AD-A102 886 MITRE CORP BEDFORD MA F/6 20/6

FIBER OPTIC RECEIVER PREAMPLIFIER DESIGN.(U)

JUN 81 G L TENUTA. F19628-81-C-0001

UNCLASSIFIED WP-23100 RADC-TR-81-150 NL

1 OF 1

AD A
102886

END
DATE
FILMED
9-81
DTIC

RADC-TR-81-150
Interim Report
June 1981

FIBER OPTIC RECEIVER PREAMPLIFIER DESIGN

The MITRE Corporation

G. L. Tenuta

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

ROME AIR DEVELOPMENT CENTER
Air Force Systems Command
Griffiss Air Force Base, New York 13441

This report has been reviewed by the RADC Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be releasable to the general public, including foreign nations.

RADC-TR-81-150 has been reviewed and is approved for publication.

APPROVED: Thomas A. Ross

THOMAS A. ROSS
Project Engineer

APPROVED: Bruno Beek

BRUNO BEEK, Acting Technical Director
Communications and Control Division

FOR THE COMMANDER: John P. Huss

JOHN P. HUSS
Acting Chief, Plans Office

If your address has changed or if you wish to be removed from the RADC mailing list, or if the addressee is no longer employed by your organization, please notify RADC (DCCT) Griffiss AFB NY 13441. This will assist us in maintaining a current mailing list.

Do not return this copy. Retain or destroy.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: RADC-TR-81-150	2. GOVT ACCESSION NO.: AD-A102886	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): FIBER OPTIC RECEIVER PREAMPLIFIER DESIGN.	5. TYPE OF REPORT & PERIOD COVERED: Interim Report
	6. PERFORMING ORG. REPORT NUMBER: WP-23100
7. AUTHOR(s): G. L. Tenuta	8. CONTRACT OR GRANT NUMBER(s): F19628-81-C-0001
9. PERFORMING ORGANIZATION NAME AND ADDRESS: The MITRE Corporation, Bedford MA 01730	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62702F, 45192142
11. CONTROLLING OFFICE NAME AND ADDRESS: Rome Air Development Center (DCCT), Griffiss AFB NY 13441	12. REPORT DATE: Jun[redacted]81
	13. NUMBER OF PAGES: 30
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): Same	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE: N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Same

18. SUPPLEMENTARY NOTES

RADC Project Engineer: Thomas A. Ross (RADC/DCCT)

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Fiber Optic
Fiber Optic Receiver
Preamplifier
Receiver
Low Noise Preamplifier
Wide Bandwidth Preamplifier
High Gain Preamplifier

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the technical problems associated with the design of wide bandwidth, low noise optical receivers for use within fiber optic communication systems. Noise model analysis is performed for three detection techniques using preamplifiers (resistive loading, transimpedance and high impedance). A Low Noise High Impedance Preamplifier Design is presented as well as a prototype Ultra High Gain Wide-Band Transimpedance Preamplifier. Component values are shown to allow easy implementation of the designs.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

TABLE OF CONTENTS

	Page
INTRODUCTION	1
PHOTODETECTORS FOR OPTICAL FIBER COMMUNICATIONS	1
PREAMPLIFIER FUNDAMENTALS	2
BIASING THE FIRST TRANSISTOR STAGE	5
NOISE IN FIBER OPTIC SYSTEMS	7
HIGH IMPEDANCE PREAMPLIFIER DESIGN	17
TRANSIMPEDANCE DESIGN	20
REFERENCES	23
DISTRIBUTION LIST	25

LIST OF ILLUSTRATIONS

Figure		Page
1	Common Preamplifier Configurations	3
2	Noise as a Function of Bias Current for FET's and BJT's	6
3	Preamplifier Noise Model	9
4	Optical Power Vs. Bandwidth for Analog Systems	14
5	Optical Power Vs. Bandwidth for Digital Systems	15
6	Optical Detector Power Requirements as a Function of Preamplifier Input Capacitance and CNR	16
7	Performance Curves for PIN FET's and APD's	18
8	Low Noise High Impedance Preamplifier	19
9	Prototype Ultra-High-Gain 100-MHz Transimpedance Preamplifier	21

LIST OF TABLES

Table		Page
1	Preamplifier Performance Parameters for PIN's and APD's	12
2	Definition of Preamplifier Noise Terms	13

INTRODUCTION

An essential component for the design of long-haul, high capacity fiber optic systems is the receiver preamplifier. The preamplifier is the first stage of the receiver consisting of an optical photodetector diode and, ideally, a very low noise/high sensitivity/high bandwidth amplifier.

The main function of the preamplifier is to provide conversion of light (which has been intensity modulated) into electrical form where it may be processed using conventional analog or digital techniques. Because the detected light is often at a very low optical level, generally in the nanowatt region, the preamplifier must possess high sensitivity and noise rejection to preserve the intended signal to noise ratio (SNR) or bit error rate (BER) objective of the system. In high bandwidth/long-haul capacity systems, high receiver sensitivity is particularly important since it reduces the requirement for optical regeneration (e.g., repeaters), offers greater design flexibility in the source selection process associated with the transmitter, and typically lowers both the cable cost and maintenance aspect of the overall system.

PHOTODETECTORS FOR OPTICAL FIBER COMMUNICATIONS

Photodetectors for fiber optic systems rely on the use of either a PIN photodetector, a semiconductor consisting of an intrinsic (or nearly intrinsic) region between a P and n region, or an APD (avalanche photodetector diode). Both devices, once matched to the spectral characteristics of the source, find a wide variety of applications for fiber optic work at frequencies up to or exceeding 1 Gb/s.

A PIN detector exhibits poorer noise performance than an APD but costs less and requires a lower operating bias voltage, typically 5 to 100 V. An APD, on the other hand, while costing more provides internal optical gain through photoelectrical multiplication. Nevertheless, because the gain mechanism of an APD is statistical in nature, excess noise above that of the PIN is introduced in the system; however, sensitivity is generally greatly improved.

The gain of an APD may be varied, via the bias supply, between 1 to 1000, although 100 to 200, depending on the specific application, is more typical. Even at unity gain, the APD seldom performs worse than a PIN. The ADP, however, suffers from gain instability brought about through changes in temperature coupled with the typically high bias requirements, in the order of 200 to 600 V. Although it may include complications in the electronics and other system related considerations (e.g., cost, excess noise), a PIN is often found more suitable for a specific application, either as a cost/performance compromise or on its own merits.

PREAMPLIFIER FUNDAMENTALS

As mentioned previously, the photodiode and amplifier combination comprise the preamplifier. Because they are inextricably linked, the noise/bandwidth performances of the detector and amplifier tend to be obscured by the performance of the overall preamplifier. Nevertheless, knowledge of the structure of the amplifier, taken by itself, is fundamental to a firm understanding of the design of high sensitivity, high bandwidth fiber optic systems.

The subject of amplifier design is somewhat complicated by the fact that the performance of the amplifier depends on many factors: type of detector, bandwidth, application (analog or digital), whether bipolar or field-effect transistors (FET) are used, fabrication technique (hybrid, discrete, stripline, microstrip, and others), use of equalizers and neutralization schemes, shot noise currents and effective temperature of the primary first-stage transistor, layout and other factors. However, a good understanding of the subject will enable the designer to determine the best amplifier suited to his particular needs.

