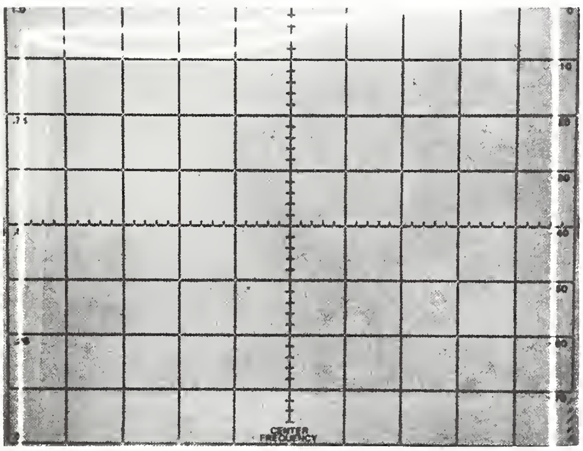


Figure 9b HEADEND CONFIGURATION



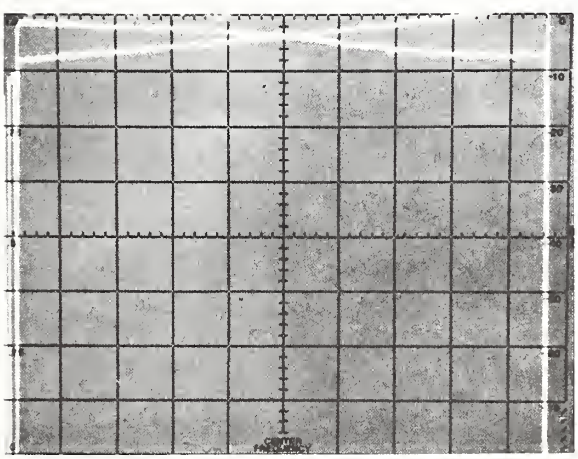
50 MHZ per Division
ATTN 10 dB per Division
Start Frequency 10 MHz
Top trace is reference

Figure 10a CABLE PLANT SWEEP



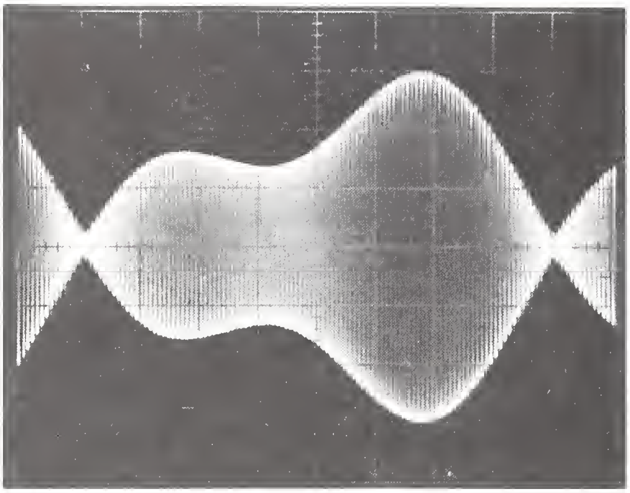
Center Frequency 258 MHz
Span 18 MHz
1 dB per division
Straight line is reference

Figure 10b FORWARD CHANNEL

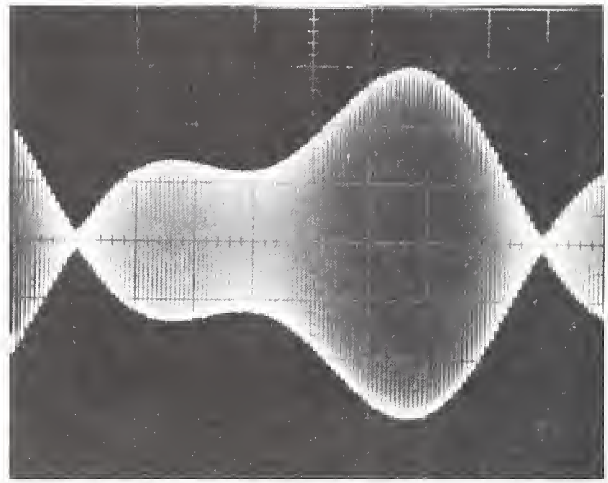


Center Frequency 65.75 MHz
Span 18 MHz
1 dB per division
Negative slope is reference

