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ASSESSMENT OF THE EBN ADAPTIVE ECHO CANCELLING MODEMS FOR DIGITAL LOOP ACCESS

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ABSTRACT

This report describes and reports on an assessment made on four EBN echo cancelling 80kbit/s full duplex modems.

The modems were purchased in 1983 to supplement theoretical ISDN access studies in the Line and Data Systems Section.

The results of the assessment indicate that the modems had a transmission range shorter than expected.

CONTENTS

1. INTRODUCTION

Echo Cancellation is now seen as a viable method of full-duplex two-wire digital loop access for ISDN development. However, the transmission range of echo cancellation equipment is limited by near end crosstalk (NEXT), impulsive noise interference, and forward echoes caused primarily by bridged line taps and tails.

Four EBN echo cancelling 80kbits/s full duplex modems were purchased in 1983 to supplement theoretical transmission studies in the Line and Data Systems Section with experimental laboratory and field measurements.

This report details the results of a laboratory assessment of these modems.

A paper on echo canceller structures [1] is currently being prepared. This paper analyses various echo canceller filters and adaptation algorithms, including those used in the EBN modem.

2. MODEM STRUCTURE

The modem block diagram (Fig. 1) and other details have been derived from published papers [2-5], modem documentation, and laboratory examination. Parameters are listed in Table 1.

The EBN modem uses a conditioned diphase line code. The balanced nature of this code permits the use of a single Random Access Memory (RAM) echo cancelling filter addressed by the last 5 transmitted data bits. The modem was designed for 0 to 40 dB range (at 80kHz) on uniform lines. The receiver input analogue to digital converter (ADC) is a simple sign detector and the received signal is approximately reconstructed from 8 sign samples per symbol period. The receiver weights the 8 sign samples to approximate a matched (integrate and dump) detector. The echo canceller convergence is controlled by a variable amplitude, triangular dither noise input to the adaptation control loop.

The external interfaces to the modem are the two-wire line and a simplified V. 24 interface with 2 clocks (both from the modem) for the transmit and receive timing. There are no signal detectors, such as carrier detect, and no alarms or maintenance facilities.

3. PERFORMANCE

3.1 ECHO CANCELLATION

The echo canceller convergence has been monitored by observing the receiver eye pattern. The extent of any uncancellable echo (i.e. delayed by more than 5 symbol periods) has not been checked. The modems have generally exhibited stable operation, except for one unit which occassionally behaved erratically and produced high error rates for short periods. This erratic behaviour could not be intentionally induced, and the cause is as yet unknown.

The line coupling bridge (hybrid) is designed to match 0.64mm pair cable (Return Loss Ratio (RLR)=26dB)[4] rather than 0.4mm (RLR 13 dB). This mismatch is the source of an echo tail whose echo attenuation per time interval is greater in the smaller diameter pairs. Nevertheless, matching to uniform lines is adequate allowing the maximum cancellation amplitude (memory and digital to analogue converter (DAC) saturation level) to be set 6dB below the transmit signal level.

The memory resolution (equal to the convergence increment q) is determined by the dither noise amplitude (a) and the limit on mean square cancellation error (aq/2)[1,4]. A simple dither noise amplitude tracking circuit allows a convenient 16 bit memory to be used (dual 8 bit packages). The quantising noise requirement is then satisfied by a 10 bit DAC.

In case large reflections are encountered that are outside the range of the echo canceller, for example from a bridged tap located close to the modem, the transmitter output level can be reduced by 6dB. However, the transmission range will be reduced due to inherent noise and offsets in the receiver.

The echo is cancelled only at the receiver sample instants (8 per symbol period). Midway between sample instants the memory content is incremented and the address is changed for the next sample. The uncancelled echo residue between the sample instants superimposes spectacular diamond patterns on the receiver eye pattern, with large spikes superimposed on the apex of the diamonds. These large spikes occur at the instant that the memory is updated.

RAM echo canceller filters can cancel echo path and DAC nonlinearities (including DC offsets) in the adaptation control loop. Thus the EBN modem does not have any DC trimming on the DAC. (If the transmit signal is disabled, and the adaptation control loop broken by forcing the DAC digital inputs to zero (by operation of switch #4), the DAC offset then limits the transmission range). Nonlinear echo cancellation is readily demonstrated by shunting a small signal silicon diode across the two wire line, via a step up transformer, and noting that convergence to an echo-free eye proceeds normally.

In the receiver, the eye pattern appears to be noisy at the sample instants and has a small DC offset. It is not known whether the noise is induced from the digital circuits in the modem, or whether it is uncancellable echo beyond 5 symbol periods delay. The DC offset observed is caused partly by static and dynamic input offset differences between the receiver and echo cancelling sample comparators [Fig. 1](rated at 2mV typical offset error under static conditions).

