A DC-to-100-GHz InP HEMT 1 : 2 Distributor IC Using Distributed Amplification

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***Abstract*— This letter describes a 1 : 2 distributor IC for future very-high-speed optical communication systems. Wideband performance is obtained by applying a distributed amplification technique to a differential circuit. This IC uses a 0.1-μm-gate-length InAlAs/InGaAs/InP HEMT and a coplanar-waveguide technology. It has a 3-dB bandwidth of 100 GHz with a low-frequency gain of −2.5 dB. Up to 100 GHz, return loss and isolation are better than −10 dB and −20 dB. We believe the bandwidth is the widest ever reported for multi-RF-port wideband IC's.**

I. Introduction

Very-high-speed optical fiber transmission systems are expected to be the backbone of future multimedia communications, and high-speed integrated circuits will be the key components to these systems. Ten-Gb/s IC's and their modules have been developed in the last few years, but there is now increasing demand for bit rates above 40 Gb/s. Jumping beyond 40 Gb/s, however, is a real challenge, and we should find innovative ways of greatly improving the old technologies. The design for optical-communication IC's is traditionally based on a low-frequency, lumped-element design techniques. But, because our target speed is in the millimeter-wave region, we should replace the design with a new mixed baseband and microwave design that incorporates microwave design techniques into the traditional lumped-element circuits. We need transistors that perform at more than 120 GHz in order to make essential components of optical-communication systems, so the device technology should be based on millimeter-wave devices. The InP HEMT is one of the best candidates because of its inherent millimeter-wave performance, and we have already developed a number of key-component IC's using 0.1–0.15 μm-gate-length InP HEMT's and new design techniques: a dc-32-GHz preamplifier [1], a 34–40-GHz limiting amplifier [1], a dc-38-GHz distributed Gilbert cell [1], and a dc-90-GHz distributed baseband amplifier [2]. We also reported a 40.4-GHz static frequency divider using novel recess-etch stopper and pn diode level shifter technologies [3]. In this letter we describe a dc-100-GHz 1 : 2 distributor IC, which also has the important role of distributing signals in optical-communication systems. A feature of the circuit design is the application of a distributed amplification technique to a differential circuit in order to enhance wideband performance.

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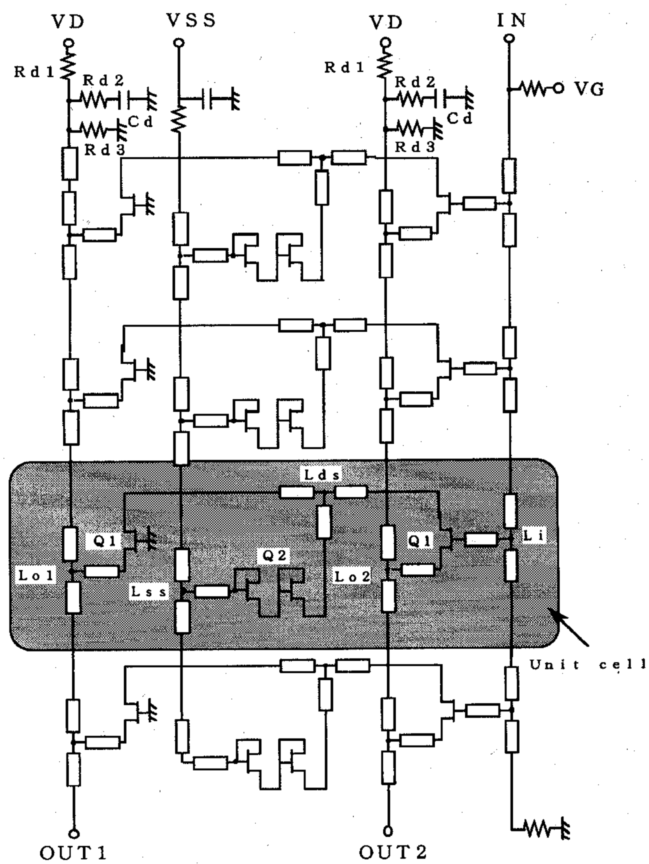


Fig. 1. Schematic circuit of the 1 : 2 distributor circuit.

