PERFORMANCE HISTORY IN TWO-WAY CABLE PLANTS
UTILIZING A PSK COMMUNICATION SYSTEM

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ABSTRACT

Pay-Per-View video programming has become a new source of revenue for cable operators. To achieve maximum potential, a true, low cost two-way impulse delivery system is needed. Two-way cable systems are the most economical method to supply this need. However, minimal reverse cable plant maintainance results in significant ingress and impulse noise that can hinder two-way data communication. The communication system must be rugged and reliable to work in such an environment. A low cost, coherent PSK system has been developed and field tested. Results indicate that field performance correlates within 1-2 db of white noise tests done in the lab. Also, a safety "margin" of greater than 24 db has been observed in the field.

INTRODUCTION

With the advent of satellite delivery Pay-Per-View (PPV) programming, the need for a low cost, true impulse delivery system now exists. Two-way cable represents the least expensive method of providing this service. However, the typical cable system's reverse plant has significant noise and ingress problems. This is the result of normal forward plant maintainance and minimal reverse plant maintainance. Upgrading these reverse plants to video quality levels is prohibitively expensive. However, a low cost data communication system has been designed to operate reliably in such a system and has been successfully field proven.

TYPICAL TWO-WAY REVERSE PLANT CHARACTERISTICS

A brief description of return plant characteristics is necessary before going into two-way cable data communication performance. A more detailed description of these characteristics can be found in Ref. 1.

There are five major degradation characteristics of a return plant: white noise, ingress, common mode distortion, amplifier nonlinearities and impulse noise.

White noise is the thermal noise generated by a 75 ohm termination. In a two-way cable plant, the headend is the focal point for all signal sources, including white noise from all the terminations and return amplifiers. All the noise is "funnelled" into the headend. This "noise funnelling" increases the thermal noise measured in the return plant at the headend. This noise can be found by using equation 1 assumming a 0 db system.

$$\text{WN floor (dbmv)} = -59 + 10\log(BW/4MHz) + nf + 10\log(N) \quad (1)$$

where

- -59 = noise generated by a 75 ohm resistor in a 4MHz bandwidth, in dbmv
- BW = bandwidth other than 4MHz
- nf = amplifier noise figure (assuming the same for all amplifiers).
- N = total number of amplifiers in the cable system

Ingress is defined as unwanted external signals entering the cable plant at weak points in the system with the most common weak points being drops and faulty connectors. Common ingress sources are amateur radio operators, citizens band operators, local AM braodcasts and local and international shortwave. Figure 1 is a plot of reverse plant ingress of an existing cable plant. The cable plant has 31,000 subscribers and 2312 amplifiers. The solid bars indicate shortwave bands; the crosshatched bar citizens band; the diagonal bars amateur radio bands; and the dotted bar AM broadcasts. The white noise floor using equation 1 and 100KHz BW is -31 dbmv.

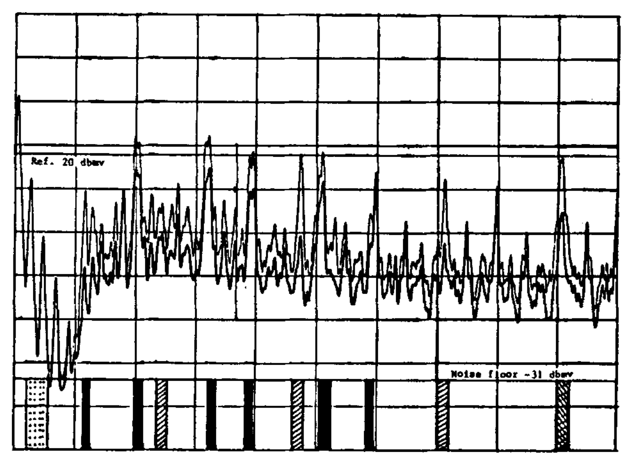


Fig 1 Reverse plant ingress of an existing cable system that has 31,000 subscribers and 2312 amplifiers.

Common mode distortion is the result of nonlinearities in the cable plant that are not due to active devices but rather to passive devices. The nonlinear function is generated by corrosion in connectors, and results in a weak diode effect that creates distortion products. The forward plant contains many video channels separated by 6 Mhz. The nonlinear effect of these "diodes" causes sum and difference frequencies; the sum frequencies fall into the forward plant's spectrum while the difference frequencies fall within the reverse plant's spectrum. Therefore, the reverse plant will have these products at 6, 12, 18, 24, and 30 Mhz.

Amplifier nonlinearities, although not very common, occur when marginally stable amplifiers are misterminated resulting in transmission line oscillations.

Impulse noise is by far the most dominant peak source of noise in a return plant and it is caused by the presence of high voltage lines at close proximity to the cable plant. Two kinds of impulse noise are caused by these high tension lines; corona noise and gap noise. These sources are primarily found on 300KV or higher lines and are random in nature. Weather conditions play a major role in the intensity of these noise sources with humidity being the prime factor. Corona noise is created by the ionization of the air surrounding high voltage lines while discharge or gap noise occurs when insulators break down creating a large spark or discharge. This occurs semi-periodically and takes on a sin x/x frequency distribution. Figure 2 shows a plot of impulse noise in the return plant at the headend of another cable plant.

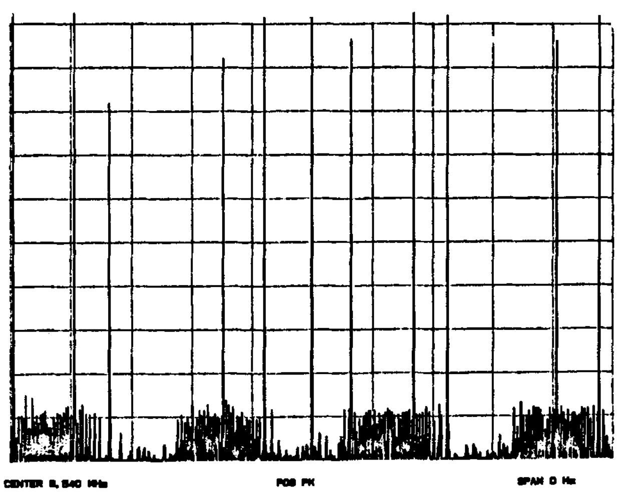


Fig 2 Impulse noise in the reverse plant of an existing cable system.

