Broadband GaAs Monolithic Equalizing Amplifiers for Multigigabit-Per-Second Optical Receivers

H. Kikuchi, Y. Miyagawa*, and T. Kimura

NTT LSI Laboratories
3-1, Morinosato, Wakamiya, Atsugi-shi,Kanagawa Pref., 243-01, Japan
* NTT Transmission Systems Laboratories
1-2356, Take, Yokosuka, Kanagawa Pref., 238, Japan

ABSTRACT

A preamplifier IC, a gain controllable IC, and main amplifier ICs with and without a three-way divider for multigigabit-per-second optical receivers have been developed using a single-ended feedback circuit, two peaking techniques, and advanced GaAs process technology. These ICs have a 3-dB bandwith of more than 5 GHz and can be applied to optical receivers transmitting NRZ signals in excess of 7 Gb/s.

INTRODUCTION

High-speed systems must be developed to support large-capacity optical transmission systems.[1] A key component to realize these systems is an equalizing amplifier for implementation in optical receivers. To push up the speed of amplifiers, monolithic integration is necessary not only to improve performance and reliability but also to reduce the size and cost. GaAs IC technology is particularly attractive to play this role because of its wideband, low-noise capabilities in the microwave region. So far, considerable attention has been focused on preamplifier ICs.[2] A GaAs equalizing amplifier IC set capable of operating up to 2.4 Gb/s has also been described for application in next-generation systems.[3] These ICs are expected to be instrumental in the higher frequency region.

In this paper, we describe the circuit designs for GaAs equalizing amplifier ICs -- a preamplifier, a gain-controllable amplifier, and main amplifier ICs -- using a single-ended feedback circuit and peaking techniques to be proposed. The performance of the fabricated ICs are also evaluated.

OPTICAL RECEIVER CONFIGURATION

A block diagram of a optical receiver system is shown in Fig.1. The preamplifier, gain-controllable amplifier, and main amplifier with three-way divider are integrated by GaAs process technology. This set of ICs is needed to transform the small output current of the photodiode into sufficient output voltage to operate the decision circuit. Out of a consideration for the equalizing amplifier gain and stability of the ICs mounted in the package, the voltage gain of each amplifier is designed to be as about 20 dB.

CIRCUIT DESIGN

To realize high-frequency performance of the amplifier ICs, a single-ended feedback circuit[4] is applied. Two peaking techniques are introduced for the first time, one using a spiral inductor and the other an MIM (Metal-Insulator-Metal) capacitor. In addition, two MMIC techniques have been applied: (1) coplanar waveguides are used to reduce the coupling effect between adjacent lines, (2) airbridges are applied to decrease the stray capacitance between the first and second layer lines.

The preamplifier circuit is shown in Fig.2. It is implemented in two stages, each consisting of a common source circuit (CS) with a source follower (SF). The output impedance matching is realized with a CS. To obtain wide bandwidth and optimize the input impedance and noise characteristics, parallel feedback was applied. Furthermore, inductor peakings are applied to the drain in the CS and the gate in the SF. Three level shift diodes are inserted in the SF to deliver proper dc bias to the CS. Diodes are fabricated using an FET produced using a conventional GaAs process. Resistance components of the diodes degrade the frequency performance of the SF. To correct this problem, a capacitor is inserted parallel with the diodes so that ac signals bypass the diodes. This arrangement permits in an increase in high-frequency gain and expansion of the bandwidth. The simulated effect of the peaking technique is shown in Fig.3. In the figure, curves (a), (b), and (c) show simulated results without peaking, with inductor peaking, and with both inductor and capacitor peaking, respectively.

The gain controllable (GC) amplifier adopts basically the same configuration as the preamplifier shown in Fig.4. The gain of the amplifier is controlled by varying the transconductance gm of the FET of the output stage with control voltage V_{GC} . To get the RF ground in the high frequency region, an MIM capacitor has been inserted between the source and the ground.

The output of the main amplifier must be divided among decision, timing, and gain-controller circuits. Amplifiers with a three-way divider applying resistors and FETs have been studied. Since the output power of the amplifier with the divider using FETs is greater than that of the one using resistors, we designed a main amplifier with three-way divider using a common source circuit.The configuration of the circuit is shown in Fig.5. To maximize the isolation between the three outputs, output lines were fabricated using the coplanar waveguide technology.

