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Considerations in the Measurement of Crosstalk Noise Figure on Local Digital Reticulation Systems Utilising Adaptive Echo Cancellers

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CONSIDERATIONS IN THE MEASUREMENT OF CROSSTALK NOISE FIGURE ON LOCAL DIGITAL RETICULATION SYSTEMS UTILISING ADAPTIVE ECHO CANCELLERS

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REPORT 7746 - CONSIDERATIONS IN THE MEASUREMENT OF CROSSTALK NOISE FIGURE ON LOCAL DIGITAL RETICULATION SYSTEMS UTILISING ADAPTIVE ECHO CANCELLERS

BY R.B. COXHILL

Telecom is currently planning for the introduction of an Integrated Services Digital Network (ISDN). An essential part of the ISDN is the local digital reticulation system, which forms the digital link between the local exchange and the customer. These systems will initially operate over existing metallic cable pairs. Before the widespread introduction of these systems, some assessment of the expected performance of these systems to be used in the network is necessary. The system's immunity to crosstalk interference from similar systems can be assessed by measurement of a parameter known as Crosstalk Noise Figure. This report discusses the technical problems which arise in the measurement of Crosstalk Noise Figure on local digital reticulation systems that utilise echo cancellers.

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RESEARCH LABORATORIES REPORT 7746

CONSIDERATIONS IN THE MEASUREMENT OF CROSSTALK NOISE FIGURE ON LOCAL DIGITAL RETICULATION SYSTEMS UTILISING ADAPTIVE ECHO CANCELLERS

1. INTRODUCTION

Digital transmission techniques are rapidly penetrating into various segments of the Australian Telecommunications Network. This penetration is in line with the decision by Telecom to establish an Integrated Digital Network (IDN) on a national basis.

Telecom is currently planning and preparing for the introduction of an Integrated Services Digital Network (ISDN). An ISDN enhances the IDN by extending digital services to customers, providing them with a range of digital transmission facilities. An essential part of the ISDN is the local digital reticulation system. These systems form the digital link between the exchange and the customer, and will initially utilise existing metallic cable pairs.

Before the widespread introduction of local reticulation systems operating on existing metallic cable pairs, assessment of the performance of these systems will be necessary to determine such information as the limits of system penetration within a cable and the merits of a particular transmission technique or system design. One performance criterion that can be applied is the measurement of a parameter known as Crosstalk Noise Figure (XTALK NF). The theory and technique of measuring this parameter was originally developed for use on repeaters used in primary level PCM systems [2]. The technique is now well established and commercial instrumentation is currently available to perform the measurements. However, the instrumentation is restricted in use to primary level PCM repeaters only.

This report discusses the problems, techniques and considerations of measuring XTALK NF on local digital reticulation equipment that operates on metallic cable pairs and incorporates echo cancellers. A laboratory based technique of measuring this parameter has been devised, and this is also described.

Measurements of XTALK NF on an 80 kbit/s echo cancellation system have been performed using the devised technique, and the results of these measurements are reported in Transmission Systems Branch Paper No 122 [1].

2. DESCRIPTION OF ECHO CANCELLATION SYSTEMS

It is desirable that local digital reticulation systems are designed to operate over a single pair of wires. The reason for this is that existing customer telephone distribution is via a single pair of wires, and it is not economic to add extra pairs for 4-wire transmission.

In systems utilising echo cancellation, both customer and exchange directions transmit and receive continuously over a single cable pair for the duration of the line connection. Both directions operate in the baseband mode, and hybrids (line coupling bridges) are used to separate the directions of transmission. Echoes of the transmitted signal will be received by the local receiver due to imperfections in the impedance match between the equipment and the cable, and any cable discontinuities. These echoes will impair operation of the receiver unless special techniques are employed to cancel them. In echo cancellation systems, an adaptive process is used to create a replica of the received echo using information derived from the transmitter, and this replica is used to cancel the received echo.

3. CROSSTALK NOISE FIGURE

3.1 Description

The detailed principles of XTALK NF have been reported elsewhere [2, 3]. However, to make this report complete, a brief description is given here.