TWO-WAY CABLE SYSTEM REQUIREMENTS FOR DATA COMMUNICATION

In light of the previous description of typical cable plants, the first major requirement for a data communication system is good noise performance. Noise performance is important in any communication system. However, in the case of a two-way cable plant, the conditions can be severe due to the "noise funnelling." Not only is white noise funnelled into the headend but ingress as well. Therefore, the data communication system must be extremely rugged and have good noise/interference performance.

An advantage of two-way data communication on a cable system is that typical operation allows for data throughput to be less than 100% and still provide satisfactory performance. Return messages not received or received in error can be repeated automatically. This is true for either contention or polling systems.

A second major factor is the cost of the equipment in the system. Obviously, the thousands of home terminal units (i.e. two-way, addressable decoders) connected to the cable system must be simple and inexpensive while the headend equipment may be more complex and costly.

The reverse plant's spectrum is also important. Typically, the 5-30 Mhz return plant spectrum is divided into 4 video channels, T7,T8,T9,and T10. However, rarely more than two of these channels are ever used in the same system. This leaves sufficient room for data communication channels, although this available bandwidth should not be wasted through indiscriminate use of the spectrum. Therefore, minimal bandwidth utilization for data signals is desired.

Power levels of the signals on a return cable plant are required to be within certain ranges in order to not overload or "crossmod" the return amplifiers. This is especially important when there is video information being transmitted through the reverse plant to the headend. Typically, data signal levels into the input of a reverse plant line extender are 20-22 dbmv, in order to keep them 20 db down from any video signal carriers (40 dbmv).

DATA COMMUNICATION TECHNIQUES FOR TWO-WAY CABLE SYSTEMS

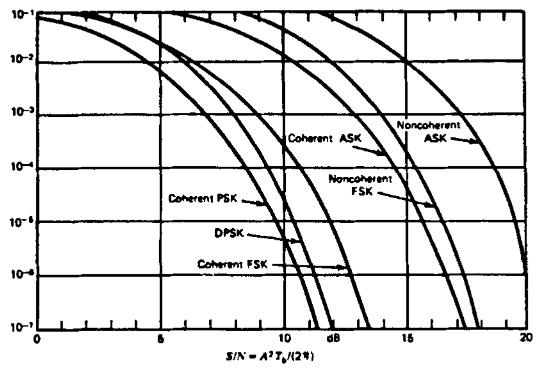
Various techniques exist for digital data communication on a cable medium. They are:

1. Coherent PSK
2. Noncoherent differential PSK
3. Coherent FSK
4. Noncoherent FSK
5. Coherent ASK
6. Noncoherent ASK

Each of these techniques has advantages and disadvantages. In choosing which one to use, they must all be weighed against the particular requirements of a two-way cable system. Parameters such as signal power level, signal bandwidth, noise performance, and cost will determine which technique best fits the need of the cable environment.

These six data communication techniques can be broken down into three categories and rated according to the requirements of a two-way cable system. Fig 3 (obtained from Ref 2) illustrates the comparison of these techniques. From this graph and the corresponding table, one can quickly draw some reasonable conclusions.

(a)



(b)

DIGITAL MODULATION METHOD	COST TRANSMITTER	COST RECEIVER	BANDWIDTH	S/N PERFORMANCE FOR 10E-4 BIT ERROR RATE
COHERENT PSK	LOW	HIGH	Fbit	8.45 db
NONCOHERENT DPSK	MED	MED	Fbit	9.30 db
COHERENT FSK	MED	HIGH	2*dF + Fbit	10.6 db
NONCOHERENT FSK	LOW	LOW	2*dF + Fbit	15.3 db
COHERENT ASK	LOW	HIGH	Fbit	14.5 db
NONCOHERENT ASK	LOW	MED	Fbit	18.3 db

Fig 3 (a) Probability of error curves for binary digital modulation schemes. (Note that the average signal power for ASK schemes is (A*A)/4 whereas it is (A*A)/2 for the others). (b) Table comparison of binary digital modulation schemes. (2*df=F2-F1 is the frequency shift and Fbit is the baseband data bit rate). Obtained from Ref 2.

First, coherent methods of detection allow for better noise performance at the expense of higher cost in the receiver. However, in two-way cable applications, the receiver is in the headend and cost is not as critical as it is for the transmitter in the home terminal units. Therefore, in terms of noise performance, coherent PSK has a great advantage over the other techniques.

Secondly, the bandwidth requirement of FSK techniques is larger, due to nonlinear modulation, than PSK or ASK techniques that employ linear modulation. Not only does this take up more of the spectrum, but also allows for more ingress to fall within the signal bandwidth and degrade data throughput. Also, the phase linearity of the bandwidth-determining filter is more critical in FSK. Another aspect is that impulse noise, which is a prime source of ingress in a cable system, has an adverse affect on FSK systems since they deal with the derivative of the phase function rather than with the phase function directly, as in PSK. Therefore, the cost savings of noncoherent FSK are cancelled by its larger bandwidth requirements and poor performance in both white and impulse noise.

Thirdly, in ASK techniques, signal level variation requires either the data decision levels to be varied or automatic gain control to be employed. This adds to the cost and complexity of the system and still gives relatively poor noise performance. In two-way cable systems, not only does the gain of the reverse plant vary with time, but the signal level from all the home terminal units will not be identical. On the other hand, PSK and FSK techniques allow for signal limiting since the data is contained in the carrier phase rather than in the amplitude. Consequently, gain or level variation is inconsequential for these techniques.

Therefore, it can be concluded from the previous three points that the best technique for two-way cable data communication is coherent PSK since it offers the lowest bandwidth and the best noise performance. The cost of the home terminal unit's transmitter is low and the additional cost that is in the headend receiver is not prohibitive. Also, the superior performance in noisy cable environments allows for less effort and cost in the return plant's maintainance.

NEW PSK DATA COMMUNICATION SYSTEM

The two-way cable communication system used in the field tests employed binary coherent PSK techniques. The home terminal unit consisted of an addressable converter/decoder for reception of the forward plant's video and control signals and a PSK transmitter for transmission of digital information on the reverse plant. At the cable headend, a coherent PSK receiver was connected to the reverse plant's cable, which often consisted of multiple trunk lines. A computer was connected to the headend receiver for collection and statistical analysis of the received digital data. The computer also controlled the forward plant's data channel and video encoders. The cable systems themselves were typical two-way cable designs with trunk, bridger, and line extender amplifiers. A block diagram of the cable system test is shown in Fig 4.

The home terminal unit's transmitter is shown in Fig 5a. It can be seen that it is quite simple and straight forward, consisting of a crystal oscillator and a multiplier. This meets the requirement of low cost for the high volume home terminal unit. Another advantage of the PSK transmitter is that its linear modulation allows the signal bandwidth to be controlled by baseband filtering rather than by RF filtering.