Although much has been written on the subject of preamplifier design, much confusion remains primarily because of the method of characterization. Virtually all amplifiers designed for fiber optic work can be classified into one of three categories: resistively loaded, high impedance, or transimpedance (see figure 1). Variations, of course, exist and include transistor technology (bipolar/FET), type of equalizer used, load impedance, and so forth, as stated earlier. However, for any configuration, a hybrid circuit design offers the ultimate performance solution since grounding is usually better; distributed inductance and capacitance are lower, allowing wider bandwidth or higher gains; and shielding, owing to proximity of components and packaging, provides the highest immunity to external fields while confining those generated internally. For reasons associated primarily with cost, special requirements, and availability of standard off-the-shelf components, many designers, however, find that the only acceptable alternative is to design their own preamplifiers.

Of the three configurations, the resistively loaded preamplifier is the simplest to implement and understand since it requires only simple adjustment of the RC bandwidth product of the amplifier. The

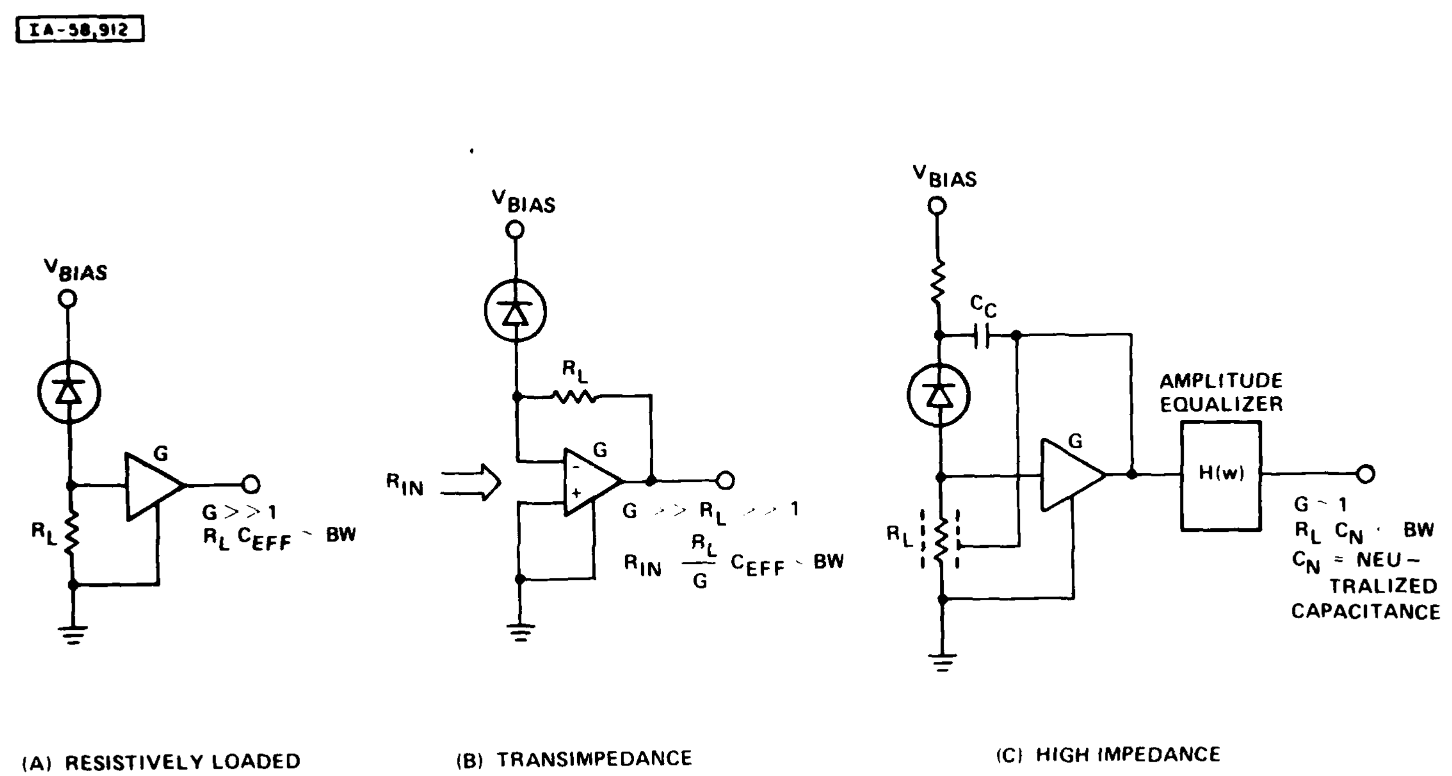


Figure 1. Common Preamplifier Configurations

capacitance C is generally fixed by the total (sum) effective input capacitance of the amplifier and photodiode. The photodiode is represented electrically as a current source having some capacitance which contributes (e.g., adds) to the existing capacitance of the amplifier. The total capacitance, diode and amplifier, then represents the effective input capacitance of the preamplifier C.

The input impedance of the amplifier R is under control of the designer and is generally selected in conjunction with the preamplifier capacitance to meet the system bandwidth requirements:

$$f_{(sys)} = \frac{1}{2\pi RC} .$$

Unfortunately, for high bandwidth, the preamplifier input impedance must be kept small; but keeping R small increases the noise of the amplifier (Johnson or thermal noise) and limits the utility of the preamplifier for low-noise system applications.

The transimpedance amplifier, so-called current mode amplifier, circumvents this problem enabling low input impedance and low noise without compromising performance. The penalty, however, is that higher gain is usually needed in the open-loop path of the amplifier since the amplifier is operated in a closed loop. Consequently, more gain stages, typically two, are required; but the noise of the amplifier is then lowered by G, the open loop gain (see figure 1). The gain results because the feedback impedance R now accounts for the thermal noise, while the normally high input impedance of the amplifier is reduced by the open loop gain (figure 1). The transimpedance preamplifier, for the same bandwidth, offers a clear noise advantage over the resistively loaded configuration. Primarily for this reason the transimpedance preamplifier has become quite popular for low-noise, high-bandwidth fiber optic design.

The remaining configuration (figure 1c) is the high-impedance preamplifier, a variant of the resistively loaded case. For this configuration, the input impedance R of the preamplifier is increased beyond the system bandwidth, and neutralization (e.g., positive feedback) and/or amplitude equalization is used to recover the original bandwidth. Unlike the previous configuration (figure 1b), the high impedance preamplifier operates as a unity gain buffer with the optical gain provided by the load resistor R_L. The problem here, however, is that it becomes exceedingly difficult to design active equalizers with adequate gain and good signal-to-noise properties at high signal frequencies. Similarly, neutralization, which reduces capacitance through positive feedback and hence extends bandwidth, begins to deteriorate and ultimately limits the extent of capacitance that can be effectively neutralized, thus setting a limit on the maximum attainable bandwidth.

