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MANUFACTURING IMPLICATIONS OF FIBRE OPTIC SYSTEMS

S.D. ROY, P.T. GARDINER

WESTLAND HELICOPTERS LIMITED

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1. INTRODUCTION

Fibre optic data transmission offers powerful advantages over conventional copper based links. Increased bandwidth, smaller diameter, lower weight, elimination of crosstalk and complete immunity to electromagnetic interference make this technology particularly attractive to the military user. The massive investments in component development, stimulated by the telecommunications industry has produced many important advances in optical sources, cables, detectors and couplers.

There are many potential applications for optical fibres systems in helicopters ranging from simple point to point links, in flight control applications, to data bus structures for general avionics.

One of the major factors which has hindered the introduction of fibre optic systems has been the lack of properly developed manufacturing and repair techniques to produce systems which have an adequate performance compatible with operation in the airborne environment. An experimental manufacturing programme was established at Westland to assess the performance of operation, tooling systems and airborne system performance.

2. HELICOPTER APPLICATIONS

Any form of signal transmission technique can be characterised in terms of type of interconnection and data handling requirements.

There are three basic types of interconnection required on helicopters or any other aircraft type. These are:

- Point to Point links
- Single-source, multi-sink links
- Multi-sink, multi-source links

These are shown diagrammatically in Fig. 1.

A diversity of signals and data i.e. digital, analogue and video require to be carried on these links with signal bandwidths ranging from a few hertz to several megahertz. In the future we can expect to see an increase in the amount of data which requires to be transmitted, usually at low signal levels, the latter being a result of the trend towards the use of low power digital systems.

These factors, i.e. large amounts of data, transmitted at low power, require the aircraft manufacturer to expend a significant effort to ensure that the signal transmission integrity is preserved in the presence of all forms of potentially interfering electromagnetic radiation. Such radiation can occur from sources onboard the vehicle such as high power communications systems, electrically noisy components such as de-icing systems etc, and ground or shipborne systems such as high power radars.

In many military applications, systems are required to be hardened against the effects of nuclear weapons. In the tactical nuclear environment the main effects on avionics systems are from the Electromagnetic Pulse (EMP) and nuclear radiation. Metallic cables are vulnerable to electrical noise, interference and EMP while fibre optic transmission lines are, for practical purposes, invulnerable to EMP and electrical interference. It has been estimated (ref 1) that a hardened fibre optic cable can offer up to a 90% reduction in weight over a hardened wire cable.

3. OPTICAL SYSTEM POWER

One of the major differences between metallic cables and fibre optic cables is the technology and procedures for joining cable sections. Whether it is a permanent joint (a splice) or a demountable or re-entrant junction (a connector), the key requirements are accurate radial alignment of the fibre ends usually with a small longitudinal gap between the two ends of the fibre.

The loss through a fibre to fibre joint is about 1.5 dB if a radial offset of one quarter of one core radius is introduced. A loss of approximately 0.2 dB requires alignments within about 3% of the core radius. For the all-silica fibres being developed for avionics applications, 3% of the core radius corresponds to around 6 m; this represents a demanding alignment requirement with standard airborne connector designs.

The sources of loss in connectors are attributable to two basic mechanisms, those arising from imperfections in the fibre (intrinsic losses) and those arising from imperfections in the join (extrinsic losses).

Instrinsic losses are due to variations in core diameter circularity profile, concentricity with the cladding etc. These effects are completely independent of the extrinsic or connector losses. These arise from lateral, angular and axial misalignment of the axes and the deviation of both fibre ends from the desired perpendicular mirror finish.

Figs. 2, 3, and 4 describe the optical power loss due to these factors.

The other source of loss in a fibre optic system is the fibre attenuation. The UK Ministry of Defence is developing an "all silica" fibre for avionics applications. This is a fibre in which the fibre core and cladding consist of silicas with different refractive indices. These fibres have losses of <10dB Km^{-1} over a wide temperatue range of $-55^{o}C$ to $125^{o}C$. A typical helicopter installation system wiring schematic is shown in Fig. 5.

The military user, in comparison with many commercial or industrial applications, requires systems and system components which operate with the required performance over the required environmental range. Additionally mobility, repairability and testability requirements invariably dictate the use of connectors in systems rather than splices.

Splice techniques are, however, attractive since they provide a means of rapidly re-establishing a link should damage occur. In the field a suitable splicing technique will provide an effective means of minimising repair time and costs. Of primary importance is the need to obtain low optical loss with a repair method that is easy to implement in a wide range of weather and climatic conditions.

For the point-to-point system as illustrated in Fig 5 the optical power losses can be attributed to two sources:

(a) Internal equipment losses
(b) Cable loom losses

Internal equipment losses are due to coupling of optical energy from the source (LED) into a fibre pigtail which introduces a loss of the order of 3dB. Loom losses are made up as follows:

- Fibre loss (10 metres @ 10dB Km^{-1}, i.e. 0.1dB)
- Connectors (Multiway 2.5dB per mated pair)

The state of the art in source and receiver technology enables devices to be produced which can launch in excess of 1mW of optical power in a 200 m fibre core and detectors with responsivity of approximately 0.7 Amps per Watt (AW^{-1}). This results in optical systems with dynamic ranges of around 35dB being feasible.

The point to point link in the example has a theoretical total loss of approximately 14.5dB, subtracting this figure from the achievable dynamic range gives an excess system margin of approximately 20dB. This margin represents the allowable excess optical energy available to accommodate variations in components, additional losses and system life degradation.

One of the objectives of the manufacturing exercise was to confirm that repeatable looms could be constructed in a realistic manufacturing environment to these tolerances.

4. EXPERIMENTAL MANUFACTURING PROGRAMME

Little practical data or information is available to support the theory of optical fibre systems in adverse environmental applications. Extensive experience is being gained in the telecommunications industry but the application in this environment is of little practical value to the aerospace community. A manufacturing exercise was undertaken to develop such a database and methodology for the operational use, maintenance and general integration of of optical fibres into Westland's Helicopters. Specifically the programme aimed to:

(a) Establish the likely performance which could be obtained from fibre optic looms.

(b) Define procedures and techniques for the fabrication, inspection and test of optical cable looms.

(c) Assess the performance of 'state-of-the-art' tooling systems and test equipment.