The headend's receiver is shown in Fig 5b. The receiver is more complex and sophisticated since it must employ coherent detection of the PSK signal. This means that the carrier must be regenerated from the incoming signal while it is being synchronously detected. In addition to amplification and narrow band filtering on the front end, the data packet must be detected and recognized in order to determine the beginning of the data as well as remove the phase ambiguity that exists with all PSK systems. Packet detection is accomplished through digital correlation thus allowing accuracy and good noise performance.

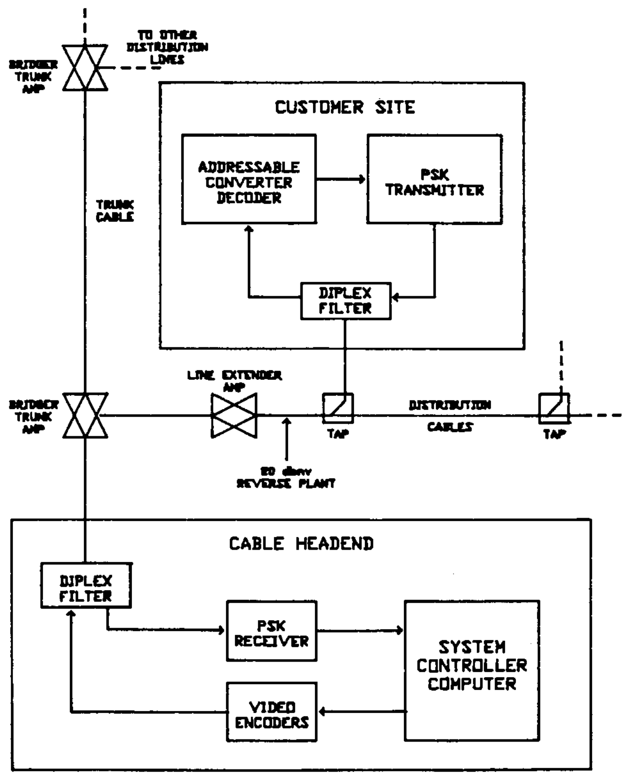


Fig 4 Block diagram of a PSK data communication system connected in a typical cable plant.

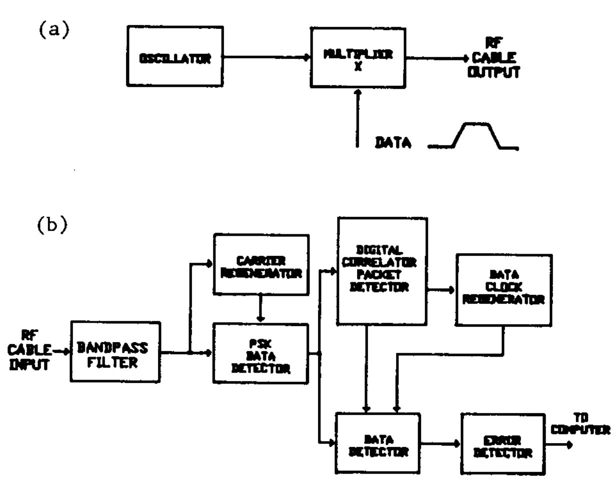


Fig 5 PSK data communication system used in field test.

Error protection is employed through the use of a cyclic redundant code (CRC) which flags all data packet messages that contain errors. No error correction is attempted since two-way cable communication systems are designed around repeating messages when errors occur. Finally, a computer is used to analyze the data, providing the statistical information needed to characterize the data communication system.

Additional parameters determine the communication system's performance. The carrier frequencies used were selected carefully by avoiding the known ingress frequencies and searching for "gaps" in the ingress spectrum. Two carrier frequencies were used in the field test; 5.5 Mhz and 11.0 Mhz. These two frequencies fit well into the ingress spectrum and allow optimum performance even when a minimally maintained reverse plant has severe ingress problems.

The data bit rate was selected to be 45 Kbits/sec. Since PSK is a linear modulation technique, the bandwidth of the channel is equal to the bit rate. This determined the bandwidth required in the reverse plant's spectrum and in the headend receiver. A double-sided bandwidth of 60 Khz was selected for the headend receiver. Regarding the bit rate, the trade-off was between faster throughput and lower bandwidth. Lower bandwidth not only has the advantage of conserving frequency spectrum but also of minimizing the chances of ingress falling within the data signal bandwidth.

Signal levels on the reverse plant are of importance to the cable operator. When video sources are being transmitted along with the data signals, then data carriers should be small in order to avoid "crossmod" problems due to non-linearities in the return amplifiers. However, if data carriers are too small, their performance in heavy noise or ingress will be degraded. These field tests were typically run with data carriers between 20-22 dbmv, which is 20 db below any video carriers on the reverse plant. It should be noted that when no return video services are offered in a particular cable system, these levels can be run higher since "crossmod" products 56 db down are not required for data communication as in video transmission.

FIELD TEST RESULTS

The two-way cable data communication system described above was taken to four different cable sites for system testing. Data signal levels from the home terminal unit were adjusted so that levels into a line extender on the reverse cable plant were 20 dbmv. Data packets were continually sent at a predetermined rate in order for the computer to calculate the statistical throughput of the system. Various conditions were simulated during the tests. In particular, the level of the data carriers was lowered in various increments until the overall system throughput was reduced to 90% (i.e. 90% of the data packets were received without error). Operation of the PSK communication system with this reduced data carrier level then provided a performance "margin" for the cable system based upon actual system noise/ingress levels.

Test site #1 had about 15,000 subscribers on the two-way plant, which consisted of three trunks. An FSK security system was already in service.

Fig 6 shows the entire reverse plant spectrum, while Fig 7 shows an expanded view of the two data channels. Notice that the C/N around the two carriers is about 50 db while the C/N at the high end of the reverse plant's spectrum is 60 db. The presence of impulse noise can be seen in both data channels with greater amounts in the 5.5 Mhz channel. The overall noise/ingress is small since the average of the ingress peaks are greater than 30 db below nominal data carrier levels. This is an indication of a well-maintained system which is necessary when FSK data carriers are present or when video signals need to be transmitted back to the headend.