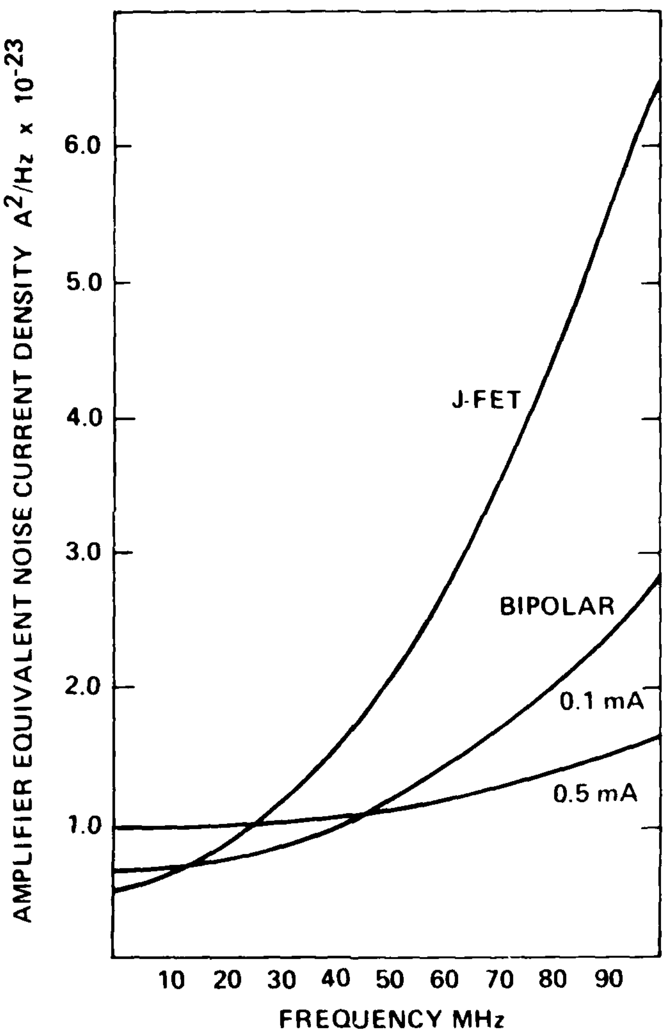
The above is a consequence of the inevitable effects of distributed capacitance and inductance and not necessarily of the effectiveness of the technique. Albeit there are apparent drawbacks, the high impedance amplifier, or integrating amplifier as it is sometimes called, offers the lowest noise for those applications in which the required bandwidth can be realized.

BIASING THE FIRST TRANSISTOR STAGE

The design of a high-performance preamplifier requires that the first transistor stage be biased for both wide bandwidth and low noise. The first transistor stage is perhaps the most important stage of the receiver since noise in subsequent receiver stages is offset (divided) by the composite gain of preceding stages, and hence provides a limiting effect on the overall SNR of the receiver.

In any preamplifier configuration, the first transistor stage may be implemented with either a bipolar junction transistor (BJT) or field-effect transistor (FET), and succeeding stages may be of the same technology or mixed, depending on specific design requirements. Deciding which transistor type to use is a key decision. For example, a 20-Mb/s receiver may use a transimpedance front end with an FET as the first stage and BJT's for the remaining stage(s). The latter mixed design is one in which an FET is exploited for its typically low-noise characteristics and the BJT for its usually high-gain bandwidth capability and cutoff frequency extending into the gigahertz region. Whether a BJT or an FET is used, the designer must decide on the proper biasing method and the correct bias for the first transistor stage.

Unfortunately, low noise and wide bandwidth are conflicting requirements, and a decision concerning which is the more important for a particular design must often be made. Figure 2, for example, illustrates how biasing can affect the noise/bandwidth performance of a preamplifier, depending on whether a transistor or an FET is used for the first stage. In passing, we note that noise occurs because electrons flow as discrete charges and not continuously as a steady electric fluid. For that matter, noise exists in any active circuit in which there is a flow of current (e.g., shot noise and flicker).



IA-58,913

Figure 2. Noise as a Function of Bias Current for FET's and BJT's (After GTE)

NOISE IN FIBER OPTIC SYSTEMS

A well designed fiber optic system generally begins with a detailed analysis of noise. Noise in a fiber optic system manifests itself as a reduction of SNR or increase in timing jitter. Sources of noises include the transmitter, particularly if a laser is used, selective losses in the fiber, and noise in the preamplifier. The last excludes related effects such as switching transients, clipping or saturation, and 60- or 120-Hz harmonic noise in the power supply. It also assumes adequate decoupling and bypassing of all active components.

The first two sources of noise are difficult to quantify since research is presently continuing and the subject is not rigorously understood.

For purposes of this report, noise associated with lasers operating at high data rates (e.g., 200 Mb/s and above) includes:

- Laser noise (e.g., spectral intensity variations)
- Partition noise (e.g., wavelength intensity variations)
- Modal noise (e.g., amplitude noise resulting from mode selective losses, particular in the laser/fiber interface and connection alignments, assuming graded-index fibers)
- Delay noise (e.g., timing jitter in the arrival of optical signals)

Another type of noise associated with a laser is self-oscillation or self-pulsation, a tendency of the laser to pulsate in high data rate (e.g., high frequency) fiber optic applications. LED's, it should be noted, are immune to these problems but suffer other deficiencies such as slower speed and reduced output power. A detailed discussion of laser noise is treated in reference 1.

As noted earlier, a high sensitivity receiver design starts with a careful analysis of the transmitter. To keep the noise level down a laser should be biased above or below threshold, never in the vicinity of the threshold itself. Operating above or below threshold avoids the avalanche noise that occurs at threshold where the laser changes modes between spontaneous and stimulated emission (e.g., a source of noise). Of course, for digital systems, it is desirable to operate above threshold to minimize turn-on time and to preserve the rise and fall time symmetry of the optical output signal. However, operating above threshold reduces the margin between ONEs and ZEROs (e.g., extinction ratio). The designer must therefore seek a compromise between speed of response (e.g., requiring high threshold) and discrimination between ONEs and ZEROs (e.g., requiring low thresholds). The depth of modulation, for either analog or digital systems, must also be maximized, within the thermal ratings of the device, to optimize the SNR at the receiver. Full depth modulation for analog systems combats the effects of signal shot noise at the receiver, a critical factor in the design of long-haul systems, especially when using APD's.

The noise performance of a preamplifier is made up of amplifier noise, shot noise in the detector, and excess noise due to impact ionization of an APD (references 2, 3, 4). The SNR and BER along with actual link measurements, including eye-pattern evaluation for digital systems, are extremely valuable tools to quantitatively characterize the noise performance of a receiver. Digital systems (reference 5) are typically more complex since the detection process (e.g., ONE or ZERO), pulse shape, and transmitting/receiver filters are vastly different. Despite these differences, however, analog and digital systems are relatable by the SNR or CNR (carrier-to-noise ratio) of the system.

A general noise model of a preamplifier is shown in figure 3. Sources of noise in the preamplifier include signal shot noise or average optical signal current flowing in the detector under the presence of light, detector shot noise resulting from the detector dark current, and amplifier noise consisting of thermal noise and quantum shot noise. The detector load resistor, present in the resistively loaded and high-impedance preamplifier configurations, is generally lumped together with the input impedance of the amplifier, as an equivalent parallel impedance, to form the amplifier thermal noise contribution. For the transimpedance configuration, the thermal noise comes from the amplifier feedback resistance, or transimpedance. The amplifier noise can alternately be modeled by a resistor at a temperature that gives rise to the same noise spectral density as the amplifier. In figure 3 the individual noise sources of the amplifier are equivalently represented by a voltage and current noise source acting at the input to the amplifier. Amplifier noise, generally the most significant form in a nonsignal shot noise limited receiver, is a dominant factor when using APD's.

