RS data

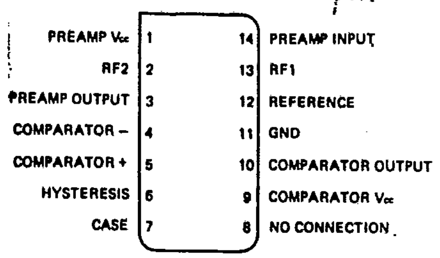
Optical communication receiver i.c.

Stock number 303-668

A high-speed transimpedance amplifier and comparator stage on a thick film circuit configured in a 14 pin glass-sealed metal package. The large gain-bandwidth product of the amplifier allows fast response, even with high capacitance photodiodes. The analogue output permits reception of 20 MHz signals, whilst the internal comparator allows 15 Mbit/s NRZ data to be received and converted for C-MOS/TTL compatibility. Equivalent to NS LH0082 CD.
Caution: All handling should be carried out under ANTI-STATIC conditions.

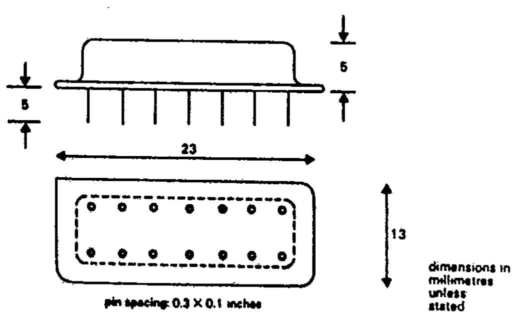
Absolute maximum ratings

Supply voltage	+15V
Power dissipation, $T_A = 25°C$	0.5W
Junction temperature	150°C
Storage temperature	−65°C to +150°C
Operating temperature range	−25°C to 85°C
Lead temperature (soldering, 20 seconds)	300°C
Input current	±10mA



TOP VIEW

Pin 1 is identified by square corner



WARNING!

ESD SENSITIVE DEVICE

CAUTION:
ESD (Electro-Static-Discharge) sensitive device

Features

- Ideal for low noise fibre optic links
- Easily integrated into systems design
- 2 GHz gain-bandwidth FET-input amplifier
- Internal voltage reference incorporated
- Internal comparator has 'built-in' hysteresis
- All feedback and coupling components incorporated
- 50 Mbit/s data rate possible with external comparator
- Single 5 V supply operation
- Pin selectable sensitivity and 80 dB dynamic range

Introduction

Before proceeding to a discussion of the Receiver i.c., it is very useful to first of all consider the general design criteria for optical communication receivers.

Optical sensors

The design of receiver circuitry for fibre optic transmission is an involved topic. First, we will discuss the basic characteristics of the most commonly used photodetectors.

The four most popular photosensors are shown in Fig. 1. The photodiode, phototransistor, PIN photodiode and avalanche photodiode all operate on the same basic principle. An incident photon creates a hole-electron pair near or within the depletion region. The electrical field separates the pair and causes current to flow in an external circuit. Fig. 1 also shows an equivalent circuit for a photodiode. R_S is usually of the order of 10 to 100 ohms, R_p is 10^9 to 10^{10} ohms typically, and C_p is the photodiode's capacitance, dependent upon processing and area. Note the direction of photo-induced current flow, as conventional current is sourced by the anode. This is not the same mode typically used for solar cell operation – the photovoltaic mode. In this mode, a portion of the photocurrent flows through the photodiode itself, producing a voltage from anode to cathode. The photocurrent mode, however, is superior to the photovoltaic mode in linearity, speed of response, stability and temperature coefficient. Thus, we will limit our circuitry discussion to using the photodiode in the photocurrent mode alone.

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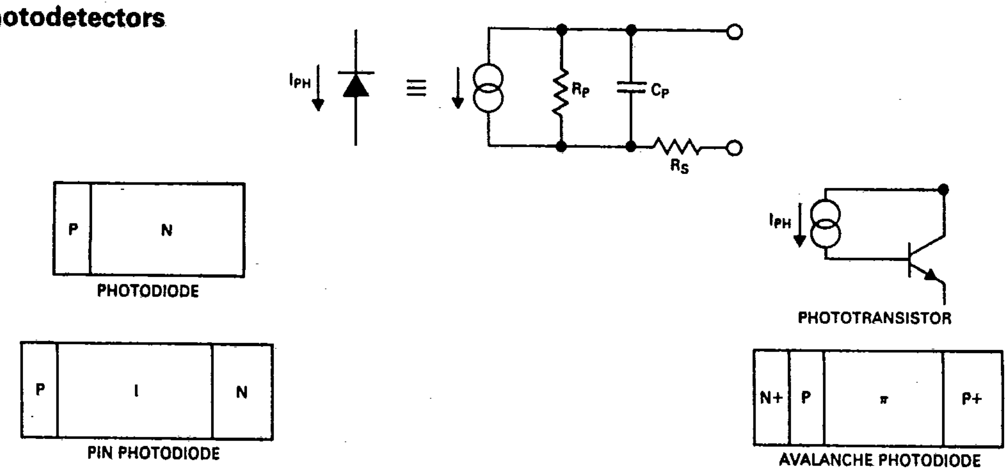
Electrical characteristics $V_{CC} = 5V$ $T_A = 25°C$