(d) Assess the implications of fibre optics on the skill levels and training required for manufacturing and personnel.

(e) Develop preliminary Quality Assurance measures.

The procedures and processes which were developed during this exercise followed, as far as possible, the normal procedures used in aircraft construction. This provided a means of assessing the maturity of the technology in terms of application to aircraft systems either in new build or retrofit programmes and also provided a ready and easily quantifiable comparison with current production methods.

Many techniques differ in detail yet have an extremely significant influence on the overall performance of the completed system. For example in any connector joint or splice a properly prepared fibre end is essential. One procedure for achieving this is to score and break the fibre in a process called cleaving. Simple cleave techniques will yield a partially rough surface often with a lip at the outer edge. Fig. 6 shows a number of fibre ends with various faults which have occurred through incorrect cleaving. Ref. 2 describes cleaving techniques in some detail. A more refined art of end preparation involves simultaneous radius bend and tension after the usual scoring. Prototype tools which achieve this process have been developed but need further work before they could be considered as viable tools for everyday use on the shopfloor.

Space does not permit a detailed discussion of all aspects of the tooling systems and procedures assessed during this study, however the major findings are summarised in the following section.

4.1 Results of Study

(a) Performance

The optical performance of the loom and its constituent components were measured at all stages of fabrication. A repeatable connector loss of typically 3dB was achieved, comparing well with the theoretical loss of 2.5dB.

(b) Termination Procedures

The various methods for fabrication of fibre optic cable assemblies were studied and as a result of some practical work, formal step procedures for fibre optic termination were established. Step procedures were written to enable a skilled operator to repeatedly terminate optical fibres to the required standard. Figs. 7 - 11 show various stages of a termination technique based upon fibre cleaving, photographs of this type were used to illustrate the written procedures.

(c) Tooling Assessment

It was appreciated that the hardware used was at prototype level but nevertheless, all hardware and tools were evaluated to establish any shortcomings in the mechanical designs and operation. Performance of the tool, along with ease of handling and suitability to the shopfloor environment were addressed, hence areas of improvement and development required were identified. A requirement exists for more robust, less bulky tools which require minimal re-calibration.

(d) Skills and Training Levels

It was observed that a minimal level of formal training is required if accurate written procedural standards exist and are followed. Within one or two days the personnel used could competently and efficiently use existing fibre optic hardware and in fact made very useful observations on performance. A skilled Westland electrician, which we believe is representative of the skilled person throughout industry, possesses the necessary skills and aptitudes to handle fibre optics.

(e) Quality Assurance

Along with the procedures for fibre optic loom fabrication, inspection and quality assurance measures have been established. It is felt that a visual inspection technique is vital to assess fibre optics even though subjective techniques are generally not favoured. The visual inspection methods will be used in conjunction with an objective test method which involves the measurement of the optical power attenuation showed by fibre optic links. Step inspection and test procedures have been written to define these two approaches. One important point to note is that during and after, installation control is maintained over the minimum bend radii in optical cables. It was shown that this could be achieved in a realistic production environment with the minimum changes to existing loom installation procedures.

5. DISCUSSION

The results of the experimental study confirm that it is possible to manufacture optical systems, in a realistic aircraft production environment, with sufficient performance to enable practical airborne systems to be designed for helicopter applications. So far this discussion has dealt with the simplest form of link namely a point-to-point link.

In many system applications more complex interconnection configurations are required. Two examples are a multi-source, multi-sink link or data bus and the single source, multi-sink interconnection.

Electrical databus systems such as MIL-STD-1553B consist of a twisted pair cable connected to equipments or subsystems by means of transformer coupling arrangements. The theoretical loss for an equivalent optical data bus with 16 terminals is 64dB, which is well outside the dynamic range achievable with existing sources and receiver technology.

The single source multi sink interconnection can be satisfied by using an optical component called a star coupler. This is a component in which the input fibre is connected to all the output fibres. The theoretical loss for a 16 part coupler, including connectors is 18dB.

The two optical coupling methods as described are shown schematically in Fig. 12.

6. CONCLUSIONS

The major conclusions reached from the study were:

(a) A complete set of components exist, albeit in the prototype stage to enable a range of applications.

(b) The system performance obtainable is adequate for many interconnection applications.

(c) Aircraft electricians, familiar with conventional electrical cables can readily adapt to the procedures and techniques required to handle optical systems.

7. REFERENCES

1. H. Wichansky, L. U. Dworkin, S. Divita and A. Mondric, Survivability of Army Fibre Optic Systems, Proceedings SPIE VOL. 296 1981 Fibre Optics in Adverse Environments.

2. D. Glodge, P. W. Smith, D. L. Bisbee and E. L. Chinnock, Optical Fibre End Preparation for Low Loss Splices, The Bell System Technical Journal, Vol. 52, No. 9, November 1973.

