Adaptive Transversal Preamplifier for High Speed Lightwave Systems

A. P. Freundorfer, *Member, IEEE*, D. H. Choi, and Y. Jamani

***Abstract*—A nine-tap transversal preamplifier using cascode MESFETs in a distributed structure has been designed for pulse shaping data, AGC and group delay control in high speed lightwave systems. The circuit was fabricated in a microwave monolithic integrated circuit (MMIC) implementation using 0.8 μm GaAs MESFET technology. The AGC capability was demonstrated. The best noise measured for this preamplifier was 15 pA/$\sqrt{\text{Hz}}$.**

I. Introduction

To compensate for distortion in long haul lightwave transmission, equalizers in the form of a tapped delay line filter can be used between the preamplifier and the threshold detector. This tailors the pulse shape at the input of the decision circuitry, thereby improving the receiver sensitivity. Recently, experiments have shown that an 11 dB improvement could be obtained in a 10 Gb/s long haul system to compensate for the effects of polarization-mode dispersion (PMD) by using tap delay line filters [1], [2].

Transversal filters that have been designed for lightwave systems have been reported [3], [4] but suffer from limited band shape control. An adaptive four-tap SiGe equalizer [2] was reported in a 10 Gb/s system that showed a 5 dB improvement on the receiver sensitivity. A five-tap equalizer microwave monolithic integrated circuit (MMIC) with cascode gain block [5] was designed and demonstrated adaptive pulse shape control. The principle of [5] has been extended and presented here as a transversal preamplifier with nine-taps. It is now capable of preamplification, AGC and group delay control on a single chip. This conceptual idea was first expressed in [7] but no measured results were given.

II. Theory

The wide bandwidth of the distributed amplifier (DA) structure makes it an attractive component for use in high-speed lightwave systems [6]. As a distributed preamplifier, the noise and gain characteristics are often superior to those of more traditional methods of preamplification [6]. Using the same structure, a transversal preamplifier can be constructed, as shown in Fig. 1. It differs from the distributed preamplifier in that the output is taken at the opposite end of the drain line. Gain and pulse shape control is achieved by individually controlling the transconductance gains (tap weights) of the gain blocks [5]. From input to output, the signal has to travel to and from the gain blocks along the distributed gate and drain lines, and for each gain block, the delay to the output is different. It is easy to show, by superposition of the output voltages for a given input voltage, that the frequency response is the same as a transversal tap delay line filter [3]–[5]. The pulse shaping capability of this type of circuit was shown in [5].

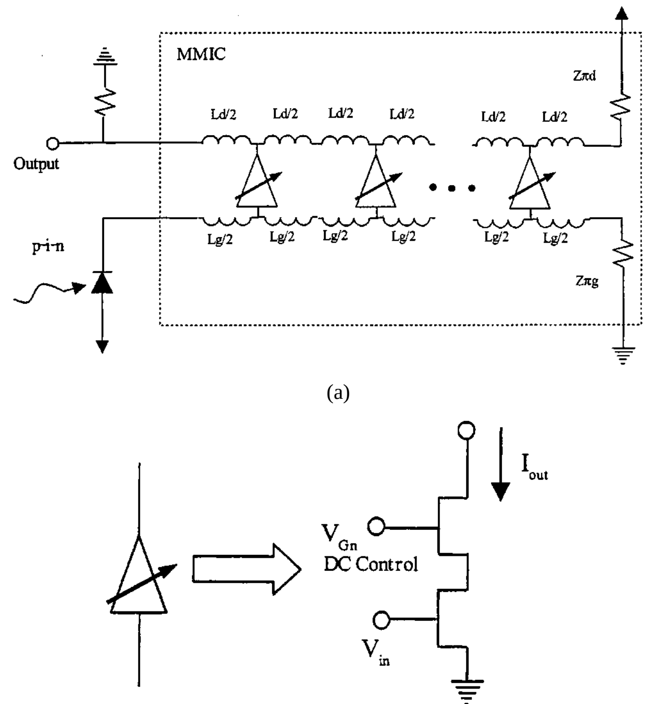

Fig. 1. (a) Distributed transversal preamplifier. (b) Variable gain block.

