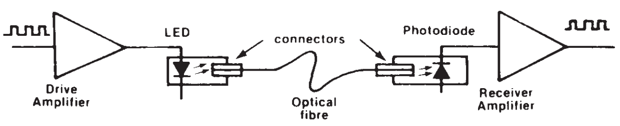
Fibre optics

This data sheet discusses fibre optics in general terms and gives details of some of the basic RS products.

Fibre optics can offer solutions to many of the problems associated with traditional electrical hard wired transmission systems.

Figure 1 **Basic fibre optic link**



Fibre optics vs copper wire

In an optical system, (Figure 1), signals are transmitted in the form of photons (light) which have no electrical charge and, therefore, cannot be affected by the electric fields as experienced in high voltage environments or during a lightning discharge. Similarly, high magnetic fields from motors, machinery, transformers etc., have no effect on optical transmission. There are no crosstalk problems as the small leakage of flux which may occur at the fibre boundary interface is retained by the opaque primary jacket ensuring that optical signals cannot interfere with each other when fibres are in close proximity. This factor also guarantees security of transmission, for the signal is unable to be externally detected throughout the length of the fibre.

Features

- Freedom from electro-magnetic interference
- Freedom from crosstalk
- Security of transmission
- Elimination of sparking and fire hazards
- Electrical isolation
- Absence of ground loops
- Low weight coupled with high strength
- Increased bandwidth and lower transmission losses than in coaxial cables at high frequencies.

The insert nature of optical fibres means they can tolerate most kinds of weather and be immersed in many fluids. Their low weight and small size is useful in many applications. Complete electrical isolation is a distinct benefit, giving more freedom in the design of the transmitter and receiver and ensuring the elimination of ground loop problems. However, by far the major advantage is in bandwidth. In either coaxial or parallel wire cable the bandwidth varies inversely as the square of the length, while in fibre optic cables it varies inversely as the length, only.

Fibre optics theory

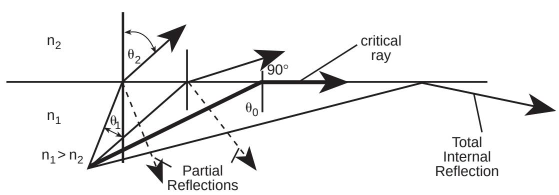
Total internal reflection TIR

Optical fibres transmit light by the phenomenon of total internal reflection. Light rays passing between the boundaries of two optically transparent media of different densities will experience refraction and change direction according to Snells Law:

$$n_1 \text{ Sin } \theta_1 = n2 \text{ Sin } \theta_2 \qquad \text{Snells Law}$$

Where n1 and n2 are the indices of refraction of the two media.

Figure 2 **Principles of internal reflection**



If rays pass from a dense to a less dense medium (ie, n1> n2) then at a certain value of qC1 the resultant qC2 will be 90°. This value qC1 is known as the critical angle and is denoted qC, (Figure 2).

$$\text{So, } n_1 \text{ Sin } \theta c = n_2 \text{ Sin } 90°.$$

$$\text{Sin } \theta c = \frac{n_2}{n_1}$$

Numerical aperture

In a fibre, rays which are internally reflected rebound along the length of the fibre and only exit at the far end. Partially reflected rays lose power at each rebound and consequently die away rapidly.

Figure 3 **Step index fibre propagation modes**

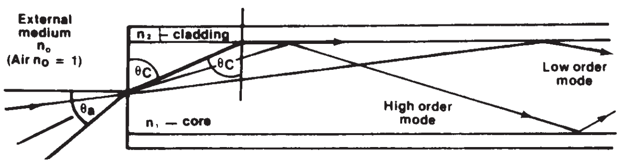


Figure 3 shows the air/fibre interface. The angle qa is the maximum angle at which a ray incident to this interface can enter the core and experience total internal reflection. qa is called the Acceptance Angle and sin qa is known as the Numerical Aperture (NA).