CIRCUIT FABRICATION AND PERFORMANCE

The amplifier ICs were fabricated by advanced SAINT (Self-Aligned Implantation for N^+ - layer Technology) process.[5] A GaAs advanced SAINT FET has a gate length of 0.3 μm , a gm of more than 200 mS/mm, a maximum oscillation frequency of more than 65 GHz, and a noise figure of 2 dB at 10 GHz.

The frequency characteristics (S_{21}) of the preamplifier were measured at 8.6 GHz for the 3-dB bandwidth. The amplifier gain (S_{21}) was 19 dB, which corresponds to a transimpedance of 55 dBΩ, as shown in Fig.3. S_{22} was less than -11 dB to beyond 10 GHz. The equivalent input noise current density (I_{eq}) was estimated from noise figure measurements: the averaged I_{eq} from dc to 7 GHz was 20.9 pA/√Hz. The frequency response of the preamplifier with InGaAs pin photodiode was measured by optical heterodyne detection[6], as shown in Fig.6. 7 GHz was obtained for the 3-dB bandwidth. Evaluating the eye-diagram and bit-error-rate (BER) performance of the preamplifier for 10-Gb/s NRZ optical pulses, a measured sensitivity of -12 dBm was obtained for a BER of 10^{-9}

The frequency characteristics of the gain-controllable (GC) amplifier are shown in Fig.7. For a gain ranging from -10 to 15 dB, a 3-dB bandwidth of 6.1 GHz was obtained. S_{11} and S_{22} were less than -8 dB and -10 dB below 6.1 GHz, respectively. The GC amplifier was mounted in a newly developed metal package. Coplanar waveguide alumina ceramic substrates are fixed in the package. 1000-pf-MIM-bypass capacitors are located immediately adjacent to the chip to reduce bonding-wire inductance.[4] A microphotograph of the IC package is shown in Fig.8. The package measures 15x15 mm^2.

Main amplifiers with and without the three-way divider were fabricated. A microphotograph of the amplifier with the divider is shown in Fig.9. The chip size is 1.5x2.5 mm^2. Frequency characteristics of the amplifiers are shown in Fig.10. The 3-dB bandwidth of the amplifiers with and without the divider were 5.2 GHz and 6.7 GHz, respectively. Gains of the devices were 17.4 and 21.2 dB, respectively. The gain differences among the three outputs above 5 GHz depends on how the IC is packaged. Taking a measurement from the wafer, a difference of less than 0.5 dB was obtained. Output powers at 1-dB gain compression were 5 dBm and 9.5 dBm for the amplifiers with and without the divider, respectively. Eye-diagram performance of the GC and main amplifiers were evaluated, and good eye-openings were obtained for 7-Gb/s NRZ signals.

CONCLUSION

GaAs amplifier ICs, key components for application in optical receivers have been developed using the advanced SAINT process. To realize high-frequency performance, a single-ended feedback circuit and two peaking techniques were introduced. These ICs have a 3-dB bandwidth of more than 5 GHz and are applicable to optical receiver systems transmitting NRZ signals in excess of 7 Gb/s.

ACKNOWLEDGEMENT

The authors wish to thank K. Hagimoto and Y. Hakamada for their helpful discussions and suggestions. They also wish to express their appreciation to K. Fujisaki, K. Nakagawa and K. Takemoto for their encouragements and supports.

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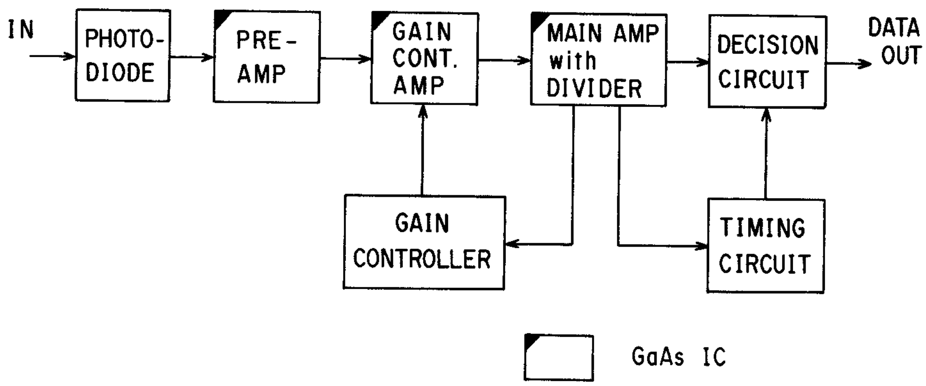