Crosstalk Noise Figure is a parameter that can be used to assist in ascertaining the limits of system penetration within a cable. It is essentially a measure of the sensitivity of a receiver in a system to crosstalk from similar systems. It is determined by a test method which, by simulating cable crosstalk conditions, determines the level of crosstalk interference required to produce a particular error rate over a transmission system. It is normally specified at a particular frequency and at a particular error rate, and can be measured for a variety of cable lengths and configurations.

Near End Crosstalk Noise Figure (NEXT NF) and Far End Crosstalk Noise Figure (FEXT NF) are the two forms of XTALK NF that are typically measured. In relation to subscriber digital reticulation systems, NEXT NF is of particular interest for systems that utilise echo cancellors, and FEXT NF for systems that utilise synchronised burst mode techniques.

3.2 Measurement Procedure

This section describes and discusses a procedure for measuring XTALK NF based on that detailed in [3], and is primarily intended to convey some of the concepts involved in the measurement. This arrangement cannot be directly applied to local digital reticulation systems for a variety of reasons which are discussed in Sect. 4.

Fig. 1 illustrates test configurations for measuring NEXT and FEXT NF. The arrangements shown, consist of a transmission link interconnected by a length of cable with the link operating in one direction only. Assume that it is required to determine the NF (NEXT and FEXT) of the receiver for particular cable configuration.

To measure NEXT NF, simulated near end crosstalk noise (from similar systems) is added to the receiver input signal at a level that produces a particular error rate through the transmission link.

A good approximation of the NEXT NF is determined by measuring the dB difference between the narrowband RMS power (at reference frequency F1) of the simulated crosstalk at the receiver input (P2), and the narrowband RMS power (also at reference frequency F1) of the transmitted signal sent and measured at the opposite end of the cable to that connected to the receiver under test (P1). P1 is effectively the level of the signal sent from the disturbing cable pair, and is measured at this point for convenience.

Similarly, FEXT NF is determined by adding simulated far end crosstalk power (P2) at the input to the cable (the other end of the cable to the system under test) and again measuring the difference between the two powers.

As discussed in [3], the measurement procedure described above is equivalent to the measurement of a limit on the NEXT or FEXT attenuation. However, it has also been shown in [3] that NEXT attenuation is a good approximation of NEXT NF providing that an infinitely narrowband filter is used. In practice, it has been shown that if narrowband is defined as a Q of about 10 or more, the results of measurements are sufficiently accurate to be applied to NEXT NF.

4. CONSIDERATIONS IN THE MEASUREMENT OF CROSSTALK NOISE FIGURE

In Sect. 3.2 a procedure for measuring XTALK NF is described. In applying this procedure to local digital reticulation systems utilising echo cancellers, a number a factors need to be considered that do not arise in the case of measuring PCM regenerators [3]. These are listed and discussed separately below.

4.1 Minimising Disturbances to the Transmission Configuration

In practice, a local digital reticulation system utilising echo cancellers operates simultaneously in both directions over a single pair of wires, with the potential of being connected to a wide variety of cable configurations. Therefore, the systems must be tested using a method which is tolerant of the resulting impedance mismatches, and does not alter the characteristics of the transmission path in either direction. Impedance disturbances will change the amplitude of the echo and thus affect the conditions under which the system is being tested. In addition, externally induced unbalance of the cable can modify its transmission characteristics, and this will also affect the test conditions.

The implications of this are, that any test equipment placed in series or parallel between the cable and the system under test must have minimal effect on the impedance and cable balance seen by the system.

In practical terms, it would be difficult to devise series connected test equipment that complied with the above considerations. For these reasons, the test method described later relies on high impedance parallel connected equipment for both addition of simulated crosstalk noise, and the measurement of signal levels. This is the major difference between the requirements for determining XTALK NF for the PCM regenerator case and the local digital reticulation case, and considerably complicates the measurement requirements and associated measurement procedure.