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Preamplifier						
Input bias current	I_B				200	pA
Input capacitance	C_{IN}				5	pF
Voltage gain	A_V		70	90		V/V
−3dB frequency	f_{3dB}			18		MHz
Output quiescent voltage	V_Q		2.0	2.1	2.5	V
Temperature drift of V_Q	$\Delta V_Q/\Delta T$			−6		mV/°C
Output impedance	R_O			15		Ω
Output noise		10 Hz to 10 MHz		300		μV rms
Output swing	V_O	No load	3.5	4.0		V
Transimpedance		Low sensitivity	90	100	110	kΩ
Transimpedance		High sensitivity	0.9	1.0	1.1	MΩ
Supply current	I_S		10	22	30	mA

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Comparator reference **Typical fibre optic receiver**						
Comparator input resistance	R_{IN}		0.95	1.00	1.05	kΩ
Hysteresis voltage			7	9	11	mV
Output pull-up resistor	R_O		0.95	1.00	1.05	kΩ
Reference voltage	V_R		2.2	2.4	2.6	V
Temperature drift of V_R	$\Delta V_R/\Delta T$			−2		mV/°C
Reference voltage output impedance	R_O (V_{REF})			15		Ω
Low level output voltage	V_{OL}	$I_{OL} = 3.2$ mA		0.3	0.5	V
High level output voltage	V_{OH}	$I_{OH} = -1$ mA	3.8	4		V
Propagation delay time	T_{PD}	$V_{IN} = 30$ mV		160		ns
Rise time	T_R			80		ns
Fall time	T_F			60		ns
Supply current	I_S	Output high	4.5	8	17	mA
Supply current	I_S	Output low	9.5	13	22	mA

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Typical fibre optic receiver		Photodiode: responsivity = 0.5 A/W. bias = −2.5 V, C= 3pF				
Input power for 10^{-9}BER	P_{IN}	500 kbit/s NRZ $R_F = 1$ MΩ 2 Mbit/s NRZ $R = 100$ kΩ		30 300		nW nW
Analogue output: rise or fall time	t_r, t_f	$R_F = 1$ MΩ $R_F = 100$ kΩ		1.5 50		μs ns
Maximum date rate (NRZ)		$R_F = 1$ MΩ $R_F = 100$ kΩ		650 5		kbit/s Mbit/s
Noise equivalent power	P_N	$R_F = 1$ MΩ $R_F = 100$ kΩ		1 10		nW nW
Equivalent input noise current	i_N	10 Hz to 10 MHz $R_F = 1$ MΩ $R_F = 100$ kΩ		300 3		pA rms nA rms
Total supply current	I_S			35		mA

Figure 1: **Photodetectors**



Phototransistor

The phototransistor can be modelled by a photo-induced current source between the collector and the base. Beta multiplication produces a much larger photocurrent at the emitter or collector; however, this is at the expense of speed of response. The small photocurrent must charge the base-emitter capacitance, producing slow rise and fall times. Gain-bandwidth is typically 200 MHz. The uncertainty in sensitivity due to beta variations, and the slow response relegate the phototransister to relatively low performance fibre optic receivers.

PIN photodiode

The PIN photodiode enhances the conventional photodiode's utility by producing the same amount of photocurrent from a lower capacitance source, thus giving higher speed operation. In normal operation, the entire intrinsic region is depleted, thus spreading apart the 'plates' of the capacitor. Frequency response is typically to 1 GHz.

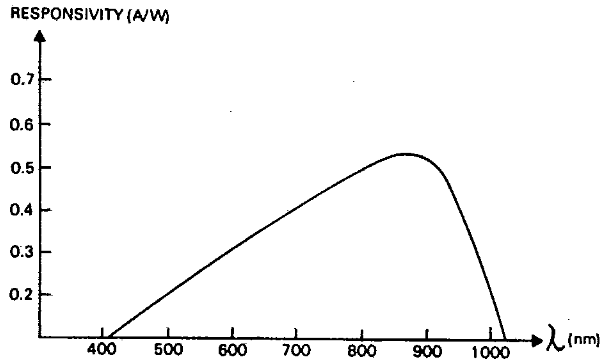
Avalanche photodiode

The avalanche photodiode requires 150 to 300 volts of reverse bias to operate. Photo-induced carriers are swept into a high field region where avalanche multiplication takes place. This produces front-end signal gain (50–500) without paying a speed penalty. Gain-bandwidth product of an avalanche photodiode is in the neighbourhood of 100 GHz. The drawbacks to avalanche photodiodes are the high bias voltage needed, and the temperature compensation necessary for stable operation.