3.2 TRANSMISSION

The transmission range limit is much shorter than anticipated, even with the transmitter of one modem switched off and the DAC input set by static switches for optimum DC offset at the receiver decision point. Thus the one-way limit is not determined by any problem in the RAM echo cancelling, but by a more basic problem such as equalisation or timing recovery errors.

The measured transmission range limits with no bridged taps are as follows:

For 0.4mm Cable:

3.3km (28dB at 80kHz) full-duplex.
3.6km (One way, switch 4 "off", ie. DAC input zeroed).
3.9km (One way, with DAC input set by static switches to produce optimum DC offset at the receiver decision point).

For 0.64mm Cable:

6.7km (33 dB at 80kHz), Full Duplex (anticipated from [2-5]: 40 dB)
(Other configurations not tested)

An unexpected transmission limitation was observed when testing with 2.8km of 0.4mm cable (23.9dB loss at 80kHz). With this length of cable, the receive clock of the modem that was configured as network terminating equipment (NTE) was jittering over a one-eight symbol period, and this modem would not operate without producing errors in the received data stream. This situation could be produced in either modem by changing the NTE/CTE (customer terminating equipment) configuration. The test arrangement used allowed the cable length to be modified in increments of 50m, and for cable lengths of greater or less than 50m from 2.8km, the modems operated normally.

This unexpected limitation was not investigated in detail. However, it has highlighted the need to test such modems over a wide range of cable lengths.

The fixed equaliser is not designed to accommodate the transmission distortion caused by a variety of bridged taps, and because there is no decision feedback equaliser (DFE), the range limit with the presence of bridged taps is correspondingly shortened (note that the echo canceller itself handles the backward echoes from bridged taps).

The self synchronising data scramblers are set to different pattern lengths depending on the NTE/CTE switch. Both (together with the line precoders) are adequate to ensure convergence of all memory locations even with static or disconnected V. 24 interfaces.

Simple crystal controlled clocks are used in the modems. The CTE receive and transmit clocks are controlled by a digital phase locked loop (PLL) which tracks the NTE clock after convergence of the echo canceller. Three CTE clock phases, separated by 1/64 of a symbol period, are simultaneously observed on an oscilloscope synchronised with the NTE clock, indicating much more CTE clock jitter than anticipated in [4]. The NTE receive sample clock is usually locked relative to one of the 8 NTE transmitter phases. The measured transmission range limit is dependent on the NTE/CTE configuration, with the maximum transmission range limit being slightly lower for the direction CTE-NTE, because of receive clock jitter in the NTE.

3.3 CROSSTALK NOISE FIGURE

Results of measurements of crosstalk noise figure [9-11] are shown in Figs. 2 and 3. These results have been obtained using the method described in [6]. See also [8].

Included in Figs. 2 and 3 are some results from computer simulations for cable lengths of 2 and 3 km, based on measurements of the EBN modem transmit and receive filter responses. The results of computer simulations do not take into consideration the detection technique used in the EBN modem which possibly improves the noise figure by 3 to 4 dB.

The results of crosstalk noise figure measurements performed with bridged taps are within the expected range, and some results are included in figs 2 and 3. However, further theoretical and practical studies are required on the EBN modem and other echo cancellation systems to supplement the work in this area.

4. CONCLUSIONS

The EBN modems are simple transmission units with approximately 30 dB (at 80kHz) range on uniform lines free of bridged taps. There is no provision for external clocking which limits any network applications. Slow convergence and lack of any activation/deactivation procedures require that the modems be continuously powered. In their present form they are restricted to specialised applications. Several modifications, including external clocking and inclusion of a decision feedback equaliser [1,7] would be required for digital loop access applications.

The modems' short range and inability to equalise tapped lines have prevented field experiments on the longer lines in which impulse and crosstalk noise are expected to be a fundamental limit on the performance of echo cancelling modems. However, the EBN modems have demonstrated the feasibility of the RAM type of echo canceller and supported the development of crosstalk noise figure measurement procedures for two-wire full-duplex digital transmission [6].

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TABLE 1. EBN MODEM PARAMETERS

Power:

Local mains input (240V, 50Hz).
Regulated to +5V at 130mA, -5V at 42mA (total 860 mW).
LED Indicator.

Two-Wire Line:

Balanced, isolated.
Matches 0.64mm PIQL.
Longitudinal balance >60 dB at 80 kHz.
Signal level 1V p-p each way (approx 0dBm/150ohm).