4.2 Allowing for the Effects of Bridged Taps

Systems that operate over customer cable loops are subject to wide variations in cable configuration. Gauge changes, and in particular bridged taps, can present the system with wide variations in impedance. It is therefore essential to be able to assess the performance of a system with the presence of these various configurations. Bridged taps can cause large variations in the impedance vs frequency characteristics of the cable at the point where the bridged tap is added. Furthermore, these variations can be reflected to other points of the cable depending on the loss of the cable and the length of the bridged tap. These impedance variations can cause errors in the measurement of XTALK NF unless special precautions are taken to minimise the effect of the variations. The main source of error is due to the impedance variations altering the spectrum of the injected simulated crosstalk.

To simulate the effects of a bridged tap in a laboratory based test arrangement, the tap would be added at either end of a drum of cable which interconnects the transmission system under test. This would simulate the worst case effects of a bridged tap and the associated impedance variations.

The method of minimising the impedance variation effects consists of adopting two conditions in the measurement setup.

The first condition is that XTALK NF measurements are generally not performed with cable losses of less than about 15 dB (2 km 0.4 mm cable). For NEXT NF, this condition does not limit the usefulness of the measurement, as it is normally only of interest for the longer cable lengths where crosstalk has a greater effect.

The second condition requires that the bridged tap be located at the opposite end of the cable to where the simulated crosstalk is injected. For NEXT NF, this means that the bridged tap must be located at the opposite end of the cable to the receiver of the system under test, and the measurement procedure modified from that described in Sect. 3.2, so that both signal level measurements are performed at the opposite end to where the bridged tap is located (see Sect. 5.1). For FEXT NF, the bridged tap must be located at the same end of the cable as the receiver of the system under test.

An important consideration in this arrangement is that the error performance of the system must be simultaneously monitored in both directions. It is possible that the system may be operating error free in the direction under test, but in error in the other direction. Therefore, before the simulated crosstalk is added, and with the bridged tap incorporated into the test arrangement, the system must be operating error free in both directions.

4.3 Considerations Associated with Signal Measurements

The measurement procedure described in Sect. 3.2 required the measurement of the level of the simulated crosstalk, and the level of the transmitted signal. In systems utilising echo cancellors, both these signals must be measured under the transmission conditions that apply when the transmission system is operating normally in both directions. However, it is not possible to measure the level of these signals with the presence of the normal transmission signals. One means of allowing the measurement, is to disable the transmitter in one or both of the systems. Disabling the transmit signal in both directions will allow the measurement of the simulated crosstalk, and disabling the transmit signal in one direction will allow the measurement of the transmit level of one of the transmitters. In later generation systems, it is unlikely that facilities will be provided to independently control the transmitter, and therefore the systems will have to be replaced with terminations to perform the measurement. In this case, is is highly desirable that the terminations represent the same impedance as the system.

If it is possible to disable the transmit signal in the system, then performing this action must not disturb the impedance match between the cable and the system under test. Furthermore, due to the low level of some of the signals to be measured, the transmit signal must be completely disabled, i.e. there must be minimal leakage of any transmitted signals from the system.

4.4 Specifications of Test Equipment

With reference to the measurement procedure detailed in Sect. 3.2, and as applied to local digital reticulation systems in Sect. 4.1, the test equipment used for the injection of simulated crosstalk and the measurement of RMS power must have the following attributes:

(i) A high impedance balanced output (input).

(ii) A dynamic range of at least 60dB.

There may also be a need to measure the performance of systems operating at other bit rates. In this case the following additional attributes would be required by the measuring equipment:

(i) Selectable filter bandwidths.

(ii) Tunable filter centre frequency.

4.5 Simulated Crosstalk Considerations

(i) Generation of Simulated Crosstalk

The test equipment configuration used in [3] generated the simulated crosstalk by firstly passing a wideband, white gaussion noise source through a shaping filter, and then passing this signal through a "NEXT" or "FEXT" filter. These filters simulate the 15 dB or 20 dB/decade mean NEXT or FEXT attenuation characteristics of pair cable.

Problems with low peak to RMS ratios, skew and instability in various commercial gaussion noise sources, coupled with difficulties in realising the shaping filters (separate shaping filters are required for each line code and bit rate), led to the development of a digitally generated shaped noise source [4], and this source has been utilised in the measurement system described later to produce an artificial test signal. The output from this source is then passed through the NEXT or FEXT filters described above to produce the required simulated crosstalk.