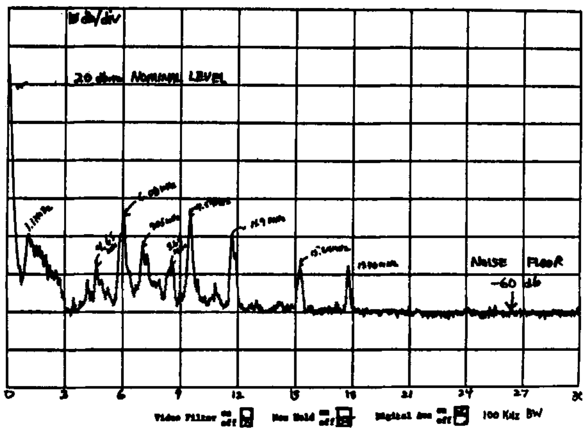


Fig 6 Reverse plant spectrum at Site #1.

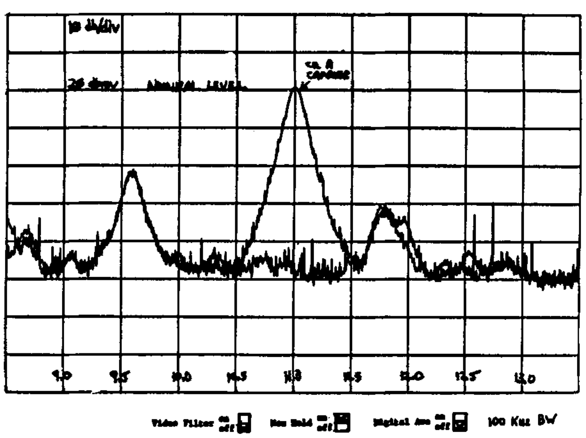


Fig 7 (a) Expanded view of 11 Mhz channel of Site #1.

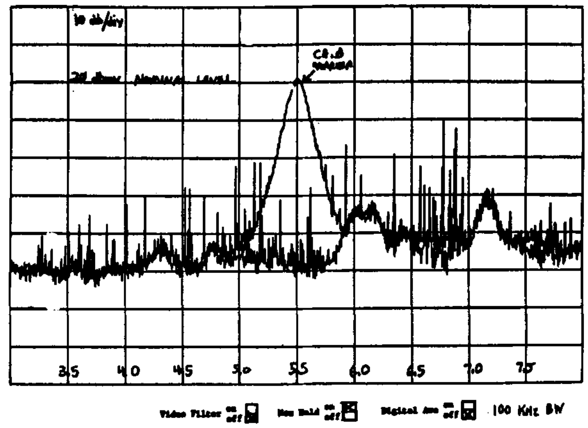


Fig 7 (b) Expanded view of 5.5 Mhz channel of Site #1.

The ingress that is present is the usual AM broadcast, amateur, and international shortwave bands. Also, impulse noise was present. The throughput under these conditions was 100%. Under these plant conditions, the data carriers were then lowered to 30 db below nominal level and Fig 8 illustrates that the throughput was over 97%.

Ch	Sent	Rec'd	Bad	Good	Rec'd /Sent	Good /Sent	Good/ Rec'd	Signal	Noise	Car+Noise /Noise
			6:38:59 pm							
A	1000	1000	0	1000	100.000	100.000	100.000	201.38	1.02	45.91
B	1000	1000	0	1000	100.000	100.000	100.000	202.09	1.05	45.68
			6:40:15 pm							
A	1000	1003	0	1003	100.300	100.300	100.000	201.27	1.03	45.81
B	1000	1002	0	1002	100.200	100.200	100.000	201.97	1.05	45.72
					TOTALS					
A	2400	2343	0	2343	97.625	97.625	100.000	199.87	1.49	42.54
B	2400	2343	0	2343	97.625	97.625	100.000	200.39	1.50	42.50

Fig 8 Throughput results at Site #1 with carrier levels 30 db below nominal.

An overnight run with the data carriers reduced to 46 db below their nominal levels was also performed. Fig 9, which displays the reverse plant's spectrum, indicates that the impulse noise has increased substantially, but more so at the lower frequencies. The results, shown in Fig 10, indicate that 94% of the total data packets were received without error. However, the 5.5 Mhz channel throughput was reduced to 88.5% while the 11 Mhz channel was still greater than 99%. This difference is due to the greater impulse noise in the 5.5 Mhz data channel.

After further testing, it was determined that a throughput of 90% could be maintained with the data carriers reduced by 47 db. Therefore, the "margin" of this particular cable system was approximately 47 db.

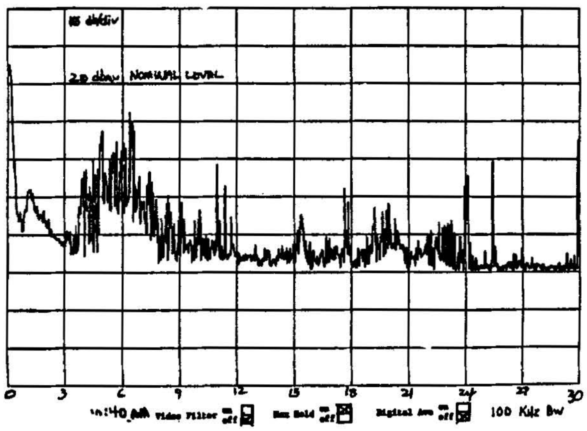


Fig 9 Reverse plant spectrum, with impulse noise, at Site #1.

Ch	Sent	Rec'd	Bad	Good	Rec'd /Sent	Good /Sent	Good/ Rec'd	Signal	Noise	Car+Noise /Noise
			1:29:40 am							
A	1000	999	1	998	99.900	99.800	99.900	36.35	ɔ.37	16.61
B	1000	989	36	953	98.900	95.300	96.360	38.16	6.72	15.09
			2:28:08 am							
A	1000	1000	5	995	100.000	99.500	99.500	36.34	5.54	16.34
B	1000	982	59	923	98.200	92.300	93.992	38.72	7.30	14.49
			3:27:52 am							
A	1000	997	6	991	99.700	99.100	99.398	35.98	5.65	16.07
B	1000	984	37	947	98.400	94.700	96.240	38.18	6.70	15.12
			4:28:51 am							
A	1000	999	1	998	99.900	99.800	99.900	35.83	5.21	16.75
B	1000	987	26	961	98.700	96.100	97.366	38.09	6.33	15.59
			5:28:35 am							
A	1000	999	1	998	99.900	99.800	39.900	35.66	5.33	16.51
B	1000	983	61	922	98.300	92.200	93.794	37.78	6.77	14.94
			6:30:47 am							
A	1000	999	1	998	99.900	99.800	99.900	35.60	5.11	16.86
B	1000	986	39	947	98.600	94.700	96.045	37.82	6.89	14.78
			7:29:17 am							
A	1000	999	1	998	99.300	99.800	99.900	35.83	5.96	15.57
B	1000	953	143	810	95.300	81.000	84.995	38.15	7.73	13.87
			8:29:01 am							
A	1000	999	1	998	99.900	99.800	99.900	35.75	5.63	16.05
B	1000	944	175	769	94.400	76.900	81.462	38.10	8.48	13.05
			9:29:59 am							
A	1000	999	0	999	99.900	99.900	100.000	35.92	5.65	16.06
B	1000	948	116	832	94.800	83.200	87.764	38.30	8.22	13.36
			10:28:30 am							
A	1000	999	1	998	99.900	99.800	99.900	36.11	5.65	16.11
B	1000	931	146	785	93.100	78.500	84.318	38.31	7.98	13.62
			TOTALS							
A	442800	443049	469	442580	100.056	99.950	99.894	35.97	5.60	16.15
B	442800	429147	37188	391959	96.917	88.518	91.334	38.14	7.33	14.33

