ANADIGICS®

ATA SERIES

TRANSIMPEDANCE AMPLIFIERS

PRELIMINARY

INTRODUCTION

The ATA series of Transimpedance amplifiers (TIA) is intended for use as a preamplifier in fiber optic receivers. Used to amplify the weak currents generated by the photodiode at the receiver input, these devices provide high dynamic range, good sensitivity and bandwidth to enhance overall system performance. The chip, fabricated in gallium arsenide (GaAs), replaces 15 to 20 components in a typical discrete design, thereby reducing manufacturing costs and improving reliability. Devices are supplied in both packaged and die form.

The ATA series is suitable for most fiber standards, including SONET, HIPPI, FDDI, B-ISDN and Fiber Channel.

FUNCTIONAL DESCRIPTION

A block diagram of a typical optical receiver is shown in Figure 1. Light transmitted through a fiber is incident at the input of the optical receiver, where it is converted from an optical signal to an electrical signal by the photodetector. Depending on the application, either an avalanche or PIN photodiode is used.

The weak current generated by the photodetector is then amplified by the Transimpedance amplifier (TIA), which also converts the input current to an output voltage. The voltage signal is then amplified again for further processing in the decision circuit, which includes clock recovery and other signal processing functions.

Figure 2 shows the functional block diagram of TIAs with automatic gain control. The device is comprised of two gain stages, a feedback network and an automatic gain control circuit.

Figure 3 shows the functional block diagram of devices without AGC. Unlike the chips with AGC, these devices offer no overload protection and require both a positive and negative supply voltage.

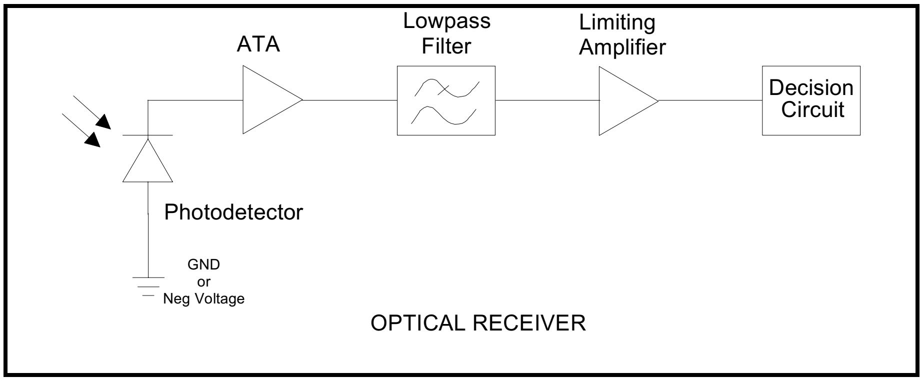
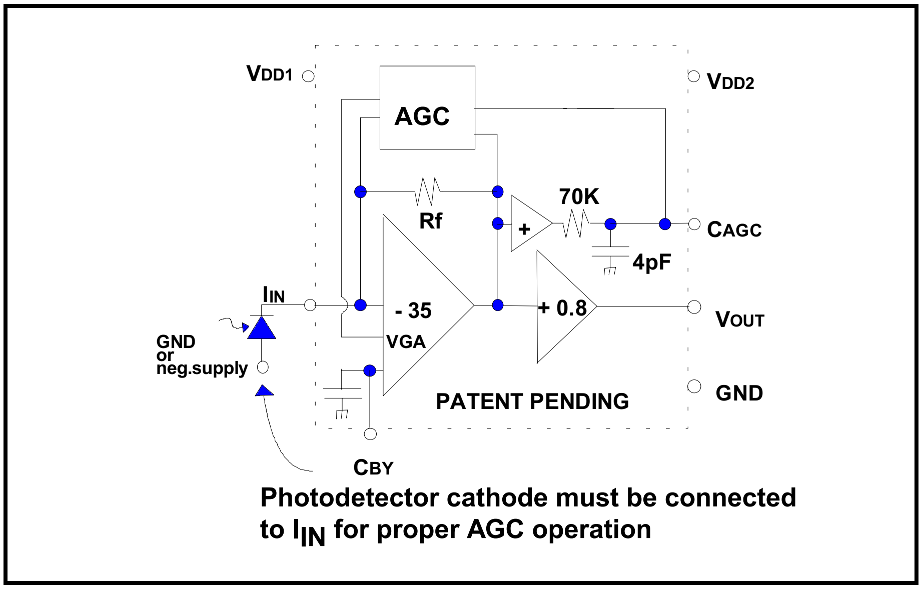