(ii) Low Frequency Cable Crosstalk Cable Characteristics

Theoretical studies have indicated that below about 100 kHz, pair cable does not fully follow the 15 or 20 dB/decade mean NEXT or FEXT attenuation characteristics. Furthermore, non-uniform cables (mixed gauges), complicate the low frequency crosstalk model. Thus, the NEXT and FEXT filters described above only roughly approximate the cable behaviour at frequencies below about 50 kHz.

While the XTALK NF is slightly cable dependent, a technique for the measurement of XTALK NF should produce results which are cable independent; these could be based on some average frequency dependance over the various cable gauges, or more approximately on the 15 or 20 dB/decade characteristics.

While XTALK NF of systems on non-uniform cables may be measured using the proposed technique, the application of the XTALK NF to system design in such cases meets with considerable difficulties in the computation of the overall statistics of the crosstalk noise [5]. However, measurements of XTALK NF on non-uniform cables still provides valuable information for the system designer.

4.6 Measurement Considerations

As discussed in Sect. 3.2, the NF is determined by the difference in power between two signals. If the two signals are measured at the same point, or in the same impedance, then this power difference can be determined by the voltage difference between the two signal levels (if measured with a true RMS meter).

For FEXT NF, the two signals are measured at the same point and the method described above can be used.

However, for NEXT NF, one signal level would normally be measured at one end of the cable, and the other signal level at the other end of the cable. The impedances at each end of the cable cannot be assumed to be equal (particularly with a bridged tap added at one end), and there is no simple way of determining the impedance at these points. Furthermore, with a bridged tap in the test arrangement, the effects outlined in Sect. 4.2 must be considered. For these reasons, the procedure for measuring NEXT NF is modified to allow the two signal levels to be measured at the same point.

Analysis of the NEXT model shows that this is in fact a more realistic measurement. However, it is assumed that identical cable configurations are used for the disturbed system and for the disturbing system which would be the normal situation. Fig 2 shows 2 pairs of a typical connection between a two customers and the exchange with a bridged tap jointed into the cable close to the customer end. The diagram only shows the directions of transmission that pertain to the NEXT path shown. Assume cable 1 is being disturbed, and cable 2 is the source of the disturbing signal. It can be seen that the level of the transmit signal of either system at the exchange end is equivalent to P1 (Sect 3.2). Therefore, it is valid to measure both the transmit signal level (P1), and the simulated crosstalk level (P2) at the same point (assuming identical cable configurations).

5. A PRACTICAL LABORATORY MEASUREMENT SYSTEM

A block diagram of the measurement system is illustrated in Fig. 3. A detailed step by step measurement procedure is detailed in Sect 5.2.

The test equipment shown in the lower half of Fig. 3 is divided into "measurement" and "injection" sections, each of which can be connected to either the "A" or "B" end of the system under test. The system under test in Fig. 3 includes switches to turn off the transmitter at either end. The cable interconnecting the system under test could consist of one gauge type, with or without bridged taps, or a mixture of gauge types, with or without bridged taps. The data test sets connected at both ends of the equipment under test are monitor the error rate over the link.

The injection section generates and injects the simulated crosstalk into the test arrangement via a high impedance as discussed in Sect. 4.1. Special circuitry has been developed to achieve this high impedance injection. The impedance of this circuitry is greater than 10 kohms over the frequency range that pertains to the measurement requirements. A switch allows the simulated test signal to be turned on or off.

The measurement section consists of a commercial high impedance differential probe connected to a spectrum analyser. A commercial true RMS meter is connected to the IF output of the spectrum analyser. The spectrum analyser is operated in a "manual" mode whereby it effectively functions as a tunable filter with selectable filter bandwidths.

In Sect. 4.4 a dynamic range of at least 60dB for the test equipment was specified. Unless special measurement techniques are used, this specification would apply to the high impedance injection, the high impedance probe, and the spectrum analyser. However, by the use of an attenuator substitution technique, the 60 dB specification can be restricted to one of the above items. In the attenuator substitution technique, an accurate attenuator is used as the source of the measurement result, and the RMS meter is effectively used as an equal level comparison source (see Sect. 5.1).

