

ECE1371 Term Paper
Fiber Optic Preamplifier

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April 8, 2001

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1 INTRODUCTION

Optical communication is one of the hottest industries in the present. This paper talks about one of the major component in this communication system: the optical preamplifier. Some problems and requirements and the corresponding solutions are presented.

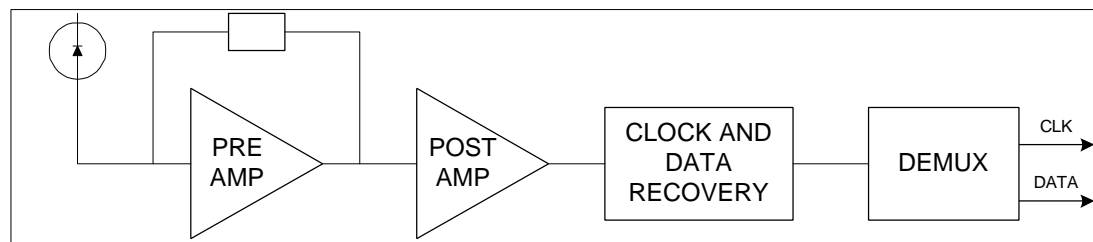
2 STANDARDS

The following table shows the specifications of some optical communication standards.

Standards	Bit Rate	Distance	Light Source
SDH/SONET	51.48 Mbps		
	155 Mbps		
	622 Mbps		
	2.5 Gbps		
	9.95 Gbps		
B-ISDN	622 Mbps		
HIPPI	6.4 Gbps	220m	
Gigabit Ethernet	1.25 Gbps	5 km	single mode
		550 m	multi mode
Fiber Distributed Data Interface (FDDI)	100 Mbps	2 km	single-attached multimode fiber with 1,300-nm LED source
		60 km	single-attached, single-mode fiber with high-power laser diode light source
Fiber Channel	10 Gbps	10 km	

3 STRUCTURE AND MAJOR COMPONENTS

The following block diagram shows some major components of a optical communication receiver.



3.1 Photodetector types

Photodetector commonly used in fibre optic applications are PIN and MSM types. The capacitance of the photodetector plays an important role in stability and bandwidth of a TIA. Its value is $C_{ph} = K_s \epsilon_0 A / L$.

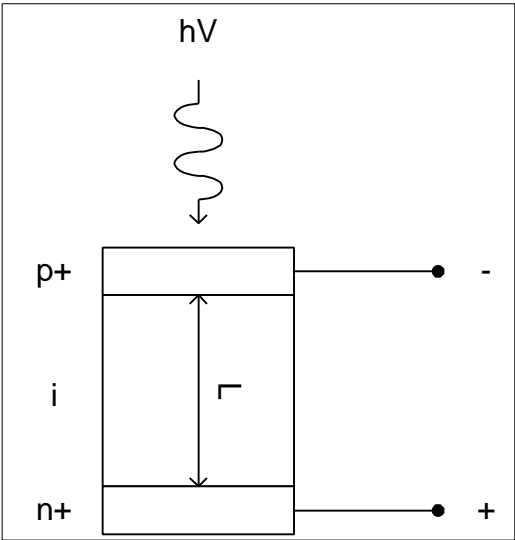
A and L is the cross section area and the length of the photodetector respectively.

3.1.1 PIN diode

PIN photodetector is a simple diode structure with heavily doped p- and n- regions separated by an intrinsic or near-intrinsic layer with a thickness $\leq 1/\alpha$, where α is the optical absorption coefficient of the intrinsic region. The structure of the photodetector will determine the -3dB frequency. According to [1],

$$f_{-3\text{dB}} = 5.2 V_h / (2 \pi L)$$

Where L is the thickness of the intrinsic and V_h is the hole velocity.

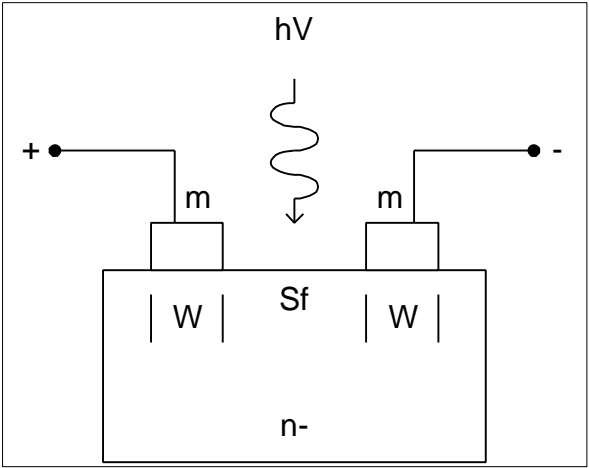


3.1.2 Avalanche (MSM)

An avalanche photodetectors are operated near the avalanche breakdown point. The structure of a MSM photodetector is shown in. The primary advantage of the avalanche of the avalanche photodiode is a photo-signal gain leading to improvement in the signal-to-noise ratio [2]. Again from [1],

$$f_{-3dB} = 4.2 V_h / (\pi^2 Sf)$$

Provided that Sf roughly equals to W .