Figure 1



Photodetector cathode must be connected to I_{IN} for proper AGC operation

Figure 2

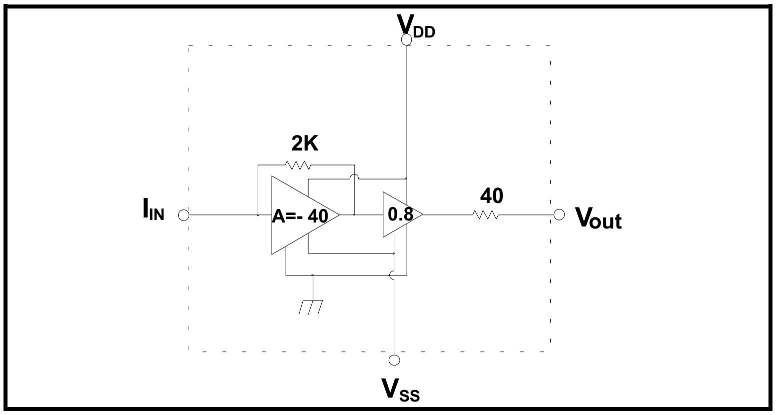


Figure 3

AUTOMATIC GAIN CONTROL

AGC is used to protect the devices from optical overload while significantly improving the dynamic range of the device. The AGC circuit becomes operational when the input current reaches the AGC threshold. At this point the transresistance is 50% of its original value.

AGC is a continuous function, with Transimpedance decreasing as a function of input current. Larger input current swings cause the Transimpedance to decrease, thereby holding the output swing constant.

The cathode of the photodiode must be connected to the input of the device for proper AGC operation. The device will operate when the anode is connected to its input, provided the input current is low enough (see Table 1). Connecting the detector this way for higher input levels will result in pulse width distortion.

BIT RATE, MB/s	MAXIMUM INPUT CURRENT, μA*
50	8
155	25
622	70
1200	125
2.5	165

TABLE 1

* Nominal values based on the actual Transresistance, which may vary slightly from device to device .

INTEGRATING THE DEVICE

In order to achieve good TIA performance, proper interfacing of the device is required. Figure 4 describes the proper configuration for test purposes.

The hybrid circuit should be laid out in accordance with good RF practices. This includes a low inductance ground plane with via holes for RF grounding of external components. Circuit traces should be made as short as possible, particularly at the detector-TIA interface.

V_{dd} and V_{ss} should be bypassed as close to the chip as possible with chip or metal insulator metal (MIM) capacitors of good RF quality (low inductance). This is essential for good high frequency and low noise performance. This will also serve to prevent oscillations. Dielectric Labs, Inc. makes a variety of chip and MIM capacitors. A low inductance ground plane with via holes should be made available for proper power supply bypassing.

C_{by} is also needed to ensure good high frequency and low noise performance. Two bond wires should be used to connect the chip to the bypass capacitor in order to keep the inductance to a minimum, since any high frequency signals present here will result in loss of Transimpedance bandwidth. Two bond pads are available for this purpose. Typical capacitor values are 56 pF and 220 pF. Larger capacitors can be used in parallel to enhance low frequency performance.

Care should be exercised when selecting a capacitor for Cagc. Choosing a capacitor that is too small can lead to data errors; a recommended minimum is 56 pF. This will provide the minimum amount of protection against pattern sensitivity and pulse width distortion on repetitive data sequences (typical of SONET data encoding) during high power conditions. The time constant can be calculated as follows :

$$\mathrm{T}_{AGC} = 70 \times 10^{3} \left[C_{AGC} + 4\mathrm{pF}\right)$$

It is important to choose a photodetector that has low capacitance, and that the capacitance between the photodetector and the TIA be kept as low as possible. Excess capacitance will limit the bandwidth and degrade the sensitivity of the device. The capacitance of the photodetector should not exceed 0.6 pF.