It is possible to place the substitution attenuator in one of three positions. Before the high impedance injection, after the high impedance probe, or after the spectrum analyser. In the first case, the 60 dB specification would apply to the high impedance injection. In the second case the specification would apply to the high impedance probe, and in the last case the specification would apply to both the probe and the spectrum analyser.

Analysis of the dynamic range characteristics of the three items showed that the high impedance probe had by far the best performance over the required range. Therefore, the attenuator is placed after the high impedance probe.

5.1 Measurement Technique

A detailed description of the measurement technique is given in Sect. 5.2. Briefly, the technique is to record via the RMS meter, the signal level of the transmitter (Measurement 1), with the substitution attenuator set to a high attenuation. The simulated crosstalk level adjustment attenuator is then adjusted to cause a specified error rate over the transmission link. The substitution attenuator is then adjusted to cause the same reading on the RMS meter as recorded in measurement 1 (measurement 2). The XTALK NF is the difference in attenuation recorded on the substitution attenuator for the last two measurements. Although the various signals used in this arrangement may not have the same frequency spectra, the measurements are performed narrowband, which removes any frequency spectrum dependence from the measurement.

5.2 Measurement Procedure

To simplify the measurement procedure description, only the case of determining the NEXT NF of the receiver at the "B" end, with the cable configured with a bridged tap at the "A" end will be described. The necessary measurement connections for this situation are shown in Fig. 3.

(i) Initial Setup

(a) Configure the test setup as shown in Fig. 3. Both transmitters and the simulated test signal are initially on. The particular cable configuration is determined by the test requirements.

(b) Configure the injection section with the NEXT filter in circuit.

(ii) Transmit signal level measurement.

(a) Turn off the transmitter at the A end (or substitute a termination in place of the system at the A end).

(b) Turn off the simulated test signal.

(c) Set the substitution attenuator to a high attenuation.

(d) Measure and record the signal level on the RMS meter. Record the range and reference level settings on the spectrum analyser.

(e) Record the substitution attenuator setting.

(iii) Simulated Crosstalk Level Adjustment

(a) Turn on the transmitter at the A end (or remove termination and reconnect system at the A end).

(b) The transmission system must now be operating error free in both directions. If not, cable configuration must be changed (e.g. shorter cable).

(c) Turn on simulated test signal and the adjust following attenuator until the required error rate is obtained on the data test set at the B end. To obtain a confident estimate of the error rate, at least 100 errors must be counted.

(iv) Final Attenuator Adjustment

(a) Turn off the transmitters at the A and B ends (or substitute terminations in place of the systems).

(b) Adjust substitution attenuator until the RMS meter reads the same level on the RMS meter as that in (ii)(d) using the same range and reference level settings on the spectrum analyser.

(c) Record attenuator setting.

The NEXT NF is the difference in the attenuator settings recorded in (ii)(e) and (iv)(c).

6. FINAL REMARKS

In this report various aspects associated with measuring the crosstalk noise figure of echo cancellation systems has been discussed. A laboratory based system for performing the measurements has been described and the system has been used to perform measurements on an experimental echo cancellation system. The results of these measurements has been compared with results from computer simulations and good correlation has been obtained.

The measurement system described is well suited for adaption to an automated test arrangement.