Fig 10 Throughput results at Site #1 with carrier levels 46 db below nominal.

Test site #2 had approximately 15,000 subscribers on the two-way plant. Four trunks, carrying all the plant's signals, were combined together in the headend. Fig 11 illustrates the two data carriers, some security data carriers (24 Mhz) and the reverse plant's noise/ingress. The ingress can be seen to come up to within 20 db of the nominal carrier levels.

The throughput under these conditions was 100% since the carrier-to-noise (C/N) in the 60 Khz bandwidth was better than 35 db despite the heavy ingress. Fig 12 illustrates this relatively good C/N at 5.5 Mhz and 11 Mhz while the common mode distortion at 6 Mhz and 12 Mhz is noticeably large. Fig 13 shows the reverse plant with the data carriers reduced by 20 db. However, the data communication system still had an average throughput of 97% at this reduced level.

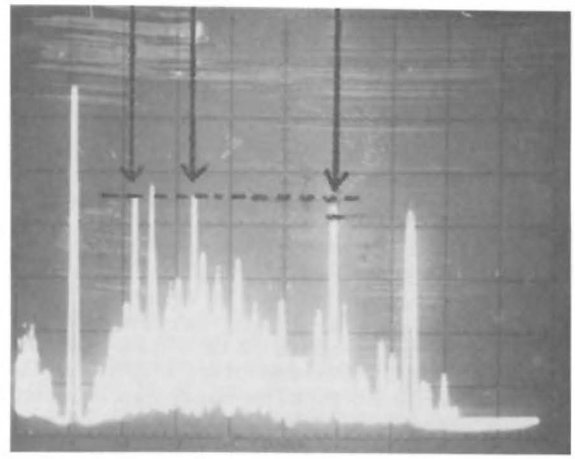
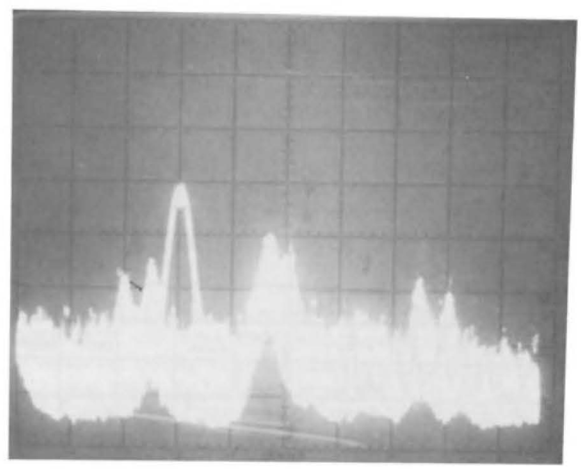
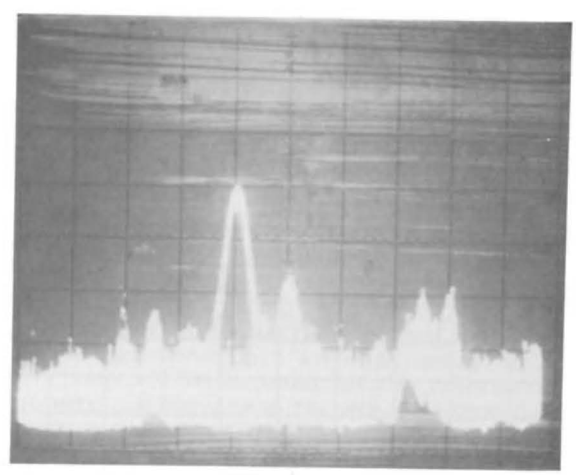


Fig 11 Reverse plant spectrum at Site #2.



(a)



(b)

Fig 12 (a) Expanded view of 11 Mhz channel at Site #2. (b) Expanded view of 5.5 Mhz channel at Site #2.

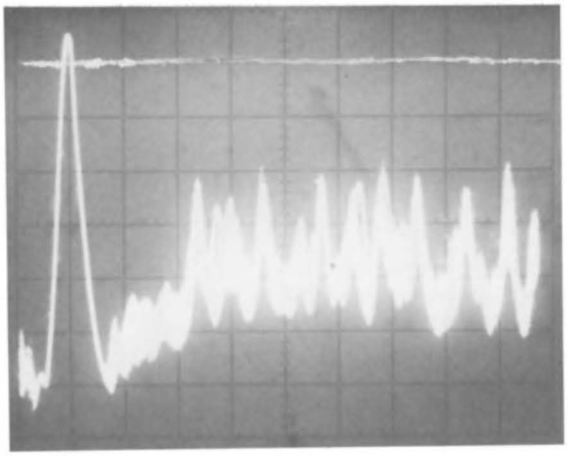


Fig 13 Reverse plant spectrum at Site #2 with carrier levels 2Ø db below nominal.

It was further determined that a throughput of 9Ø% could be maintained with data carriers reduced by 3Ø db. Therefore, a "margin" of 3Ø db was given to this system.

Test site #3, a relatively new system, had about 3,ØØØ subscribers on the two-way plant. The reverse plant was balanced and initially had low levels of ingress, 25-3Ø db below nominal carrier levels. However, some corona impulse noise was noticed on the plant. Under these conditions, it was found that 1ØØ% of the data packets were received without error.