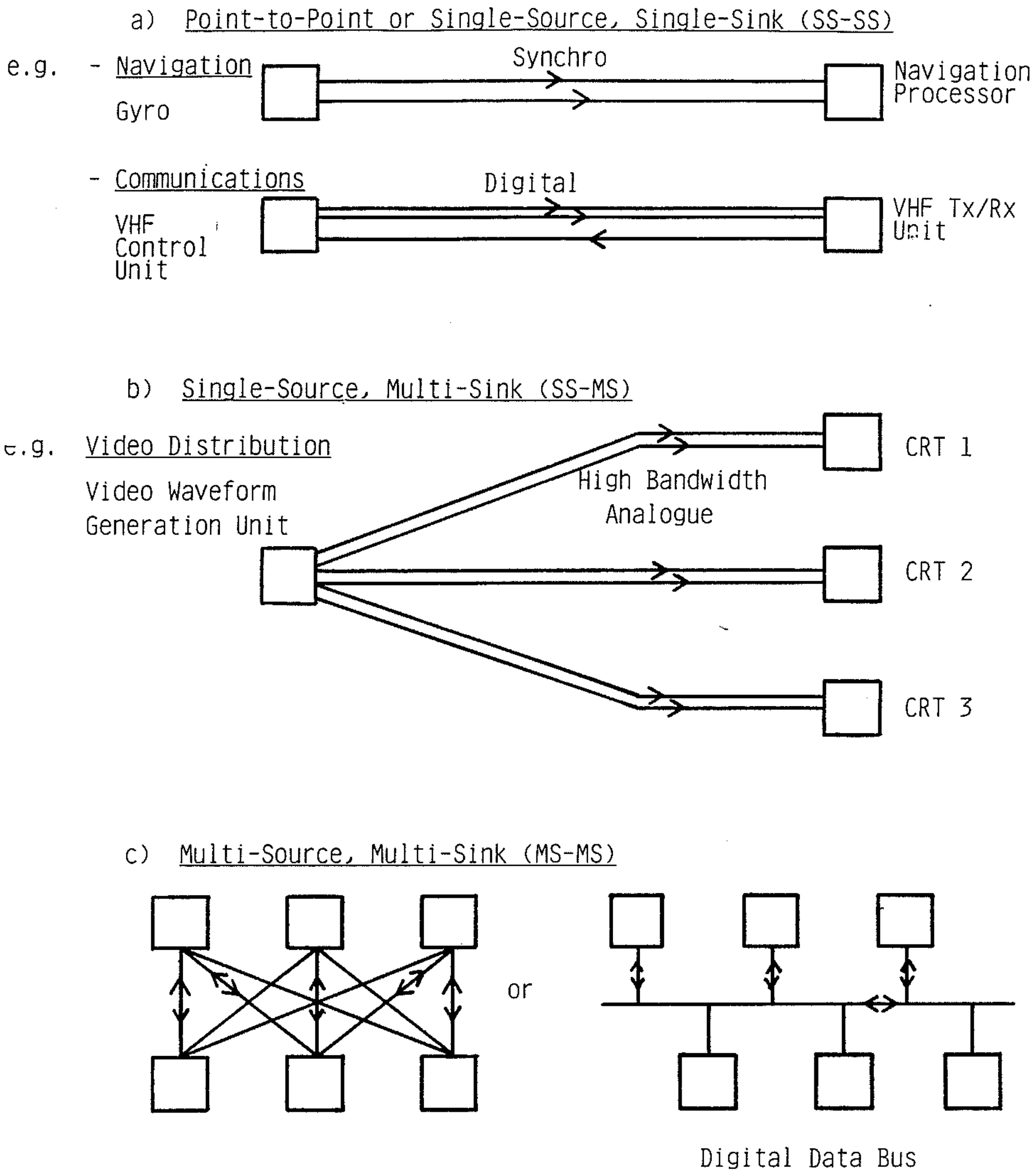
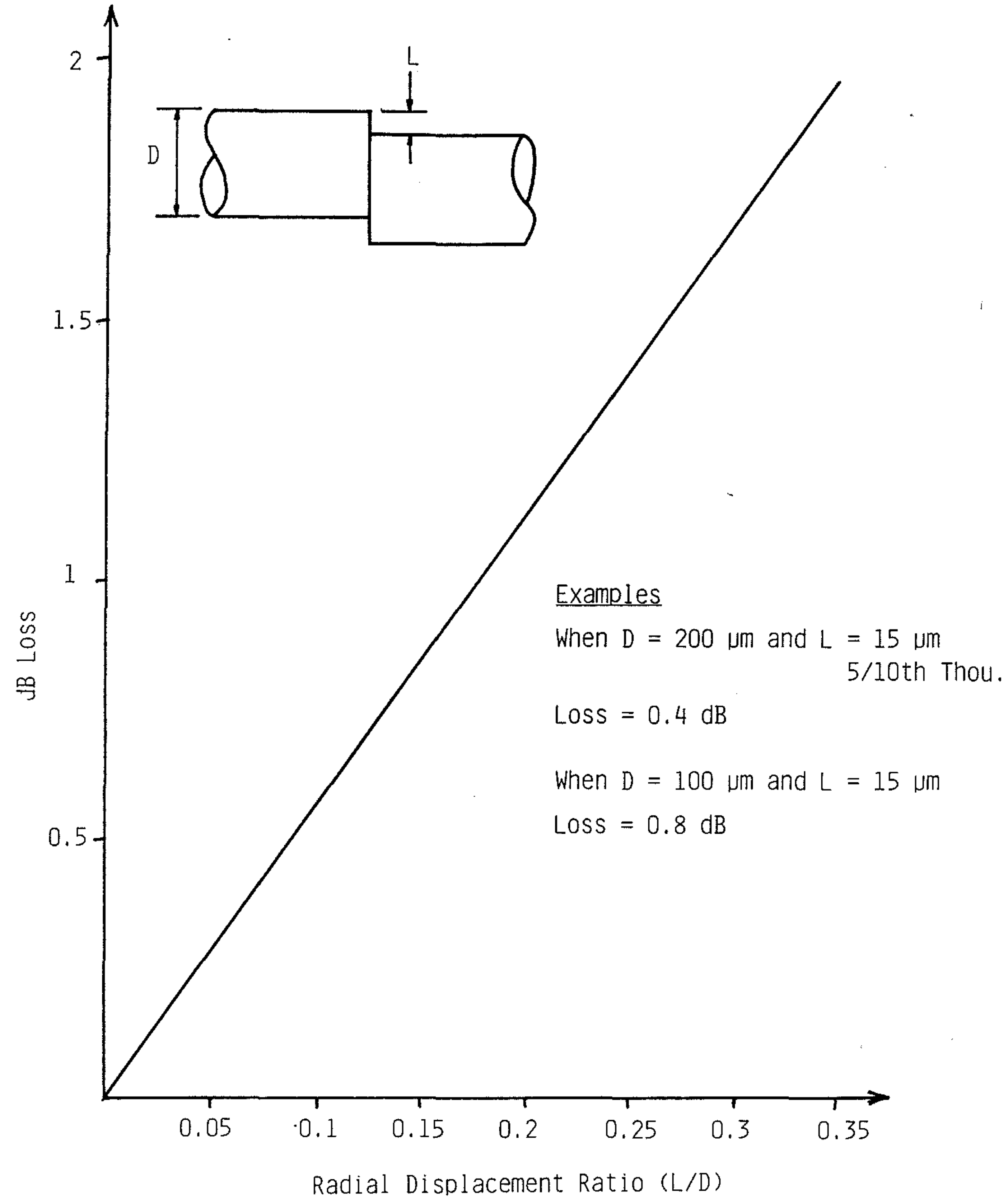