7. ACKNOWLEDGEMENTS

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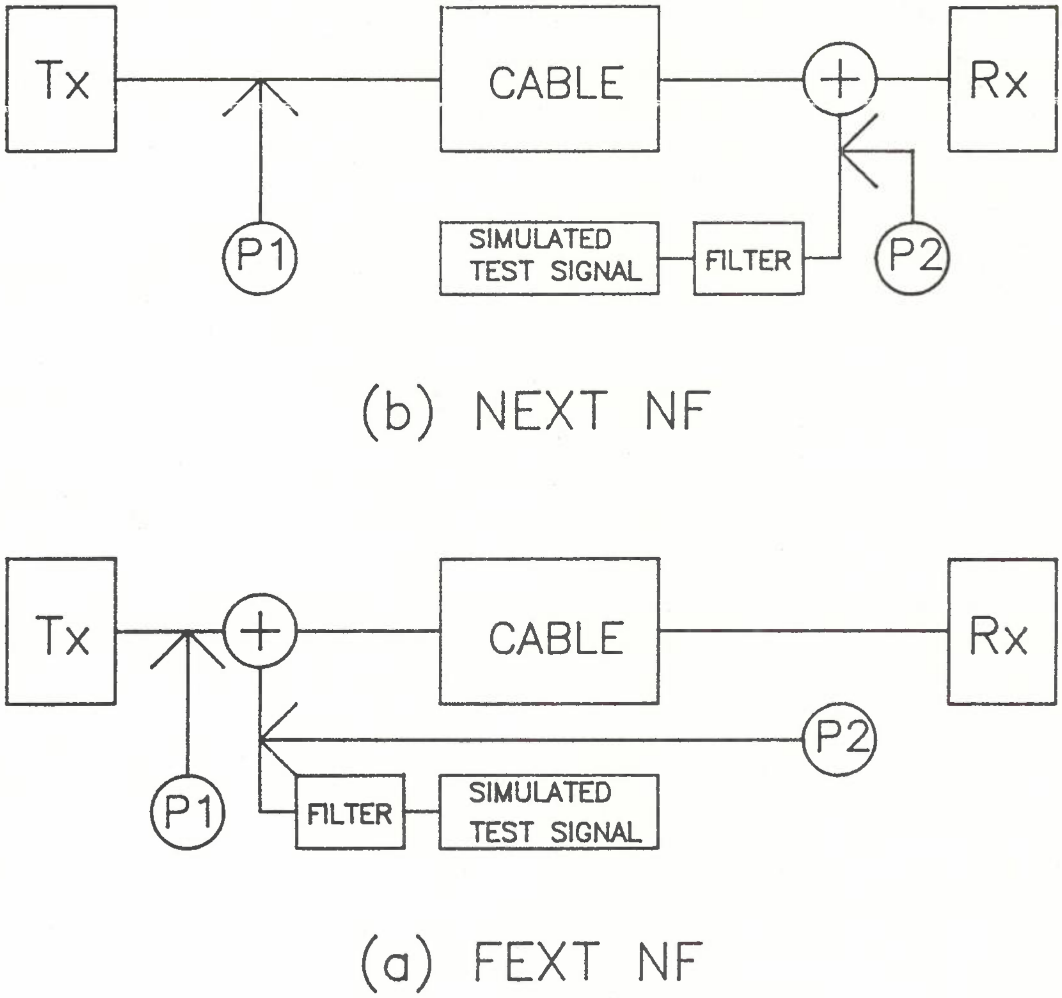