V. 24 Interface (DCE side):

Cct 103 Tx Data, Cct 104 Rx Data, Cct 114 Tx Clk (from modem),
Cct 102 Gnd, Cct 115 Rx Clk (from modem).
Ccts 106,107,109 strapped to 10V.
Female (network) socket.

Configuration switches:

1. 0/-6dBm output level. The reduced output power allows cancellation of unusually large echoes from nearby line taps or tails, but reduces range.
2. Not used.
3. Function unclear.
4. Transmitter off/on. When off, also presets DAC inputs to zero.
5. CTE/NTE. Changes clock recovery and scrambler/descrambler patterns to suit designated location.
6-8 Various V. 24 interface control functions.

Transmission Characteristics:

80 kbit/s, unframed, transparent.
Scrambled, conditioned diphase line code.
Fixed pre-and post-equalisation designed for 0 to 40 dB loss at 80kHz over 45nF/km, 0.6mm copper pairs. Active filters used.
Decision point signal +/- 1V at 0 dBm receive level.
Error propagation: 4 or 6 data bits in error/line error, depending on CTE/NTE function.

Echo Canceller:

RAM filter data address 5 bits (at 80 kbit/s).
Oversampling address 3 bits (8 x line rate)
RAM wordlength 16 bits.
DAC wordlength 10 bits.
Max. DAC output +/- 0.6 V.
RAM resolution 0.018 mV.
DAC resolution 1.2mV.
Quantising noise 0.3mV RMS.

Sign-algorithm adaptation:

Dither amplitude max. +/- 1.25 V.
min. +/- 0.08 V to +/- 0.2 V. (depending on modem).
Excess noise 1mV RMS with +/- 0.12 V dither (calculated from [4] eq 12)
Convergence time : Max 25 sec for 0.12 V min. dither (from [1]).
Observed 0 to 20 sec approx.

