systems are immune to the dc component of dark current but are subject to shot noise resulting from the discrete (electron) nature of both dark and signal currents. In addition, there is a source of noise created by the incident light itself, which arrives as quantum packages of energy, known as photons.

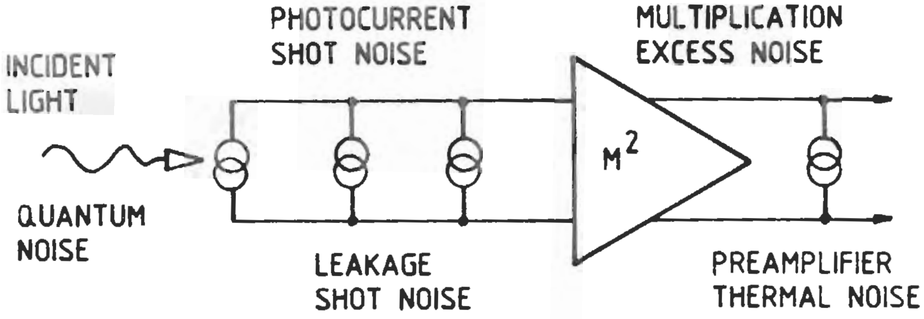


FIG 8.41 SOURCES OF NOISE IN AVALANCHE PHOTO DIODES

170 In avalanche photodiodes, both these sources of noise are subjected to avalanche gain, together with an additional factor introduced by the randomness of the multiplication process (excess noise).

171 However, avalanche gain is usually helpful in multiplying both the signal and the shot noise to a level where the thermal noise of the following preamplifier is no longer dominant, as is typically the case in PIN diode receivers. This is considered in more detail in the following chapter.

ELECTRONIC INTERFACES

172 A comprehensive study of the electronic communication technology associated with fibre optics links is beyond the scope of this publication which is primarily concerned with the special optical characteristics of such systems. However, it is useful to consider the design principles of the opto-electronic interfaces, and in particular the optical receiver, since this is unique to the special task of handling low level optical signals.

Receiver Sensitivity

173 Perhaps the most important factor in the performance of an optical system is the characteristic of the optical detector and its associated preamplifier, since noise introduced at this point will limit ultimate receiver sensitivity.

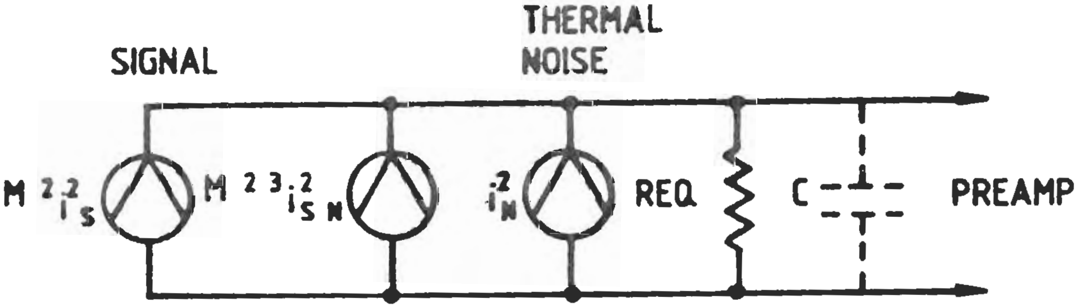


FIG. 8.42 DETECTOR EQUIVALENT CIRCUIT

Disregarding optical contributions, noise can be broadly divided into two fundamentally different types.

174 Thermal Noise. Associated with all resistive circuit elements and consequently all amplifiers.

175 For a resistive amplifier input, the equivalent thermal noise can be written as:

$$\langle in^2 \rangle = \frac{4.\ K.\ To.\ B.}{Req.} \quad F1$$

where K = Boltzmann Constant (1.38×10^{-23} J/K)
B = transmission bandwidth (Hz)
Req = equivalent input resistance
To = absolute temperature (°K)

F1 is an 'excess noise factor' associated with amplifiers. For convenience, this is often combined with To to produce an equivalent temperature Teq = To F1.

176 Shot Noise. This is the result of the discrete electron nature of current flow, and occurs whenever a potential barrier is encountered. The contributions of both signal current (Is) and dark current (ID) must be considered.

$$\text{ie} \quad \langle isn^2 \rangle = 2e\ (Is + ID).\ B$$

where e = elemental electron charge (1.60×10^{-19} coulombs).

177 The signal current resulting from incident optical power P is given by the expression

$$Is = \frac{n.e.M}{h.v}\ .P$$

where n = quantum efficincy (~ 70%)
h = Planck's constant (6.624×10^{-34} J-sec)
v = optical frequency (typically 3.33×10^{14} Hz)

Thus Is = 0.51 M.P amps (per watt)

M is the multiplication factor associated with avalanche photodiodes (M = 1 for PIN diodes). This multiplication introduces an excess noise factor F2 (typically $F2 = M^{0.3}$)

Thus any noise introduced before the multiplication process (eg shot noise) will be subjected to an avalanche gain of $M^{2.3}$

178 Receiver sensitivity (in terms of optical carrier/noise power ration, C/N) can now be estimated by summing powers referred to the preamplifier input, but it is more convenient to use $(\text{current})^2$ which is proportional to power.

$$\text{ie} \quad \frac{\text{carrier power}}{\text{noise power}} = \frac{(\text{signal current})^2}{(\text{shot noise})^2 + (\text{thermal noise})^2}$$

$$\text{Thus } C/N = \frac{\frac{1}{2}\left[0.51M.P\right]^2}{2eBM^{2.3}\left[0.51P + ID\right] + 4K.\ Teq.\ B/Req}$$

The value of P used is the mean optical input (ie the signal amplitude when 100% sine wave modulated). However since the C/N value is expressed in terms of rms carrier/noise ratio a factor of ½ has been included in the numerator.

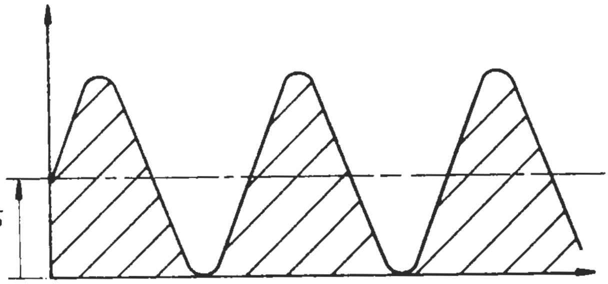


FIG 8.43 RECEIVED OPTICAL SIGNAL (SINSUSOIDAL MODULATION)

179 It can be seen from the above relationship that increasing the preamplifier resistance Req leads to a decrease in thermal noise and hence an improvement in carrier/noise ratio (or conversely a reduction in the Minimum detectable power). However a maximum value of Req is imposed by the need to maintain the required system bandwidth,

ie $Req = 1/2\pi\ BC$

where C is the detector capacitance, although higher values can be tolerated if equalisation is employed in following stages.