Figure 1. Aircraft Data Transmission Architectures

Figure 2. Extrinsic Loss - Radial Misalignment Contribution



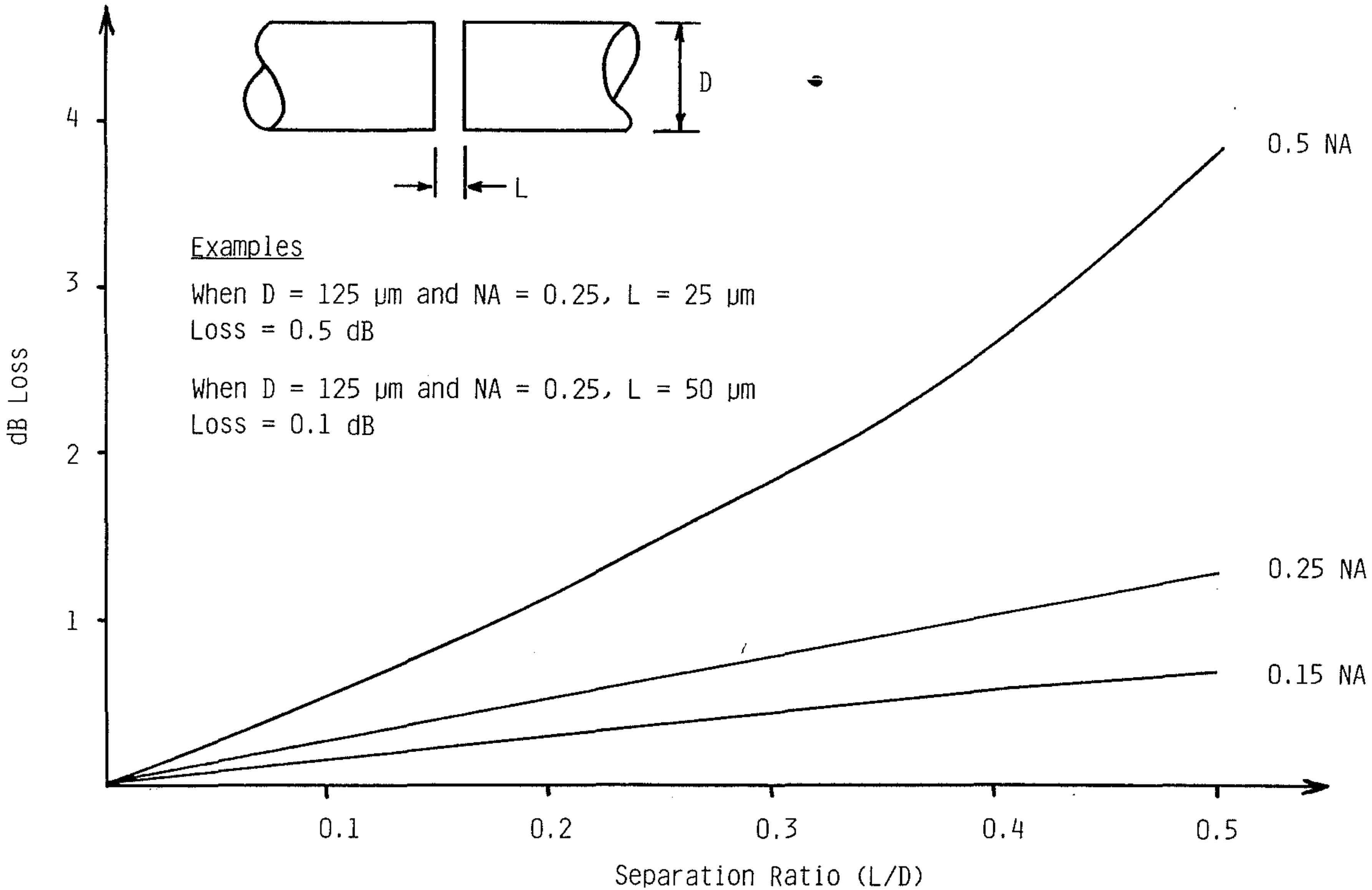
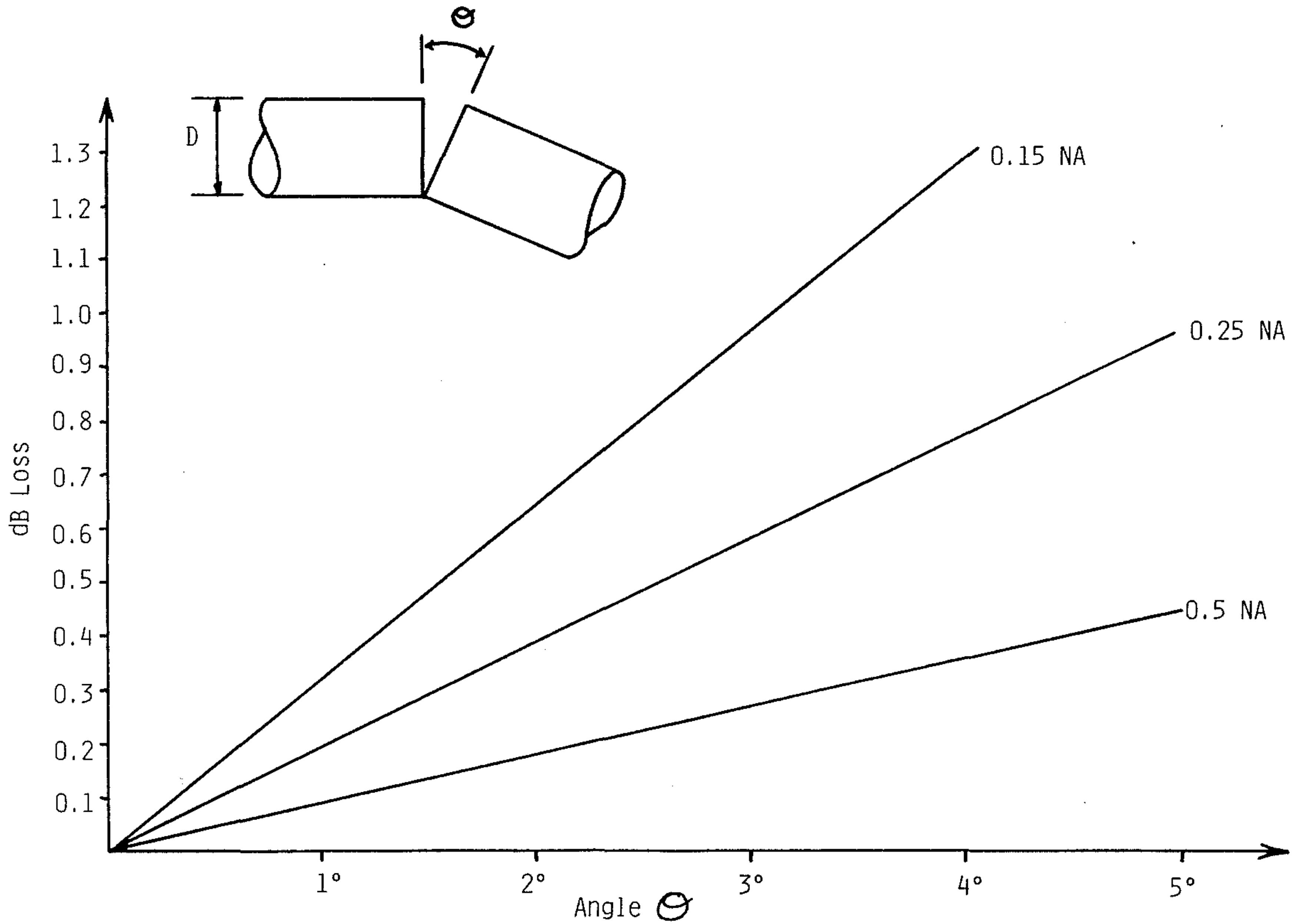