An overnight test was performed with the data carriers reduced to 3Ø db below their nominal levels. Fig 14 illustrates the reverse plant's spectrum for the evening and next morning. Note how the noise/ingress changed greatly during the night (by as much as 3Ø db) yet the throughput,shown in Fig 15, was 99%, even with carriers reduced by 3Ø db. Throughput remained constant through the night even though the noise/ingress varied greatly. This is due to the C/N in the two 6Ø Khz data channels changing very little (less than 2 db).

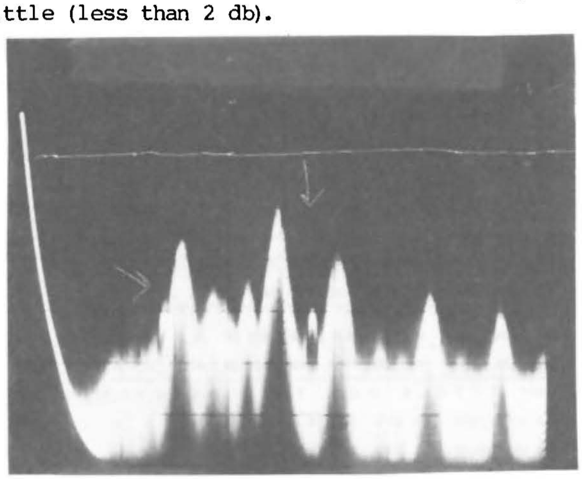


Fig 14 (a) Reverse plant spectrum at night at Site #3.

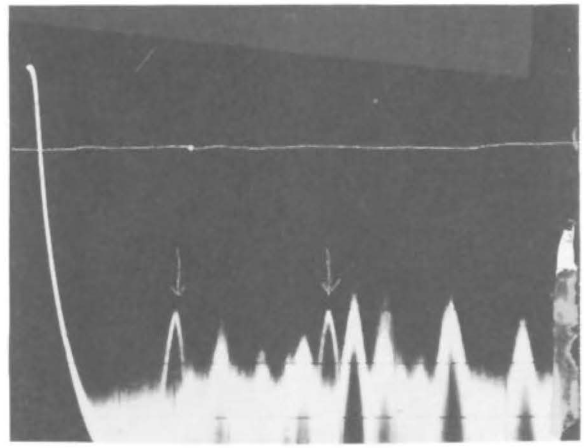


Fig 14 (b) Reverse plant spectrum next day at Site #3.

PARAMETER LIST:
NUMBER OF MESSAGE SLOTS PER GROUP 25Ø
RUN-IN DETECTOR CORRELATION NUMBER IS ... 48
SYNC. DETECTOR CORRELATION NUMBER IS 56
HIGH NOISE THRESHOLD LEVEL IS 1Ø
RELATIVE SIGNAL LEVEL IS ....-3Ø DB

CH C/N DB	MESS. SENT	PREAM. DET.	ERROR MESS.	GOOD MESS.	PD/MS %	GM/MS %	GM/PD %	AVE. COR.	AVE. [illegible]	ADV. THR.	[illegible] AVE.	
A 23.3	15ØØ	15ØØ	1	1499	1ØØ.ØØ	99.93	99.93	53	4	Ø	Ø	7:22 PM
B 21.9	15ØØ	15ØØ	Ø	15ØØ	1ØØ.ØØ	1ØØ.ØØ	1ØØ.ØØ	51	4	Ø	Ø	
A 23.7	15ØØ	15ØØ	Ø	15ØØ	1ØØ.ØØ	1ØØ.ØØ	1ØØ.ØØ	53	3	Ø	Ø	
B 21.8	15ØØ	1499	1	1498	99.93	99.87	99.93	51	4	Ø	Ø	
A 25.3	15ØØ	15ØØ	Ø	15ØØ	1ØØ.ØØ	1ØØ.ØØ	1ØØ.ØØ	54	3	Ø	Ø	11:22 PM
B 21.4	15ØØ	15ØØ	1	1499	1ØØ.ØØ	99.93	99.93	51	4	Ø	Ø	
A 25.4	15ØØ	1499	Ø	1499	99.93	99.93	1ØØ.ØØ	54	3	Ø	Ø	
B 21.5	15ØØ	15ØØ	Ø	15ØØ	1ØØ.ØØ	1ØØ.ØØ	1ØØ.ØØ	51	4	Ø	Ø	
A 25.7	15ØØ	15ØØ	Ø	15ØØ	1ØØ.ØØ	1ØØ.ØØ	1ØØ.ØØ	54	3	Ø	Ø	3:22 AM
B 22.6	15ØØ	15ØØ	Ø	15ØØ	1ØØ.ØØ	1ØØ.ØØ	1ØØ.ØØ	51	4	Ø	Ø	
A 25.5	15ØØ	15ØØ	Ø	15ØØ	1ØØ.ØØ	1ØØ.ØØ	1ØØ.ØØ	54	3	Ø	Ø	
B 22.8	15ØØ	15ØØ	Ø	15ØØ	1ØØ.ØØ	1ØØ.ØØ	1ØØ.ØØ	51	4	Ø	Ø	
A 25.9	15ØØ	15ØØ	Ø	15ØØ	1ØØ.ØØ	1ØØ.ØØ	1ØØ.ØØ	54	3	Ø	Ø	7:22 AM
B 22.9	15ØØ	1499	Ø	1499	99.93	99.93	1ØØ.ØØ	51	4	Ø	Ø	
A 25.7	15ØØ	15ØØ	Ø	15ØØ	1ØØ.ØØ	1ØØ.ØØ	1ØØ.ØØ	54	3	Ø	Ø	
B 22.3	15ØØ	15ØØ	2	1498	1ØØ.ØØ	99.87	99.87	51	4	Ø	Ø	

***** T O T A L S F O R T H I S S E S S I O N A R E :

A 24.9	9755ØØ	975441	139	9753Ø2	99.99	99.92	99.98	54	3	1	[illegible]	8:40 AM
B 22.1	9755ØØ	97513Ø	374	974764	99.96	99.8Ø	99.94	51	4	6	[illegible]	

Fig 15 Throughput results at Site #3 with carriers 3Ø db below nominal.

A second overnight run with the data carriers 43 db below nominal produced a throughput of 97%. Further tests indicated that a "margin" of 46 db (for 9Ø% throughput) existed in this two-way cable system.

Test site #4 was about seven years old and had about 30,000 subscribers on its two-way plant with five trunks feeding the headend. The reverse plant had been maintained for 1200 security boxes. The plant had significant ingress as seen in Fig 16 where the peak of the ingress came within 15 db of the nominal data carrier levels. Also, some noticeable CB interference was observed. Under these conditions, the throughput of the PSK data communication system was found to be 100%.