Numerical Aperture = Sin θ_a.
From Snells Law:

$$n_o \sin\theta_a = n_1 \sin(90° - \theta_c)$$
$$= n_1 \cos\theta_c$$
$$= n_1 \sqrt{1 - \sin^2\theta_c}$$
$$= n_1 \sqrt{-(n_2/n_1)^2}$$

When $n_0 = 1$ (i.e air)

$$\sin\theta_a = \sqrt{n_1^2 - n_2^2}$$

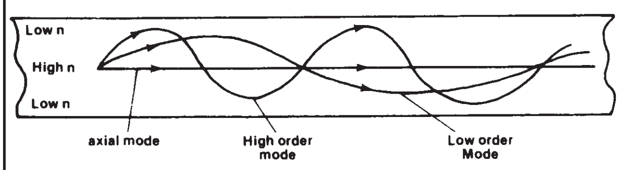
Propagation modes

Light rays in a fibre may be classified as meridional and skew. Meridional rays are those that pass through the axis of a fibre after each rebound, while skew rays never intersect the fibre axis. There are also parallel rays which travel directly down the fibre, never being reflected. Basic fibre theory is concerned with meridional rays. These fall into two categories, low order modes and high order modes (Figure 3). Low order modes are those rays launched at small angles within the acceptance angle, while high order modes occur when rays are launched at large angles. Single-Mode fibres result when the core area and the NA are so small that only one mode can propagate. Other modes of propagation do exist but these disappear or do not affect the basic theory.

Fibre construction

Two types of fibre construction are commonly in use. A **step-index** fibre which consists of a cylindrical core of glass, silica or plastic of refractive index n1, covered by a thin cladding of a lower refractive index n2. The second type is a **graded index** whose refractive index changes gradually from a high refractive index at the centre to a lower index towards the perimeter. This causes the rays to propagate as in Figure 4.

Figure 4 **Graded index fibre propagation modes**



Dispersion

Two types of dispersion are encountered in fibres which limit bandwidth. **Material** dispersion and **Modal** dispersion. Material dispersion results from the fact that different wavelengths travel at different velocities in the same medium. Consequently, the various wavelengths launched simultaneously within the flux will not arrive at the receiver simultaneously but will suffer time dispersion due to differences in travel time. This effect can be reduced by using an emitter with a narrow spectrum of emission (eg. laser).

Modal dispersion is caused by the difference in path lengths between low order modes and high order modes. As can be seen in Figures 3 and 4 the high order modes have a longer travel time than the lower order modes and simultaneously launched rays will suffer dispersion on arrival. Modal dispersion can be reduced in step-index fibres by decreasing the NA to allow only the lower modes to propagate. In graded-index fibres the effect is compensated for by the high order modes travelling faster in the lower-index regions, so the time differential between high and low order modes is not as large in graded-index fibres as it is in step-index fibres.

Dispersion is generally only a problem in long distance communications and consequently graded index fibres, although more costly than step-index fibres are used in these applications in conjunction with lasers. For shorter distances (< 500m) and/lower bandwidth step-index fibres are favoured for lower costs and easier coupling methods.

Transmission loss

There are four main causes of transmission loss in optical fibres:

1. Material absorption
2. Material scattering
3. Scattering due to irregularities at the core/cladding interface
4. Radiation due to curvature.

Material absorption is caused by molecular impurities within the core of the fibre which absorb certain wavelengths. High purification processes during manufacture limit the problem - but are costly. Alternatively, a suitable emitter is chosen whose peak wavelength corresponds approximately to the spectral region of maximum transmission of the fibre. Plastic fibres, for example generally have minimum absorption between 630 and 670nm and are therefore recommended to be used with visible red emitters.

Material scattering is caused by particle impurities and by fluctuations in temperature and composition (Rayleigh scattering) which interrupts the reflection paths of the light rays.

Further scattering is caused by **irregularities** at the core/cladding interface which results in transmission into the cladding and subsequent loss of energy on reflection.

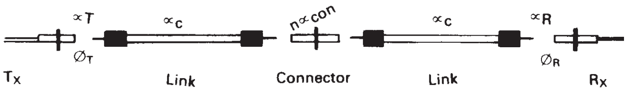
Curvature of the fibre may also cause losses. If the curvature is too great some rays will strike the boundary at angles less than the critical angle and partial transmission into the cladding will occur with a resultant loss of reflection.

The first three conditions contribute to the overall attenuation of the fibre given in dB/km.