Fig. 1. XTALK NF MEASUREMENT BLOCK DIAGRAM

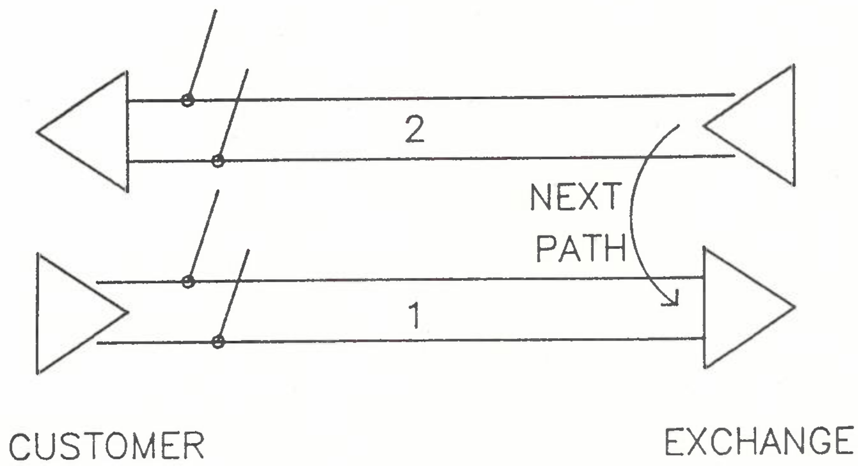

Fig. 2. NEAR END CROSSTALK

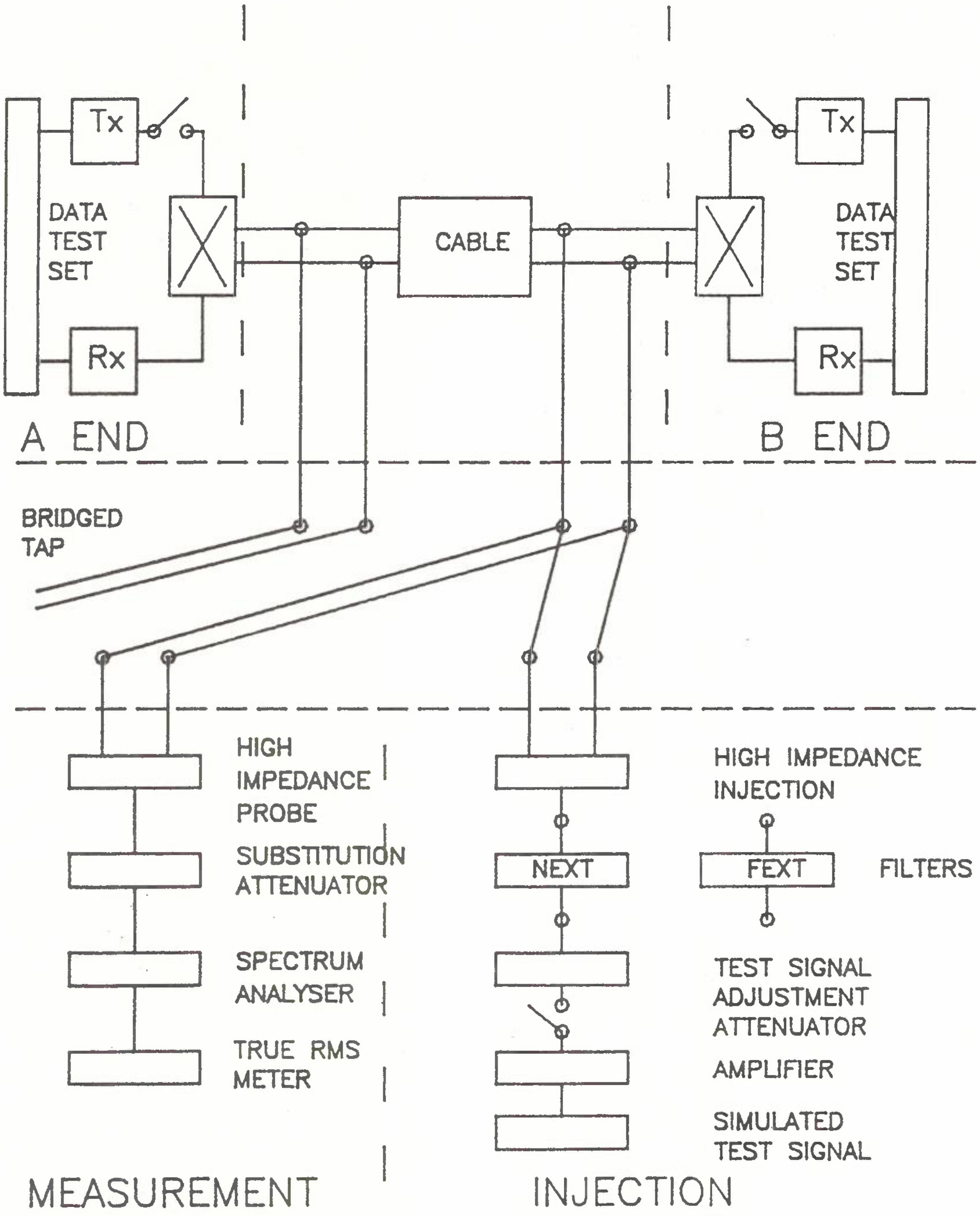

Fig 3. TEST SETUP FOR MEASUREMENT OF XTALK NF