Shot noise depends on the type of detector. Shot noise for a PIN, for example, consists of reverse dark current, the leakage current

IA-58,914

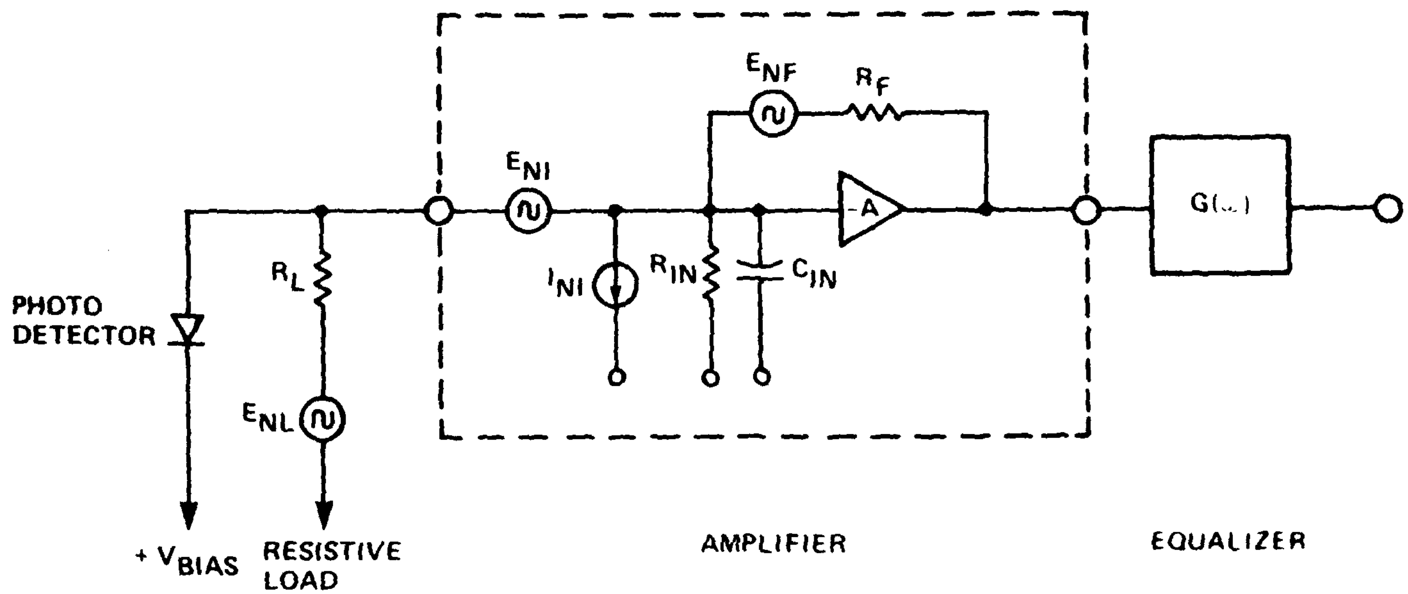


Figure 3. Preamplifier Noise Model

that flows in the absence of light. In an APD, however, both the bulk and surface contributions of the dark current must be taken into account.

Surface current (which can be one to three orders of magnitude higher than bulk current) in an APD is treated simply as shot noise.

Bulk current, however, is multiplied by the gain of the APD producing an excess noise that depends on the quality of the detector (e.g., impact ionization coefficient K). For a good quality silicon APD the noise factor is typically very low (e.g., K = 0.2) whereas for germanimum APD's it is somewhat high (e.g., K = 1). If the dark current is also high, the excess noise will have minimal effect on the receiver because of dominance by the dark current noise. In addition, the excess noise in an APD will increase with gain at a faster rate than the multiplied optical signal. Eventually a point will be reached where an increase in gain for a given optical power will produce a reduction in sensitivity. The gain at which this occurs is called the optimum gain of the APD. For a low noise device, it is generally fixed by the noise of the amplifier.

To complicate matters, an APD is also extremely temperature sensitive, and therefore care must be exercised that proper gain control be provided; otherwise the optimum gain setting will change with temperature and significantly degrade sensitivity. Because dark current will also change, e.g., double for approximately every 10°C rise in temperature, gain control should be based on optical signal power variations, not necessarily average d.c. optical output power. This precaution will prevent an erroneous d.c. error signal resulting from the dark current from developing in the gain control circuitry. However, for wide-band systems in which dark current is usually dominated by amplifier noise, d.c. coupling is acceptable as long as the average optical power remains approximately constant. One technique of doing this and providing optimum gain control automatically at the same time is to bias the APD from a constant current source. The current source must be set for optimum gain at ambient temperature for the technique to work properly. Moreover, the APD must be shunted by a capacitor, across which the voltage maintains the APD at optimum gain under varying levels of optical signal power and changes in temperature (e.g., provides 100 percent gain control).

Mathematically, the signal to noise ratio (SNR) of an optical preamplifier is expressed as (assuming full-depth modulation):

$$\mathrm{SNR} = \frac{\text{Signal Power}}{\text{Signal Shot Noise + Detector Shot Noise + Amplifier Noise}}$$

$$= \frac{(mRMP_o)^2}{2eB_n \left| I_s M\ F + (I_{DB} M^2 F + I_{DS}) + I_A \right.}$$

A description of the above parameters for PIN's and APD's is presented in table 1 and comprehensive description of all parameters is provided in table 2.

Examination of this equation reveals that the SNR performance of a preamplifier is determined solely by the type of amplifier and detector used for the preamplifier. A simplification can usually be made for a PIN detector, which provides a gain of unity:

$$= \frac{(mRP_o)^2}{2eB_n \ (I_S + I_D + I_A)}$$

Note that the detector dark current I_D now consists of the bulk and surface currents I_{DB} and I_{DS} respectively.

To select a detector, the designer need only be concerned with the application and have in mind some preliminary formulation of the design requirements. For instance, consider an analog application in which the SNR requirement is typically high, 40 to 50 dB (e.g., CATV). Here an APD would provide little advantage over a PIN because of the high SNR coupled with the type of modulation being considered, e.g., analog. Some typical results showing a comparison of the performance between a PIN and APD in a typical application are provided in figure 4 (reference 6).

The above argument, however, is not necessarily appropriate for digital systems where an APD will generally provide approximately 10 to 15 dB of additional margin over a PIN in figure 5 (reference 6). The SNR requirement is inadequate here, since the criteria of interest for digital systems is the detection probability of a signal exceeding a certain threshold, specifically the number of primary electrons produced by the optical pulse, the distribution of gain statistics if an APD is being used, and the effective noise electron charge of the amplifier. A principal feature of an APD is its performance at high frequencies where dark current effects begin to diminish (reference 7) and where bandwidth generally becomes limited by the amplifier/detector capacitance as shown in figure 6. It follows from the above, that gain can be traded between sensitivity and bandwidth. However, the designer will probably come

Table 1. Preamplifier Performance Parameters for PIN's and APD's

IA-58,920

OPTICAL SIGNAL POWER	CURRENT SYMBOL	PIN	APD
• DETECTOR SIGNAL CURRENT	I_S	$(mRP_o)^2$	$(mRP_oM)^2$
NOISE POWER			
• SIGNAL SHOT NOISE	I_S	$2qI_SB_n$	$2qM^2FI_SB_n$
• DETECTOR SURFACE CURRENT NOISE	I_{DS}	$2qI_{DS}B_n$	$2qI_{DS}B_n$
• DETECTOR BULK CURRENT NOISE	I_{DB}	$2qI_{DB}B_n$	$2qM^2FI_{DB}B_n$
• AMPLIFIER NOISE	I_A	$\frac{2KT_{EFF}}{qR_{EFF}}$	$\frac{2KT_{EFF}}{qR_{EFF}}$

Table 2. Definition of Preamplifier Noise Terms

m = OPTICAL MODULATION INDEX

R = DETECTOR RESPONSIVITY AT λ

$= \frac{qK}{hc/\lambda}$ WHERE: q = ELECTRON CHARGE; c = VELOCITY OF LIGHT

h = QUANTUM EFFICIENCY; λ = WAVELENGTH OF LIGHT

K = PLANK'S CONSTANT

P_o = AVERAGE OPTICAL POWER

M = MEAN AVALANCHE GAIN

$= \frac{1}{1 - \left(\frac{V}{V_\beta}\right)^a}$ WHERE: a = CONSTANT; V_β = BIAS VOLTAGE