Referring to Fig. 1, the inductance L_g and the input capacitance C_{in} of the cascode amplifier form a transmission line with impedance $Z_{\pi g} = \sqrt{L_g/C_{\text{in}}}$. Similarly, the drain line impedance is given by $Z_{\pi d} = \sqrt{L_g/C_{\text{out}}}$ and C_{out} is the output capacitance of the cascode amplifier. The gate and drain lines were matched to $Z_{\pi g}$ and $Z_{\pi d}$ to keep the input and output of the transversal preamplifier matched over a large bandwidth. The transimpedance gain can be given by

$$Z_r = -\frac{1}{2} Z_{\pi g} Z_{\pi d} \sum_{i=1}^{N} g_{mi} e^{-j(2i-1)\phi} \quad (1)$$

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where

- g_{mi} transconductance of the ith stage which can be individually controlled [5];
- N number of stages;
- $\phi = \omega\sqrt{L_g C_{\text{in}}} = \omega\sqrt{L_d C_{\text{out}}} = \omega\tau_g = \omega\tau_d$.

Using noise analysis similar to [6], it can be shown that the modeled equivalent input noise current is given by (2), shown at the bottom of the page, where

$$Z_f = -\frac{1}{2} Z_{\pi g} Z_{\pi d} e^{-jN\phi} \sum_{i=1}^{r} g_{mi},$$

$$|i_{Z_{\pi g}}|^2 = \frac{4kT}{Z_{\pi g}}, \quad \text{and} \quad |i_{Z_{\pi d}}|^2 = \frac{4kT}{Z_{\pi d}},$$

$$A(r,\phi) = \Re e\{C(r,\phi)+1\}, \quad \text{and}$$

$$B(r,\phi) = \Im m\{C(r,\phi)\}$$

$$C(r,\phi) = \frac{\sum_{i=1}^{r} g_{mi} + \sum_{i=1}^{N-r} g_{mr+i} e^{-j(2i)\phi}}{\sum_{i=1}^{N-r} g_{mi} e^{-j(2i-1)\phi}}.$$

k is Boltzmann's constant and T is in degrees Kelvin. The first two terms in (2) are the noise contributions due to the terminations $Z_{\pi g}$ and $Z_{\pi d}$. The remaining contributions are the noise sources produced by the two MESFETs. $|i_g|^2$ and $|i_d|^2$ are the gate and drain noise of the MESFETs and $i_{gr} i_{dr}^*$ is the correlation between the sources [8].

III. Results

A fractionally spaced nine-tap transversal preamplifier MMIC with cascode gain block was designed using the same principle in [5] and was constructed in a 0.8 μm self-aligned gate process. The MESFET had the following process parameters: $V_p = -1.2$ V, $I_{\text{dss}} = 120$ A/mm, $f_t = 20$ GHz. The transversal preamplifier chip was then wire bonded to a 35 mm p-i-n photodiode. With $L_d = 1.25\,\text{nH} = L_g$ and $C_{\text{in}} = 500\,\text{fF} = C_{\text{out}}$ the delay difference, between gain blocks, of the gate and drain line were made to be identical and given by $\tau_g = \tau_d = 25$ ps which gives a total delay $\tau = \tau_g + \tau_d = 50$ ps. C_{in} and C_{out} were obtained by adding additional capacitance to the input and output of the cascode. This also gives a $Z_{\pi g} = 50\ \Omega = Z_{\pi d}$. The maximum transconductance of the cascode was $g_{mi\,\text{MAX}} = 30\ \text{m}\Omega^{-1}$. A photograph of the nine-tap transversal preamplifier chip is shown in Fig. 2. Each tap weight is controlled by changing the applied voltage V_{Gn} to the common-gate transistor of the cascode. Measured AGC capability is shown in Fig. 3. It can be seen that the above cascode transversal filter cannot only

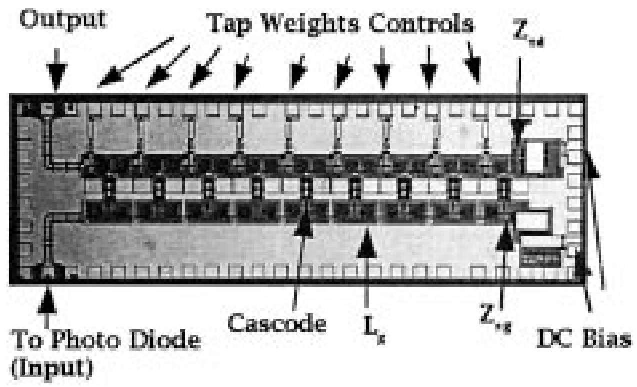

Fig. 2. Photo of nine-tap transversal preamplifier.