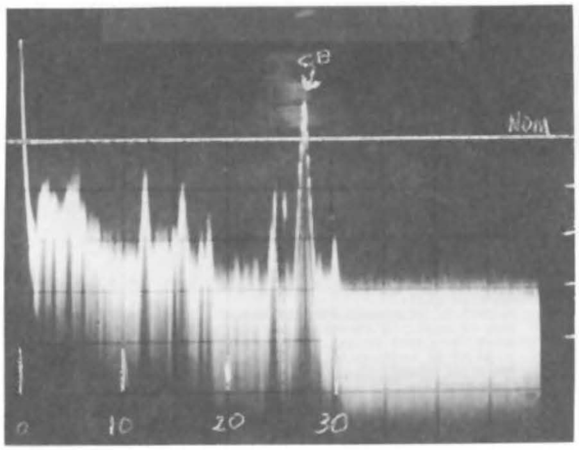


Fig 16 Reverse plant spectrum at Site #4.

A test was performed with the data carriers 26 db below their nominal levels. Fig 17 shows that an average of 74% of the data packets were received without error. However, it should be noted that the 5.5 Mhz channel throughput is significantly less than the 11 Mhz channel throughput. Fig 18 reveals that the reverse plant's spectrum has a "comb" structure at the low frequency end (4-8 Mhz) and that the 5.5 Mhz channel did indeed have a lower C/N ratio than the 11 Mhz channel. It was subsequently found that a trunk amplifier had been oscillating in the form of a pulse regenerative oscillator.

PARAMETER LIST:
NUMBER OF MESSAGE SLOTS PER GROUP 250
RUN-IN DETECTOR CORRELATION NUMBER IS ... 48
SYNC. DETECTOR CORRELATION NUMBER IS 56
HIGH NOISE THRESHOLD LEVEL IS 50
RELATIVE SIGNAL LEVEL IS ....-26 DB

CH	C+N /N	MESS. SENT	PREAM. DET.	ERROR MESS.	GOOD MESS.	PD/MS %	GM/MS %	GM/PD %	AVE. C+N	AVE. NOS.	ADV. THR.	[illegible] AVE.
A	9.3	2300	2013	94	2319	96.52	92.76	96.10	196	66	7	85
B	6.3	2300	1930	570	1300	78.32	55.52	70.89	190	96	8	116
***** TOTALS FOR THIS SESSION ARE :												
A	9.3	2300	2013	94	2319	96.52	92.76	96.10	196	66	7	85
B	6.3	2300	1930	570	1300	78.32	55.52	70.89	190	96	8	116

Fig 17 Throughput results at Site #4 with carriers 26 db below nominal.

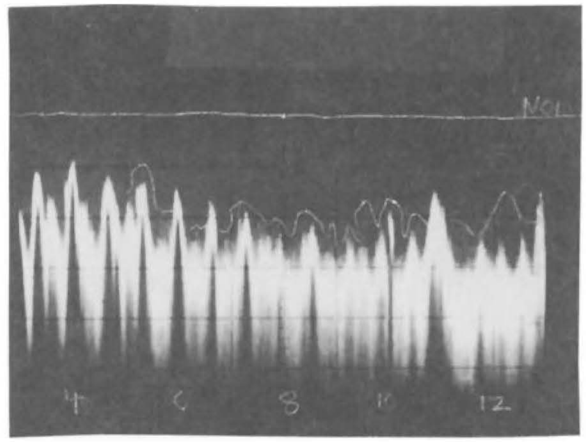


Fig 18 Reverse plant spectrum at Site #4 with carriers 26 db below nominal. Note "comb" characteristics in low frequency spectrum due to trunk amplifier oscillations.

An overnight run with the data carriers 20 db below nominal was performed with results in Fig 19 showing a throughput of about 90%. This system had a significant amount of other ingress and common mode distortion that changed over time yet the C/N within the two 60 Khz data channels changed only slightly thus allowing the data communication system to perform very well.

CH	C+N /N	MESS. SENT	PREAM. DET.	ERROR MESS.	GOOD MESS.	PD/MS %	GM/MS %	GM/PD %	AVE. C+N	AVE. NOS.	ADV. THR.	[illegible] AVE.	
A	14.6	2300	2300	29	2071	100.00	98.04	98.04	140	26	0	0	7:05 PM
B	12.9	2300	2470	127	2351	99.12	94.04	94.87	176	40	0	0	
A	13.6	2300	2493	34	2459	99.72	98.36	98.64	135	30	0	0	
B	11.7	2300	2275	109	2106	91.00	84.24	91.76	153	40	0	0	8:10 PM
A	12.7	2300	2479	35	2444	99.16	97.76	98.59	116	27	0	0	
B	11.1	2300	2345	202	2143	93.80	85.72	91.39	139	39	0	0	
A	13.6	2300	2400	22	2466	99.52	98.64	99.12	133	30	0	0	
B	11.6	2300	2387	174	2213	95.40	85.52	92.71	140	39	0	0	9:12 PM
A	14.9	2300	2301	17	2404	100.04	99.36	99.32	141	25	4	0	
B	11.3	2300	2411	119	2292	96.44	91.60	98.04	139	43	0	0	
A	12.6	2300	2447	49	2398	97.88	95.92	98.00	134	32	0	0	
B	11.4	2300	2410	127	2283	96.40	91.32	94.73	140	40	0	0	10:17 PM
A	17.2	2300	2507	19	2488	100.28	99.52	99.24	144	30	0	0	
B	11.0	2300	2440	36	2404	97.60	96.16	98.52	175	45	3	12	
A	14.5	2300	2504	17	2487	100.16	99.48	99.32	144	22	0	0	
B	11.8	2300	2430	32	2406	97.32	96.24	98.69	180	46	2	31	11:15 PM
A	13.5	2300	2451	69	2382	98.04	95.30	97.18	116	33	0	0	
B	10.4	2300	2322	172	2150	92.88	86.00	92.59	135	30	0	0	
A	14.3	2300	2497	36	2471	99.88	98.84	98.96	119	22	0	0	
B	10.5	2300	2359	74	2285	94.36	91.40	96.86	130	41	0	0	
***** TOTALS FOR THIS SESSION ARE :													
A	14.0	197305	195350	3394	191956	98.91	97.19	98.26	129	26	0	0	
B	11.2	197300	184787	14671	170036	92.52	84.09	92.06	146	40	37	84	

Fig 19 Throughput results at Site #4 with carrier levels 20 db below nominal.