Responsivity

A photodiode's most fundamental characteristic is its responsivity, i.e., the amount of current it will produce in response to the incident light power. Responsivity is given in amperes per watt. Fig. 2 illustrates a typical responsivity versus wavelength for a silicon photodiode. The responsivity drops below 900 nm due to absorption, and above 900 nm due to the band gap of silicon (1.2 eV). A similar graph could be shown for a phototransistor or an avalanche photodiode. The y-axis would simply be multiplied by beta or the avalanche gain respectively. Note that when the incident light is measured in watts, the area of the detector does not play a part in the quantity of current produced. A photodiode whose responsivity at a given wavelength is 0.5 will produce 1 μA in response to an incident light power of 2 μW as long as all of the light falls on the photodiode's sensitive area.

Figure 2: **Typical photodiode responsivity**



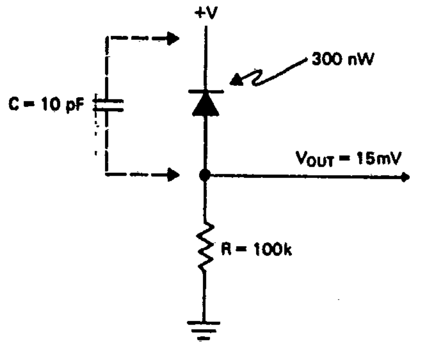
Receiver circuitry

The most challenging aspect of many fibre optic links is the design of the receiver. The receiver must convert the low level current output of a photodiode to a high level analogue or digital signal with accuracy and speed.

Fig. 3 illustrates the simplest of fibre optic receivers. The photodiode is back biased with a resistor to convert the photo-induced current to a voltage. Let us assume that we want to convert an input light power of 300 nW to a 15 mV signal. If the photodiode's responsivity is 0.5 A/W, then the photodiode will produce 150 nA, and for a 15 mV signal level, the resistor must be 100 k. If the capacitance of the photodiode is 10 pF, then the rise time of the voltage output in response to a step light input will be approximately 2.2 μs ($t_r = 2.2$ RC). This also implies that our analogue bandwidth is limited to a −3 dB frequency of 159 kHz. (Since $\omega = 1/(RC)$, where $\omega = 2\pi f$.)

How is it possible to obtain higher frequency performance at the same sensitivity without sacrificing signal-to-noise ratio? Decreasing the size of the resistor and using voltage amplifiers can achieve the same responsivity at a higher speed but it will sacrifice signal-to-noise ratio since a resistor's noise current contribution increases as the value of the resistor decreases. (This is because $i_n = \sqrt{4KTB/R}$). As we will see later, signal-to-noise is not only important for analogue communication, but also sets the limiting bit error rate for digital signalling.

Figure 3: **Simple receiver**



A single circuit topology can be practically applied in two ways to help us out. Fig. 4 illustrates the general topology, with the first of the two specific implementations shown below. This is known as the bootstrap configuration as the function of the amplifier is to chase the voltage developed by the photocurrent flowing through the resistor, and to apply this voltage to the opposite end of the photodiode. By keeping the voltage change across the photodiode's capacitance small, the effect of this reactance is reduced, and the circuit will respond faster. By rearranging the general topology once again, we arrive at the second implementation, known as the transimpedance approach as shown in Fig. 5. Since the negative input of the amplifier can be considered a virtual ground, the voltage change across the photodiode's capacitance is kept small and thus its effect is reduced. The choice between either of the two approaches is left to the designer; however, the constraints placed on either of the amplifiers are the same when speed of response is used as the criterion.

To give us an idea of how fast an amplifier we need to produce the desired speed of response, we will analyze the transimpedance circuit of Fig. 6. We first define a time constant t that is equal to the product of the feedback resistor and lumped circuit capacitance C. C is the sum of stray capacitance, amplifier input capacitance and photodiode capacitance. The only other parameter to define is t_A, the inverse of the gain-bandwidth product of the amplifier. When we solve this simple circuit analysis problem we find that the rise time of V_{OUT} is:

$$t_R = \pi \sqrt{t \cdot t_A}$$

$$t = RC,\ t_A = \frac{1}{2\pi(GBW)}$$

Rise time is chosen as the prime indicator of circuit speed performance as it allows us to make rapid calculations of the maximum bit rate for a digital communications link. The equation given above is an approximation as it assumes that the open loop gain of the amplifier is greater than 10 and $t < 2A_O t_A$, where A_O is the open loop gain of the amplifier.