180 If thermal noise is still the dominant term in the denominator, then avalanche gain may be usefully employed. Clearly there is an optimum value of M leading to the minimum input power requirement to achieve a specified carrier/noise ratio. In order to illustrate this graphically, it is necessary to make two assumptions:

(1) Firstly that dark current is insignificantly small compared to the signal current so that ID = 0 (the validity of this will be verified).

(2) Secondly that the preamplifier input resistance is the maximum consistent with full receiver bandwidth. This permits the establishment of universal relationships in terms of power per unit bandwidth.

This and other relationships have been evaluated and the resulting graphs are illustrated on the following page.

181 The procedure for using these graphs is as follows:

(1) From a knowledge of the required carrier/noise ratio (in dB), use fig A to evaluate the minimum incident power requirement (in dBW/Hz) assuming ID = ,0. A suitable value for C must be assumed, but this is not very critical, especially for APDs.

(2) Since the assumption that dark current is insignificant may not be valid, evaluate the incident power requirement for a dark current limited receiver from fig B. Note that dark current is expressed in terms of ID/B.

(3) Select the greater power from stage 1) or 2) and evaluate the actual input power for the system bandwidth ie dBW/Hz + 10 log 10 (bandwidth). (0dBW ≡ 1W).

(4) If the use of an APD is dictated, determine the optimum avalanche gain from fig C. It will be noted that APDs only offer significant benefits at low to moderate C/N ratios.

Post Detector Circuits

182 The performance of the optical detector and preamplifier has been evaluated in terms of carrier/noise power ratio assuming 100% sinusoidal modulation. Overall performance (in terms of signal/noise ratio) must take into account the type of modulation by applying appropriate factors. Two of these are of particular interest in simple communication links:

(1) Analogue Modulation. LEDs and high radiance diode sources can be intensity modulated by direct variation of their drive currents, and some of these exhibit good linear characteristics over large intensity levels. A CW laser is also capable of being amplitude modulated provided operation is maintained above the threshold level. In this case, the value of P must represent the difference between the mean operating power and the threshold power.

Assuming that the characteristics of the source are sufficiently linear to provide an acceptably low level of distortion, the performance of an analogue sinusoidal signal with a modulation index m is given by:

$$\text{signal/noise ratio} = m^2 \times \text{carrier/noise ratio.}$$

(2) Direct Pulse Modulation. The performance of systems employing digital modulation is usually quoted in terms of bit error rate (BER). For simple intensity modulated binary coding, there is a well known curve relating the BER with peak signal to rms noise ratio. This is illustrated in fig D.

Since the carrier/noise ratio of a continuous optical carrier is twice that for 100% sinusoidal modulation and if P represent the mean level for the duration of the pulse (equivalent to the pulse amplitude for an ideal square wave) then:

$$\text{Peak signal/rms noise} = \text{Carrier noise ratio} + 3\text{dB}$$

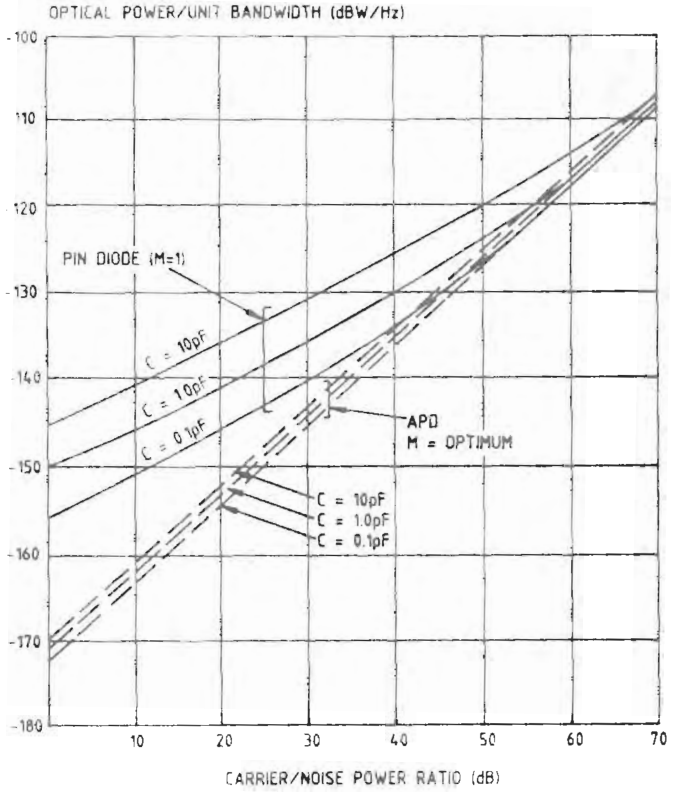


FIG 8.44A MEAN OPTICAL DETECTOR IMPUT POWER VERSUS OUTPUT C/N RATIO

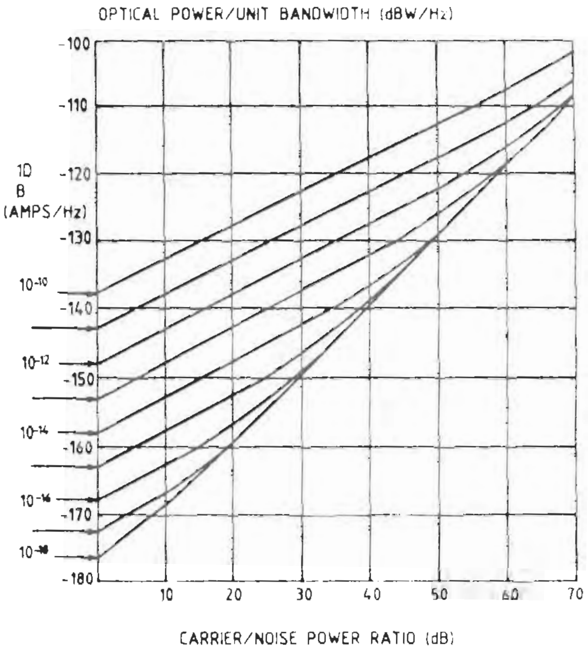


FIG 8.44B DARK CURRENT LIMITED RECEIVER SENSITIVITY

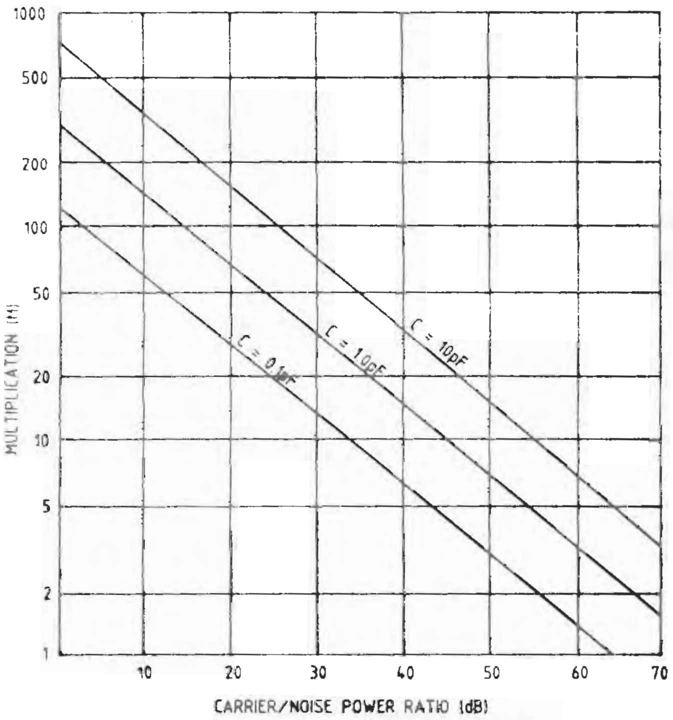


FIG 8.44C OPTIMUM AVALANCHE GAIN

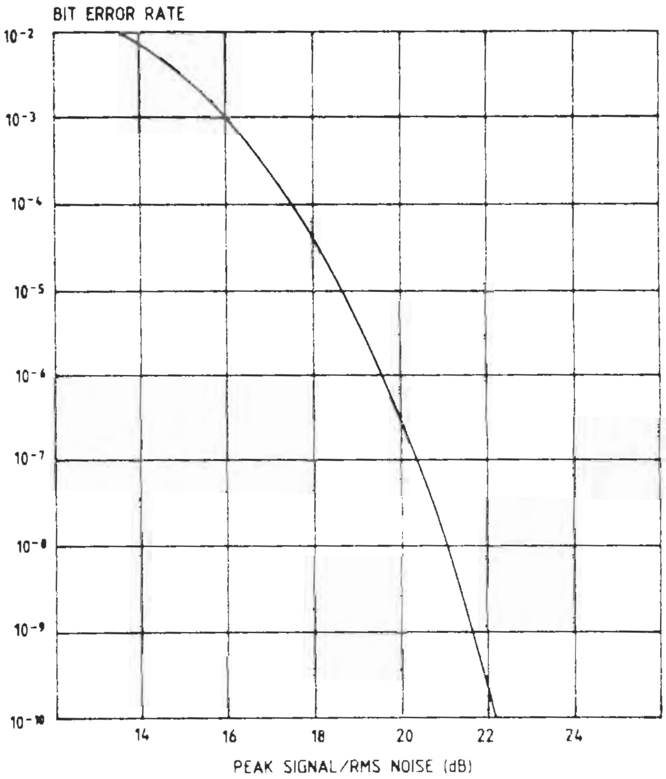


FIG 8.44D BIT ERROR RATE

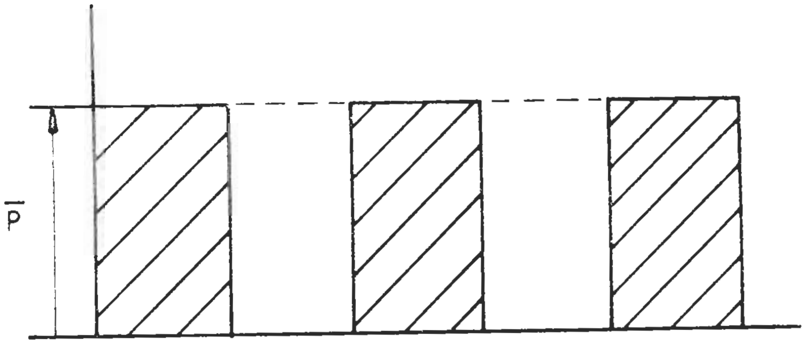


FIG 8.45 RECEIVED OPTICAL SIGNAL (BINARY MODULATION)

183 In evaluating pulse systems, therefore, it is necessary to know the mean level during the pulse duration. If the power is known only in terms of its overall mean, a very conservative estimate may be deduced from a knowledge of the duty cycle. However, this may be several dB lower than what may actually be achieved in practice.

Sample Calculations

184 In order to illustrate the receiver design procedure, two typical links involving the use of standard STC transmitter and receiver interface modules will be examined:

(1) Analogue Video Link:

Transmitter: TXA 002
Source-LED
Mean output into fibre - 30μW (ie - 45 dBW)

Receiver: RXA 002
Detector - PIN diode, capacitance typically 3pF
Assumed dark current ID = 1nA

Modulation: Analogue - 6 Mhz bandwidth.

The objective is to estimate the maximum optical path loss with the minimum picture S/N ratio of 42dB.

Standard television systems feature a peak picture amplitude which is 70% of the video amplitude. Therefore m = 0.7.

$C/N = S/N \div m^2 = 42-(-3.1) = 45.1$ dB

Step 1

Use fig A to determine receiver optical power requirement
ie - 126.8 dBW/Hz

Step 2

$ID/B = 10^{-9} \div 6 \times 10^6 = 1.7 \times 10^{-16}$ A/Hz

Use fig B to determine the dark current power requirement
ie -134.5 dBW/Hz.

This less than step 1. Thus the receiver is not dark current limited and step 1 result is valid.

Step 3

Actual power requirement = $-126.8 + 67.8$
(ie $10 \log_{10} 6 \times 10^6$)
= -59 dBW
Source power = -45 dBW
Therefore maximum path loss = 14 dB

STC quote a smaller figure (10 dB). However this takes into account approximately 3 dB of receiver optical coupling loss, and hence accounts for most of the discrepancy.

(2) Binary Transmission:

The objective of this example is to determine the input sensitivity of a digital receiver, RXD 001, handling 50nS return-to-zero (RZ) pulses. A BER of 10^{-9} is required.

RXD 001 - PIN diode, capacitance typically 3pF

Dark current $I_D = 10^{-9}$ A

Modulation - Assuming a 50% duty cycle, a bandwidth of 10 MHz is required.

From fig D - For BER of 10^{-9}, peak signal/rms noise = 21.6 dB

$\therefore$ C/N = 21.6-3 = 18.6 dB

From fig A P/B = -138.5 dBW/Hz

From fig B P/B (dark current) = 157.5 dBW/Hz

ie not dark current limited.

Therefore P = $-138.5 + 70 = -68.5$ dBW

Assuming a similar 3 dB receiver optical coupling loss, receiver input sensitivity = -65.5 dBW, ie 0.28 μW.

STC quote a figure of 0.4 μW.

AC and DC Response

185 Fibre optics communications receivers can be either dc or ac coupled, depending on whether or not the required frequency response extends to zero.