Most optical receivers use either a PIN or avalanche photodiode (APD) to detect the optical signals. A PIN photodiode requires only a small reverse voltage (approx. 1.5 volts) and is less expensive than an APD. While APDs require large reverse voltages (> 30 volts), they offer the advantage of gain. This is useful in long distance telecommunication systems where sensitivity is a key concern. Sources for photodetectors include AMP-Lytel, AT&T, Epitaxx, Hewlett Packard and Nortel.

The purpose of the filter shown at the output of the device is to improve the receiver's sensitivity. Excess bandwidth results in excess noise and sensitivity degradation. Most system designs set the filter bandwidth at 0.7 times the bit rate. Fairly good performance can be achieved without the filter, but overall system sensitivity will be degraded. 3-pole low pass filter values for the various bit rates are shown in Table 2.

Although there is no particular sequence to follow when applying bias voltages, it is good practice to start at zero volts and gradually increase the bias to the required level when testing devices in the lab. This will help eliminate damage due to surges and transients.

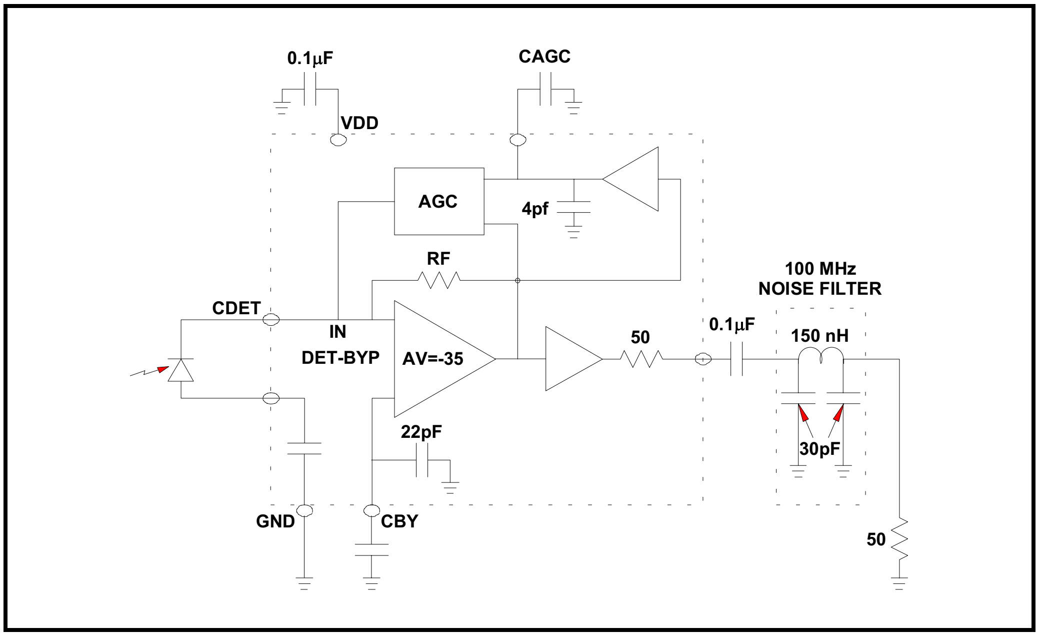


Figure 4

BIT RATE (Mb/s)	F_c (MHz)	L (nH)	C (Pf)
50	35	390	120
155	110	100	56
622	435	22	15
1200	840	18	6.8
2500	1750	3	2.7

TABLE 2

DIE ASSEMBLY

A brief outline on handling GaAs die follows. For more details, refer to the ANADIGICS Technical Brief entitled “Handling Gallium Arsenide Die”.

Since GaAs material is subject to chipping and cracking, die should be handled with care. Air bridges, which are only a few microns thick, are especially susceptible to damage from tweezers.

ANADIGICS’ die have no backside metallization and must therefore be mounted with epoxy. A thermally conductive, silver filled epoxy should be used. It is also important that the epoxy retains good mechanical properties at temperatures as high as 200°C. A recommended epoxy is Epoxy Technology H-20S. This cures at 125°C for 45 minutes. Die should be cleaned with a solvent prior to bonding. The die should be pressed into the mounting epoxy by applying pressure from the sides of the die, not to the top. Also, at least 3 corners of the die should be surrounded by epoxy, and the epoxy should not come more than half way up the side of the die.

Ball bonding is recommended at a stage temperature of 150°C with 0.0013 inch gold wire. Wedge bonding can also be used with the wedge pressure set to 50 grams. The stage should be at room temperature, and the wedge pressure should be 55 gm for aluminum wedge bonding.