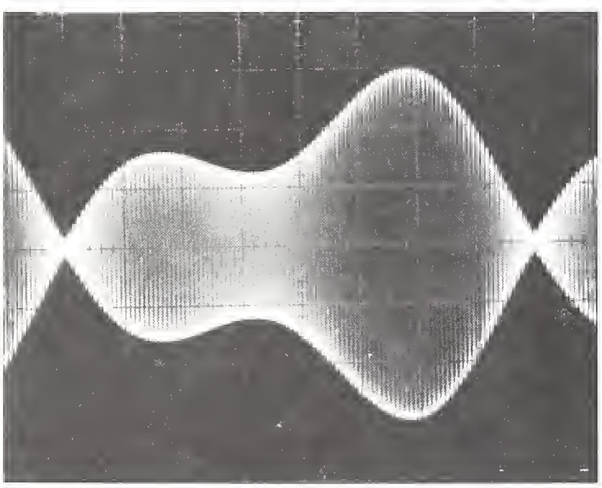
Figure 10c REVERSE CHANNEL



11a



11b



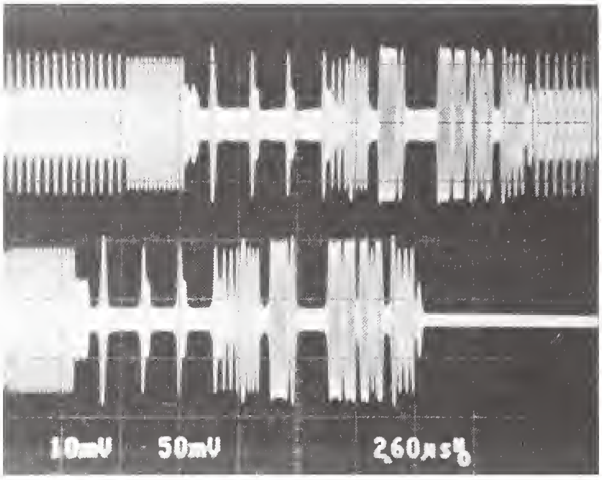
11c

Figure 11. PSEUDO SILENCE

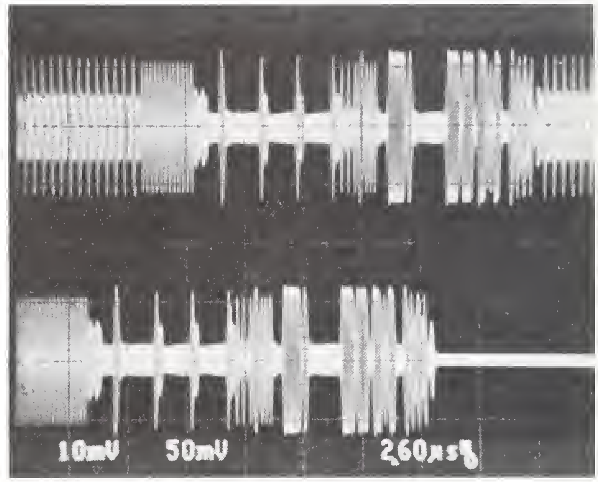
6.2. SHORT FRAME TEST

Test frames A and A' (prime) are transmitted during the short frame tests. Each test run consisted of a modem transmitting a large number of the test frames through a remodulator to the receiving modems. Each receiving modem (controller) reports the number of frames received correctly and, when possible, the number received in error. The number sent, the number received correctly by each modem, and, when possible, the number received incorrectly by each modem is recorded. After each modem has transmitted the test frame through the remodulator, another remodulator is selected and the process repeated.

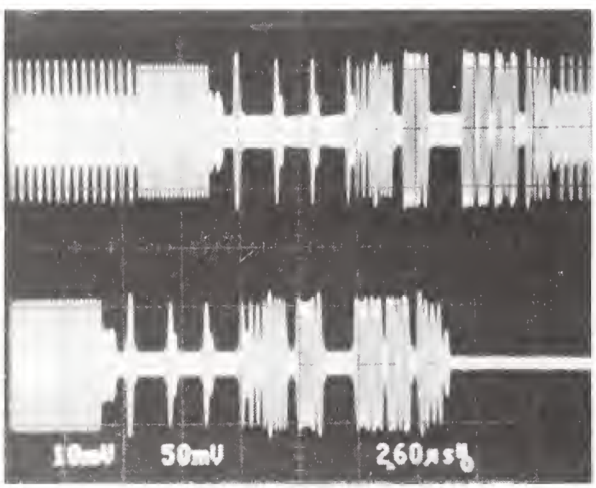
Test frame A is shown in figures 12a, 12b, 12c and 12d. The bottom trace shows the reverse channel; the top trace shows the forward channel. Notice the {0}s and {0} kickers. While the interframe time is not shown, it was 500 microseconds. Notice that each vendor's test frame A is similar.



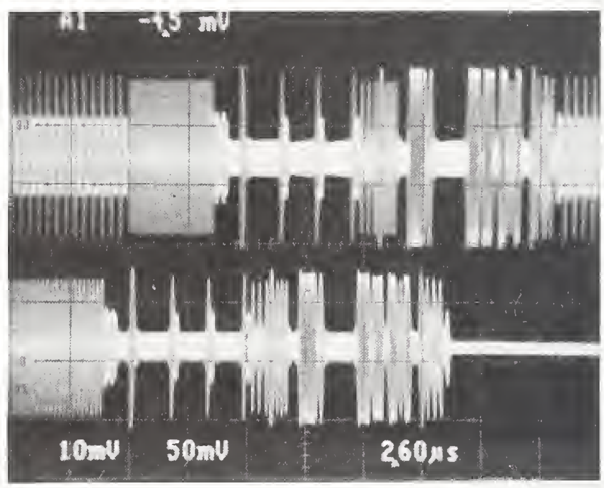
12a



12b



12c



12d

Figure 12. TEST FRAME A

The results of testing interoperability by transmitting and receiving test frame A under a variety of test conditions is summarized below. "ok" indicates proper operation under all conditions tested. "E" indicates that errors were observed under some test condition tested. A blank indicates that a full set of tests could not be completed.

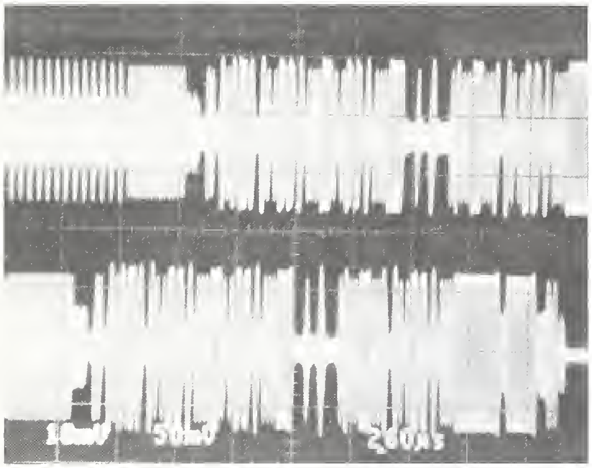
FRAME	REMOD	XMITTER	A RCVD	B RCVD	C RCVD	D RCVD
A	A	A	ok	ok	ok	
		B[1]				
		C	E	ok	ok	
		D	ok	ok	ok	
A	B	A	ok	ok	ok	
		B[1]				
		C	ok	ok	ok	
		D	ok	ok	ok	
A	C[2]	A	E	E	E	
		B[1]	E	E	E	
		C	E	ok	ok	
		D	E	ok	ok	

1. Vendor B was unable to generate Test Frame A when receiving low signal level at the transmitting modem.
2. Vendor C's remodulator was unable to operate when receiving high signal and high noise levels.

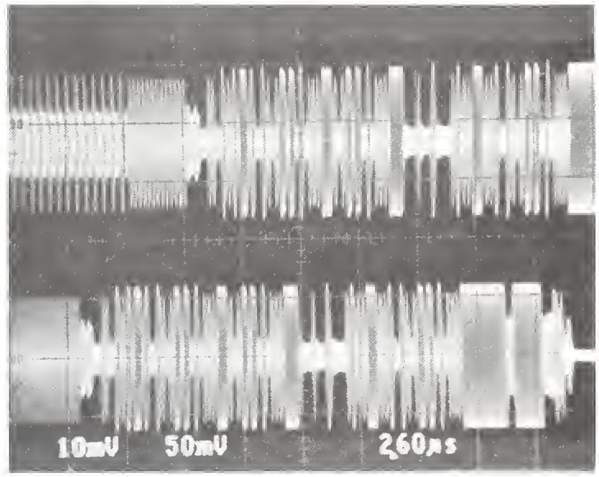
Table 1. Summary of Short Frame Tests

Test frame A' (prime) is shown in figures 13a, 13b, 13c and 13d. Notice the {4} kicker near the end of the frame. Also notice that more than 16 ones are transmitted before the kicker. Figure 14 shows a detailed trace of the last few bytes followed by the end delimiter. Notice there are four {2} symbols in a row -- the kicker for the last data symbols, then the start of the end delimiter.