V = VOLTAGE AT GAIN M

F = EXCESS NOISE FACTOR

$= M\left[1 - (1 - K)\left(\frac{M-1}{M}\right)^2\right]$ WHERE: K = IONIZATION RATIO $= \frac{\beta}{\alpha}$

& β AND α ARE THE DETECTOR IONIZATION RATES

I_S = SIGNAL SHOT CURRENT

$= p_o P_o$ WHERE: p_o = RESPONSITIVITY AT DC

I_{DB}, I_{DS} = DETECTOR BULK AND SURFACE CURRENTS RESPECTIVELY

I_A = AMPLIFIER SHOT NOISE

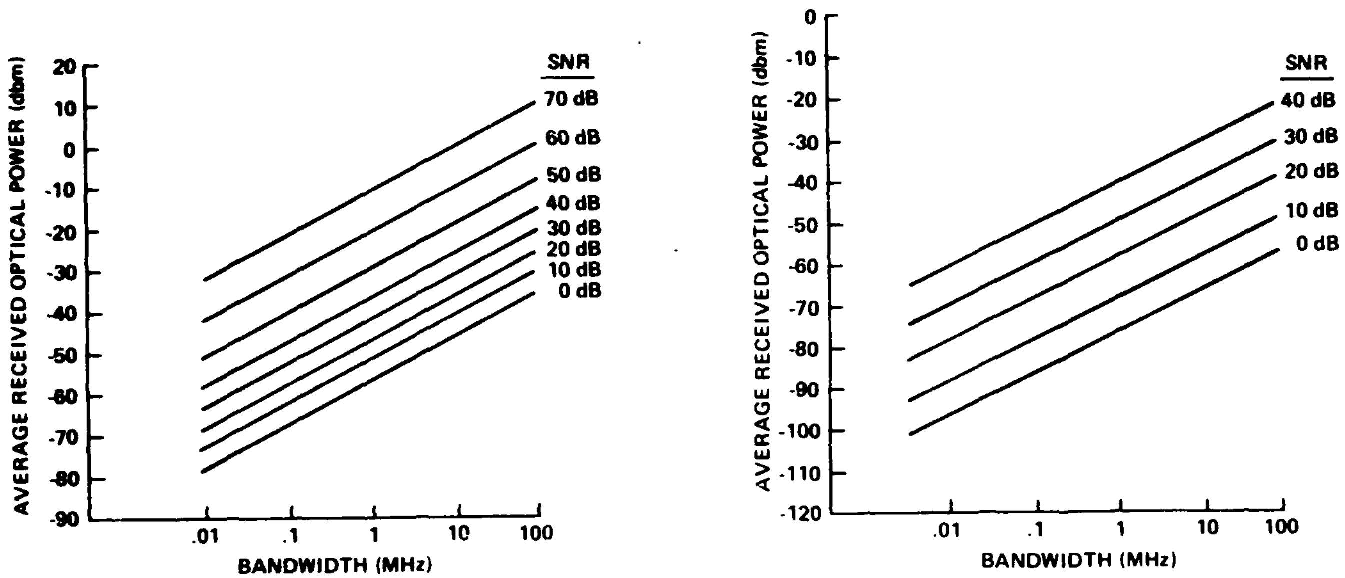
$= \frac{2KT_{EFF}}{qR_{EFF}}$ WHERE: T_{EFF} = EFFECTIVE AMPLIFIER NOISE TEMPERATURE

R_{EFF} = EFFECTIVE AMPLIFIER INPUT IMPEDANCE

β_n = NOISE BANDWIDTH; $= \pi/2 \quad BW_{3\,dB}$

IA-58,921

IA-58,915



(A) PIN DETECTOR

(B) APD DETECTOR

Figure 4. Optical Power Vs. Bandwidth for Analog Systems (Reference 6)

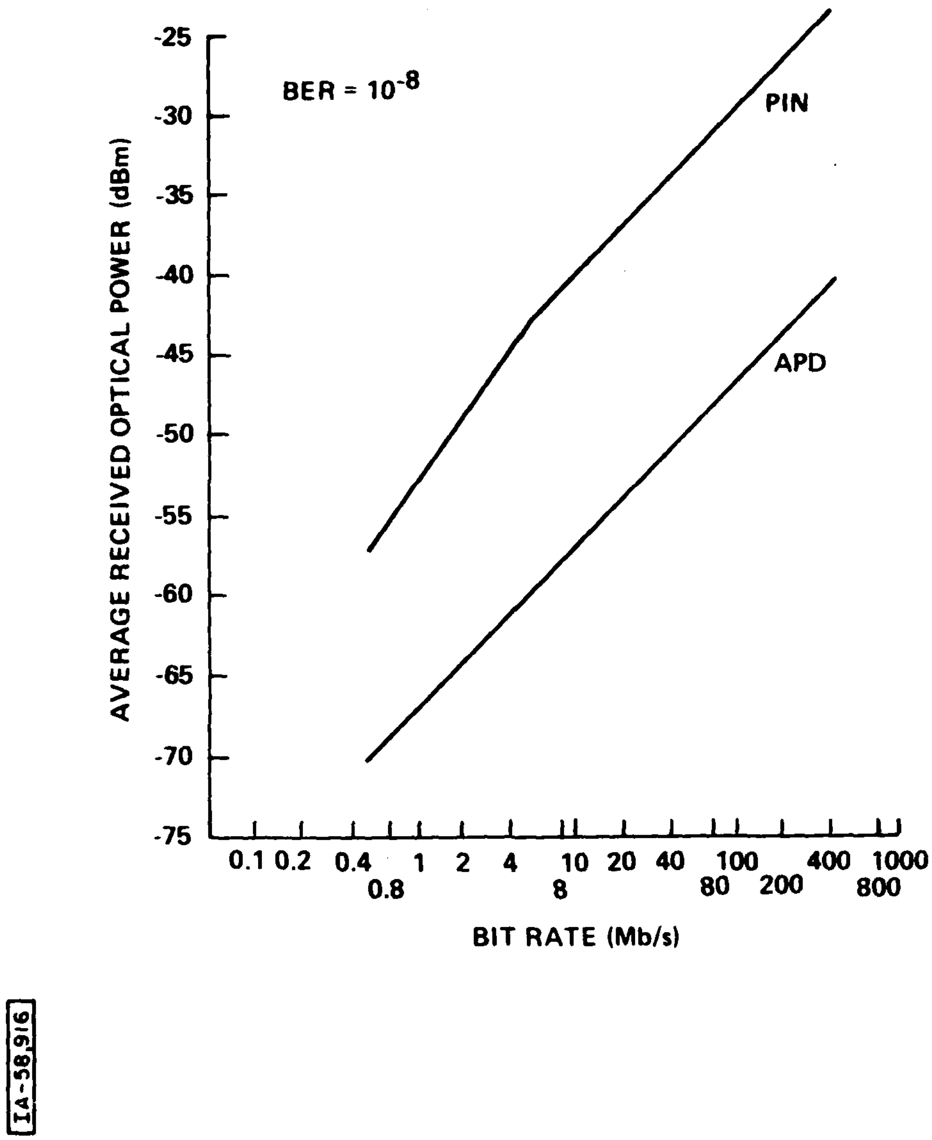


Figure 5. Optical Power Vs. Bandwidth for Digital Systems (Reference 6)