Returning to our original problem, how fast must our amplifier be to produce the desired overall fibre optic receiver speed? Let us use a specific example to determine the required amplifier speed. Suppose that we want to receive a 5 Mbit NRZ signal, our feedback resistor is 100k, and the circuit capacitance is 5.5 pF. From the data rate, we know that the rise time of the receiver must be 100 ns or less. Rearranging the above equation, we obtain:

$$\frac{1}{t_A} = \frac{\pi^2 t}{t_r^2}$$

Figure 4: **Bootstrapped amplifier**

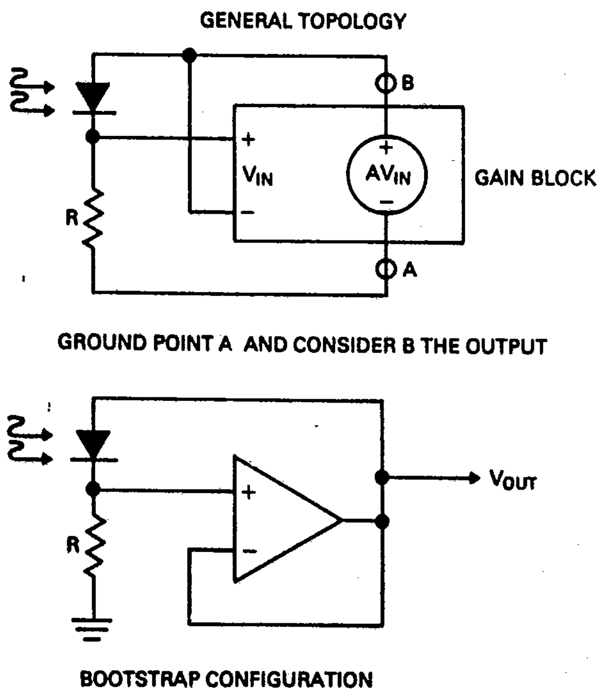


Figure 5: **Transimpedance amplifier**

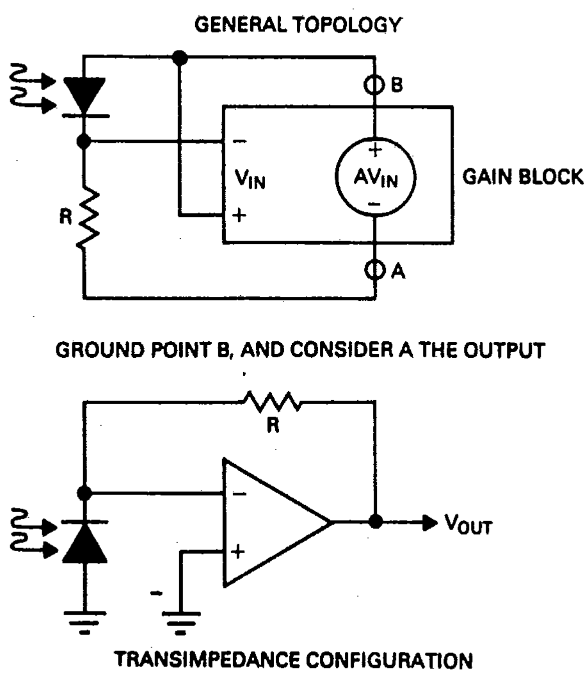


Figure 6: **Equivalent circuit and amplifier characteristic**

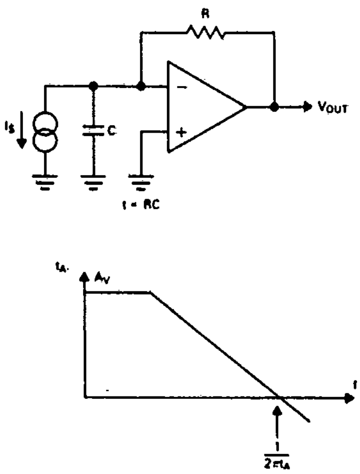
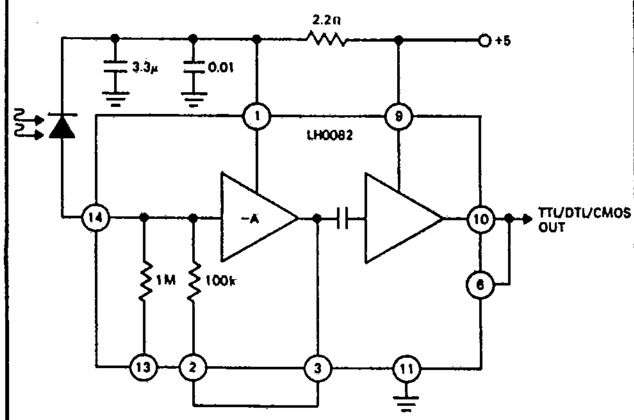


Figure 8: **LH0082 basic operating circuit – 300 nW, 5 Mbit/s**



When we plug in the numbers, we find that the gain-bandwidth of the amplifier must be 86 MHz! It's obvious that a 741-type amplifier with a gain-bandwidth of 1 MHz will not even come close to providing the speed we need. Fortunately, the LH0082 fibre optic receiver contains a preamp with a gain-bandwidth product of nearly 2 GHz. The LH0082 will provide the sensitivity and speed necessary for the example application, and it also includes a comparator for providing a TTL/DTL/C-MOS compatible output. Fig. 7 is a block diagram of the LH0082. Two internal feedback resistors are included for use with the preamp to set sensitivity. External resistors can also be used. The output of the preamp is a.c. coupled to a comparator that can be connected as an edge triggered flip-flop. In this mode, the bit error rate can be set by the amount of hysteresis applied to the comparator. Using the internal hysteresis resistor, the bit error rate is better than 10^{-10}. The entire circuit operates from a single 4.5 to 5.5 volt power supply, although the preamp can be operated to 10 volts, and the comparator to 15 volts.