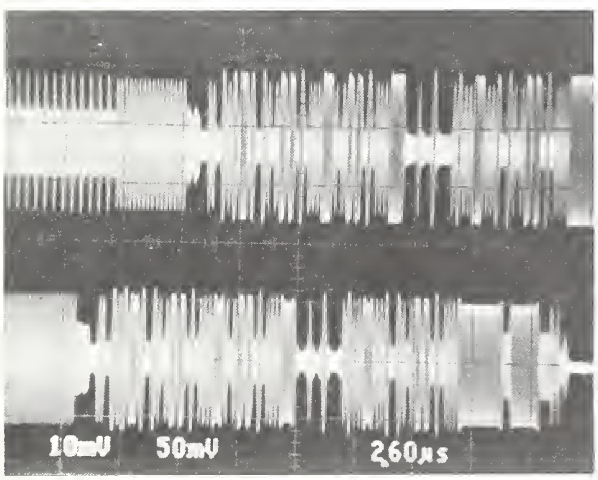
Short frame test results were found to be a function of signal level and noise level at the modem and headend remodulator receivers. Complete interoperability testing, therefore, requires that tests be run for all signal and noise level combinations listed in Figure 3.



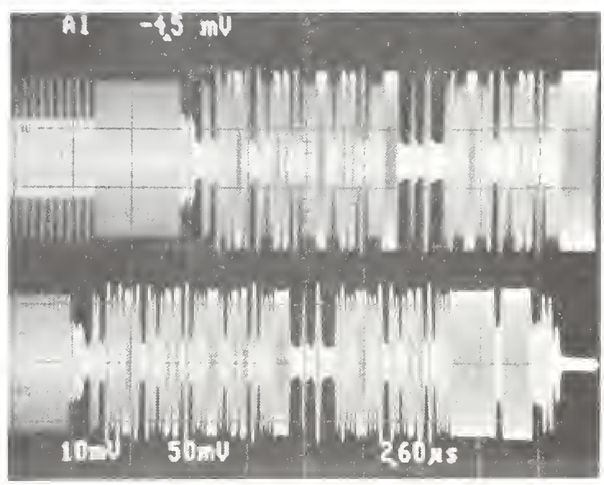
13a



13b



13c



13d

Figure 13. TEST FRAME A' (PRIME)

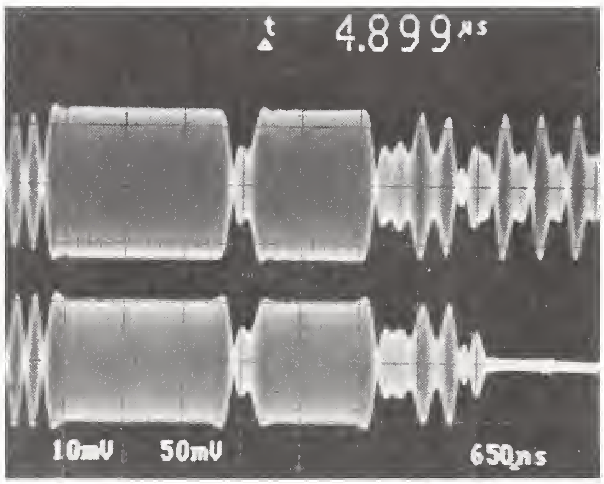
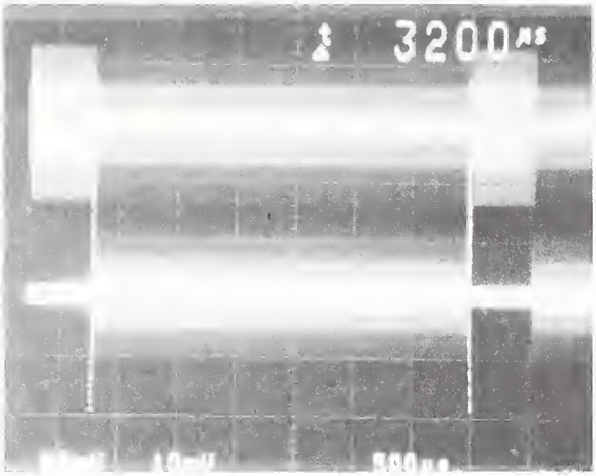


Figure 14. END OF TEST FRAME A' (PRIME)

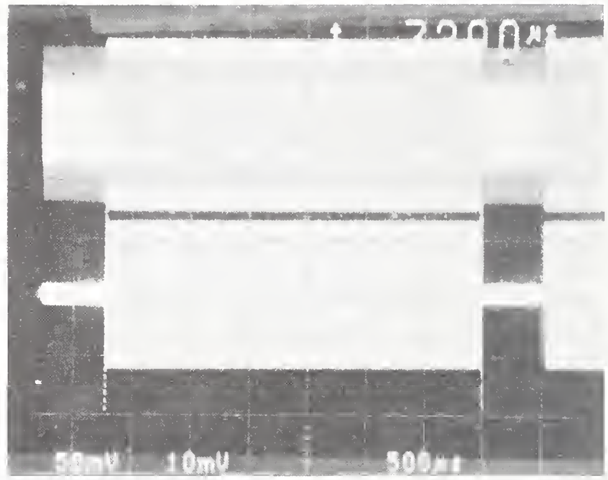
6.3. LONG FRAME TEST

Test frames B, B' (prime), C and C' (prime) were transmitted during the long frame tests. The B test frames were used during the first interoperability meeting and the C test frames were used during the second operability meeting. The C test frames are a simple modification of the B test frames, extending their length to the longest permissable frame, 8191 octets. For each test, a headend remodulator was switched into the cable plant; then, required initialization was completed and the LONG FRAME GENERATOR transmitted the test frame. Each modem reported the number of frames received and the number received in error. The tests were repeated with each headend remodulator for each test frame.