The correct combination of force and ultrasonics will result in a bond which has the shape of a rain drop.

Ultrasonic energy should be used as little as possible in the bonding process to avoid generating cracks in the die, which could lead to latent failures.

Typical bonding diagrams for devices with and without AGC are shown in Figures 5A and 5B.

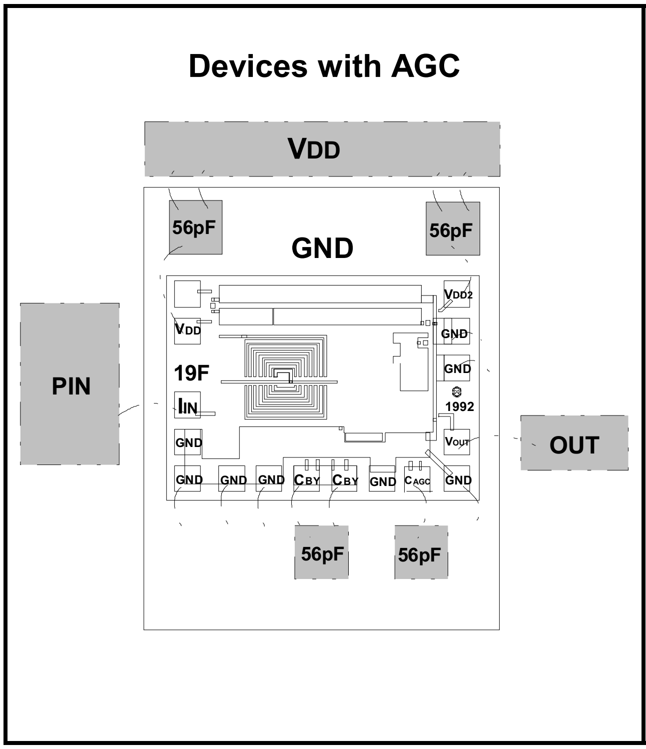


Figure 5A

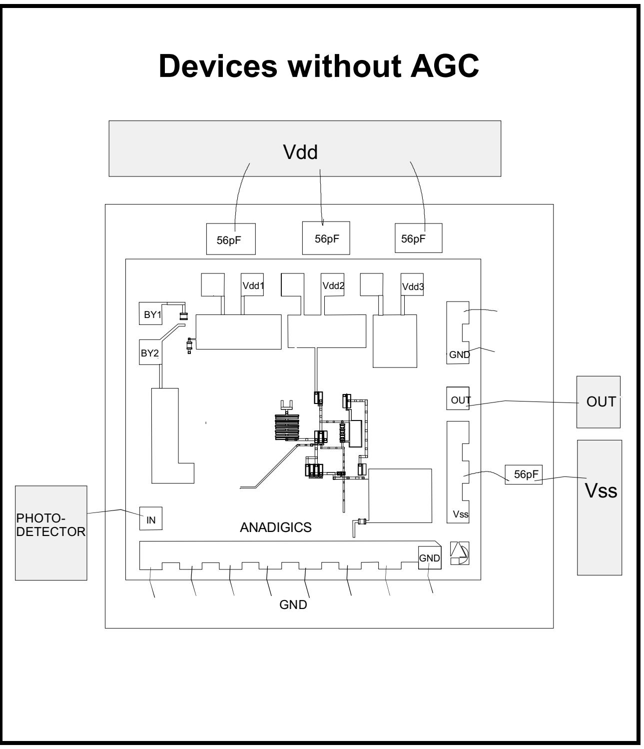


Figure 5B

THERMAL CONSIDERATIONS

Single supply TIAs dissipate approximately 150 milliwatts, while dual supply devices dissipate approximately 900 milliwatts. It is essential, therefore, that the device is mounted on a reliable heat sink, and that the epoxy used is thermally and electrically conductive.

The substrate's thermal coefficient of expansion should not differ greatly from that of GaAs, which is 6.5 ppm/°C. Acceptable substrate materials are alumina, beryllium oxide and kovar.