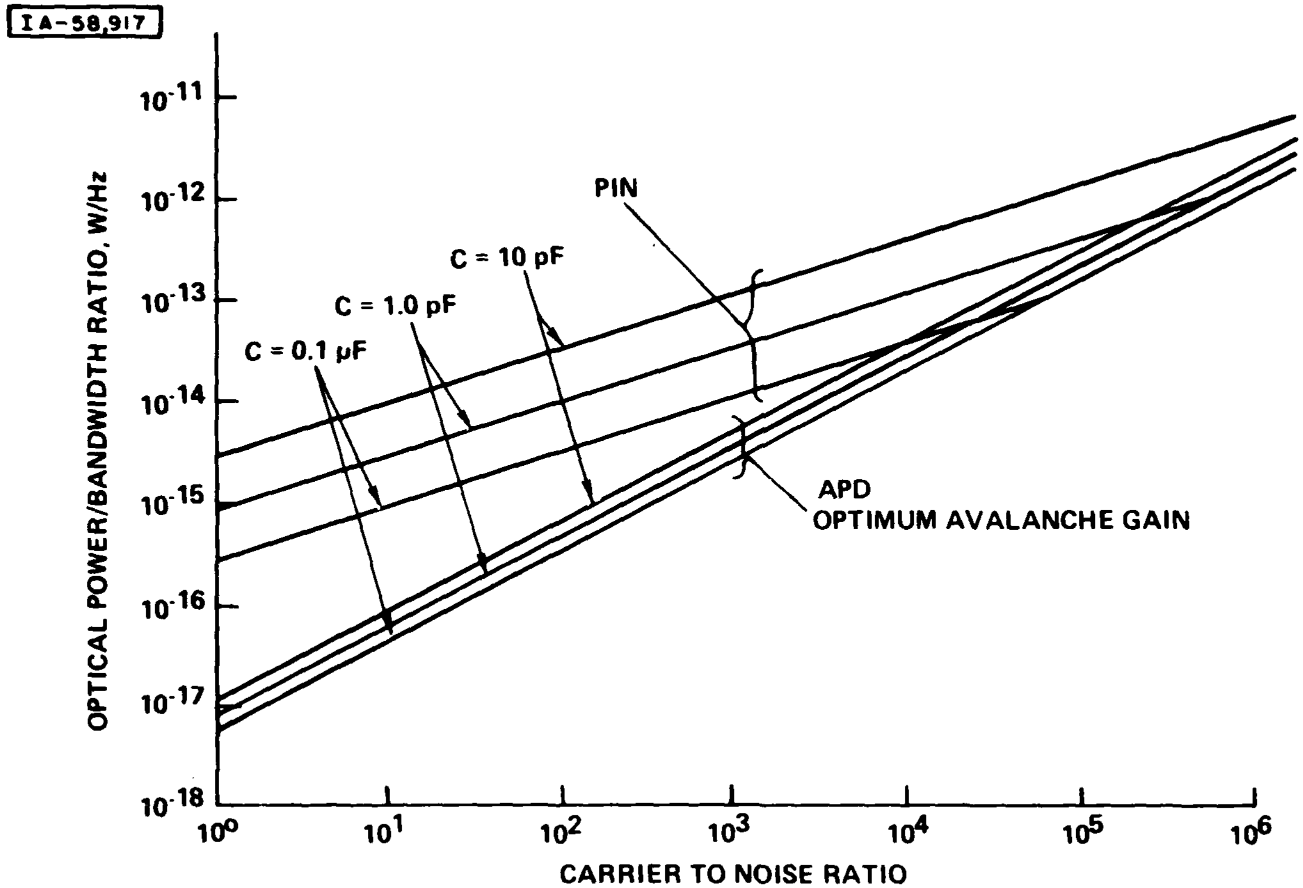


Figure 6. Optical Detector Power Requirements as a Function of Preamplifier Input Capacitance and CNR (Reference 4)

to the conclusion that the main utility of an APD lies in its ability to compensate for the inevitable, practical effects of preamplifier noise including detector dark current and capacitance (reference 8). In fact, a low noise photodiode with integrated PIN FET, reported in reference 9, provides performance comparable to the best quality silicon APD (figure 7). This APD employs a high impedance preamplifier, with digital equalizer housed in a hybrid module. Such circuits operating at the conventional 0.82 μm, as well as the longer 1.3 μm, wavelength, designed with wide-band FET and biopolar preamplifiers, are available commercially (references 10, 11, 12).

The PIN FET is, perhaps, the latest technological development in extremely low noise receiver preamplifier designs. A PIN FET module, incorporating a long wavelength PIN detector with integrated mesa structured FET, developed by Plessey Ltd. for the British Post Office (BPO), provides an input capacitance of 0.3 pF, quantum efficiency of 25 percent, and receiver sensitivity of -40.7 dBm at a BER of 10^{-9} in a 140-Mb/s system. The high impedance design, which uses a 10 M ohm load resistor at the input of the FET, provides an unequalized bandwidth of approximately 55 kHz. A one-stage integrated digital transversal filter, consisting of delay line and comparator, is then used to extend the bandwidth to the required 140 Mb/s. This novel approach avoids the general difficulties of building active, linear equalizers. In addition, applications are limited to digital systems which operate at rates set by the delay line. A functional diagram of the PIN FET, including performance characteristics compared to APD's of various material systems is shown in figure 7. Note that for a good quality FET (e.g., one with low capacitance and high transconductance), a PIN FET can provide comparable performance to an APD. However, making generalizations can be very misleading (and often is) unless specific conditions are carefully and accurately specified.

HIGH IMPEDANCE PREAMPLIFIER DESIGN

A high impedance preamplifier circuit, designed for extemely low noise optical detection and moderate bandwidth applications is presented in figure 8. Key features of the circuit include AGC, single +12 V operation, low power comsumption (e.g., aproximately 15 to 20 mA), large dynamic range and neutralized bandwidth of 10 MHz at a gain (responsitivity) of 6mV/μW. The standard output is 50 ohms. The circuit, measuring approxmately 1 inch x 2 inches, has been breadboarded and tested and found to provide virtually error-free digital transmission at an optical power level of 10 nW when