Fig. 8 shows how to use the LH0082 as a 5Mbit/s, 300 nW sensitivity fibre optic receiver. The only external components needed are the photodiode, a power supply decoupling resistor and two bypass capacitors.

Bit error rate

The bit error rate (BER) is a very important consideration in any digital communications system: fibre optic data links are no exception. A BER of 10^{-10} means that one bit of 10 billion will be a bad bit. Obviously, the smaller the BER, the better off we are. There is a very simple relationship between the signal-to-noise ratio and the bit error rate. Given δ as the RMS noise voltage, A as the peak-to-peak signal level, and we determine the presence of one or a zero with a threshold of A/2, then the BER is:

$$\text{BER} = \tfrac{1}{2}\left(1 - \text{erf}\,\frac{A}{2\sqrt{2}\,\delta}\right)$$

$$\text{Where: erf}\,(x) = \frac{2}{\sqrt{\pi}}\int_0^x e^{-Y^2}dy$$

Fig. 9 is a plot of this somewhat obtuse function. Note that we are guaranteed a BER of 10^{-10} with only 22 dB of signal-to-noise ratio. Thus, if we have a comparator threshold of 10 mV a peak signal level of 20 mV, then the RMS noise must be less than 1.6 mV to give us 10^{-10} BER.

Figure 7: **LH0082 circuit diagram**

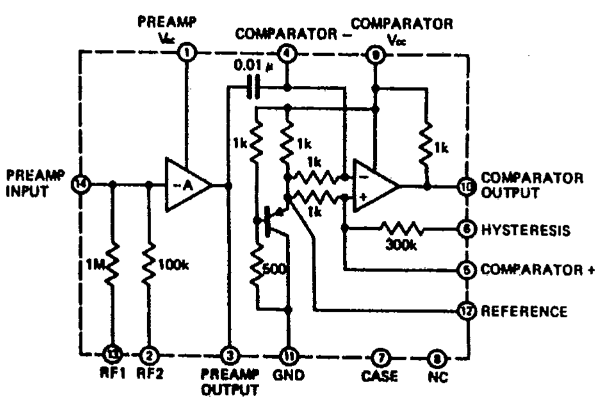
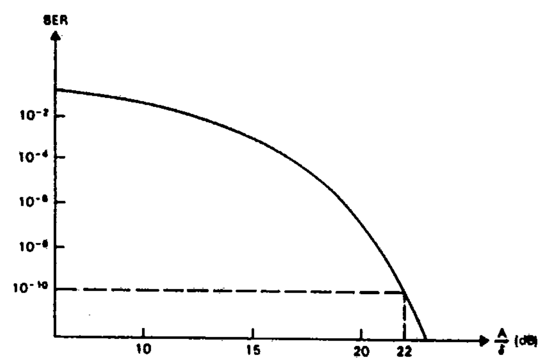


Figure 9: **Bit error vs. signal-to-noise ratio**



Stray signal pick-up problems

Although communication via fibre optic cable provides freedom from the effects of radio frequency interference, the circuitry at the receiver is not so fortunate. Let's take the example of the basic LH0082 300 nW sensitivity receiver. Assuming a 0.5 A/W photodiode, the LH0082 requires only 150 nA at its input to cause the comparator to switch states. Suppose that the output of a TTL gate is nearby and at that point the voltage can traverse 3 V in as little as 5 ns. How much stray capacitance from this TTL output to the input of the LH0082 is needed to equal the signal level generated by the photodiode?

Since $I = C\dfrac{dv}{dt}$

Then $C = \dfrac{I}{dv/dt}$

i.e. $C = \dfrac{(150\,\text{nA})\,(5\,\text{ns})}{3\text{V}}$

Thus $C = 2.5 \times 10^{-16}$ F or .00025 pF!!!

Although this may seem like an impossibly small amount of capacitance to live without, straightforward printed circuit board layout techniques can provide trouble-free operation.

A complete link

Putting together a total link is not so difficult as much literature would have you believe. We can be almost careless in our handling of the transmitter circuitry, light coupling to transducers, and connecting the cable. The expense is a little care at the receiver end.

Fig. 10 gives a sample application ideally suited to fibre optics. A data entry room is located 300 metres from a computer facility, separated by a manufacturing area containing arc welders, punch presses and so on. One-way communication from the three data entry terminals to the computer is required at 19.2 kbit/s. Let us assume that we will multiplex the three data channels with one sync. channel and send the signal through one fibre optic cable, and demultiplex the signal at the computer end. We will sample each of the three data channels and the sync. channel at 5 times the data rate or 4 × 19.200 × 5 = 384 kbit/s data rate. We will select an inexpensive red indicator LED whose total output power is only 30 μW or −15 dBm. We must now account for all of the losses involved in transferring this light to the photodiode at the receiving end:

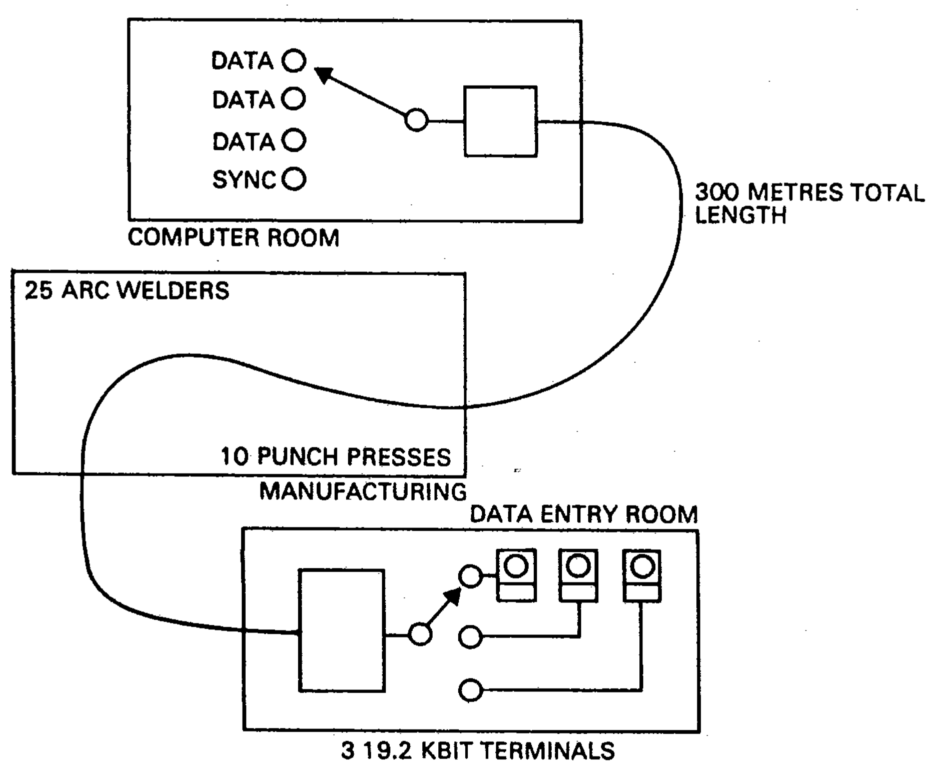
LED-transmitter connector:	−10 dB
receiver connector:	−3 dB
$300 \times \frac{40}{1000}$ dB (cable):	−12 dB
'Safety' factor:	−3 dB
Total loss =	−28 dB

Thus, the power at the receiver is:

−15 dBm − 28 dB = −43 dBm (50 nW)

The LH0082 in the high sensitivity mode (R_F = 1M) has a 30 nW sensitivity with a 0.5 A/W photodiode and can provide a maximum data rate of 650 kbit/s. The use of low cost connectors, poor coupling of light to the transmitter end, and inexpensive moderate loss cable (40 dB/km) does not prohibit a high performance data link when used with a versatile receiver such as the LH0082.

Figure 10: **Typical system**



Additional device data

These graphs give additional data to enable designers to optimise their circuits.