Fig.1 Block Diagram of Optical Receiver System

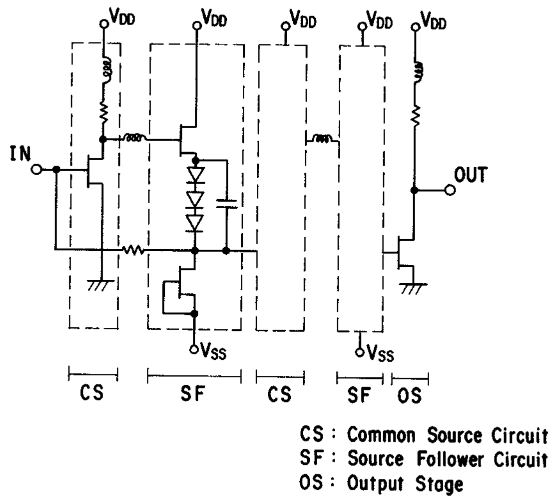

Fig.2 Circuit Configuration of Preamplifier

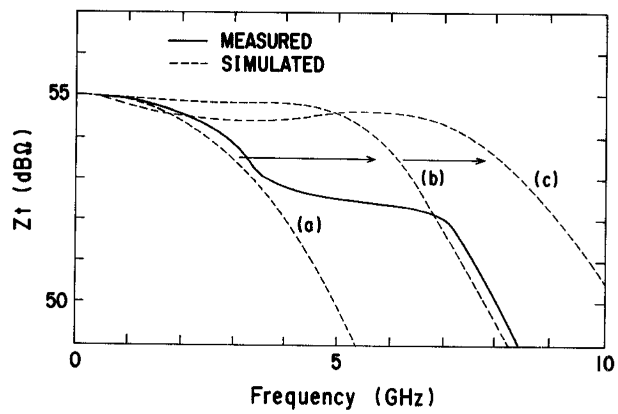

Fig.3 Frequency Characteristics of Preamplifier with and without Peaking
(a) without Peaking, (b) with Inductor Peaking
(c) with Both Inductor and Capacitor Peaking