Coupling losses

In addition to the losses inherent in a fibre, coupling losses must be considered when designing a fibre optic link. The three main loss mechanisms are, fibre to fibre (in-line), fibre to fibre (bulkhead) and fibre to emitter/detector unit. In the case of the RS systems a maximum figure is quoted for each coupling in dB. The loss is due to a number of factors but in particular, reflections at the mating faces, slight misalignment due to manufacturing tolerances and separation between the mating faces. The latter is deliberately engineered to prevent scratch damage to the fibre faces when the coupling is made.

Attenuation calculations



$$\text{Overall attenuation} = 10 \log_{10} \frac{ØT}{ØR}$$
$$= \propto_T + \propto_{C1} + n\propto_{con} + \propto_{C_2} + \propto_R$$

where $Ø_T$ and $Ø_R$ is the power in μW transmitted and received respectively.

$\propto_T$ and $\propto_R$ are the coupling losses between the fibre and transmitter and receiver respectively.

$n\propto_{con}$ is the total insertion loss due to 'n' number of coupling connectors (ie. in-line or bulkhead).

$\propto C_1$ and $\propto C_2$ are the attenuation figures of the individual lengths of cable involved in the link.

N.B. It is important for system performance to keep connections to a minimum. It may be advantageous in certain instances to use a longer length of cable rather than incur coupling losses, by using in-line connectors to join shorter lengths in order to make up the desired distance.

Generally in designing a system, the flux which the transmitter produces and the length over which the data is to be transmitted is known. From the above attenuation equation, the flux appearing at the fibre/receiver interface can be calculated and a suitable circuit designed to amplify the received signal.

Specification - Polymer system

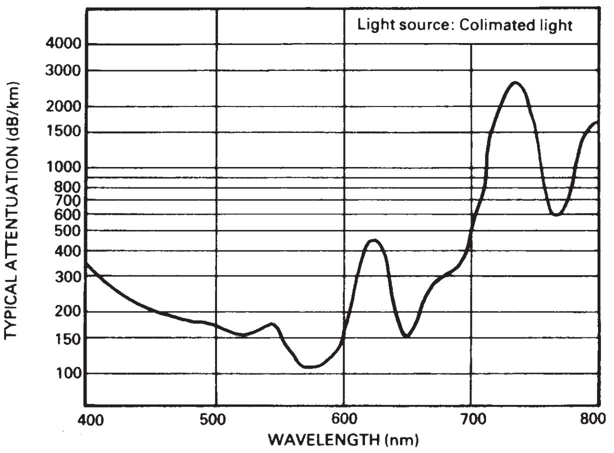
Polymer cable (**RS** stock no. 368-047 & 368-053)

Core material ____ polymethyl methacrylate
Cladding material ____ fluorinated polymer
Sheath material ____ black polyethylene
Core/Cladding diameter ____ 1.00mm
Overall diameter ____ 2.25mm
Optical construction ____ step index
Attenuation at 665nm ____ 200dB/km (max.)
Core refractive index ____ 1.492(n1)
Clad refractive index ____ 1.417 (n2)
Numerical aperture ____ 0.47 ± 0.03 (√ (n1)2 - (n2)2)
Acceptance angle ____ 56° (2 sin-1 (NA))
Minimum bend radius ____ 15mm
Tensile strength ____ 5kg
Operating temp range ____ -30°C to +85°C
Maximum temperature ____ 100°C

End termination (**RS** stock no. 655-004)

Ferrule material ____ nickel-silver
Coupling nut material ____ nickel-plated brass
Heatshrink sleeving ____ polyolefin with inner adhesive lining
Coupling loss per connector ____ 2dB (max.)

Figure 5 **Typical attenuation - polyer cables**



Bulkhead connector (**RS** stock no. 655-010)

Material ____ nickel-plated brass
Insertion loss ____ 2.5dB (max.) per coupling

Specification - 9 mm SMA system

Terminated optical leads

50/125µm

RS stock no.	Length (m)
361-254	10
361-260	20
361-276	25
361-282	50
361-298	100
361-305	200

Fibre data

Construction ____ glass
Core diameter ____ 50µm
Cladding diameter ____ 125µm
Coating diameter ____ 250µm
Attenuation at 820nm ____ 3 dB/km typical (4 dB/km max.)
Bandwidth ____ 400 MHz/km
Numerical aperture ____ 0.2