II. Circuit Design

A schematic circuit of the 1 : 2 distributor IC is shown in Fig. 1. We used a differential circuit to provide two output signals. A distributed amplification technique was applied to obtain the wideband operation. Source-coupled FET's Q1 and current-source FET Q2 form a unit differential circuit. Input and output artificial lines were formed by coplanar waveguide (CPW) transmission lines (Li, Lo1, and Lo2) and capacitances of FET's Q1. These artificial lines provide wideband gain response and impedance matching. The differential configuration also needs extra lines (Lds and Lss) for source-coupling FET's Q1 and biasing the current-source FET Q2. We also carefully designed these lines using CPW lines to optimize the frequency characteristics. Characteristic impedances of the transmission lines were designed to be 75 Ω for Lo2 and 50 Ω for Lo1, Li, Lds, and Lss. Using high characteristic impedances improves the performance of

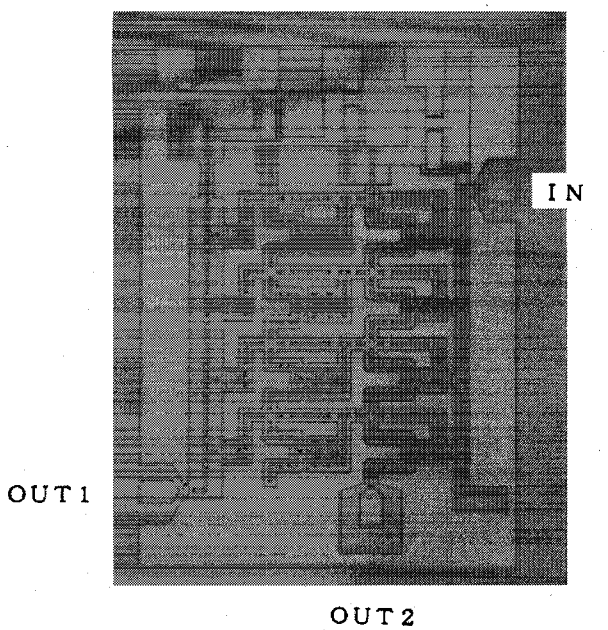


Fig. 2. Microphotograph of the 1 : 2 distributor IC.

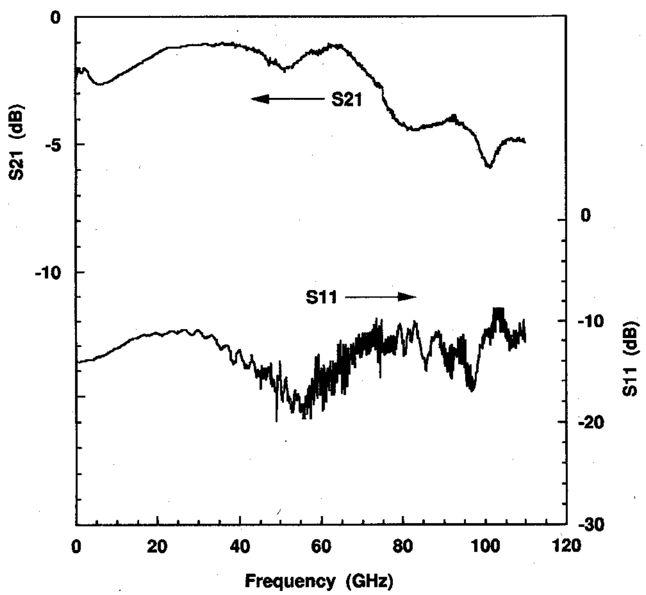


Fig. 3. Frequency dependence of S21 and S11.

the distributed circuit, but then the dense CPW-line layout hampers the high-impedance lines of wide signal-ground gaps because the ground plane between the lines becomes too small to maintain the isolation.

For optical communication systems the circuits should operate from kHz frequencies because data signals have low-frequency spectra. This means that the distributor IC needs to keep a flat gain from low frequencies. We therefore introduced frequency-dependent terminations using a capacitor-resistor network (Rd1, Rd2, Rd3, and Cd) instead of the conventional resistor terminations for output artificial lines [4]. For the resistor termination, gain is degraded in the frequency range below several GHz because of the effect of the FET's drain conductance. The frequency-dependent termination, however,