After the oscillating trunk amplifier was replaced, a 4 db improvement in system performance was observed. The "margin" for this test site was then determined to be 24 db.

CONCLUSIONS

The results of all the field tests were analyzed and compiled. Two basic conclusions can be made.

First, the field tests demonstrated that the performance of the PSK data communication system worked well in the field and correlated very well against the white noise tests performed in the lab. Fig 20 is a graph of the system performance (throughput) at the four test sites over a variety of C/N ratios. It can be seen that there is a 1-2 db degradation in the throughput at the test sites compared to the white noise test. The reason for this is that there is impulse noise in the field that has large peak power that can contaminate data but a low average power that does not show up in the C/N measurements. Therefore, the curve is shifted to the left of the white noise curve. This also explains why the throughput of the 5.5 Mhz channel at Site #1 is noticeably lower; the signal 46 db below nominal was extremely small compared to the impulse noise present. Despite the existance of impulse noise, outstanding performance is still obtained.

Second, there is plenty of safety "margin" in two-way cable plants for operation of PSK two-way data communication systems. The chart in Fig 21 reveals the various "margins" in the four test sites described above. Factors that affect the margin are the amount of maintainance provided, the number of subscriber taps, the condition that the system is in, how well it was originally built, and the proximity of the ingress signals. Even in those systems where noise/ingress is severe, a 24 db margin is obtainable. Often, the margin is much greater.

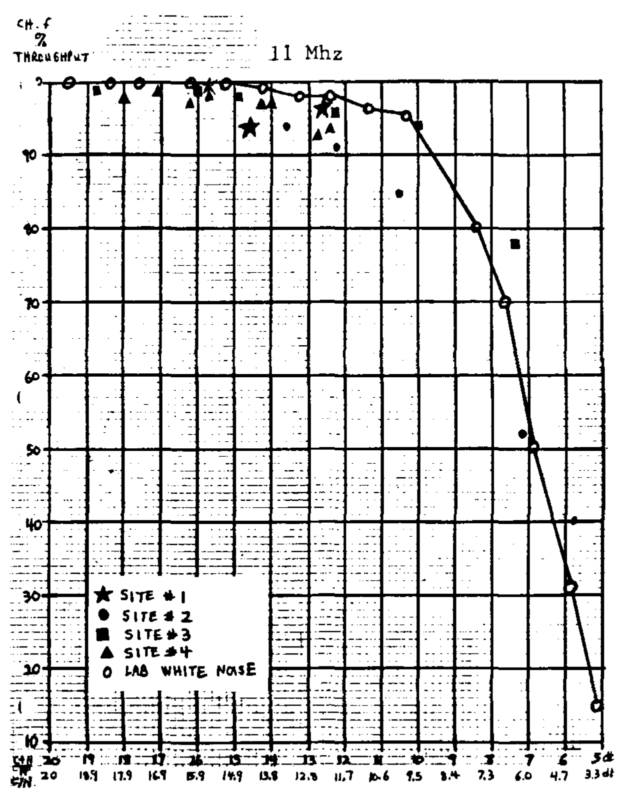


Fig 20 (a) Graph of 11 Mhz channel overall throughput versus C/N for all four test sites and white noise lab test.

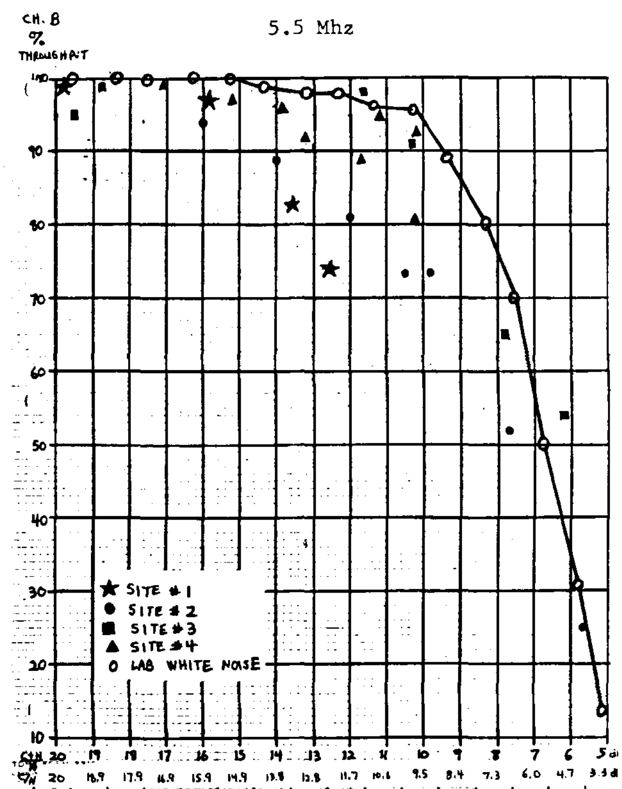


Fig 20 (b) Graph of 5.5 Mhz channel overall throughput versus C/N for all four test sites and white noise lab test.

By judicious selection of the PSK data communication parameters and carrier frequencies, large "margins" of operation are obtainable, even in cable plants with minimal two-way maintainance and significant noise/ingress.

This system has proven, in its largest installation to date, to be rugged and reliable. In three years of continuous operation in a 4500 mile two-way cable plant, the system has been shown to be technically and economically successful.

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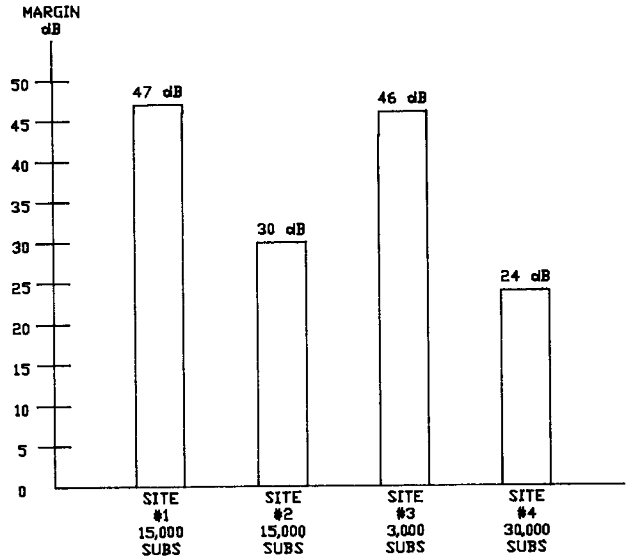

Fig 21 Chart of four field test site margins.