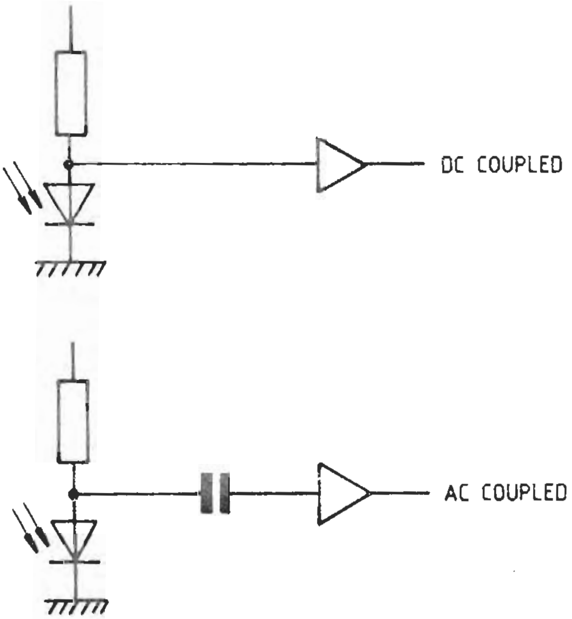


FIG 8.46 AC & DC COUPLED RECEIVERS

186 An ac coupled receiver will fail to respond to slowly changing data. Not only this, it is also likely to be less reliable with any data train exhibiting a continuous assymetric duty cycle since the mean level will drift higher or lower making one state more susceptible to noise.

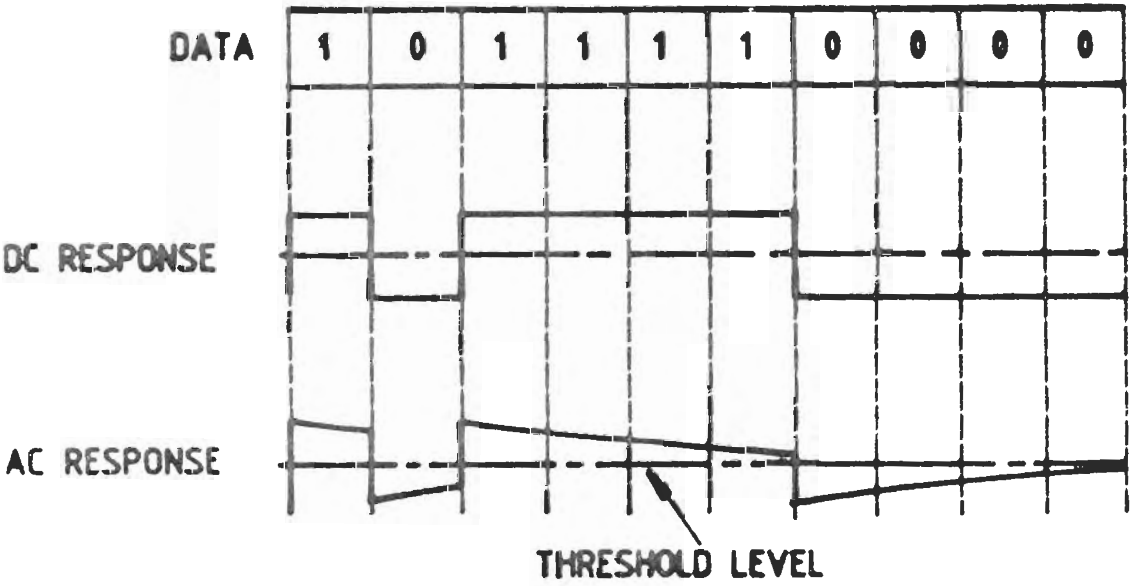
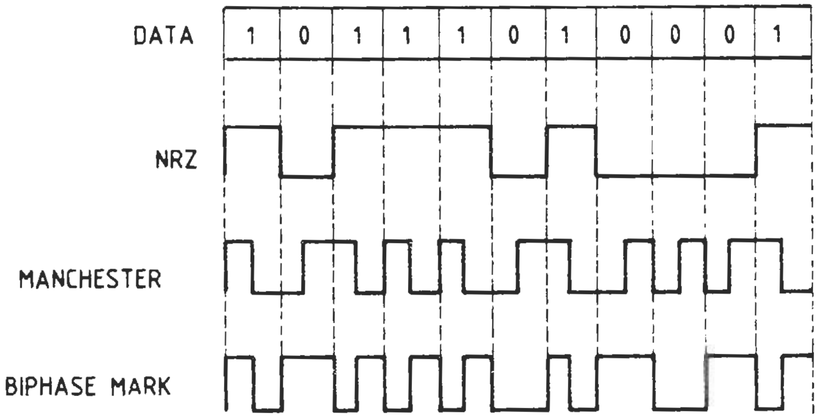


FIG. 8.47 AC & DC RESPONSE IN DIGITAL RECEIVERS

187 On the other hand, while it is possible to build receivers with dc response, these will be prone to offset and drift caused by photodiode dark current and transistor characteristic changes with temperature. Consequently they must be limited in sensitivity. In addition, it is not possible to provide automatic gain control (agc), possibly requiring the user to make preset adjustments to compensate for major changes in link attenuation (eg length, or number of in-line connectors).

188 Consequently, although fibre optics links are well suited to the transmission of digital information, care must be taken to ensure the correct choice of receiver to suit the data format.

189 The simplest method of representing data is binary amplitude modulation with 'on' for logic 1 and 'off' for logic 0 (or vice versa). This is termed Non-return to Zero (NRZ).



<table>
<tr><th>CODE</th><th>LOGIC 1</th><th>LOGIC 0</th><th>DC ?</th><th>CLOCK ?</th></tr>
<tr><td>NRZ</td><td>HIGH</td><td>LOW</td><td>YES</td><td>YES</td></tr>
<tr><td>MANCHESTER</td><td>-VE TRANSITION</td><td>+VE TRANSITION</td><td>NO</td><td>NO</td></tr>
<tr><td rowspan="2">BIPHASE MARK</td><td colspan="2">EACH BIT BEGINS WITH A TRANSITION</td><td rowspan="2">NO</td><td rowspan="2">NO</td></tr>
<tr><td>1 EXTRA TRANSITION</td><td></td></tr>
</table>

FIG 8.48 EXAMPLES OF DIGITAL CODES

190 NRZ is satisfactory provided the receiver is dc coupled: otherwise a restriction must be imposed on the maximum continuous period that can be spent in any one logic state.

191 Since there are performance advantages to be gained from the use of ac receivers, Return to Zero (RZ) codes can be used to eliminate restrictions on incoming data format. With these codes, additional transitions are inserted so that the level never remains static for more than one bit interval. For example, in Manchester code, the signal exhibits an additional negative transition during a logic 1 bit period, and an additional positive transition during logic 0 intervals.

192 RZ codes require a signalling rate (in bauds) of twice the incoming data rate (in bits/second). They do not, however, require a separate clock signal since timing can be established from the data itself.

LINK DESIGN AND SPECIFICATION

193 The majority of industrial fibre optics communications applications are loss limited - that is, the maximum operational path length is exceeded when the total link attenuation reduces the detectable signal below the level required to meet the specified bit-error-rate or signal-to-noise ratio.

194 However there are a small number of applications featuring higher bandwidth which are length restricted because of dispersion, ie the pulse spreading characteristic of optical fibres.