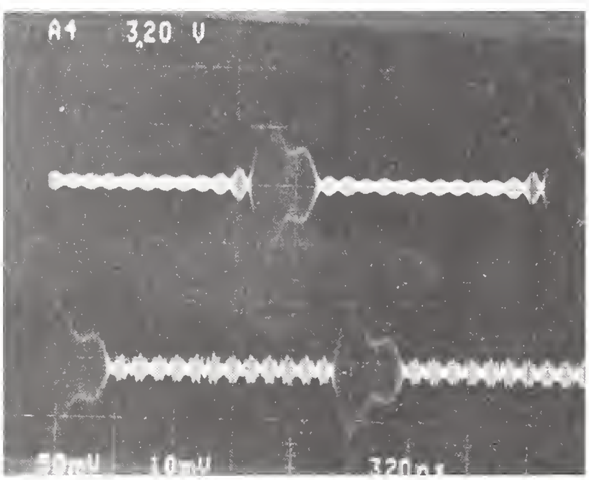
Figure 15a shows test frame B. The bottom trace is the reverse channel which turns off after 4000 bytes. The 500 microseconds interframe time is easily seen. Figure 15b expands the trace showing the {0} kicker. Figure 16a and 16b show test frame B' (prime). Here the {4} kickers are clearly visible.



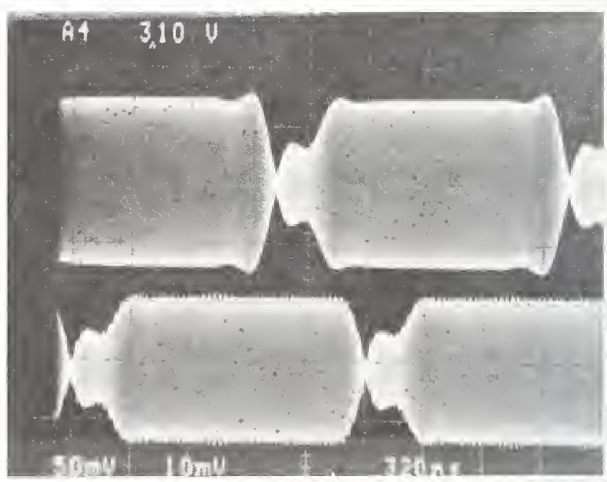
15a



16a



15b



16b

Figure 15. TEST FRAME B

Figure 16. TEST FRAME B' (PRIME)

The results of testing interoperability by transmitting and receiving long test frames under a variety of test conditions is summarized below. "ok" indicates proper operation under all conditions tested. "E" indicates that errors were observed under some test condition tested. A blank indicates that a full set of tests could not be completed.

FRAME	REMOD	A RCVD	B RCVD	C RCVD	D RCVD
C	A	E	ok	ok	
	B	E	E	ok	
	C[1]				
C'	A	ok	ok	ok	
	B	ok	E	ok	
	C[1]				

1. Vendor C's remodulator was unable to operate when receiving high signal and high noise levels.

Table 2. Summary of Long Frame Tests

Long frame test results were found to be a function of signal level and noise level at the modem and headend remodulator receivers. Complete interoperability testing, therefore, requires that tests be run for all signal and noise level combinations listed in Figure 3.

6.4. REMODULATOR RESPONSE TO SIMULATED CONTENTION

Initially, four headend response subtests to simulated contention were defined and conducted. Analysis of the subtest results led to augmentation and consideration of seven additional subtests. Section 6.4 describes the four original tests and the seven augmented tests.

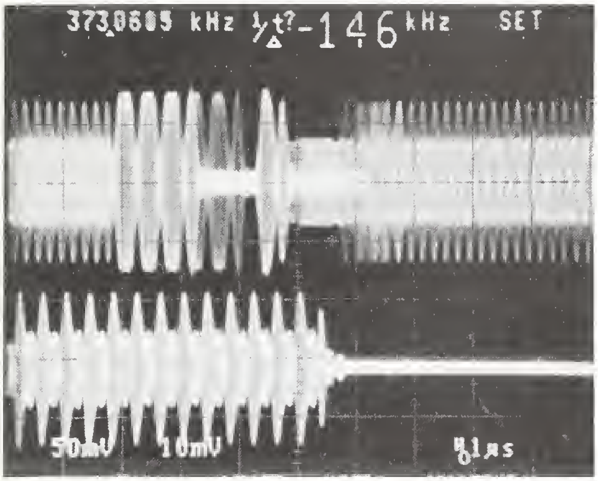
The response of each remodulator was documented by recording oscilloscope traces. Subtest 1 requires each remodulator to respond to uplink pseudo silence followed by silence. Subtest 2 requires each remodulator to respond to a frame fragment defined by pad idle, a start delimiter 32 {4} symbols then silence. Subtest 3 requires each remodulator to respond to pad idle followed by 32 {4} symbols without a start delimiter. Subtest 4 requires each remodulator to respond to 32 {4} symbols then silence.

Figures 17a, 17b and 17c show the remodulator response to uplink pseudo silence. Figure 17a shows the pattern {4}{4}{4}{0} repeated several times followed by an abort sequence. Figure 17b shows preamble followed by "garbage" followed by zeros. Note that the time scale was changed in figure 17b to 1.51 microseconds per centimeter. Also note that the sequence {4}{0}{0}{0}{4} precedes a return to pseudo silence. Figure 17c shows about 8 microseconds of preamble followed by pseudo silence.

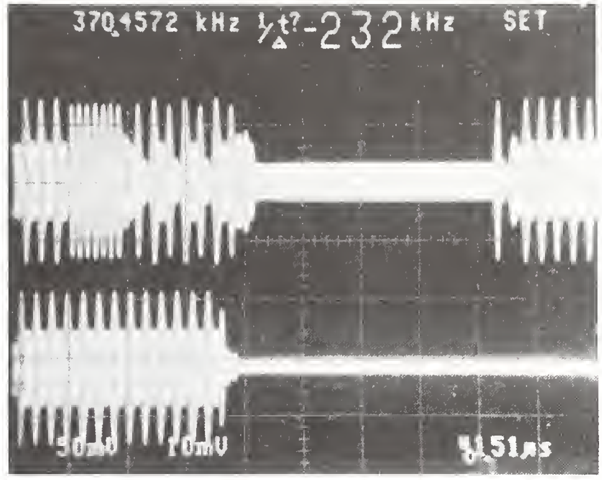
Figure 18a, 18b and 18c show the remodulator response to an uplink frame fragment. Figure 18a shows a short period of preamble; 2 start delimiters; an abort sequence; about 5 {4}; another abort sequence; then pseudo silence. Figure 18b shows repeated {4}'s followed by {2}'s followed by the sequence {4}{0}{0}{0}{4}. Figure 18c shows repeated start delimiter and 1 octet of {4}'s; pad idle; an abort sequence; pad idle; then pseudo silence.