The temperature at the underside of the die should not exceed + 85°C under operating conditions. For single supply devices, the Median Time to Failure (MTF) will be 3×10^{8} hours at this temperature and will decrease to 5×10^{7} hours at 100°C (See Figure 6A). For dual supply devices the respective MTF values arw 10^{8} hours and 8×10^{6} hours (see Fig 6B)

MTF vs Tcase
Single Supply Devices

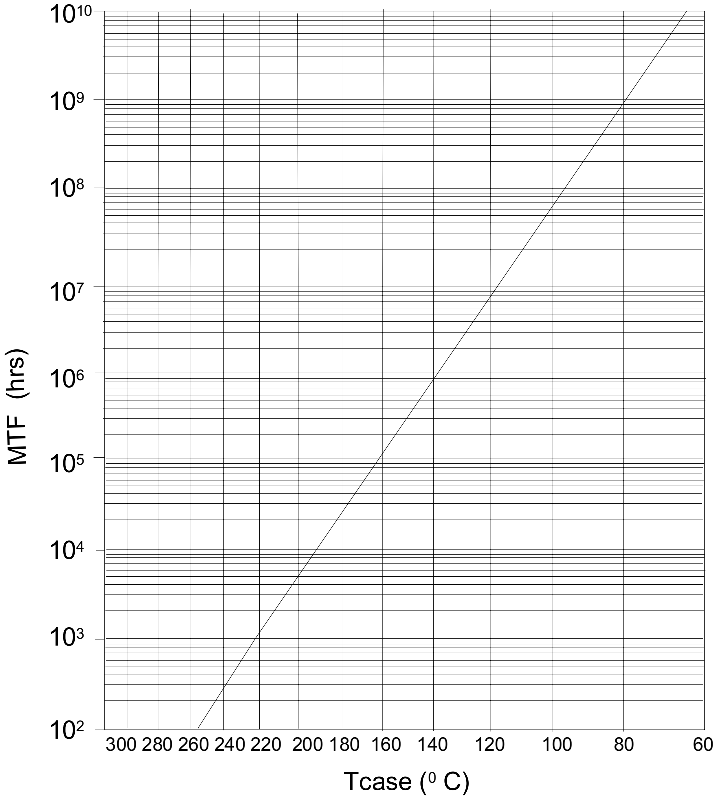


Figure 6A