Figure 11a: **Additional characteristics**

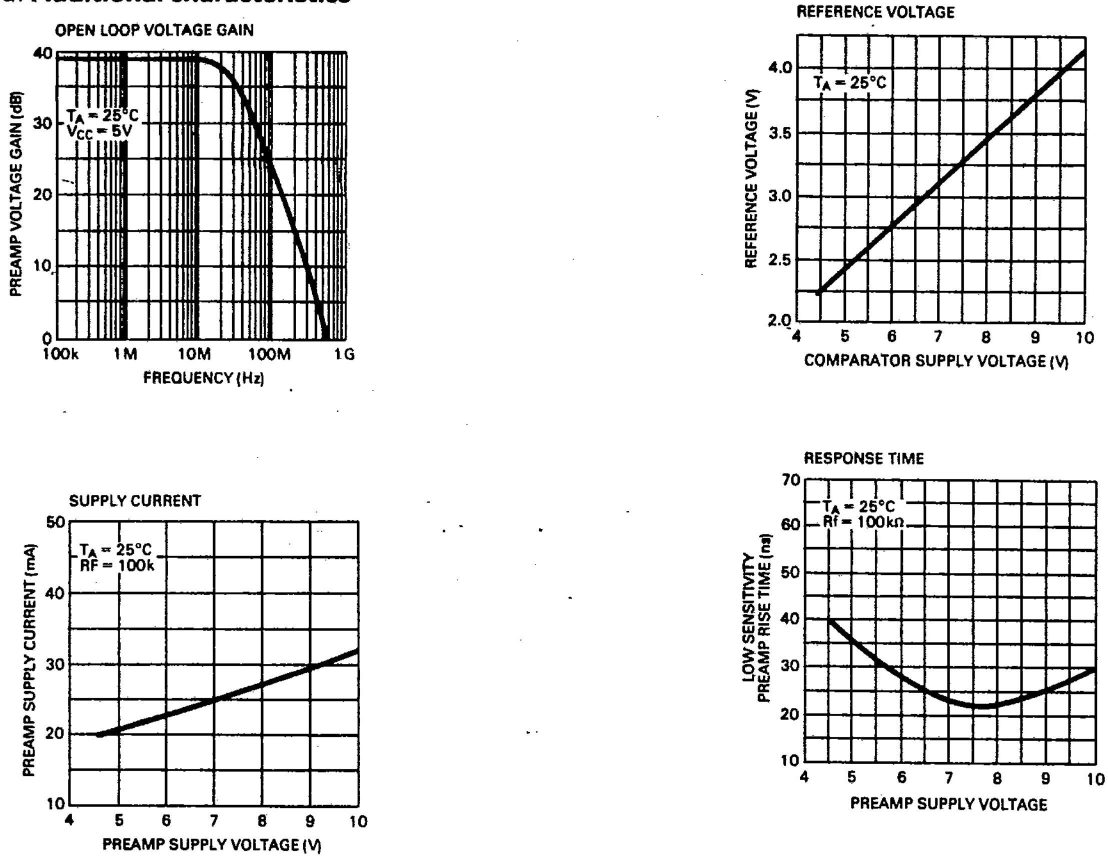
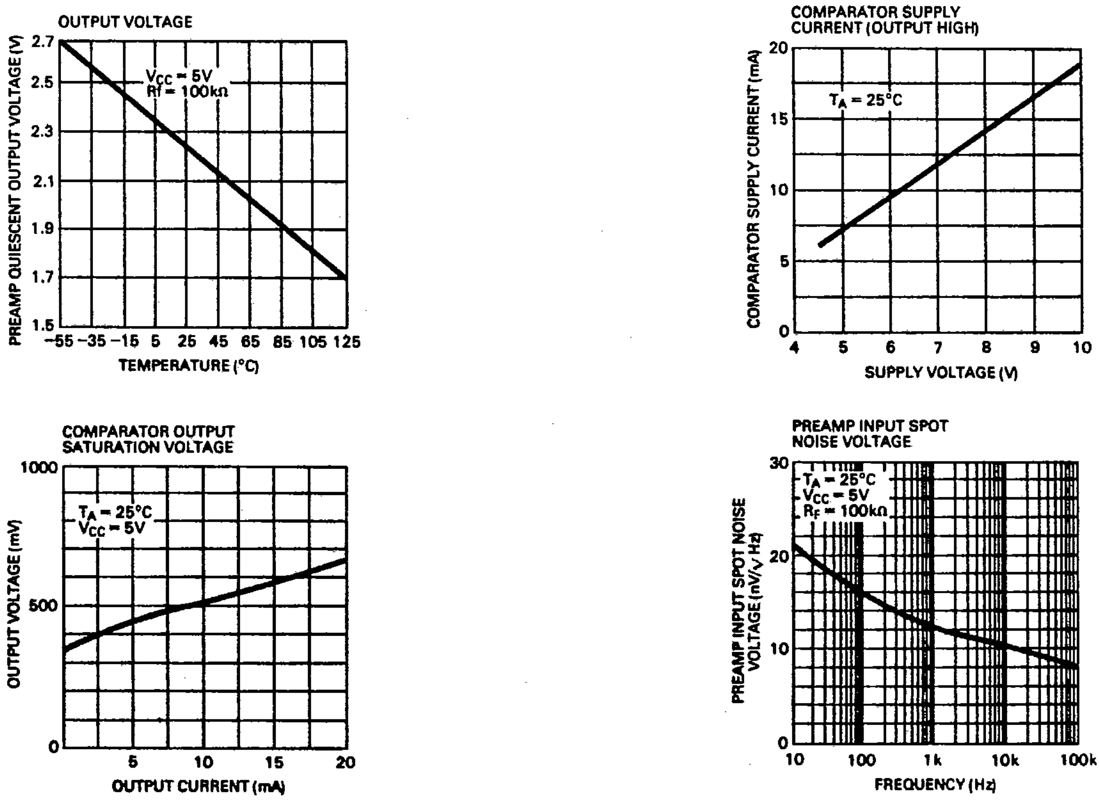


Figure 11b: **Additional characteristics**



RS data

Applications circuits

The following circuits show how the LH0082 may be used to achieve various design objectives