Figure 19a, 19b and 19c show the remodulator response to uplink continuous wave (CW) with pad idle. Figure 19a shows a switched to pad idle followed by "garbage" followed by an abort sequence. Figure 19b shows a switch to pad idle followed by several {2}{2}{0} sequences followed by a {4}{0}{0}{0}{4} sequence. Figure 19c shows only pad idle.

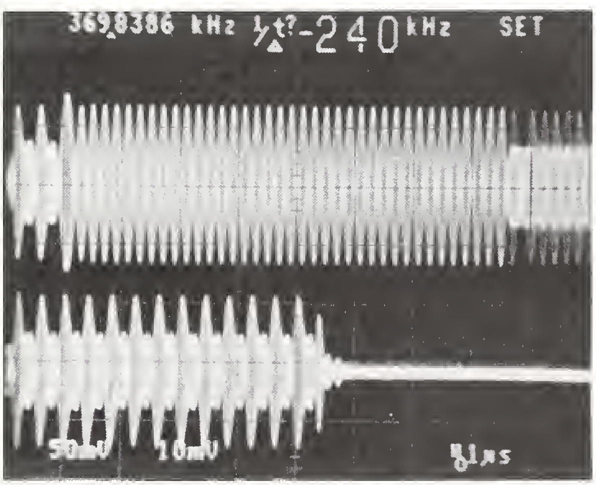
Figure 20a, 20b and 20c show the remodulator response to uplink CW then silence. Figure 20a shows pseudo silence as if nothing was received. Figure 20b shows preamble. Figure 20c shows less preamble than figure 20b.