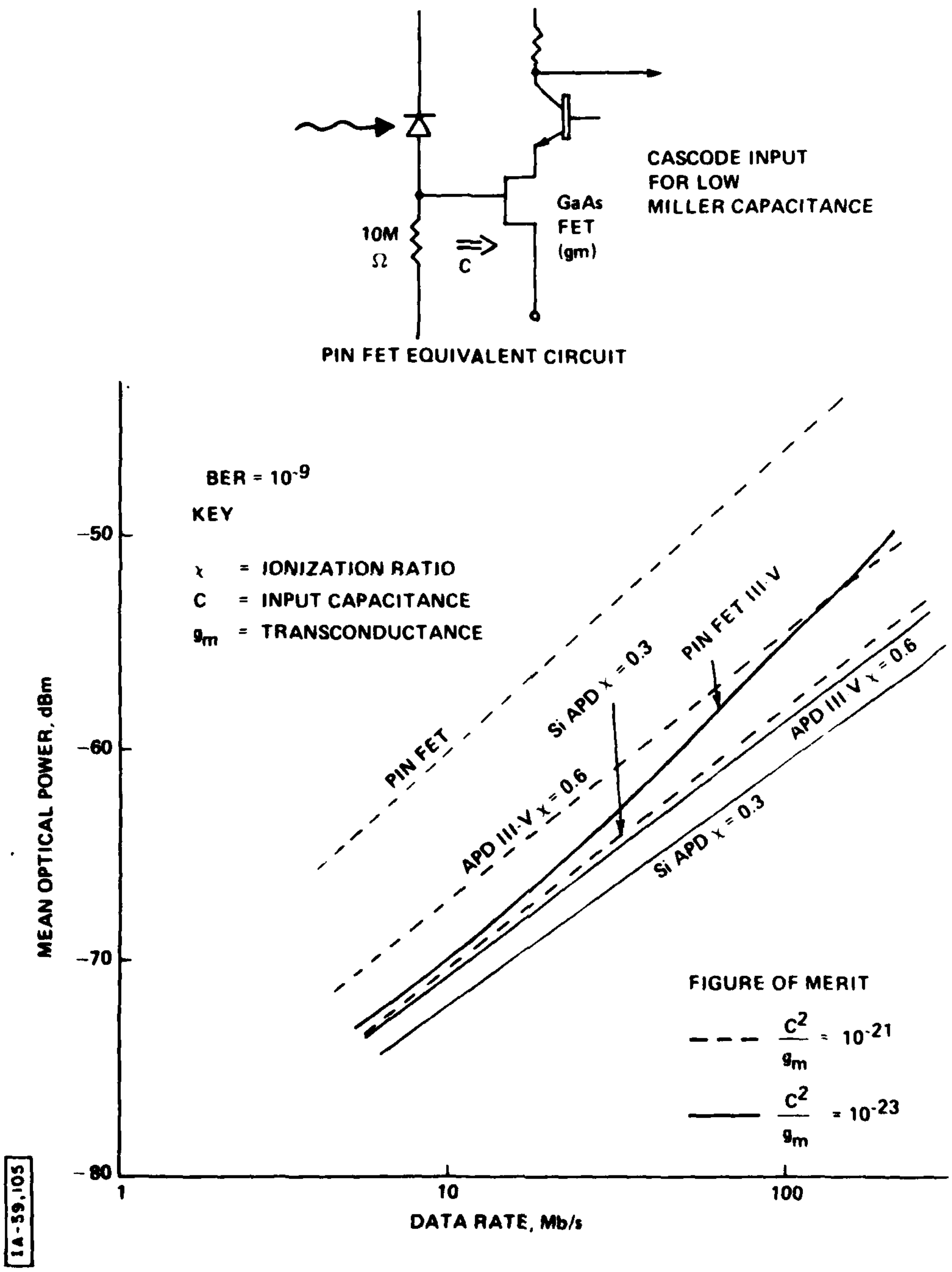


Figure 7. Performance Curves for PIN FET's and APD's (After Plessey)

IA-58,918

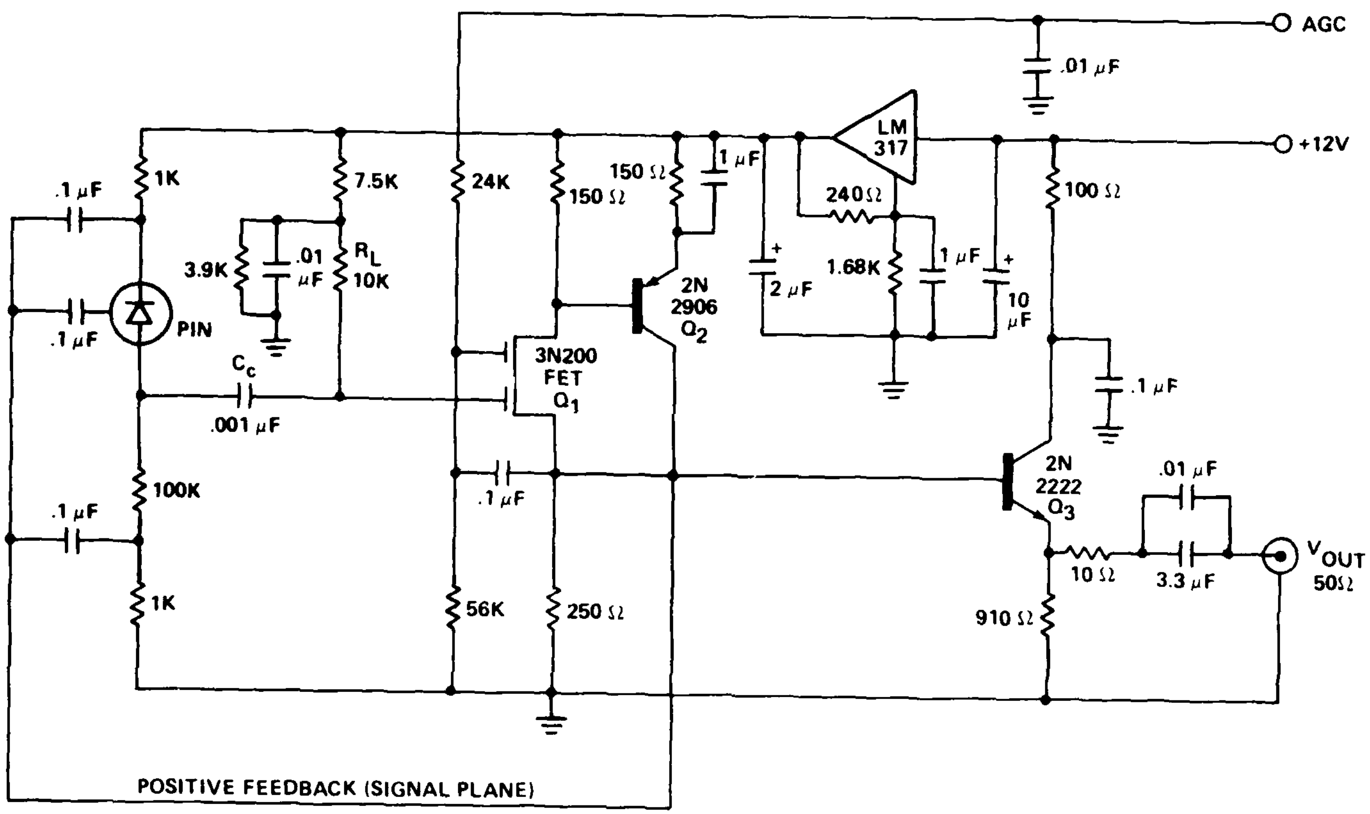


Figure 8. Low Noise High Impedance Preamplifier

operating at a data rate of approximately 600 kHz. However, better performance is expected when using a post amplifier prior to detection. An alternate version, featuring a one-stage equalizer, provides a 10-MHz bandwidth at the same sensitivity.

The preamplifier uses a dual gate MOS (metal oxide semiconductor) FET to minimize input capacitance, improve noise, and achieve extended bandwidth performance. Alternately, sensitivity can be improved by reducing the bandwidth.

The output drive capability of the FET, which was enhanced through the addition of a bipolar transistor, improves the FET gain/speed performance while additionally providing the high drive needed for neutralization.

The FET, which is operated as a source follower, acts as a unity gain buffer to reproduce the optical signal at its output gate. It also provides the feedback required for neutralization.

The feedback is in phase with the optical signal and is implemented via a signal plane which interconnects with all active components on the circuit board, principally a photodiode, a simple PIN, and the FET amplifier. The case terminal of the photodiode is neutralized so that mounting receptacles, located above the signal plane, may be used without loss in performance. In addition to capacitance neutralization, the signal plane, driven by the output of the FET, also provides impedance bootstrapping, a technique which increases the input impedance of the FET. As used here, the technique allows precise definition of the system noise bandwidth. It also extends the dynamic range of the preamplifier, allowing a wider range of optical signals to be accommodated than would otherwise be possible.

TRANSIMPEDANCE DESIGN

An experimental prototype transimpedance preamplifier, developed primarily for ultra-high-gain/low-noise wide-band applications is presented in figure 9. This particular circuit is currently under development, but preliminary testing indicates exceptional sensitivity, approximately 60 mV/μW, low noise, and a system bandwidth of 100 MHz or higher. The circuit, measuring 3 inches x 1-1/2 inches, accommodates either a PIN or APD photodiode. However, for an APD, the sensitivity is significantly improved, typically 6 V/μW. Maximum optical power, in this case, should be restricted to below 500 μW, peak to peak, to prevent saturation of the output stage.