Figure 3. Extrinsic Loss - End Separation Contribution

Figure 4. Extrinsic Loss - Angular Misalignment Contribution



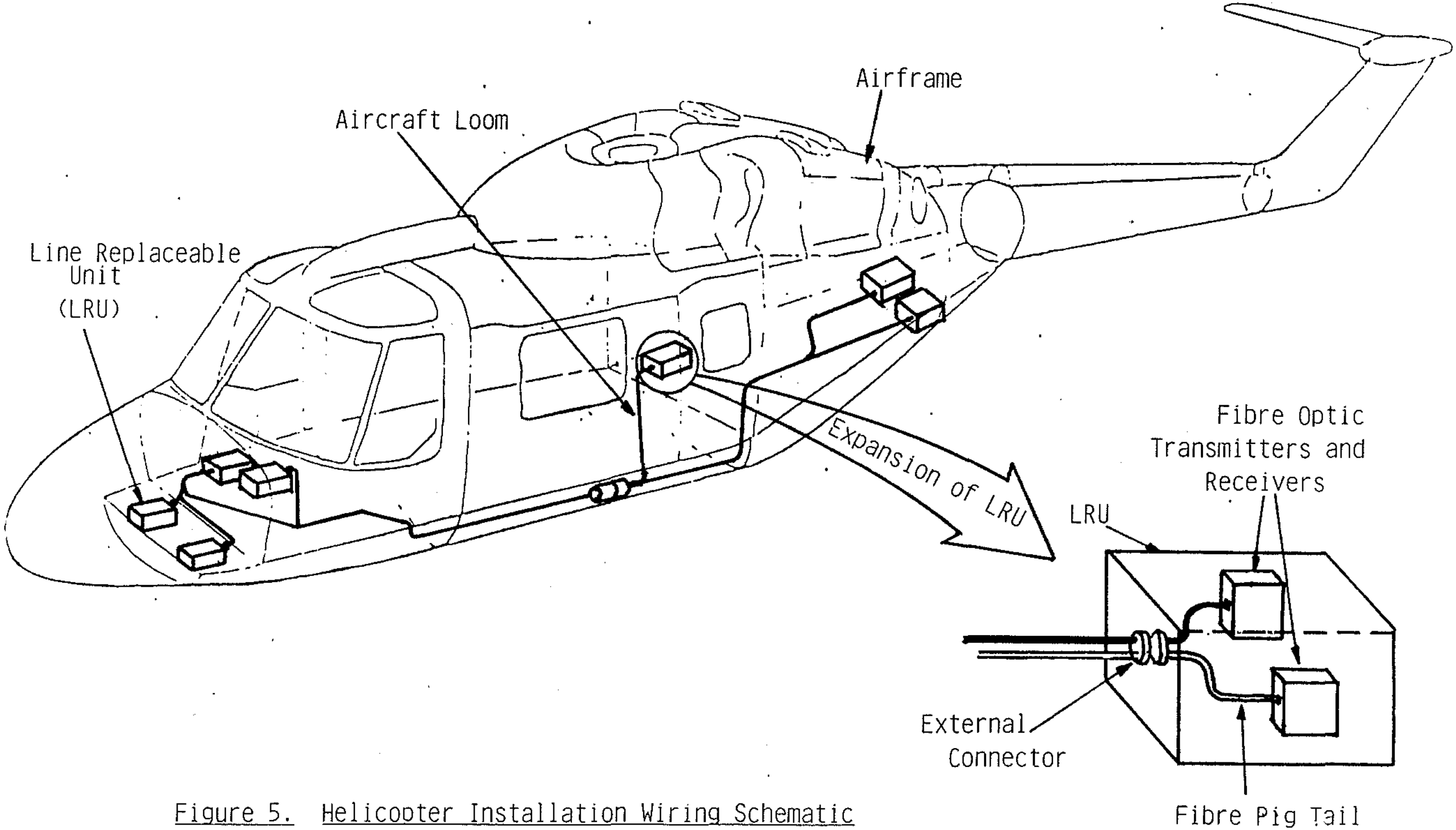


Figure 5. Helicopter Installation Wiring Schematic

a) Unacceptable cleave finish - due to wrong combination of tensile stress and bend