Optical Path Loss Budgeting

195 Optical loss budgeting is the simplest method of specifying the most appropriate set of components for any fibre optics link. It involves presenting the optical performance of the various components in graphical form.

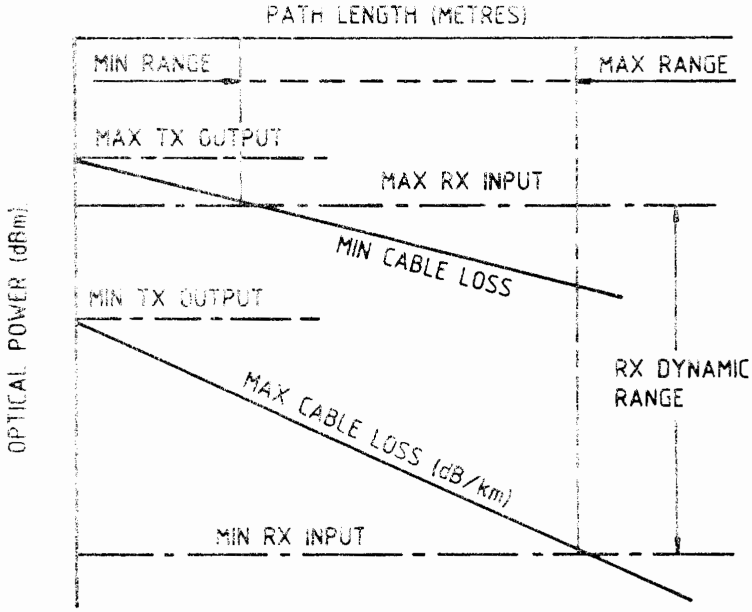


FIG 8.49 OPTICAL PATH LOSS BUDGET

196 In order to formulate an optical loss budget, it is necessary to obtain certain basic information about the various link components. Whilst less knowledge may be acceptable to set up a single link for operation over a limited period in a relatively benign environment (eg laboratory), the information to be outlined is the minimum needed to specify components which will be procured in volume. Only then can link operation be ensured with normal batch variations, and for a reasonable life in an operational environment.

197 It is convenient, when formulating loss budgets, to work in dBm units. Then simple addition of subtraction is all that is necessary in the calculation of optical loss.

This is derived from absolute power using the following conversion:

$\text{dBm} = 10.\log 10$ (optical power in mW)
eg $1\text{mW} \equiv 0\ \text{dBm}$
$100\mu\text{W} \equiv -10\ \text{dBm}$

198 Transmitter

Two values of output (in dBm) must be specified:

Maximum output

- highest specification limit
- start of life
- maximum for other conditions (temperature, supply voltage, etc)

Minimum output

- lowest specification limit
- end of life
- minimum for other conditions

These outputs should be specified for the following conditions:

- the HIGH level power for a Binary or Pulse modulated transmitter
- the MEAN level power for an Intensity or Ternary modulated transmitter
- the power measured in a short length of fibre of specified numerical aperature and core diameter, ie inclusive of source coupling loss
- the optical wavelength at which this power is emitted.

199 Optical Cable. The maximum and minimum attenuation in dB/km must be stated at the transmitter emission wavelength for the full range of specified environmental conditions. In addition, the fibre nominal core diameter and numerical aperature (including both initial and equilibrium values for plastic clad silica fibre) will be required.

200 Connectors and Couplers. The maximum and minimum insertion loss (in dB) should be specified at a high statistical confidence level, for the full range of environmental conditions.

201 Receiver. As with the transmitter, two values of input power (in dBm) are required. These are:

Maximum input
- overload condition

Minimum input
- the power appropriate to the maximum bit error rate in a digital receiver, or the minimum signal/noise ratio in an analogue receiver.

These inputs should be specified for the same conditions, ie

- the HIGH level power for a Binary or Pulse modulated transmitter
- the MEAN level for an Intensity or Ternary modulated transmitter
- the power emerging from a short length of fibre of specified numberical aperture and core diameter, ie inclusive of detector coupling loss.

Sample Loss Budget

202 To demonstrate the effectiveness of this technique, the optical loss budget for a typical fibre optics link will be illustrated. The basis of the budget is a graph plotting optical power (in dBm) on the vertical axis against path length (in metres) horizontally.

203 Maximum and minimum transmitter output power, and maximum and minimum receiver input sensitivity, are the fixed limits within which the link must operate, and are marked accordingly on the dBm scale. Subtracting transmitter power from receiver sensitivity gives the allowable optical path loss (in dB). In-line connectors (and couplers) exhibit a fixed loss which must be subtracted from the optical path loss. For convenience this is usually shown as a reduction in nett transmitter power.

204 In this example, both transmitter and receiver powers have been specified as measured in a short length of the actual fibre used in the link. In other circumstances, an additional loss will be incurred if either:

(1) The cable core diameter or NA is smaller than that used for the transmitter specification.

(2) The cable core diameter or NA is larger than that used for the receiver specification.

In either case, the additional loss (in dB) is calculated on the basis of a square law relationship:

ie $20.\log_{10}$ (diameter ratio)
$20.\log_{10}$ (NA ratio)

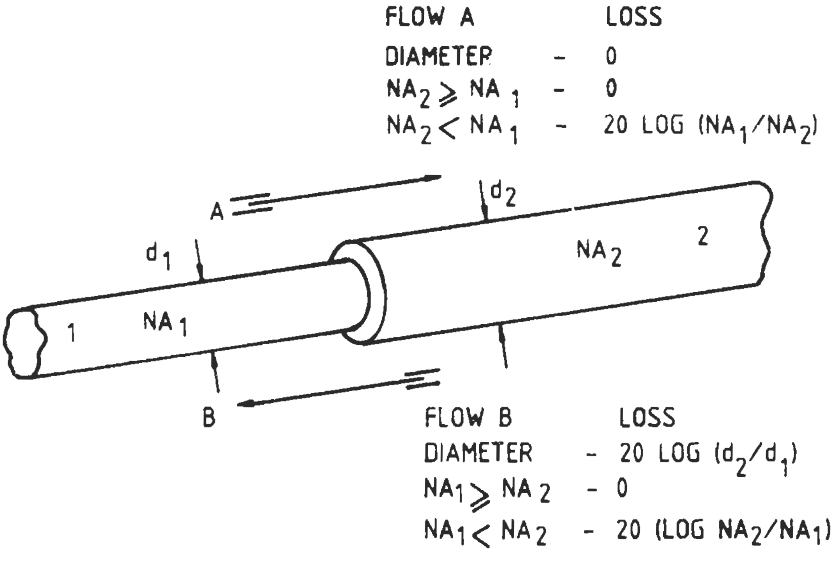


FIG 8.50 LOSS PENALTIES FOR DIAMETER OR NA MISMATCH

Again, for convenience, these are deducted from the transmitter power. Obviously no optical gain occurs if the opposite conditions apply.