3.2 Preamplifier

The most commonly used configuration in fibre optic preamp is a transimpedance amplifier. Transimpedance preamplifier converts the input current signal into a voltage signal by a feedback resistor.

3.3 Postamplifier

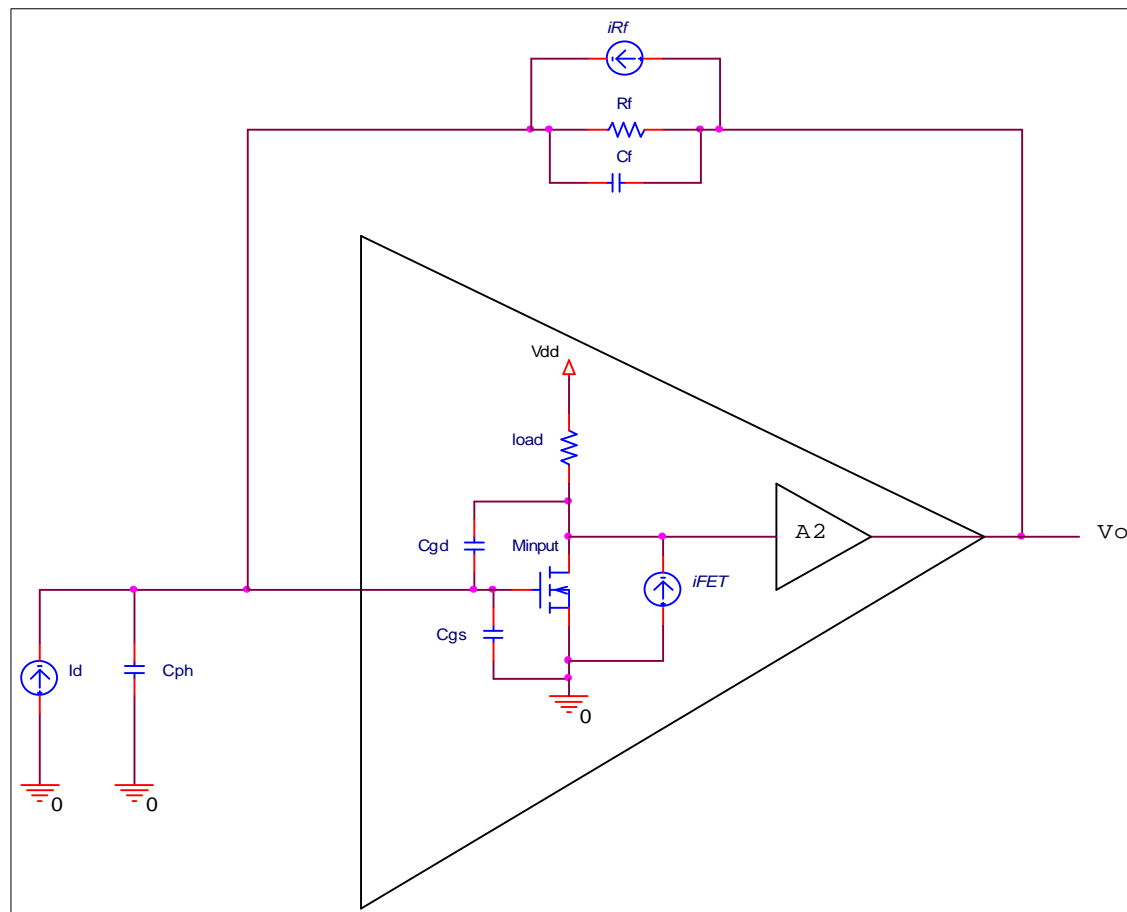
A postamp is usually a high gain limiting amplifier used after the preamp.

3.4 Clock/ Data Recovery (CDR)

This component is used to generate a clock signal base on the data stream. The clock and data signal are then ready to be processed.