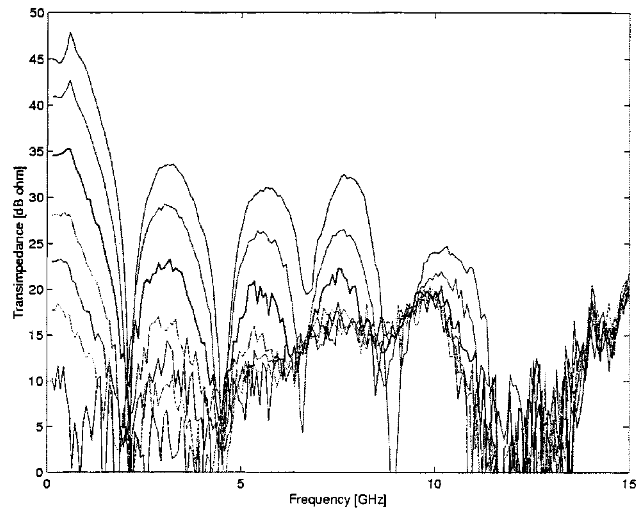

Fig. 3. Measured AGC capability of the nine-tap transversal preamplifier.

$$\sqrt{|i_n|^2} = \sqrt{\begin{aligned} &\frac{|i_{Z_{\pi g}}|^2}{4}\left|1+\frac{Z_f}{Z_r}e^{jN\phi}\right|^2 + \left|\frac{Z_{\pi d}}{Z_r}\right|^2 \frac{|i_{Z_{\pi d}}|^2}{4} \\ &+ \sum_{r=1}^{N}\left(A^2(r,\phi)+B^2(r,\phi)+\left|\frac{Z_{\pi d}}{Z_r}\right|^2 \frac{1}{\left(1+\left(\frac{f}{f_T}\right)^2\right)}\right)\frac{|i_{gr}|^2}{4} \\ &+ \frac{1}{2}\sum_{r=1}^{N}\Re e\left(i_{gr}i_{dr}^*\left\{\frac{Z_{\pi d}^*}{Z_r^*}(A(r,\phi)+jB(r,\phi))\frac{1}{\left(1-j\frac{f}{f_T}\right)} + \left|\frac{Z_{\pi d}}{Z_r}\right|^2 \frac{-j\frac{f}{f_T}}{\left(1+\left(\frac{f}{f_T}\right)^2\right)}\right\}\right) \\ &+ \sum_{r=1}^{N}\left|\frac{Z_{\pi d}}{Z_r}\right|^2 \frac{|i_{dr}|^2}{4} \end{aligned}} \quad (2)$$

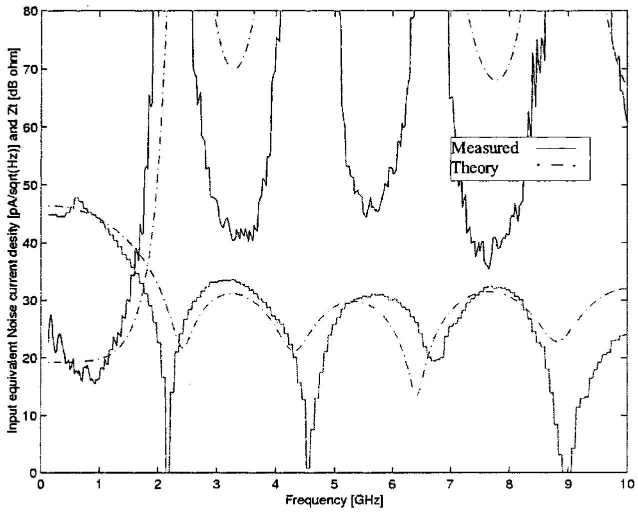

Fig. 4. Measured and theoretical transimpedance gain and equivalent input noise current density.

change the bandwidth and pulse shape [5] of the circuit, but is also capable of AGC and group delay [8]. The gain control comes from the gain block, whereas the phase shift control comes from the distributed structure in conjunction with the gain control of the gain block.

Fig. 4 shows the theoretical transimpedance gain and noise performance as given by (1) and (2) and the measured performance of the nine-tap transversal preamplifier. The dominant noise source is the gate line termination $Z_{\pi g}$. The highest bit rate of this type of circuit is 5 Gb/s [5] with adaptive pulse shaping characteristics similar to [5]. If we take an average noise of 18 pA/$\sqrt{\text{Hz}}$ across the band, then the predicted receiver sensitivity at 5 Gb/s would be -17 dBm. The performance of the circuit can be improved by increasing $Z_{\pi g}$ [6]. This would reduce the noise of the receiver. Furthermore using a higher technology, for example PHEMT, this class of circuit could be used at higher data rates.

IV. Conclusion

A fractionally-spaced preamplifier using cascode MESFETs and a distributed structure for pulse shaping has been designed for use in high speed lightwave systems. The capability of the technique is demonstrated with a MMIC implementation using 0.8 μm GaAs MESFET technology. The AGC capability of the transversal preamplifier was demonstrated and the best noise measured for this preamplifier was 15 pA/$\sqrt{\text{Hz}}$.

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