205 Cable loss increases with length, and is represented by drawing lines whose (negative) slope is the fibre attenuation. In the case of the plastic clad silica fibre used in the Fibrelux-243 link, the fibre attenuation initially varies with length due to the change in effective NA from its starting value of 0.39 to the equilibrium value of 0.25. Since the exact shape of this region is indeterminate, it is convenient to extend back this linear characteristic and use this for link calculations. This results in additional system margin for short links.

206 Once the optical loss budget has been generated, the permissible operating conditions can be seen. For example, the top line shows the performance of the link with a maximum output transmitter and minimum cable attenuation, clearly indicating that this link can be operated with zero path loss without receiver overload. This will not always be the case with other systems.

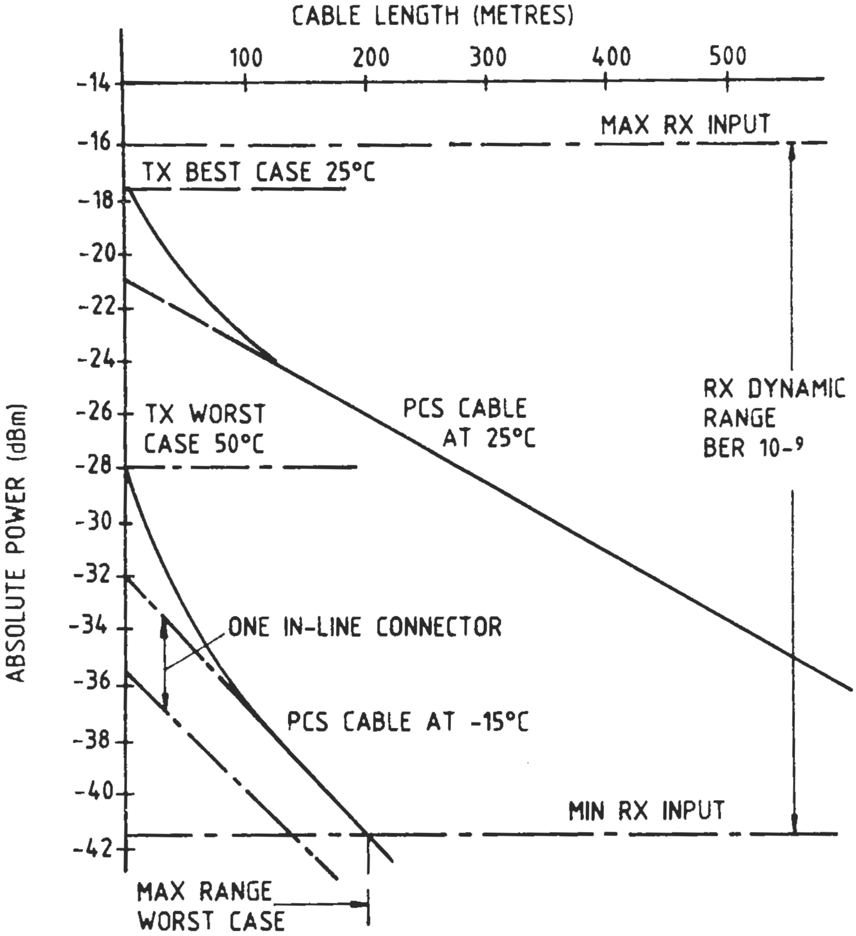


FIG 8.51 FIBRELUX 243 OPTICAL LOSS BUDGET

207 The bottom line shows the worst case performance and should be used for the procurement of production items to ensure a guaranteed link performance under all specified environmental conditions.

Pulse Dispersion

208 With some higher bandwidth fibre optic links, dispersion rather than path loss may impose the primary restriction on maximum operating range. It is important, therefore, that the user be aware of the conditions under which this may occur.

209 Fibre dispersion is usually specified in one of the following ways:

(1) ns/km - this represents the increase in width of a Gaussian shaped pulse, measured at the half amplitude level.

(2) MHz km - the maximum transmittable modulation frequency (-3 dB point) over a specified length of fibre.

These are related by the expression:

ns/km x MHz km = 310

210 Implicit in these relationships is the assumption that fibre dispersion varies as a linear function of length. In fact this is only a convenient approximation which is reasonably valid for short links. With lengths in excess of 0.5 to 1.0 km, mode mixing causes a gradual change to an approximately square root dependance.

211 Since dispersion is customarily measured over a length of 1 km, a very reasonable approach is to assume a linear function for lengths up to this value, and a square root function thereafter. In practice, little error will be introduced if the square root relation is used throughout.

Hence TL = T1 $\sqrt{L}$ where TL = dispersion (length L)
T1 = dispersion (1 km)

212 Analogue Frequency Response. If the impulse response of a fibre can be assumed to be Gaussian, the analogue frequency characteristic takes the form illustrated below. In order to provide a universal curve, this has been plotted in terms of recovered electrical signal versus the product of modulation frequency (in HMz) and total fibre dispersion (in ns).

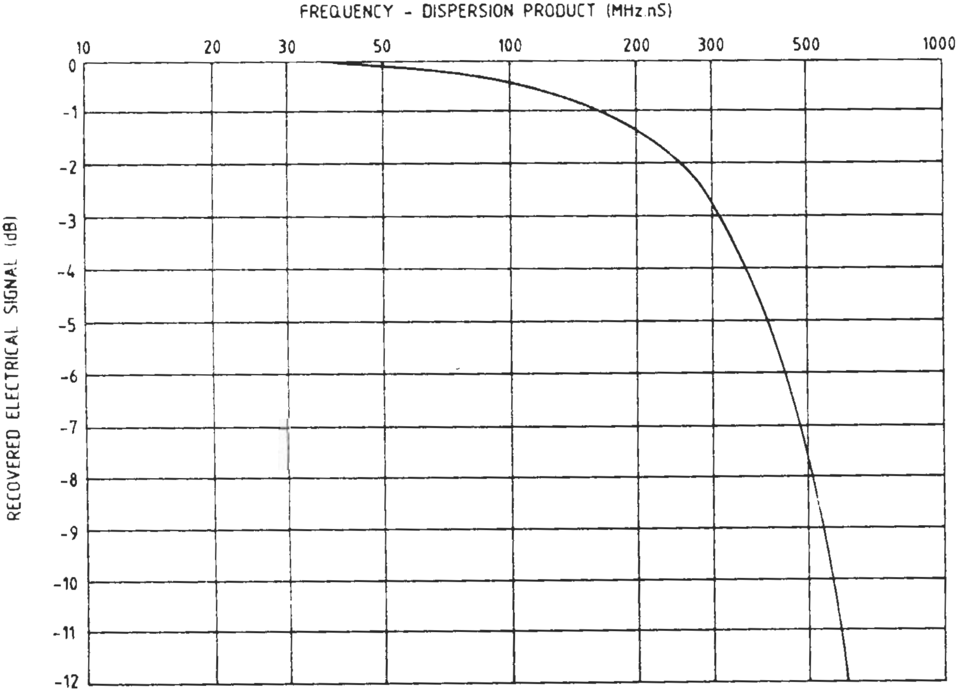


FIG 8.52 ANALOGUE FREQUENCY RESPONSE OF A FIBRE

213 Pulse (Edge) Response. The characteristics of an edge can be derived by integration of the impulse response. By this means, it is found that the 10-90% rise (fall) times are related to the measured dispersion by a factor of 1.09.