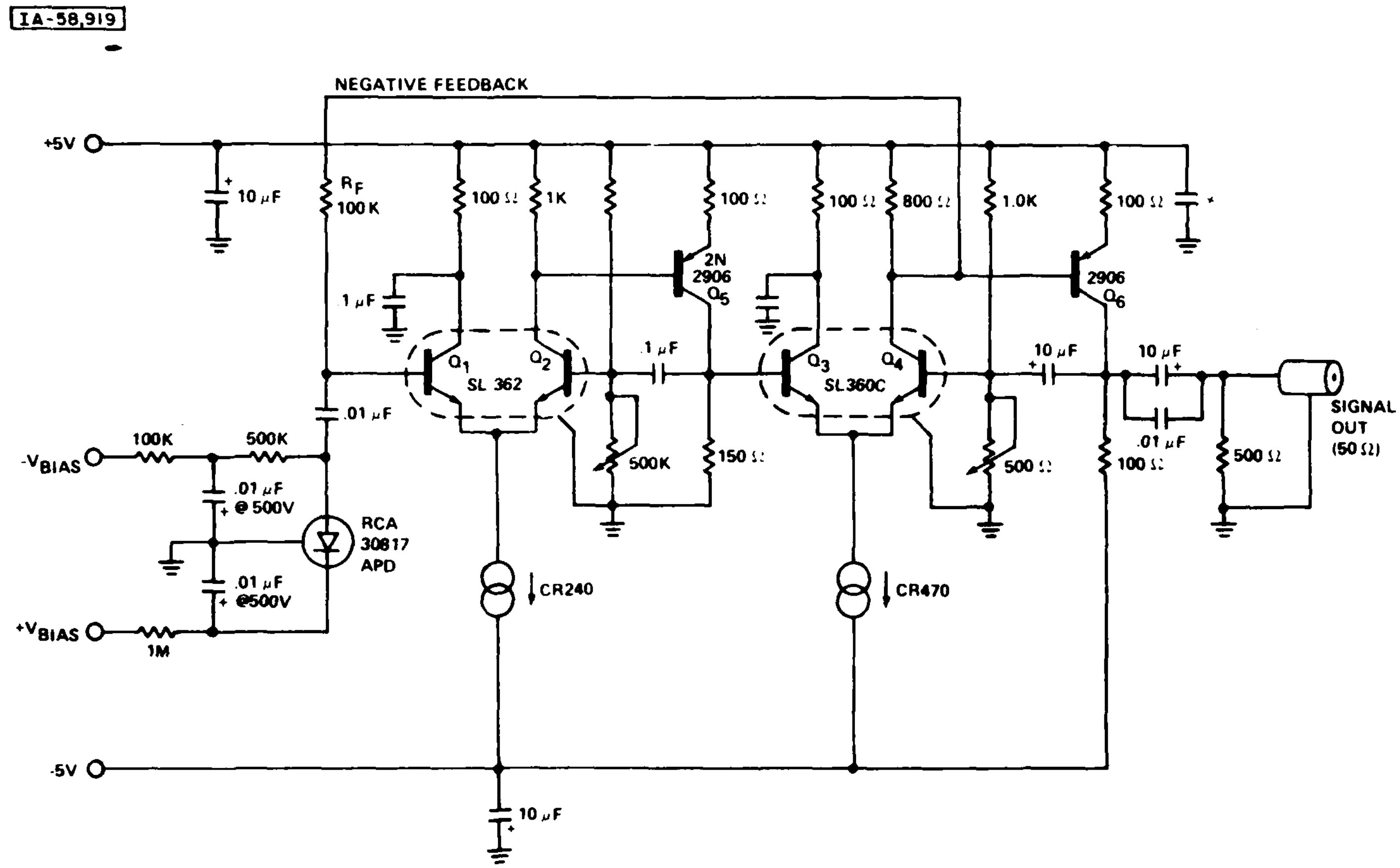


Figure 9. Prototype Ultra-High-Gain Wide-Band Transimpedance Preamplifier

The prototype circuit employs two low-noise/high-speed Plessey differential pair amplifiers to develop an open loop gain of approximately 2 x 10^6, or 130 dB. The first differential pair, Q_1 and Q_2, connected to the photodiode, uses a low noise design requiring 30 of the available 130 dB of open loop gain to reduce the input impedance of the amplifier, provide a relatively constant gain independent of component time/aging effects, and provide very wide-band/high-gain operation into the MHz region. At a bias of 1 mA, for example, provided by a constant current source CR240, and assuming an input impedance of 50 ohms, the noise figure (NF) of the first stage is set to about 2 dB. Negative feedback, provided by a second stage amplifier, optimized for high-speed, establishes the final closed loop gain of 100 dB. The output stage, Q_6, buffers the preamplifier when driving 50-ohm coaxial lines.

The choice of detector and bias supply is optional. A PIN, biased from the existing $\pm$5 V supplies, is considered suitable for moderate bandwidth systems where power availability is not particularly critical, while an APD is considered more appropriate for long-haul, high bandwidth systems where sensitivity requirements are more demanding. As designed, however, the photodetector may be biased from an existing or external power supply using either polarity or both. This flexibility combined with high gain, low noise, and the wide bandwidth capability of the preamplifier makes an ideal component for designing high performance fiber optic systems.

REFERENCES

1. E. J. Miskovic, P. W. Casper, Harris Corp., EOSD, May 1980, 27-33.

2. G. R. Elion, H. A. Elion, Fiber Optics in Communications Systems, Marcel Dekker, Inc., 1978, 245.

3. M. J. Howes, D. V. Morgan, Ed., Optical Fibre Communications, Wiley, 1980, 304.

4. C. P. Sandbank, Ed., Optical Fibre Communication Systems, Wiley, 1980, 347.

5. S. D. Personick, "Receiver Design for Digital Fiber Optic Communication Systems, II", IEEE Proceeding on Optical Fiber Technology, Edited by Detlef Gloge, IEEE Press, 1976, 402-420.

6. Technical Note R-1 on Optical Fiber Communications, Optical Fiber Communications Link Design, ITT, August 1978.

7. R. H. Buckley, "Photodetectors for Fiber Optics," IEEE Fiber Optics Lecture Series, RCA Electro Optics Dept., Quebec, Canada.

8. C. E. Hurwitz, "Detectors for the 1.1-1.6 μm Spectral Region," SPIE Proceedings, paper not yet published.

9. R. F. Leheny et al, "Integrated AlGaAs PIN FET Photoreceiver," Electronics Letters, Vol. 16. No. 10, 8 May 1980.

10. RCA Product Guide, Optical Communications Products - Solid State IR Emitters, Lasers, Photodiodes and Systems, OPT-115.

11. Plessy Optoelectronics and Microwave Ltd., Advanced Information for PIN with integrated FET, new product announcement.

12. EG&G Electro-Optics Division, MHz-Series High-Speed Photodiode/Amplifiers, Data Sheet D3009B-3.

MISSION
of
Rome Air Development Center

RADC plans and executes research, development, test and selected acquisition programs in support of Command, Control Communications and Intelligence (C^3I) activities. Technical and engineering support within areas of technical competence is provided to ESD Program Offices (POs) and other ESD elements. The principal technical mission areas are communications, electromagnetic guidance and control, surveillance of ground and aerospace objects, intelligence data collection and handling, information system technology, ionospheric propagation, solid state sciences, microwave physics and electronic reliability, maintainability and compatibility.

DATE
FILMED
-8