b) Acceptable cleave - smooth mirror like core surface

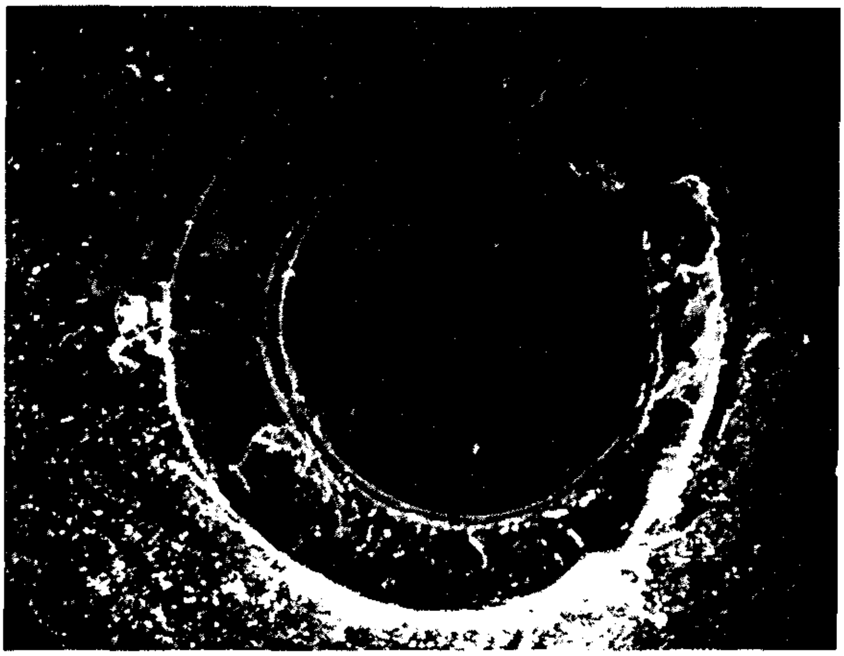


Figure 6. Cleaved Fibre Ends

Figure 7. Stripping of Optical Fibre Jacket

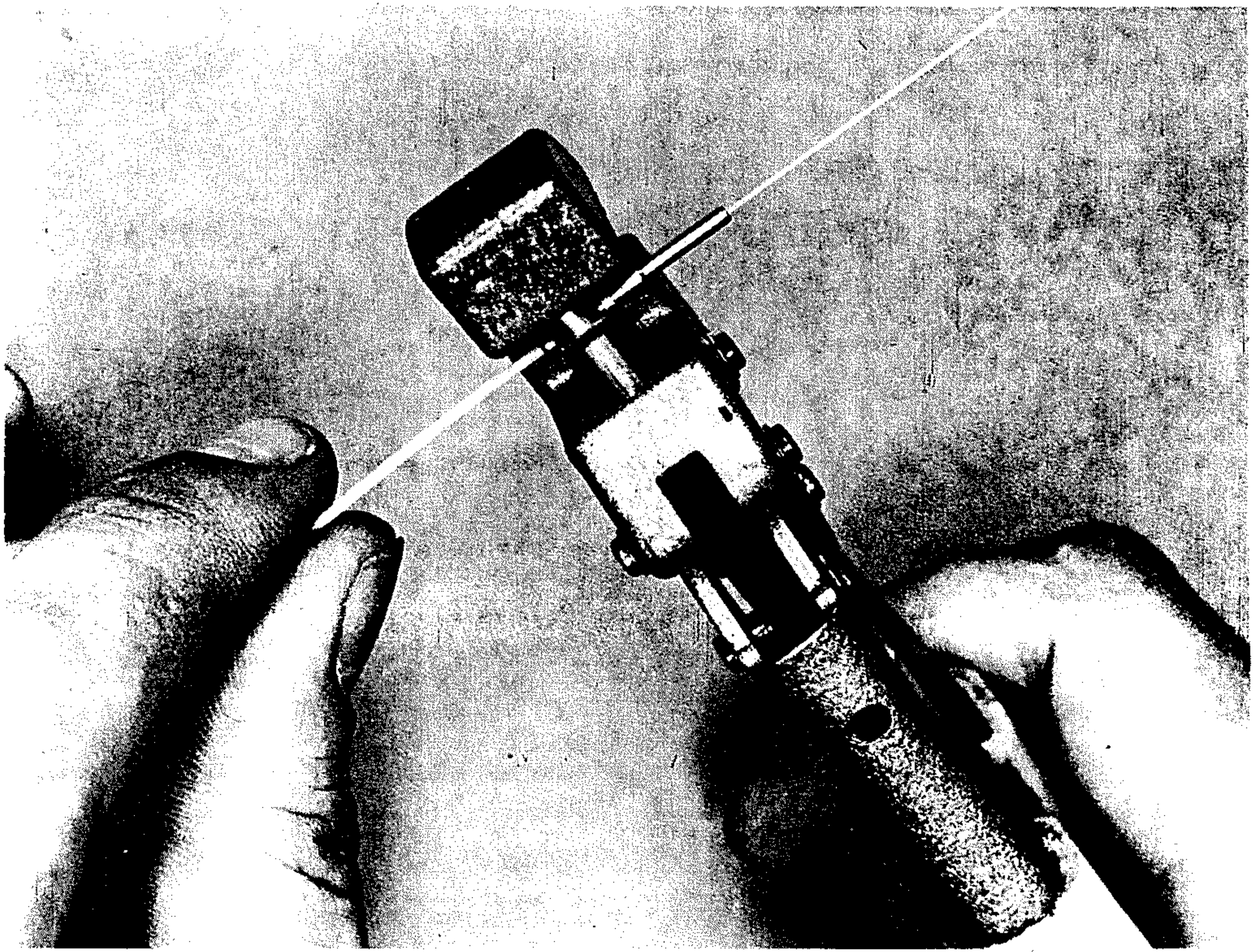


Figure 8. Crimping of Connector Alignment Ferrule

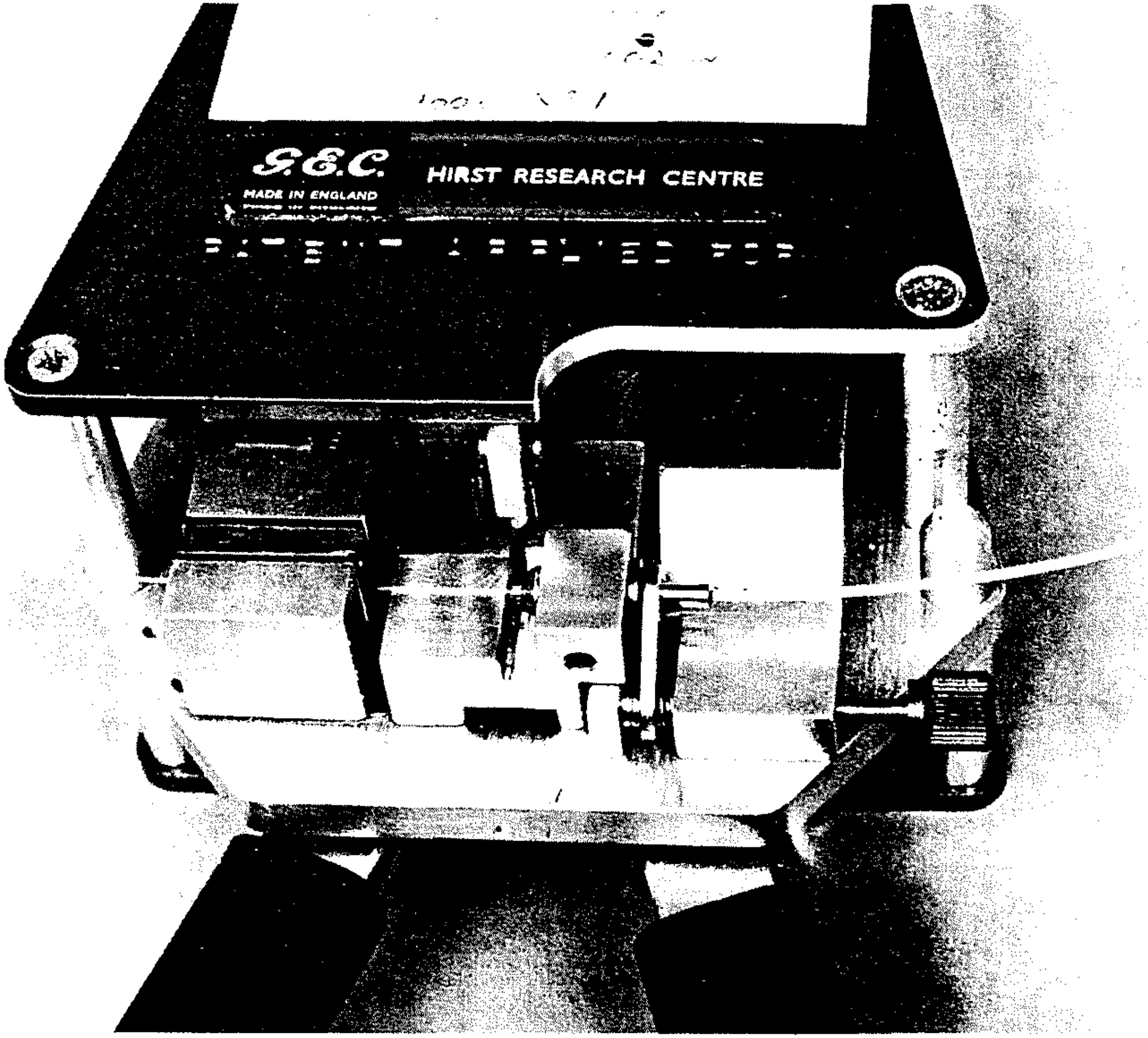