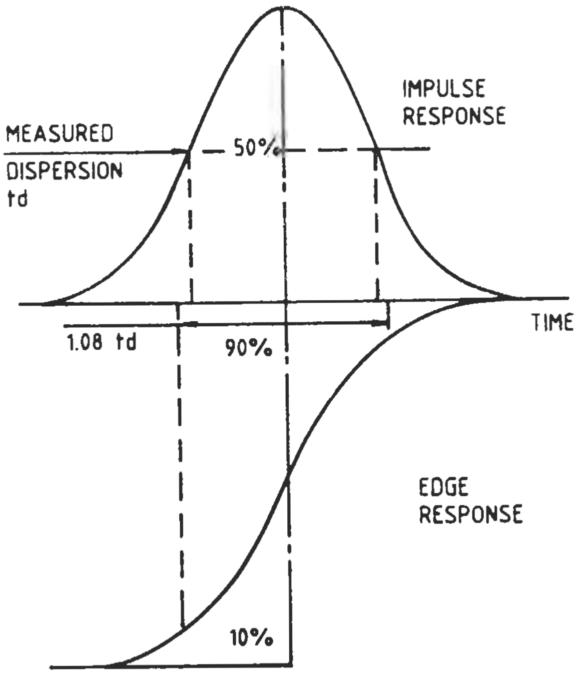


FIG 8.53 RELATION OF EDGE RESPONSE TO DISPERSION

OPTICAL MEASUREMENT

214 Optics has always been regarded as one of the more difficult of the physical sciences to quantify in an accurate and repeatable manner, and fibre optics has introduced a number of additional complications.

215 The difficulties that can be encountered, even in simple attenuation measurements, can be broadly categorised into two groups:

Measurement Errors

216 These relate to the difficulty of achieving repeatable results, even by one operator with a single set of equipment, primarily as a result of the very small dimensions of the fibre. For example, variable coupling to the source and detector can easily totally obscure the parameter to be measured (eg connector loss) and the quality of input and exit fibre surfaces will also be significant.

217 Also included in this category are problems associated with the low optical power levels generally encountered, such as amplifier drift and interference from external ambient lighting.

218 Measurement errors can usually be minimised by careful equipment design to suit the requirement. For example, a repeatability of ±0.5 dB may be sufficiently accurate in the measurement of total link attentuation (say 20-30 dB), so that input and exit coupling can be achieved in a fairly simple manner. On the other hand, connector evaluation measurements require greater accuracy in which case it may be necessary to provide micromanipulator adjustment in order that input and exit coupling can be optimised before each measurement.

219 In the extreme, for example the measurement of very low loss spliced joints ($<$ 0.1 dB), decoupling of the fibre may not be practicable at all. In this case, the fibre must be cut and rejoined without disturbing the input and exit interfaces. Obviously this is only applicable as a research and development test procedure.

220 Asociated with very precise loss measurements is the need for corresponding electronic stability, possibly dictating the use of optical feedback (to stabilise the source), chopper amplifiers and ratiometric techniques.

Test Conditions

221 Even using the best possible equipment the inexperienced operator can obtain inaccurate or even totally meaningless results because of various obscure mechanisms within the fibre. Many of these are experienced when an attempt is made to predict long distance system performance by extrapolation of test results obtained from much shorter lengths of fibre.

222 Several of these pitfalls hae already been referred to earlier in the text. For example, failing to strip cladding light from some types of primary coated fibre will lead to a grossly exaggerated estimate of available power, by as much as 12 dB! Similarly, an error of nearly 4 dB can result if the numerical aperture change of PCS is not taken into account, and of course choice of correct source wavelength is of vital importance with this fibre.

223 Less dramatic, but also significant, are the effects of source modal distribution (ie polar intensity pattern) especially in short distance applications where the degree of mode mixing in the fibre is less apparent. Small differences in attenuation can even be observed with the same fibre depending on whether it is tightly reeled on a drum, or laid out in its operating condition.

Attenuation Measurement

224 The following list itemises the major factors to be considered before making attenuation measurements. No attempt has been made to put them into order of significance since this will depend both on the application and on the choise of fibre. Neither can specific recommendations be made, but the guiding principle should be to make the test method resemble the conditions of the link application as closely as possible:

(1) Source wavelength. Avoid fibre attenuation peaks (assuming the link transmitter does so).

(2) Source NA. Substituting a wide angle LED for a narrow angle laser (with the same wavelength) may result in marginally higher attenuation, particularly with short links which include in-line connectors (because of increased gap loss).

(3) Cladding mode stripping. Vitally important with some silicone primary coated fibres. This must be provided at both input and exit, since any fibre discontinuity such as a misaligned connector will relaunch light into the cladding.

(4) Exit NA. The area of the test detector should be large enough to collect all the exit radiation (defined by the exit cone angle and detector separation). Receiver coupling loss will normally be included in the input sensitivity specification (with STC units).

225 The following items should be considered when evaluating test results:

(1) Fibre NA change (with length). Particularly with plastic clad silica.

(2) Condition of fibre. ie laid straight or reeled, temperature effects.

(3) Position of connectors (if any). Due to mode mixing and/or the presence of cladding modes, connector performance varies marginally according to its relative position in the link.

226 Proprietary test equipment such as the STC OFTS02 can be used with confidence for the majority of fibre optic link evaluations, and with caution for simple connector loss measurements. This instrument consists of separable transmitter and receiver units, each powered by internal rechargeable batteries, so that measurements can be made between the remote ends of an installed link. Optical coupling is by STC ferrule terminations, using 'V' groove alignment.

227 Before making an attenuation measurement, it is necessary to normalise the equipment to the fibre under test, using a very short length of identical fibre to establish an arbitrary 0 dB level. Cladding mode stripping must be used on both fibres, if appropriate.

Optical Reflectometry

228 Reflectometry is an advanced technique which allows the optical characteristics of a fibre to be measured given access to just one end. Equipment developed by STC launches a short, but extremely powerful pulse of light into the fibre, and then detects the minute returning echo caused by reflections from discontinuities such as breaks within the fibre. By measuring the time interval between the transmitted pulse and the returning echo, the position of major discontinuities can be established to within an accuracy of one or two metres.

229 The sensitivity required will be appreciated when it is realised that the returning reflection (which is only a maximum 4% of the incident light, even for a clean fracture) is further attenuated by effectively travelling through the fibre twice (ie there and back). Consequently, special techniques have been evolved to extract the signal from beneath the level of background noise.