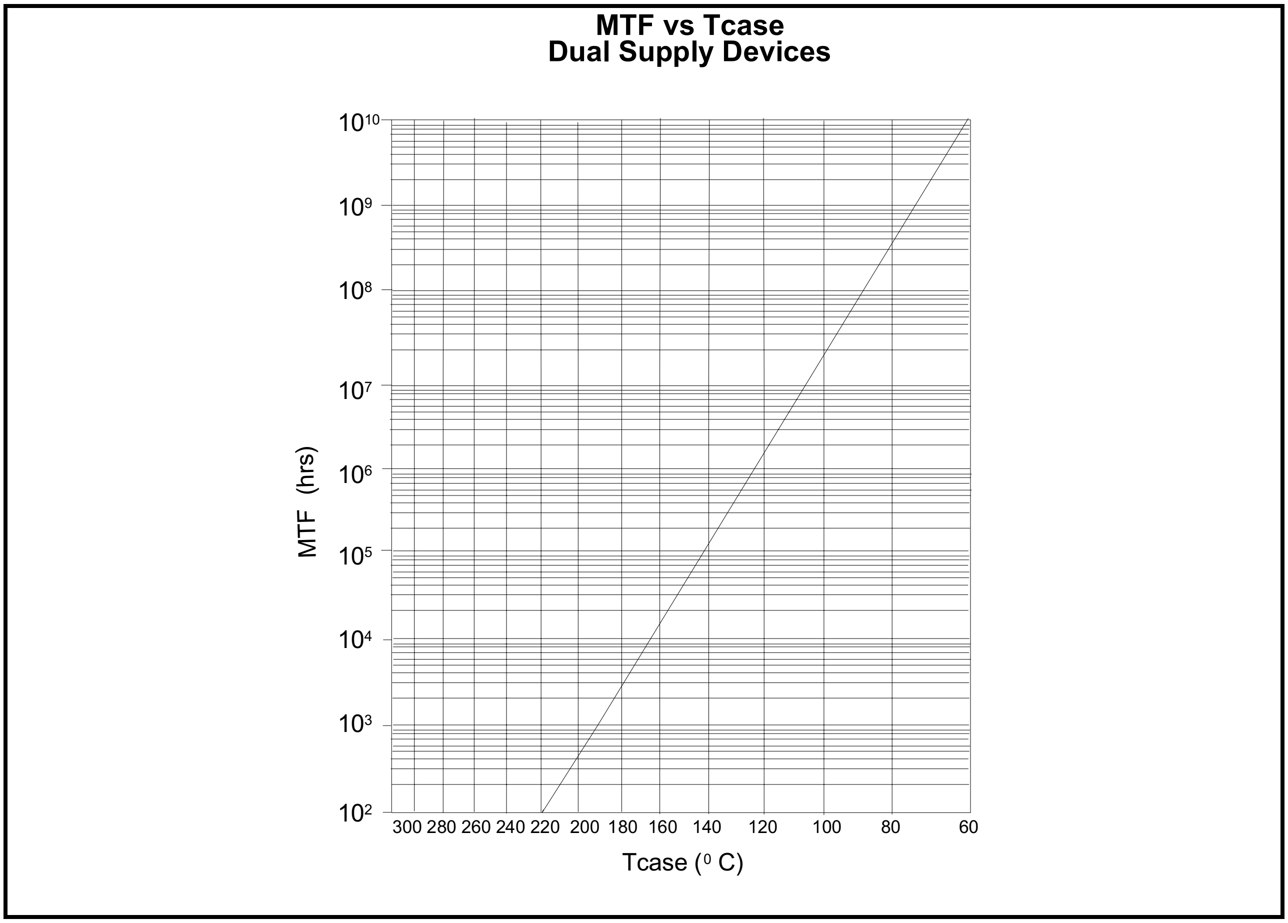


Figure 6B

ESD PRECAUTIONS

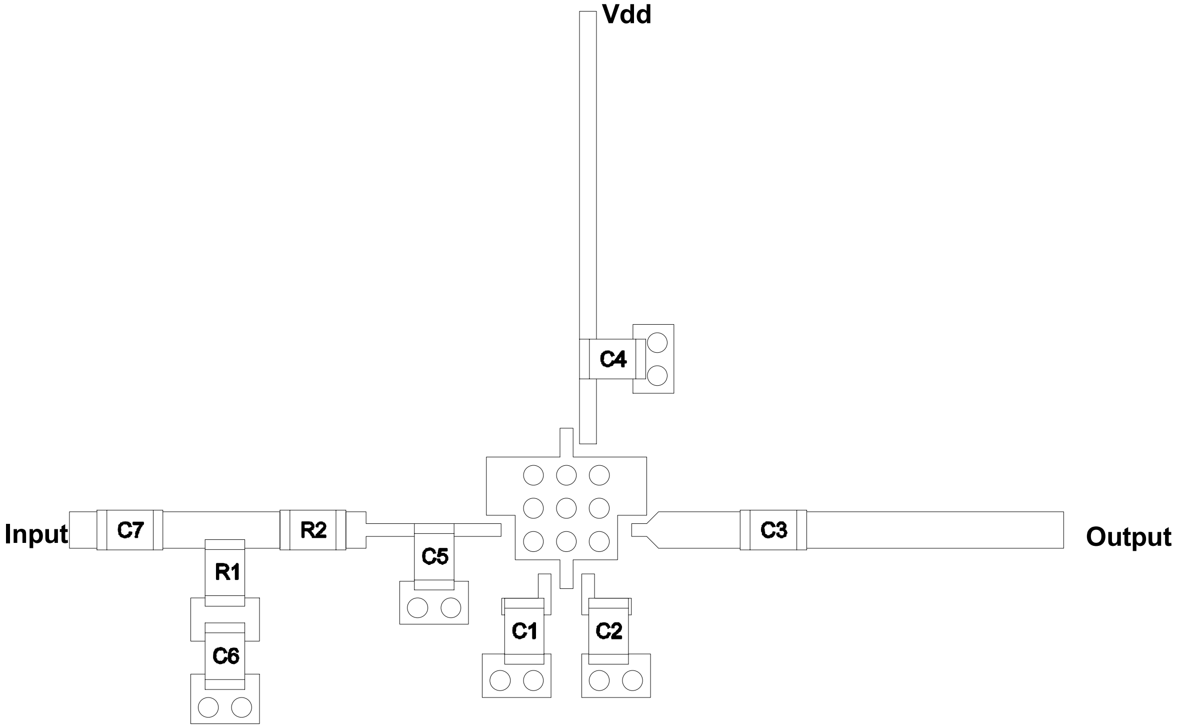
GaAs circuits, like any semiconductor, are susceptible to electrostatic discharge, and ESD induced failures may not show up until the modules are in the field. It is therefore important to protect the devices from ESD damage. Assemblers should wear dissipative wrist straps and lab coats; assembly should be done on dissipative bench mats.