Figure 9. Fibre/Ferrule Assembly in Cleaving Tool Prior to Cleave

Figure 10. Visual Inspection of Cleaved Fibre End

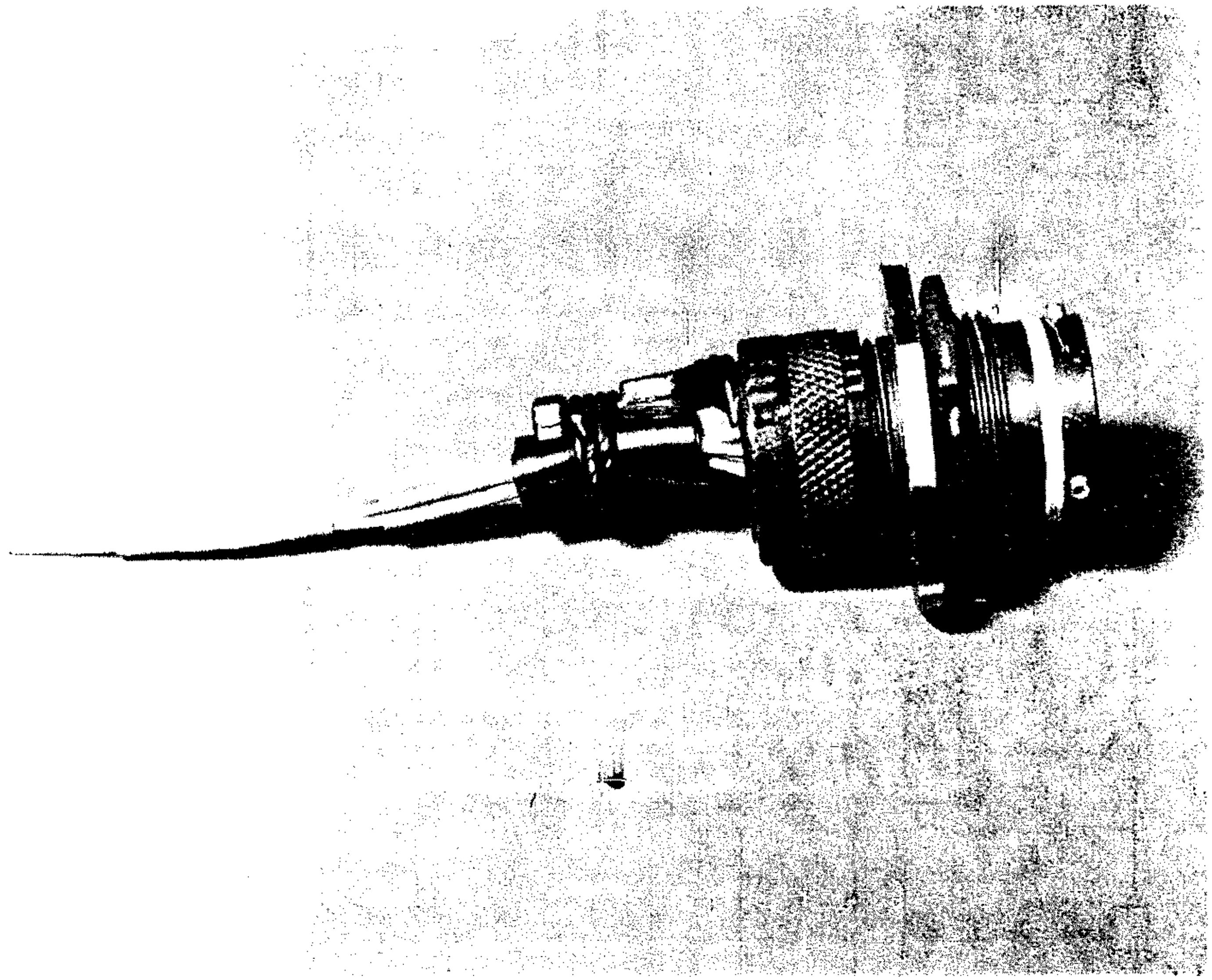
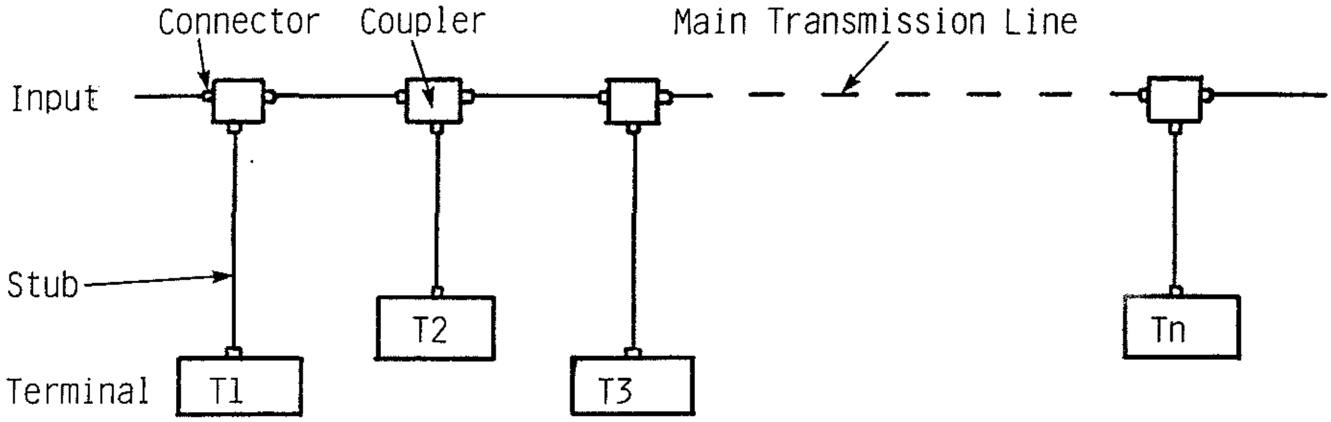


Figure 11. Completed Fibre Optic Connector Assembly

Figure 12. Fibre Optic Coupling Systems

a) Tee Coupled System

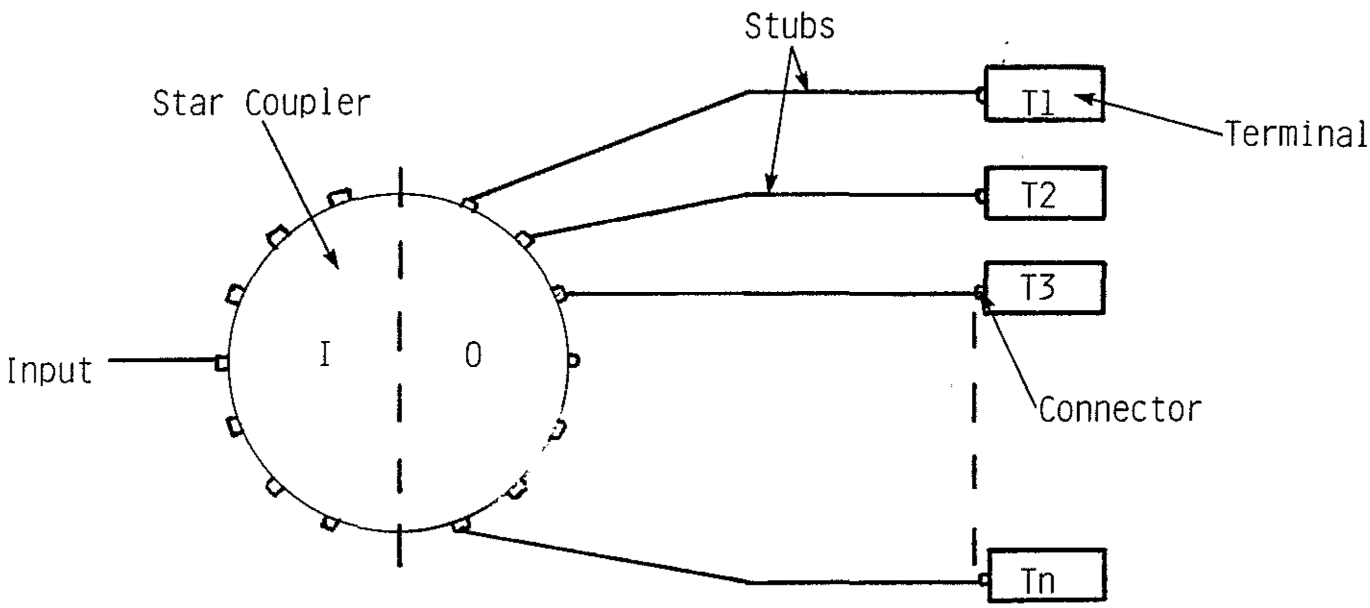


Coupling Loss

Couping Ratio = 10% = 1dB Loss
Connection and Excess Loss = 3dB Per Port } 4ndB Total, n = 16

Total Loss = 64 dB

b) Star Coupled System



Coupling Ratio = $\frac{1}{n}$ = 10 $\log_{10}$ (1/n)dB
Excess Loss for Any Port = 3dB } 3 + 10 $\log_{10}$ (1/n) dB

n = 16 (15dB)

Total Loss = 18 dB