17a

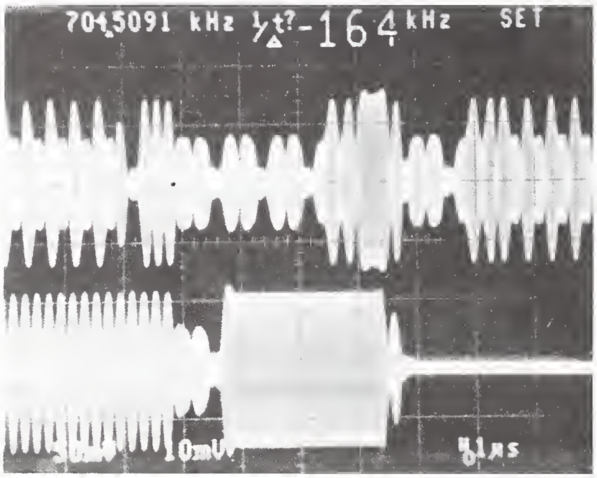


17b

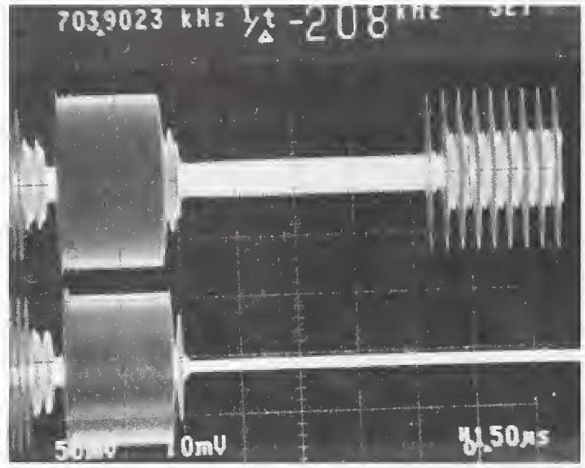


17c

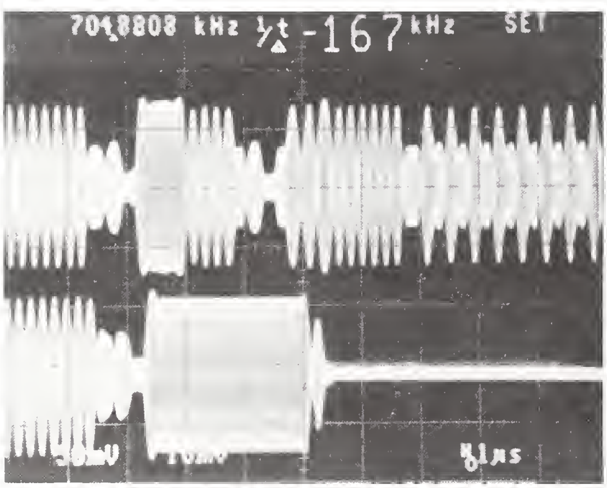
Figure 17. UPLINK PSEUDO SILENCE TEST



18a

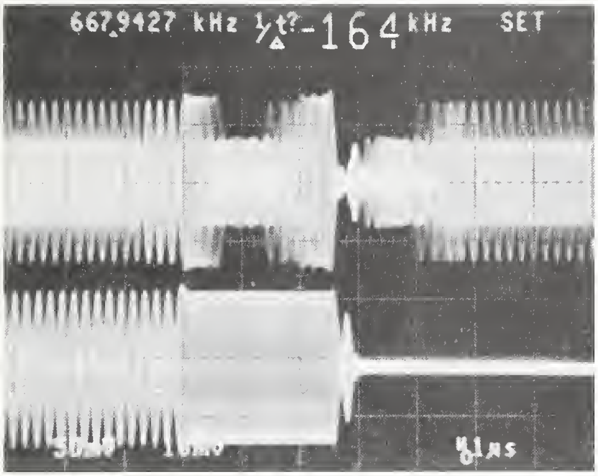


18b

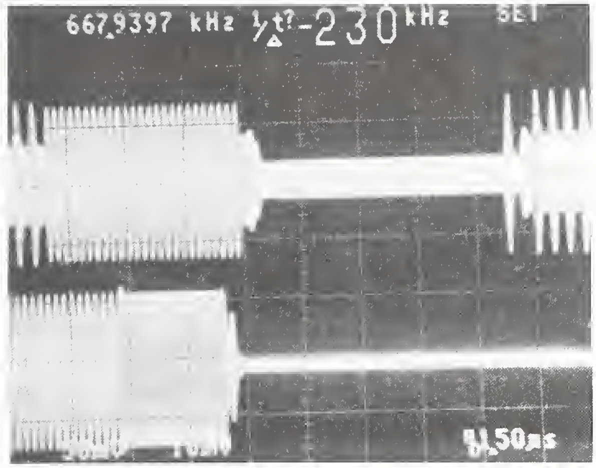


18c

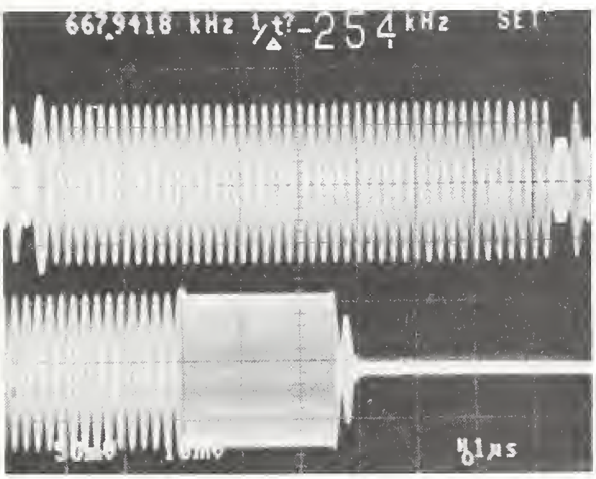
Figure 18. UPLINK FRAME FRAGMENT



19a

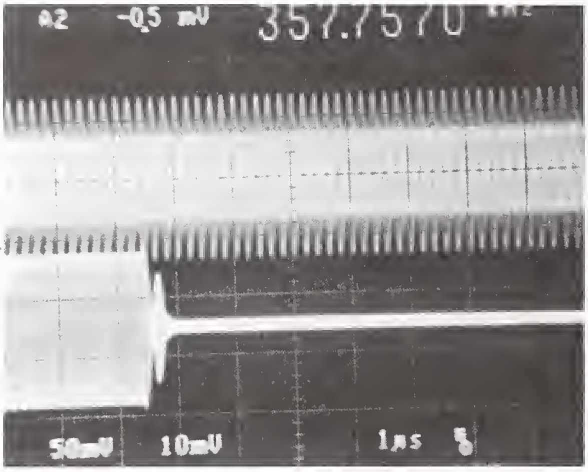


19b

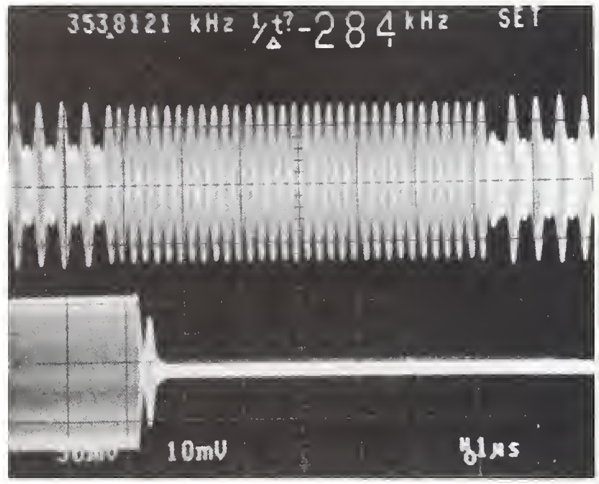


19c

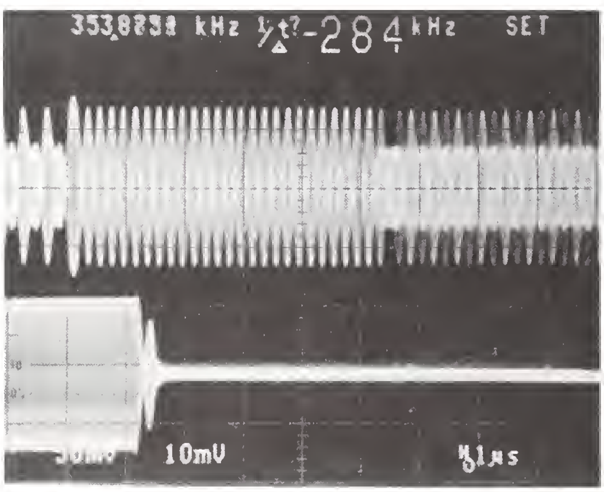
Figure 19. UPLINK CW WITH PAD IDLE



20a



20b



20c

Figure 20. UPLINK CW THEN SILENCE

Analysis of the test results above led to seven additional remodulator response tests. Even though these tests were conducted under rather severe time limitations and the results obtained require the interpretation of oscilloscope waveforms, the tests clearly show that the remodulators differ in their response to these test inputs. The test definitions and preliminary results are summarized below:

1. Contention Simulated by White Noise

   The response of each remodulator to repetitive pulses of white noise was observed on an oscilloscope. The source was a Micronetics Noise Generator, Model PNG 5109, transmitting + 3 dBmV pulses of 20 microsecond duration every 120 microseconds.

   In each case, the oscilloscope display was unstable, indicating that the response of the remodulators to white noise is not repeatable. This lack of repeatability is due to nature of the noise input; the noise may occasionally look like the beginning of a valid frame. Remodulator response tests should be repeatable, that is, the same response should be observed every time the input of the remodulator is stimulated by the simulated contention signal. Therefore, white noise is not a suitable simulation of contention.

2. Invalid End Delimiter - (E Bit Set)

   The response of each remodulator to repetitive frames with an invalid end delimiter was observed on an oscilloscope. The source was the contention generator transmitting Test Frame A at medium signal level and low noise and with the end delimiter modified:
   from {2}{2}{4}{2}{2}{4}{0}{0}
   to {2}{2}{4}{2}{2}{4}{0}{4}.

Remodulator	Response
A	E bit in end delimiter is cleared
B	E bit in end delimiter is cleared
C	Unstable display on oscilloscope

3. Invalid End Delimiter - (I Bit Set With No Frame Following)

The response of each remodulator to repetitive frames with an invalid end delimiter was observed on an oscilloscope. The source was the contention generator transmitting Test Frame A at medium signal level and low noise and with the end delimiter modified:

from {2}{2}{4}{2}{2}{4}{0}{0}
to {2}{2}{4}{2}{2}{4}{4}{0}.

Remodulator	Response
A	Repeat frame, either AS or 6 {0}, AS, PS
B	Repeat frame, 8 bits of preamble, PS
C	Repeat frame, 22 {0}, AS, AS, PS

where AS is an abort sequence and PS is pseudosilence.

4. Invalid End Delimiter - (Back to Back Frames with I Bit Reset)

The response of each remodulator to repetitive frames with an invalid end delimiter was observed on an oscilloscope. The source was the contention generator transmitting Test Frame A', 3 octets of preamble, and Test Frame A at medium signal level and low noise.