TESTING THE DEVICE

The test fixture shown in Figure 7 can be used to test devices up to 622 Mb/s. The circuit shown is suitable for devices assembled in the surface mount, plastic package.

The 5KΩ resistor (R2) and the 0.5 pF capacitor (C5) simulate the impedance of the photodiode. Photodiodes with capacitance higher than 0.5 pF should be avoided, as this capacitance has a direct effect on the bandwidth and sensitivity performance of the device.

The circuit should be laid out using standard RF techniques, and all components used should have good RF qualities. Transmission lines between the 0.5 pF capacitor and the input of the device should be kept as short as possible, since any additional capacitance here will degrade the bandwidth and sensitivity performance of the device.



Test Circuit

Notes:

1. **Material: FR4, εr = 4.8**
2. **Thickness = 0.032 inch**
3. **1 oz. copper, both sides**
4. **Input/output transmission line impedance = 50 Ω**

Parts List	
R1	50Ω
R2	5KΩ
C1,C2	220 pF
C3,C6,C7	0.01μF
C4	0.1μF
C5	0.6 pF

Figure 7

MEASURING DEVICE PARAMETERS

DC Transresistance:

This is the amount of feedback resistance in the device. It can be determined approximately by measuring the dc resistance from the input to the output of the device. Alternatively, it can be determined as follows:

1) Measure the dc voltage at the output of the device (Vos) when the input current equals zero.

2) Generate a dc current at the input of the device and re-measure Vos. The Transresistance is then ΔV divided by ΔI. It is important that the input current be kept below the AGC threshold current to prevent the AGC circuit from turning on.

AC Transimpedance:

This is defined as the output voltage (Vout) divided by the input current (Iin). The AC Transimpedance will be constant until Iin reaches the AGC Threshold, which is the input current at which the Transimpedance has decreased to 50 % of its initial value. Once the AGC circuit is active, the AC Transimpedance changes nonlinearly, and is again defined as the output voltage divided by the input current. The AC Transimpedance can be measured as follows:

1) Generate a current at the input of the device (I_{IN}) by applying a light signal to the photodetector, and measure the output voltage (V_{OUT}). The AC Transimpedance can then be calculated with the following equation:

$$\mathbf{T_Z\ (dB) = 20\ Log\ (Vout/I_{IN})}$$

Input Offset Voltage and Output Offset Voltage:

These are the dc voltages at the input and output of the device. They can be measured with a dc voltmeter, either directly at the input and output of the device, or at some convenient test point in the module. Probing should be done carefully so as not to damage any of the structures on the die itself.

Input Referred Noise Current and Sensitivity:

This parameter is directly related to the sensitivity of the device. It is defined as the output noise voltage, Vout (with no input signal), divided by the AC Transimpedance. A low pass filter (see Table 1) is used at the output when the measurement is made. The device sensitivity can then be calculated as follows:

$$\eta = 10\ \mathrm{Log}\ \{(6500 \times I_{IN})/R\} \quad [\mathrm{dBm}]$$

Where $\mathbf{I_{in}}$ is the input referred noise current, and **R** is the responsivity of the Photodetector.

Optical Overload (Indirect Measurement):

This is defined as the maximum optical power above which the bit error rate (BER) increases beyond 1 error in 10^{10} bits. The following dc measurement has excellent correlation with a psuedo-random bit stream (PRBS) measurement.

1. Measure the output offset voltage (V_{OS}) while increasing the input current (I_{IN}).

2. Record I_{IN} at the point where the output voltage collapses.

3. The optical overload (in dBm) can then be calculated with the following equation:

$$\textbf{Optical Overload (dBm)} = 10 \log \left[I_{IN} / 0.002R \right]$$

Where R is the responsivity of the photodiode and I_{IN} the current at which the output voltage collapses.