4 PROBLEM AND REQUIREMENTS

4.1 Noise Sources



The major noise sources of a fibre optic transimpedance amplifier are

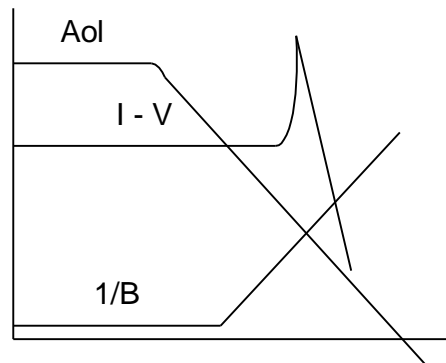
1. Feedback resistor thermal noise, $I_{Rf} = 4kT/R_f$
2. Input FET noise, $I_{FET} = 4kT/3 g_m$ [3]

4.2 Bandwidth [4]

The bandwidth of the TIA depends on the:

- 1) Open loop gain of the amplifier, A_{OL}
- 2) Feedback transfer function, $\beta = 1 / (1 + R_f (C_{ph} + C_{gs}) s)$

This function is relating to the diode capacitance, gate-source capacitance of the input FET of the amplifier, feedback resistor. Using the following model, the feedback transfer function can be approximated as follows:



Using a single-pole open loop gain amplifier model, the I-V rolls off by 40dB per decade when the open loop gain becomes less than the feedback. The -3dB point of the I-V curve defines the bandwidth of the TIA.

From the analysis, we can see that if we want to maximize the bandwidth, R_f should be kept low. This is conflicting to the noise requirement where R_f should be kept high to reduce noise.

4.3 Stability

Using the same model from the bandwidth analysis, the TIA is possible to oscillate at the point where $1/\beta$ intersects with A_{OL} . The dominant pole of A_{OL} gives the I-V transfer function 90 degrees phase shift. Another 90 degrees is generated by the pole of $1/\beta$. Together with 180 degrees from the negative feedback of the amplifier, the oscillation occurs when $1/\beta$ equals A_{OL} . The previous plot shows a gain peaking when $1/\beta$ equals A_{OL} .

4.4 Dynamic Range/ Sensitivity

Optical communication can be operated in a time division multiplexing mode (TDM). This means more than one user's data will be interleaved together in different time slots. Long strings of one's and zero's may occur in the data packets. This results in wide range of input signal amplitude. This means the preamp must handle the data packet as burst data. Variable offset and input amplitude could appear in the input of the preamp. This requires instantaneous response, wide dynamic range and high sensitivity.

4.5 Cost

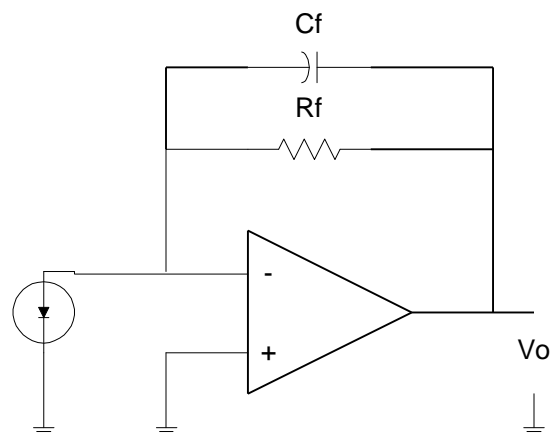
Fibre optic preamp is used in every switcher or computer that is connected to the optical network. It would be a marketing advantage to use standard, inexpensive technology with no external components in the preamp design to drive the cost down.

5 CIRCUITS

This section will talk about some methods and sample circuits that resolve the problems and requirement of a fibre optic preamp explained in section 4.

5.1 Phase compensation [4]

In order to resolve the stability problem, capacitor is added in the feedback path.



This adds a zero in the $1/\beta$ function.

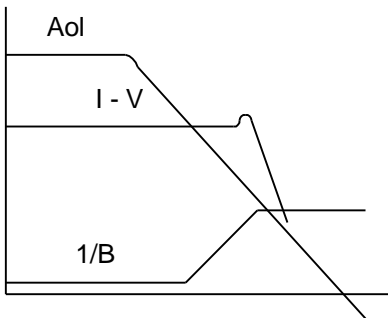
$$\beta = (1 + R_f C_f s) / (1 + R_f (C_{ph} + C_{gs} + C_f) s)$$

The addition of a capacitor gives a better phase margin. The value of the capacitor is determined as follows:

$$C_f = \text{SQRT} (C_{ph} + C_{gs} / 2 \pi R_f f_c)$$

for 45 degrees of phase margin and f_c is the unity gain frequency of the amplifier.

The bandwidth of the TIA is now enhanced by roughly 1.4 times. The following plot shows the resulting I-V plot.