Remodulator	Response
A	Repeat A', PS, No SD, Repeat A, AS
B	Exact repeat of input
C	Repeat A', PS, Preamble, No SD, Repeat A, AS

where PS is pseudosilence, SD is a start delimiter and AS is an abort sequence.

5. Invalid Frame Check Sequence

The response of each remodulator to repetitive frames with an invalid frame check sequence was observed on an oscilloscope. The source was the contention generator transmitting Test Frame A at medium signal level and low noise and with the last bit of the FCS inverted.

Remodulator	Response
A	Exact repeat of frame
B	Exact repeat of frame with E bit set
C	Exact repeat of frame

6. Octet Misalignment

The response of each remodulator to repetitive frames with a non-integral number of octets was observed on an oscilloscope. The source was the contention generator transmitting Test Frame A at medium signal level and low noise and the sequence {4}{0}{0} added between the FCS and the ED.

Remodulator	Response
A	Repeat frame, correct the ED, AS
B	Repeat frame, ignore ED, AS
C	Exact repeat of frame

where ED is an end delimiter and AS is an abort sequence.

7. Invalid End Delimiter - (ED Replaced With SD)

The response of each remodulator to repetitive frames with an invalid end delimiter was observed on an oscilloscope. The source was the contention generator transmitting Test Frame A at medium signal level and low noise and with the end delimiter replaced with a start delimiter.

Remodulator	Response
A	Repeat frame, correct the ED, AS
B	Repeat frame until ED, immediate AS
C	Exact repeat of frame, 22 {0}, AS

where ED is an end delimiter and AS is an abort sequence.

These tests demonstrate the need for agreement among the vendors on the remodulator response to various inputs. This need has been brought to the attention of the IEEE 802.4 Token Bus Task Group. Appropriate remodulator response tests can be devised when the task group has defined the appropriate response for each stimulus.

6.5. TOKEN BUS TEST

The token bus test consists of the formation of a logical ring comprised of two modems from each participating vendor. This test requires that each modem have the full functionality of the Media Access Control (MAC) sublayer of the Logical Link Control (LLC) layer of the OSI protocol. Therefore, failure to interoperate does not imply that the physical layer of the modem is deficient. This test does, however, provide the most stringent testing of the physical layer and successful operation under these testing conditions adds considerable assurance of interoperability.

The token bus tests allow each headend remodulator to host a ring while each vendor's modem pair initializes the ring. Once the ring is initialized, other vendors sequentially enter the ring. With all modems in the ring, the initializing modems transmit data. Each combination of headend remodulator and modem pair was tested. Also, each combination of sequential entry into the ring was tested. In addition, the addresses assigned to the modems were chosen so that each vendor's modems would communicate with as many other vendor's modems as possible as the token is passed around the logical ring. Each modem was set to a different transmit power level within the acceptable range of the remodulator receiver to test the remodulator's response to dynamic power level variations.

The addresses and transmit power levels assigned to the vendor's modems during the interoperability tests at NBS are given in the table below:

Address	Vendor	Signal Level
xx xx xx xx xx 2D	D	+ 3 dBmV
xx xx xx xx xx 2C	C	+10 dBmV
xx xx xx xx xx 2B	B	- 7 dBmV
xx xx xx xx xx 1D	D	+ 3 dBmV
xx xx xx xx xx 1C	C	0 dBmV
xx xx xx xx xx 1B	B	+ 6 dBmV
xx xx xx xx xx 1A	A	- 3 dBmV
xx xx xx xx xx 0A	A	+13 dBmV

Table 3. Modem Addresses and Transmit Power Levels

The results are summarized below. Interoperability between the modems is clearly demonstrated, but the summaries also show those operating conditions where reliable operation is not obtained. "E" indicates that the token was passed around the ring successfully, but some errors occur. "U" indicates unstable operation where the ring must be reformed periodically. "NO" indicates that the required operation could not be done. It is not within the scope of these tests to identify why units fail to interoperate; only to identify those situations where the modem and headend remodulator failures occur.

Date/Time	October 10, 1986 10:48 - 11:40
Slot Time	2000 octet_times
Channel	3'/4'/P/Q
Cable Length	15 Meters

	REMODULATOR	MODEM
Transmitter Signal Level	Medium	Many
Receiver Signal Level	Many	Medium
Receiver Noise Level	Low	Low

REMOD	ORDER	A	B	C	LLC DATA TRANSMISSION	
A	ABC	ok	ok	ok	A SENDS	ok
	BAC	ok	ok	ok	B SENDS	ok
	CAB	ok	ok	ok	C SENDS	ring unstable[1]
B	ABC	E	E	U	A SENDS	ok (C not in)
	BAC	ok	E	U	B SENDS	ok (C not in)
	CAB	NO	NO	NO	C SENDS	NO
C	ABC	ok	ok	ok	A SENDS	ok
	BAC	ok	ok	ok	B SENDS	ok
	CAB	ok	ok	ok	C SENDS	ring unstable[1]

1. Vendor A's modems lose tokens received shortly after receiving data frames.

Table 4. Summary of Ring Test (No Induced Noise)

Date/Time	October 10, 1986 11:45 - 12:31
Slot Time	2000 octet_times
Channel	3'/4'/P/Q
Cable Length	15 Meters

	REMODULATOR	MODEM
Transmitter Signal Level	Medium	Many
Receiver Signal Level	Many	Medium
Receiver Noise Level	Low	High

REMOD	ORDER	A	B	C	LLC DATA TRANSMISSION	
A	ABC	ok	ok	ok	A SENDS	ok
	BAC	ok	ok	ok	B SENDS	ok
	CAB	ok	ok	ok	C SENDS	ring unstable[1]
B	ABC	E	E	U	A SENDS	ok (unstable)
	BAC	E	E	NO	B SENDS	ok (C not in)
	CAB			NO	C SENDS	NO
C	ABC	E	U	E[2]	A SENDS	ok (unstable)
	BAC	E	ok	E[2]	B SENDS	ok (unstable)
	CAB	E	E[2]	ok	C SENDS	ring unstable[1]
	CBA	E	ok	ok	D SENDS	ok

1. Vendor A's modems lose tokens received shortly after receiving data frames.
2. The error rate slows when these modems enter the ring.