230 This equipment can detect fractures at considerable distances and is even capable of detecting the much smaller reflection caused by continuous backscatter along the fibre. Typically the degree of this backscatter is constant, but an exponential decay is observed at the receiver as a result of the attenuation caused by intermediate lengths of fibre. By measuring the rate of this decay, it is possible to make quite reasonable estimates of fibre attenuation, and in particular observe any local increase causd by a severe bend, etc. Alternatively a hard copy 'fingerprint' of the fibre can be obtained from a chart recorder and used for comparison at a later date (for example, after environmental conditioning).

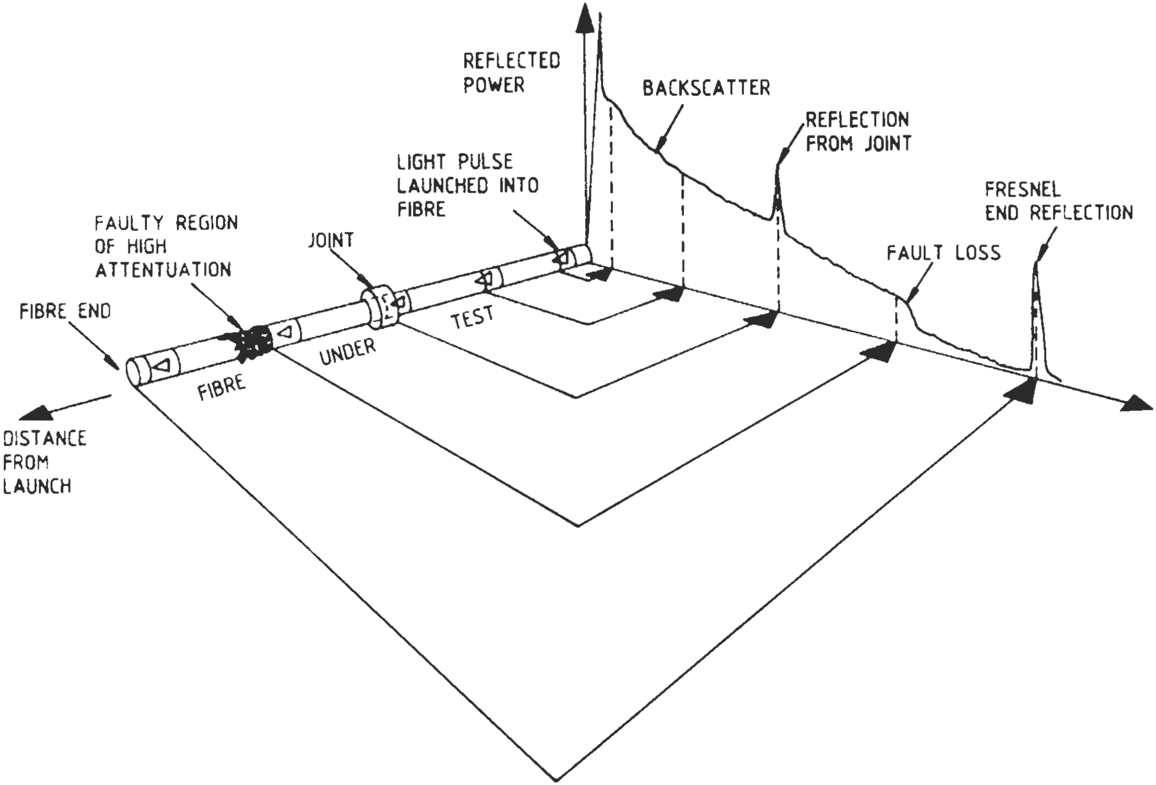


FIG 8.54 OPTICAL REFLECTOMETRY

APPENDIX 1 - GLOSSARY OF OPTICAL TERMINOLOGY

Buffer. A protective overlay, normally of resilient material, which may surround a coated fibre to provide additional mechanical isolation and protection.

Bundle. A number of optical fibres (usually) in a random arrangement, grouped together for use as a single transmission element.

Cable. One or more optical fibres or bundles, which may be individually coated, buffered or jacketed, laid up with strength members and sheathed as appropriate to the intended application.

Cable Assembly. A cable which is fitted with connectors and ready for use.

Coating. A layer or layers which surround and are immediately adjacent to the fibre to provide mechanical protection - See Primary Coating.

Cladding. That part of an optical fibre which surrounds, is immediately adjacent to, and has a lower refraction index than the core.

Connector Insertion Loss. The power loss caused by the insertion of a mated set of connectors into a cable.

Core. The central region of an optical fibre, with a refractive index higher than that of the cladding.

Coupler. An optical component, with or without connector mating faces, used to interconnect three or more optical fibres.

Coupler Loss. Loss inherent in a coupler. (See Excess Loss).

Cross Talk. The leakage of a signal from one optical component to another.

Detector. A transducer for conversion of optical energy into electrical energy.

Excess Loss. Loss in excess of that defined by the theoretical division of power in a coupler.

Ferrule. A tubular device used in the termination of an optical fibre - See Termination.

Fire Optics. The technology of passive guidance of optical energy along optical fibres.

Fibre Attenuation. The loss of power incurred in an optical fibre.

Gap Loss. A power loss caused by longitudinal spacing between the optical fibre ends in mated connectors.

Graded-Index Fibre. An optical fibre in which the refractive index of the core material varies across the core diameter, usually in a parabolic fashion, with the highest values at the core centre.

Index Matching Material. A material which has a refractive index close to that of the core or cladding which may be used, for example, in reducing connector mismatch loss or in cladding mode stripping.

Interface Diameter. The diameter of a notional circular boundary between an optical fibre and a connector. It is both (a) the maximum permissible diameter of the circumcircle of that part of the fibre or fibre bundle to be accommodated, and (b) the minimum permissible diameter of the incircle of that part of the connector structure which supports the end of the fibre or fibre bundle.

Jacket. The material which forms the external protective covering over the buffered or unbuffered fibre or fibre bundle.

Multi-mode Fibre. An optical fibre which permits only one mode to propagate.

Mono-mode Fibre. An optical fibre which permits only one mode to propagate.

Misalignment Loss. That portion of the losses which is caused by lateral or angular misalignemnt of the optical fibres in mated connectors.

Numerical Aperture (NA). The characteristics of an optical conductor in terms of its acceptance of impinging light. The maximum theoretical numerical aperture is given by:

$$NA = \sqrt{n1^2-n2^2}$$

where n1, and n2 are the fibre core and cladding refractive indices respectively, for step-index fibres.

Optical Fibre. A discrete optical transmission element usually comprising a core surrounded by a cladding of lower refractive index.

Outer Protection (Sheath). The material which forms the external protective covering of a cable.

Primary Coating. The innermost coating, in intimate contact with the cladding, applied during the drawing process.

Source. A transducer for the conversion of electrical energy into optical energy.

Splice. A non-separable juntion between two optical fibres.

Step-Index Fibre. An optical fibre in which the refractive index changes abruptly at the core-cladding interface.

Termination The method used to prepare, position and protect an optical fibre end.