5.2 Noise Minimization

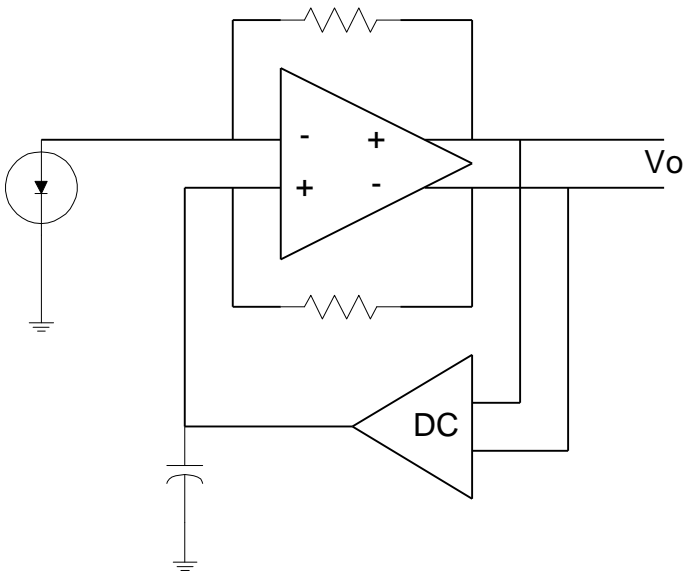
From [5], $i^2_{eq}(\text{min}) \propto w_B^2 C_{ph} / A$. This happens when $0.2 C_{ph} < C_g < 2 C_{ph}$. This gives constraint on the size of the input FET ($C_g = 2/3 W L C_{OX} + W L_{OV} C_{OX}$).

5.3 Variable Input Offset

To resolve this problem, the reference voltage of the input signal has to be adjusted to react to the changing input amplitude.

5.3.1 Feed Back Automatic Offset Control [6]

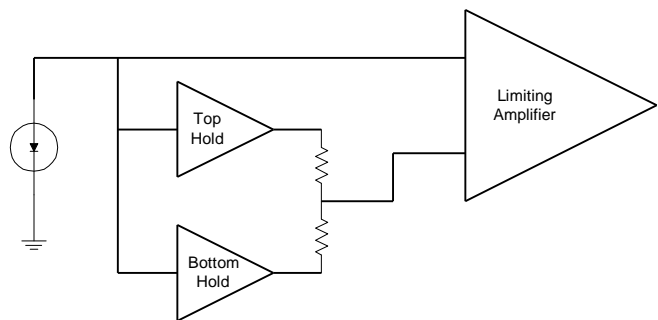
The block diagram of preamp is as follows:



A DC amplifier is connected to the output of the TIA. The output of the DC amplifier is then feed to the reference of the TIA input. A capacitor is used for decoupling.

5.3.2 Feed Forward Automatic Bias Control

As oppose to using feed back control, [7] suggested to use a feed forward technique to resolve the problem. The idea is to hold the maximum and minimum input signals and generates the reference voltage by averaging the two. The following block diagram shows the generalized circuit of the feed forward technique:



The signal and reference are then connected to a limiting amplifier which provides a desired voltage level.

In order to have high sensitivity, the gain needs to be very high. In [7], 3 stages of the automatic bias control circuit are connected in series to improve the sensitivity.

5.4 Varying Input Amplitude

To react to changing input signal amplitude, (1) variable gain or (2) high gain limiting amplifier can be used to resolve.

5.4.1 Automatic Gain Control (AGC) [8]

The idea of the circuit is to use a variable feedback resistor to adjust the gain of the preamp. When the input signal amplitude is strong, the feedback resistance is lowered to reduce the gain.

When the input signal is weak, the feedback resistance is increased to increase the gain. The following diagram shows a sample way to implement a variable resistor.

One way to implement a variable resistor is by biasing a transistor in triode region. The principle of controlling the resistance of a transistor relates to the following:

$$r_{ds} = dV_{DS} / dI_D = 1 / (\mu C_{OX} W / L (V_{GS} - V_t - V_{DS}))$$

The transistor's resistance is therefore be controlled by the varying V_{GS} .

5.4.2 Limiting Amplifier [7]

The idea of the circuit is to use a high gain amplifier to amplify a varying input signal to a certain level. Therefore, this limiting amplifier is operating in a non-linear mode. The advantage of this design is the high gain of the limiting stage can compensate for gain loss in the transimpedance stage at high frequency.

6 CONCLUSION

The development of optic communication standard has driven the design of the fibre optic preamp from 29Mbps [8] to 43Gbps [6]. Although CMOS technology is one of the most popular technologies these days, bipolar is still a main stream for fibre optic preamp design. As CMOS technology keeps advancing in speed, we shall see more preamp design utilizing it.

7 REFERENCE

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