Table 5. Summary of Ring Tests (With Induced Noise)

7.TABLES USED TO CONDUCT THE TESTING

The methodology provides a summary testing matrix that indicates completed tests. For the controlled laboratory testing conducted at the National Bureau of Standards, four vendors participated. Three vendors had headend remodulators; one vendor did not. All four vendors had modems. The vendors with remodulators were named A, B and C; the vendor with only a modem was named D. Table 6 below was used to record the test completion results.

USING REMOD	BASELINE	SHORT FRAME A A'	LONG FRAME B B' C C'	RE RESPONSE TESTS	RING
A A B C D					
B A B C D					
C A B C D					

Table 6. Test Completion Matrix

7.1. SHORT FRAME TABLES

The short frame tests required all vendors to transmit test frame A and test frame A' (prime). Table 7 was used to organize and conduct the short frame tests.

7.2. LONG FRAME TABLES

The long frame tables are less complex because each modem is not required to transmit a long frame. There was only one long frame generator. Table 8 illustrates the Long Frame Test.

SHORT FRAME TEST

Date/Time	____________	
Frame Type	____________	
Channel	____________	
Cable Length	____________	
	Remodulator	Modem
Transmit Level	______	______
Receive Level	______	______
Signal/Noise Level	______	______

REMOD	XMITTER	# SENT	A RCVD	B RCVD	C RCVD	D RCVD
A	A	____	____	____	____	____
	B	____	____	____	____	____
	C	____	____	____	____	____
	D	____	____	____	____	____
B	A	____	____	____	____	____
	B	____	____	____	____	____
	C	____	____	____	____	____
	D	____	____	____	____	____
C	A	____	____	____	____	____
	B	____	____	____	____	____
	C	____	____	____	____	____
	D	____	____	____	____	____

Table 7. SHORT FRAME TEST SHEET

LONG FRAME TEST

Date/Time	________________
Frame Type	________________
Channel	________________
Cable Length	________________

	Remodulator	Modem
Transmit Level	________	________
Receive Level	________	________
Signal/Noise Level	________	________

REMOD	# SENT	A RCVD	B RCVD	C RCVD	D RCVD
A	______	______	______	______	______
B	______	______	______	______	______
C	______	______	______	______	______

Table 8. LONG FRAME TEST SHEET

RING TEST

Date/Time	____________	
Slot Time	____________	
Channel	____________	
Cable Length	____________	
	Remodulator	Modem
Transmit Level	________	________
Receive Level	________	________
Signal/Noise Level	________	________

REMOD	ORDER	A	B	C	D	TRANSMIT
A	ABCD					A SENDS
	BDAC					B SENDS
	CADB					C SENDS
	DCBA					D SENDS
B	ABCD					A SENDS
	BDAC					B SENDS
	CADB					C SENDS
	DCBA					D SENDS
C	ABCD					A SENDS
	BDAC					B SENDS
	CADB					C SENDS
	DCBA					D SENDS

Table 9. RING TEST SHEET

8. CONCLUSIONS

While the test results indicate that all participating vendor's modems and headend remodulators interoperate at the physical layer, there is evidence that current implementations do not interoperate at all parameter settings. The test methodology described in this report finds those combinations of parameter values where implementations fail to interoperate. This methodology includes five test definitions.

The first test definition describes the baseline test. This test is the necessary first step to insure that the cable plant facility is operating correctly and to allow each vendor to satisfy himself that his equipment is operating according to his expectations.

The short frame tests exercise the scrambler/descrambler, the encoder, and the kicker mechanisms in vendor's equipment under a variety of test conditions. Headend capture, timing recovery and response to minimum preamble are also checked. Short frame tests are run for several combinations of receiver signal level and receiver noise level at both the remodulator and the modems. These tests find those combinations of vendor equipment, signal level and noise level that exhibit an abnormally high error rate.

The long frame tests check AGC stability and phase recovery. These test require a special frame generator to transmit the test frame. Long frame tests are also run for several combinations of receiver signal level and receiver noise level at both the remodulator and the modems. These tests find those combinations of vendor equipment, signal level and noise level that exhibit an abnormally high error rate.

The remodulator response tests define useful test stimuli for testing how a remodulator responds to error conditions at its input. These tests show that different remodulators respond differently to the specified test inputs.

The token bus tests exercise the equipment under test as it is used in a logical ring. Correct operation under the conditions of this test is a strong indication that equipment interoperates at the physical layer. Correct operation, however, also requires interoperation at the MAC level, so failure to operate correctly does not necessarily indicate a failure in interoperability at the physical layer. These tests also found those conditions where the error rate increased noticeably.

The methodology will evolve as experience is gained. New remodulator test frames and different environmental and electrical parameters settings are easily incorporated into an interoperability test plan that uses this methodology. A more complete set of remodulator tests is required; but, the current standard is deficient in describing responses during ring initialization and other opportunities where modem contention occurs. During these contention periods, the remodulator must respond to a wide variety of reverse channel transmissions. Once responses to these conditions are standardized, appropriate test frames can easily be added to the test methodology and then tested in a controlled and repeatable laboratory environment.

1. Manufacturing Automation Protocol Specification, Version 2.2, July, 1986. General Motors

2. International Standard ISO 7498 -1984 (E), "Information Processing Systems -- Open Systems Interconnection -- Basic Reference Model, 1984. p30.

3. "ANSI/IEEE Std 802.4-1985, ISO/DIS 8802/4," Token Passing Bus Access Method. The Institute of Electrical and Electronics Engineers, Inc., Distributed in cooperation with Wiley-Interscience, a Division of John Wiley & Sons. Inc. Approved December 17, 1984 **American National Standards Institute.** p238.

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5. "ANSI/IEEE Std 802.2-1985, ISO/DIS 8802/2," Logical Link Control. The Institute of Electrical and Electronics Engineers, Inc., Distributed in cooperation with Wiley-Interscience, a Division of John Wiley & Sons. Inc. Approved December 28, 1984 **American National Standards Institute.** p111.

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11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

A method for testing broadband token passing bus interoperability is described. The method was tested in a controlled laboratory environment at the National Bureau of Standards with four modem manufacturers' and three headend remodulator manufacturers' equipment. The tested equipment implemented specific token passing bus options found in commercially available products.

The methodology specfies seven environmental and electrical parameters; for the first set of tests, nominal parameter settings were selected. The methodology uses specific test frames developed for their unique bit patterns. These frames were transmitted, received, and counted to exercise the broadband modems and headend remodulators. The methodology organizes the frame transmissions into five test definitions. Each test definition is repeated for each headend remodulator.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

Local Area Networks; physical layer testing; protocol testing; test methodology; token bus

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