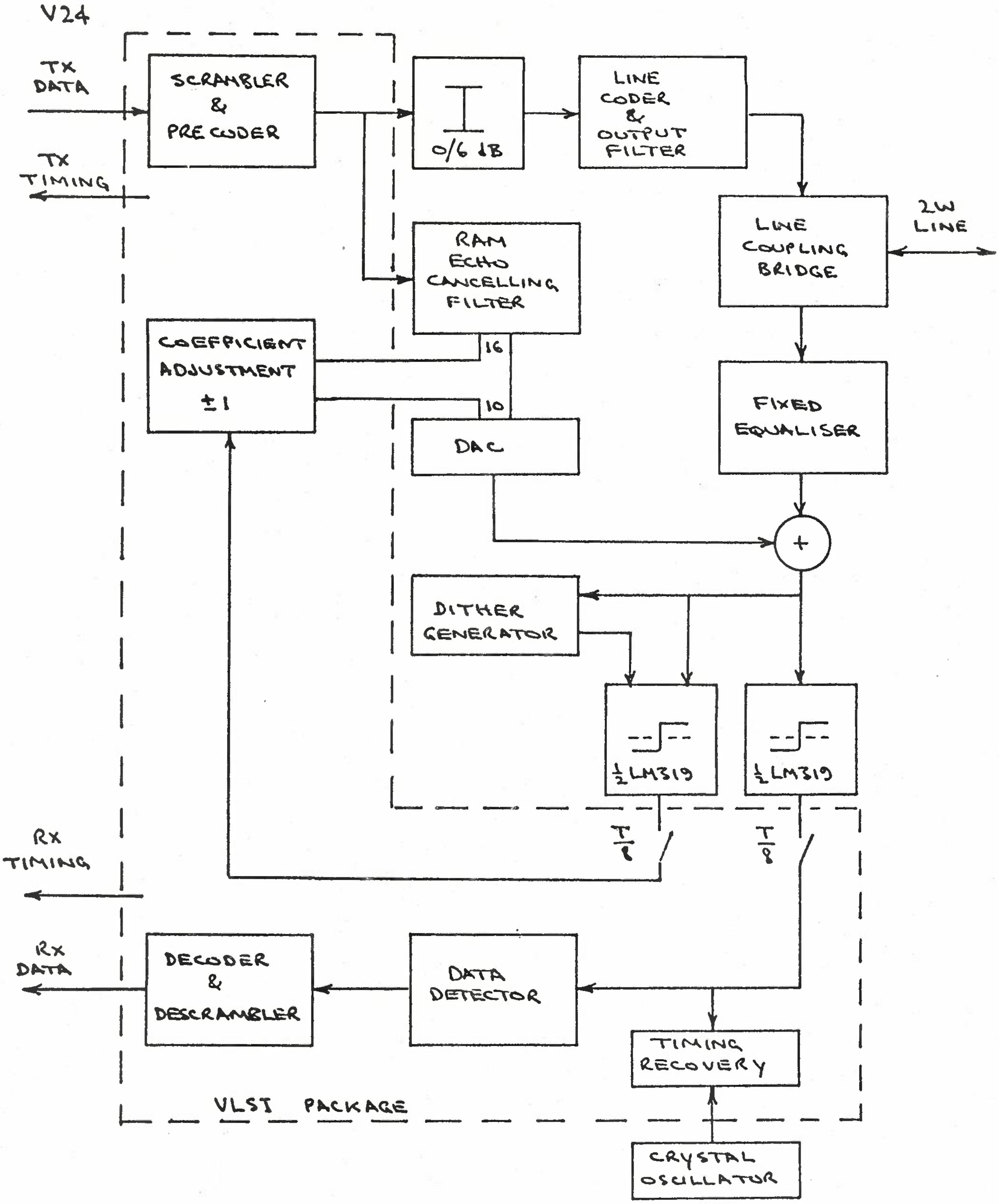

FIGURE 1. EBN 80 kbit/s FULL DUPLEX ECHO CANCELLING MODEM.

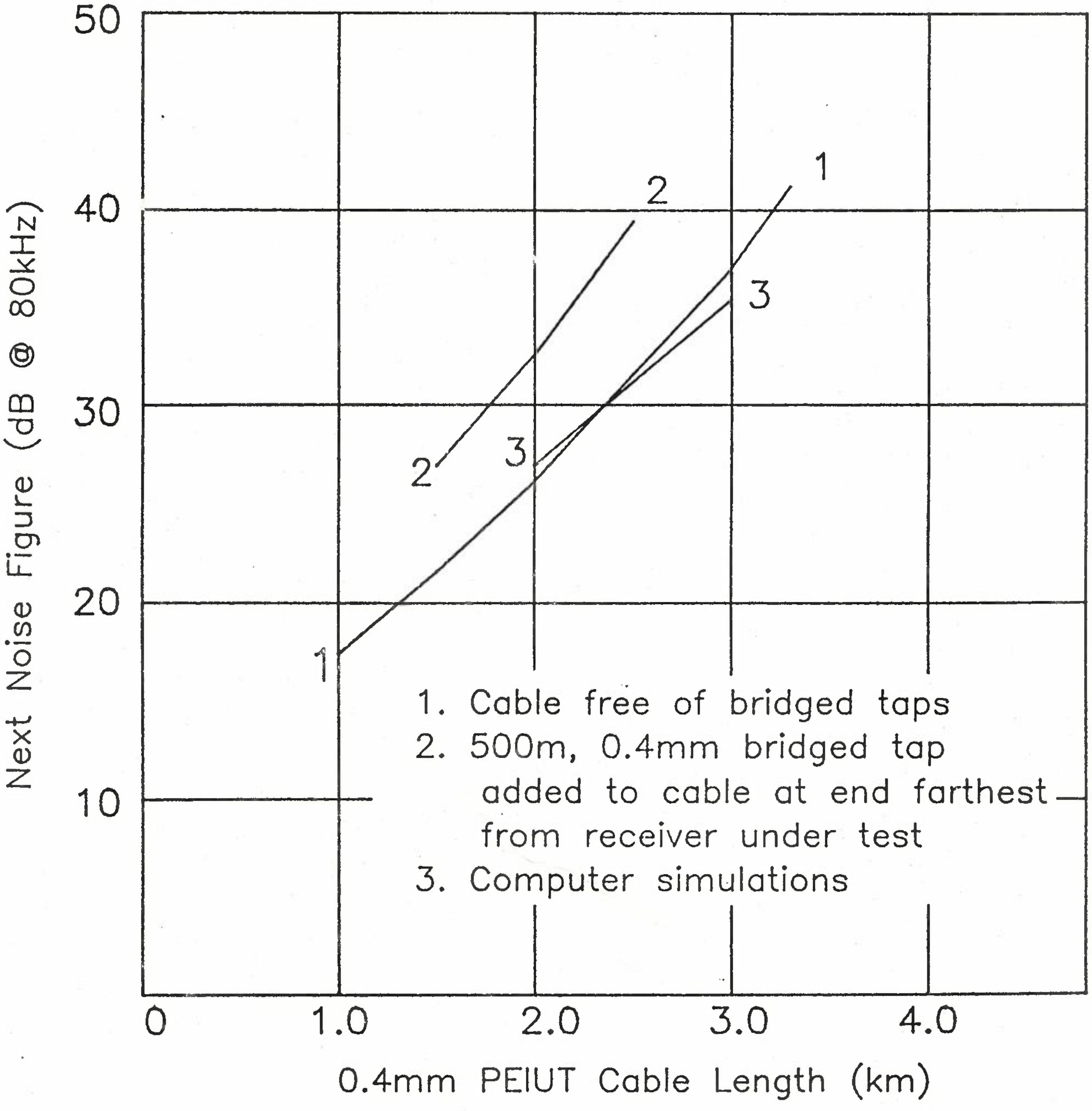

Fig. 2. Near End Crosstalk Noise Figure For EBN Modem Operating over Various Cable Configurations