Cable data

Jacket material ____ LSOH polyethylene
Overall diameter ____ 3.2mm (tight jacket)
Minimum bend radius ____ 30mm (installed)
Maximum tensile load ____ 100N
Optical construction ____ graded index
Operating temperature ____ -15°C to +60°C

Connector data

Type ____ 9 mm SMA
Material - body ____ stainless steel and ceramic
knurled nut nickel plated beryllium copper

200µm PCS

RS stock no.	Length (m)
368-564	2
368-570	5
368-586	10
361-592	20
361-609	25
361-615	50
368-637	100

Fibre data

Construction ____ plastic coated silica
Core diameter ____ 200µm
Cladding diameter ____ 389µm
Coating diameter ____ 600µm
Attenuation at 820nm ____ 7dB/km typical (10dB/km max.)
3dB bandwidth ____ 25MHz/km
Numerical aperture ____ 0.27

Figure 6 **Spectral output vs wavelength**

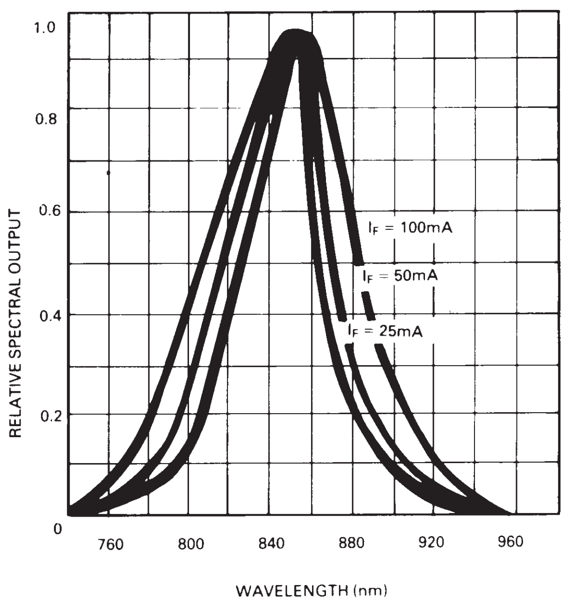
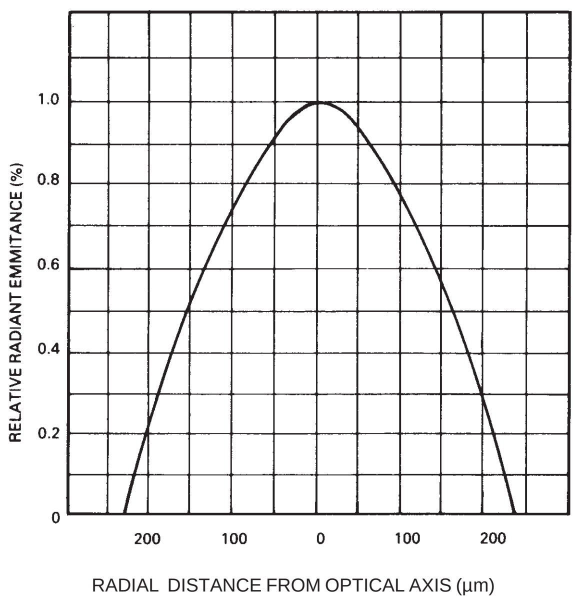


Figure 7 **Uniformity of optical output**



Electro-optical characteristics (T_A = 25°C) - Emitters

Parameter	Conditions	Min.	Typ.	Max.	Units
Forward voltage, VF	IF = 100mA			1.6	1.8 V
Reverse voltage, VR	IR = 10µA		1.0	5.0	V
Series resistance, RS				4	Ω
Device capacitance, C	VR = 0V, f = 1MHz			70	pF
Peak emission wavelength, l p	IF = 100mA			850	nm
Spectral bandwidth, Δ l				50	nm
Response time,	tr tf	I peak = 100mA Prebias = 1V			4 8 ns 6 10 ns
Launch power* Low power emitter (**RS** stock no. 633-290, 633-307)	50/125µm glass 200µm PCS	3µW (-25dBm) 50µW (-13dBm)			
High power emitter (**RS** stock no. 633-313, 633-329)	50/125µm glass 200µm PCS	10µW (-20dBm) 160µW (-8dBm)			

* Measured at the end of a 10m length of fibre optic cable.