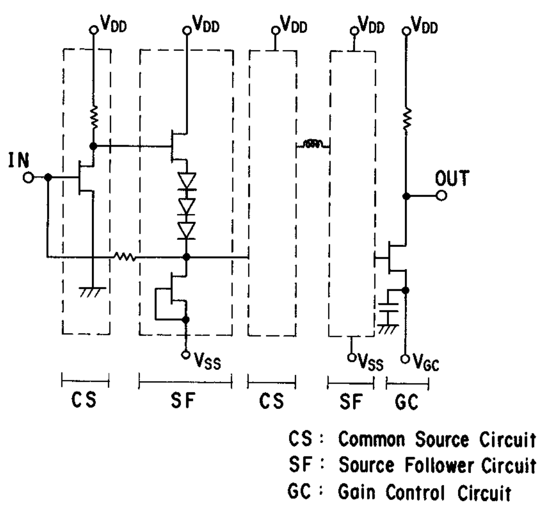

Fig.4 Circuit Configuration of Gain-Controllable Amplifier

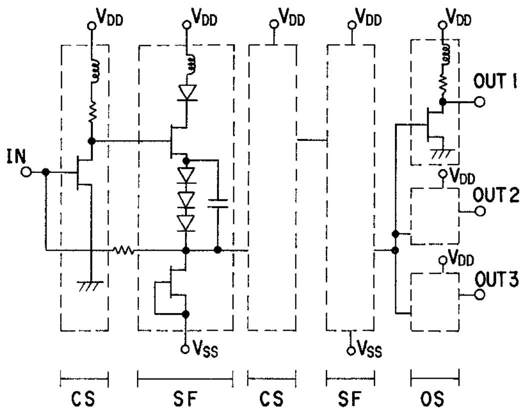

Fig.5 Circuit Configuration of Main Amplifier with Divider

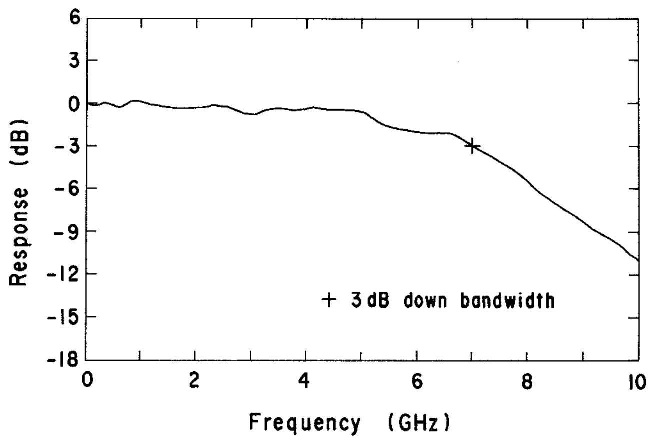

Fig.6 Frequency Response of Preamplifier with Pin Photodiode

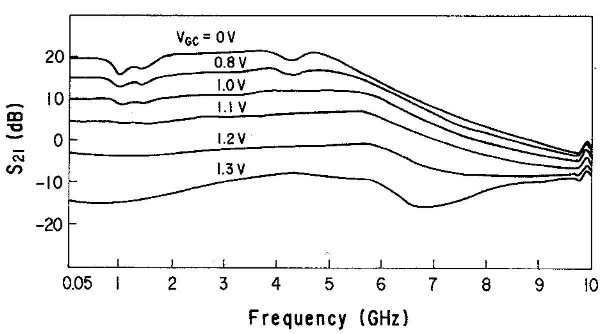

Fig.7 Frequency Characteristics of Gain-Controllable Amplifier

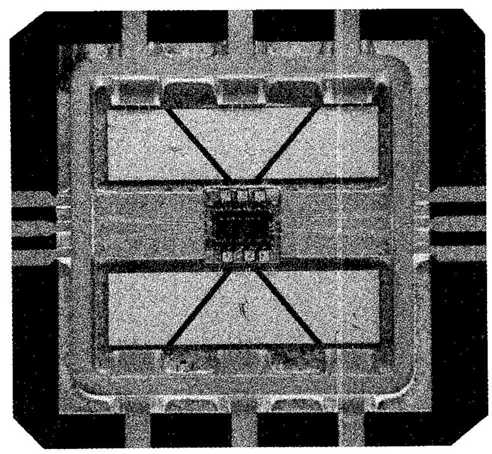

Fig.8 Microphotograph of IC Package

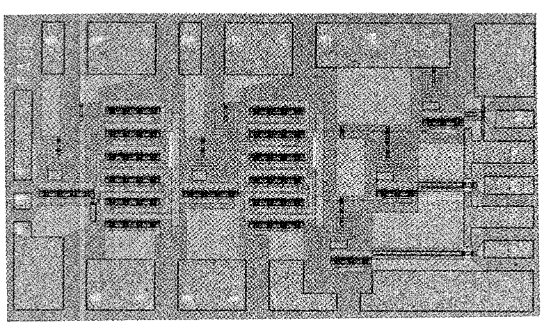

Fig.9 Microphotograph of Main Amplifier with Divider

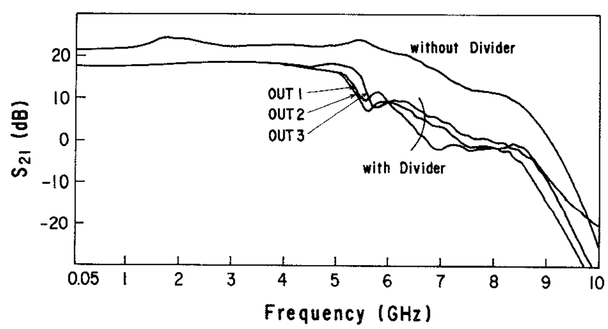

Fig.10 Frequency Characteristics of Main Amplifiers