Figure 12: **Fibre optic receiver basic high sensitivity: 30 nW, 650 kbps**

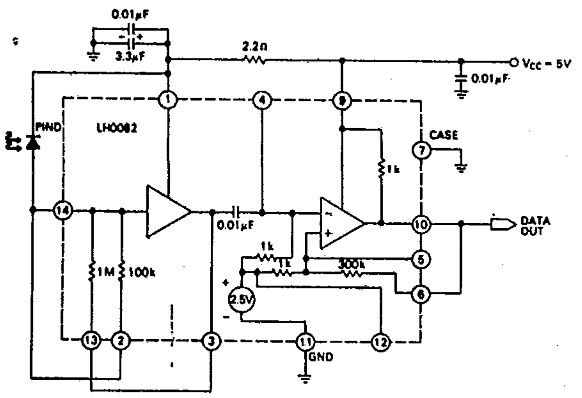


Figure 13: **Fibre optic receiver basic low sensitivity: 300 nW, 5 Mbit**

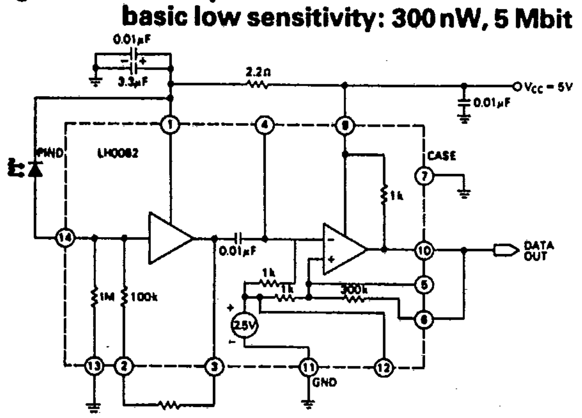
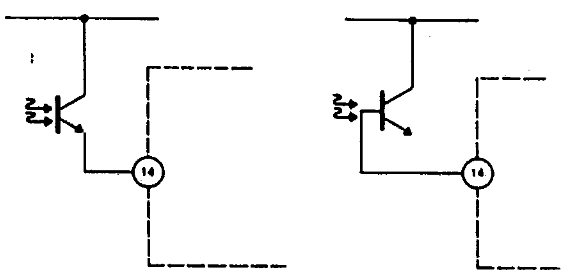


Figure 14: **Phototransistor connections**



CONNECT IN PLACE OF PHOTODIODE (HIGH SENSITIVITY, LOW SPEED)

CONNECT IN PLACE OF PHOTODIODE (LOW SENSITIVITY, HIGH SPEED)

Figure 15: **Fibre optic receiver very high sensitivity – low speed: 3 nW, 100 kbit/s**

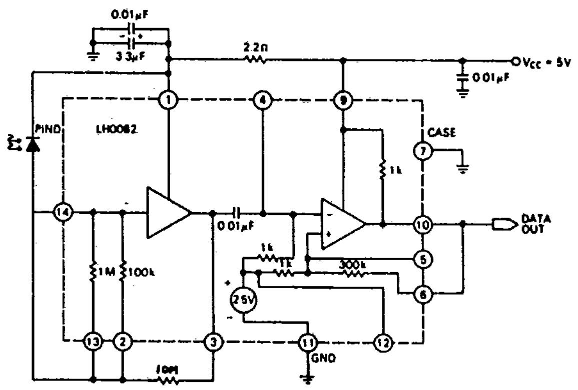


Figure 16: **Fibre optic receiver high sensitivity – improved speed**

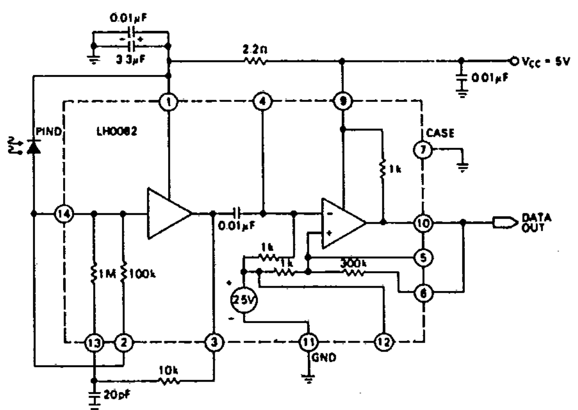
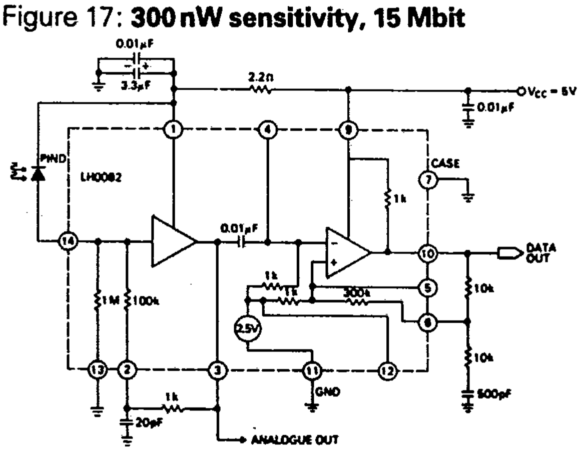


Figure 17: **300 nW sensitivity, 15 Mbit**



NOTE: FOR ANALOGUE OPERATION, USE THIS CIRCUIT WITH THE FOLLOWING MODIFICATIONS: DISCONNECT PIN 9 FROM V_{CC} AND USE PIN 3 AS THE OUTPUT. BANDWIDTH FOR THE CONFIGURATION IS APPROXIMATELY 20MHz; ANALOGUE RESPONSIVITY IS 50mV/μW. DYNAMIC RANGE IS [illegible]dB