Bandwidth:

This can be determined by measuring the Transimpedance gain of the device with a scalar or vector network analyzer. The bandwidth specified is the 3 dB bandwidth, measured in a 50Ω system.

TROUBLESHOOTING GUIDE

Low Optical Overload (Devices with AGC):

This is usually caused by a short circuit at the AGC port of the device. The AGC capacitor (C_{agc}) is sometimes inadvertently short circuited when an excess amount of conductive epoxy is used on the hybrid circuit. Short circuiting the AGC port will disable the AGC function, causing the device to overload with low optical levels.

Low Bandwidth:

The bandwidth of the device is directly related (inversely proportional) to the capacitance of the photodiode and any stray capacitance between the photodiode and the input of the device. It is recommended that only photodectors with less than 0.6 pF capacitance be used.

Degraded Sensitivity:

It is important to use a lowpass filter at the output of the device for applications where the sensitivity is critical. The filter will help reduce the noise and improve the overall system sensitivity by attenuating the out of band noise.

The input referred noise, and hence, the sensitivity of the device are also affected by the photodiode capacitance. The sensitivity can be improved by reducing the detector capacitance.

The responsivity of the photodiode can also affect the sensitivity. The sensitivity is inversely proportional to the responsivity. It is important to note, however, that there will be a tradeoff between sensitivity and optical overload when determining the optimal responsivity for the photodiode.

Oscillations, Resonances and Peaking:

One of the most common causes of device oscillation is poor RF grounding on the hybrid circuit. All ground wire bonds should be kept as short as possible, and when feasible, via holes should be used (as close to the device as possible).

The back side of the device should be mounted to a ground plane. While the device will generally work if the back side is at a negative dc voltage, the chances of oscillation are significantly increased.

Poor power supply bypassing can also cause oscillations. Good quality chip or MIM capacitors should be placed as close to the device as possible, and bond wire lengths should be minimized.

If the frequency response of the device has “suckouts” or resonances, the most likely cause is long bond wires, particularly for the Cby connection. Excess inductance here has been seen to cause low frequency resonances.

It is especially important that the input impedance of the subsequent stages be matched as close to 50 ohms as possible, particularly for the higher bit rate devices. The TIA can oscillate when terminated with a device having a high input impedance (e.g. a MOSFET post amplifier stage).

Pulse Width Distortion:

This can be caused by choosing an AGC capacitor which is too small. This capacitor is used to set the AGC time constant, which is the amount of time it takes for the AGC circuit to turn on and off. If the time constant is too short, the device will start to overload under large input signal conditions, and the result will be a distorted output signal. Therefore , the recommended minimum value (to meet SONET and SDH requirements) is 56 pF.

DEFINITION OF TERMS

AGC	Automatic Gain Control; used to protect the device from optical overload while maintaining bandwidth and sensitivity performance.
AGC THRESHOLD	The level of input current at which the AC Transimpedance decreases to 50% of its initial value.
AGC TIME CONSTANT	The amount of time it takes to achieve the required AGC level; also, the amount of time it takes to recover from AGC.
BER	Bit Error Rate; the fraction of bits transmitted that are received incorrectly.
B-ISDN	Broadband Integrated Services Digital Network
dBm	Decibel reference to 1 miliwatt; 0 dBm equals one miliwatt.
DETECTOR	The photodiode in optical receivers
DISTORTION	Any difference between the transmitted and received waveform of a given signal.
EYE DIAGRAM	Qualitative description of a digital system; the BER that can be achieved is related to the openness of the eye.
FDDI	Fiber Distributed Digital Interface; a network based on the use of optical fiber to transmit data at a rate of 100 Mb/s.
FIBER CHANNEL	A point to point and network standard for high speed interchange of data between computers.
GaAs	Gallium Arsenide; a III-IV semiconductor material from which microwave integrated circuits can be fabricated.
HIPPI	High Performance Parallel Interface; an 800 Mb/s interface to supercomputer networks.
OPTICAL OVERLOAD	A condition of high input current that causes pulse width distortion at the output of the TIA.

PHOTODIODE	A semiconductor device that converts light to electrical current.
SONET	Synchronous Optical Network; a standard for optical network components providing modular building blocks, fixed overheads and integrated operations channels.
TIA	Transimpedance Amplifier; a device used to convert input currents to output voltages.
TRANSIMPEDANCE	The transfer function of a TIA; the output voltage divided by the input current.