Schmitt receiver (**RS** stock nos. 633-335, 633-341)

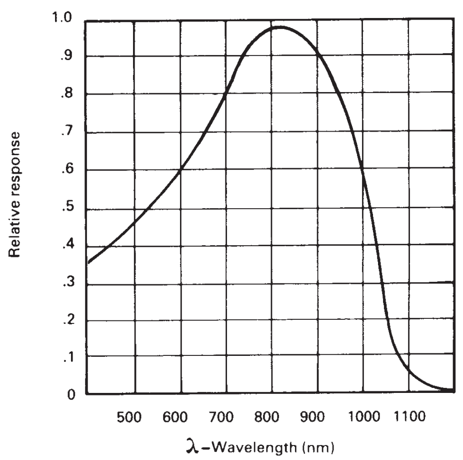
Absolute maximum ratings

Supply voltage ______________________________4.5V to 16V

Continuous output sink current ______________________18mA

Operating temperature range __________-40°C to + 100°C

Figure 8 **Spectral response**
(RS stock nos. 633-335, 633-341)



Electro-optical characteristics (TA = 25•C) - Schmitt receiver (**RS** stock nos. 633-335, 633-341)

Parameter	Conditions	Min.	Typ.	Max.	Units
Input sensitivity	l p = 820nm		3	5	μW
Rise time, tr	VCC = 5V, RL = 390R		80	150	ns
Fall time, tf			10	15	ns
Supply current	VCC = 5V		8	12	mA

The table below gives a reference guide to the usage of RS emitters and detectors with both 50/125μm and 200μm PCS terminated optical leads. The transmission distances given are the guaranteed minimum for the various combinations of emitters and detectors shown.

Note: The figures quoted below are for uninterrupted lengths of fibre and are measured with a forward current of 50mA in each case and include a 3dB excess margin.

	Fibre: 50/125μm		**Fibre: 200μm PCS**	
	Att:-3dB/km at 850nm		**Att:-10dB/km (max) at 850nm**	
	RS Emitters l = 850nm		**RS Emitters l = 850nm**	
	RS stock nos.		**RS stock nos.**	
	633-290 Bulkhead 633-307 PCB	633-313 Bulkhead 633-329 PCB	633-290 Bulkhead 633-307 PCB	633-313 Bulkhead 633-329 PCB
RS detectors RS stock nos.	Launch power 3μW (min) -25dBm	Launch power 10μW (min) -20dBm	Launch power 50μW (min) -13dBm	Launch power 160μW (min) -8dBm
Schmitt receiver sensitivity 1μW (typ) (-32 dBm). Data rate 200kBs 633-335 Bulkhead SMA	0.75km	2km	1.4km	1.4km
633-341 PCB SMA	0.75km	2km	1.4km	1.4km

Note: Add 2dBm per connector if an in-line termination is used.

Applications

General illumination

The polymer cable can be used in its own right to illuminate inaccessible areas. Using only one filament lamp or light source many independent items can be illuminated, thereby improving reliability and decreasing servicing time in terms of bulb failure. Such applications include illumination in mimic displays, teaching aids eg. maps, plans etc, panel instruments eg. meters, switches, dials etc. Other applications include illumination of microscopes, tool tips, proximity sensing and remote sensing of light sources.

Data transmission

Figure 9 **Transmitter - TTL interface**

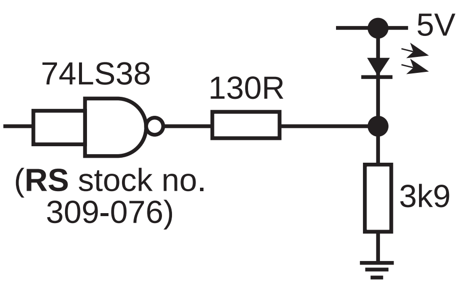
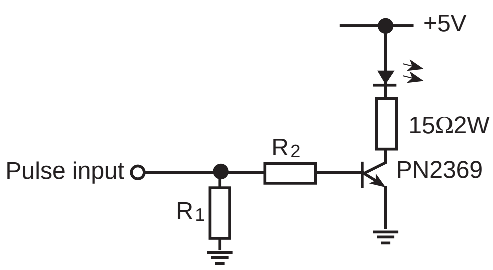


Figure 10 **Transmitter - general interface**



R1 and R2 should be chosen to match pulse source to base of PN2369.

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