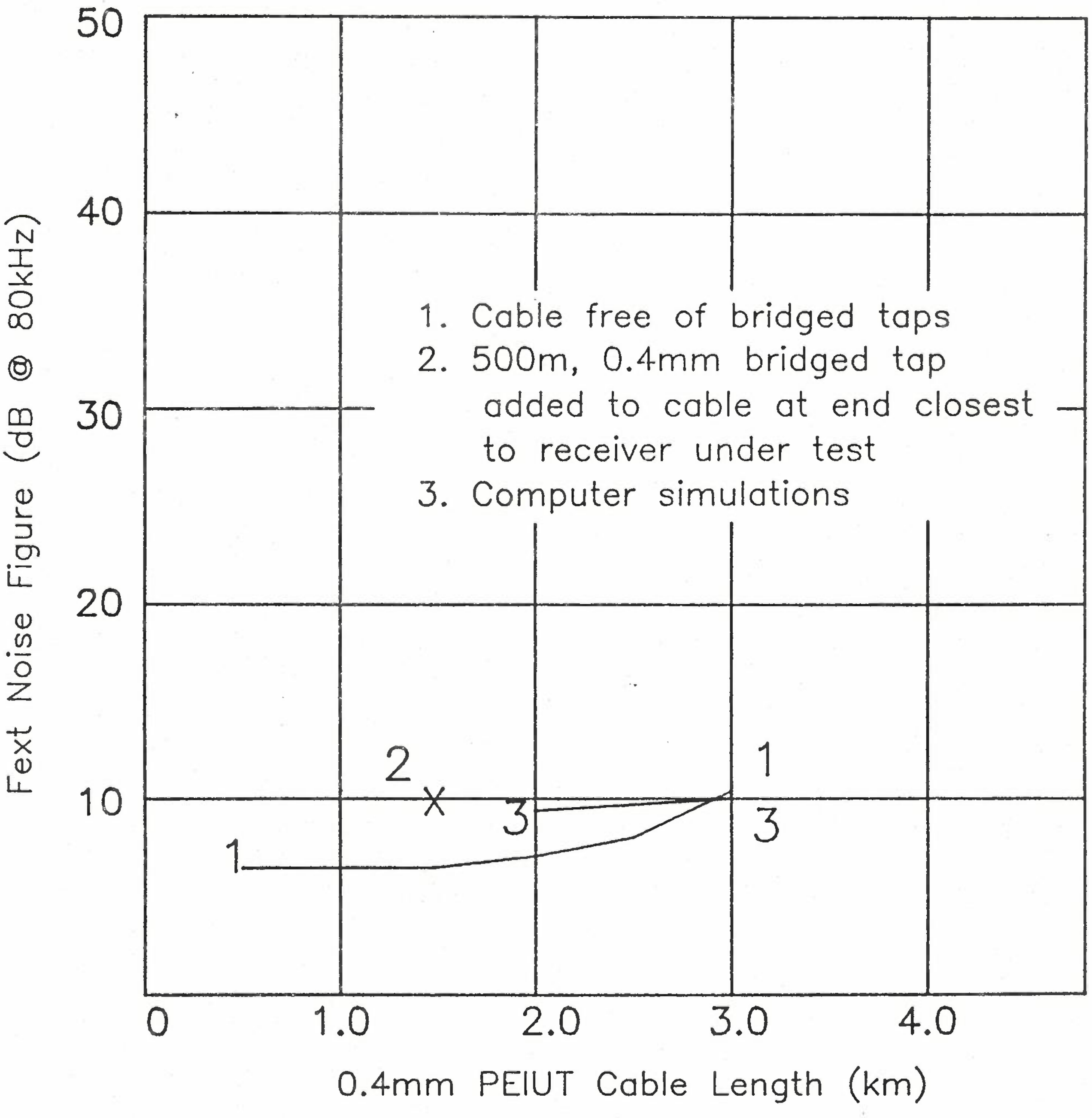

Fig. 3. Far End Crosstalk Noise Figure
For EBN Modem Operating over
Various Cable Configurations