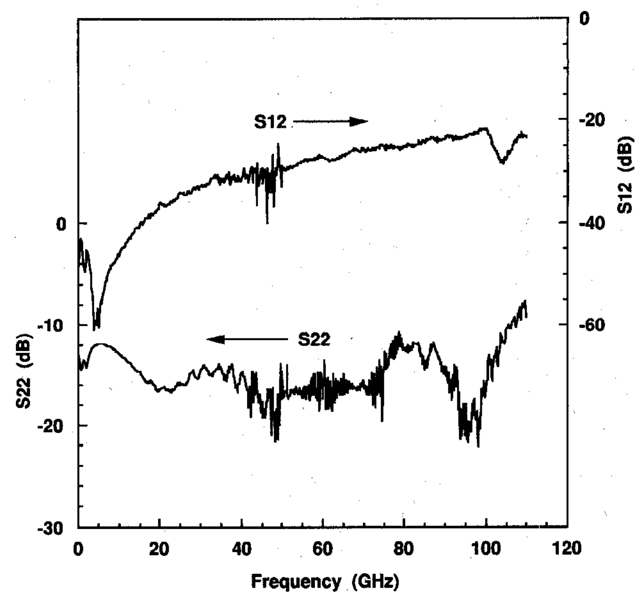


Fig. 4. Frequency dependence of S22 and S12.

compensates the degradation and maintain a flat gain response even at low frequencies.

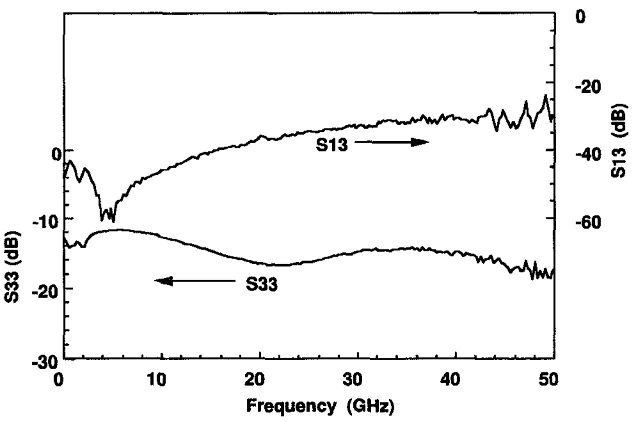
Detailed design was done using a device model with $fT = 160$ GHz and $gm = 1.3$ S/mm. Gate widths of Q1 and Q2 were 25 and 50 μm, respectively. The designed 3-dB bandwidth was 110 GHz for output 1 and 80 GHz for output 2. The bandwidth for output 2 is narrow because the characteristic impedance of Lo2 is lower than that of Lo1. The low-frequency gain was 0 dB, while the gain difference between two outputs was within 1.5 dB below 80 GHz.

III. Fabrication

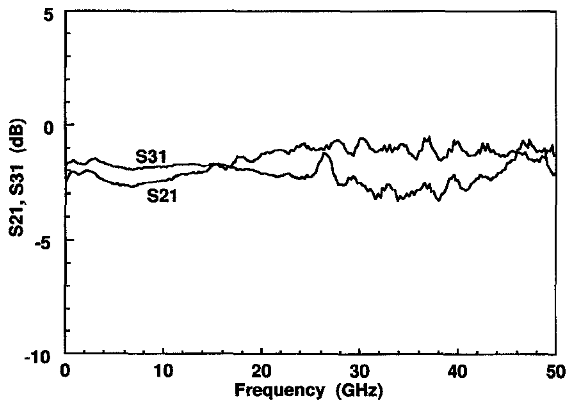
Integrated circuits were fabricated using an InAlAs/InGaAs/InP HEMT with a gate length of 0.1 μm and with a threshold voltage of about -0.4 V [5]. A microphotograph of an IC is shown in Fig. 2. Chip size is 1×1.5 mm. The circuit has a very dense CPW transmission-line layout while many air bridges maintain ground–plane continuity.

IV. Performance

We measured the frequency response using on-wafer probes and a network analyzer. We used V-band and W-band test sets and waveguide-input wafer probes for the measurement above 50 GHz. In the following figures, input and outputs 1 and 2 were defined as S-parameter ports 1, 3, and 2, respectively. The S parameters measured from input to output 2 are shown in Figs. 3 and 4. S21 was -2.5 dB at 50 MHz with a 3-dB bandwidth of about 100 GHz. S11 and S22 of the IC were better than -10 dB, and S12 was better than -20 dB up to 100 GHz. We believe the bandswidths is the widest ever reported for multi-RF-port wideband IC's [6]. The power dissipation was about 1.1 W. Fig. 5 shows the gain difference between two output ports. S21 and S31 are gains for outputs 1 and 2, respectively. The gain difference was within 2 dB for frequencies below 50 GHz. The frequency dependence of S31



(a)



(b)

Fig. 5. Frequency dependence of (a) S33 and S13 and (b) S21 and S31.

above 50 GHz was not measured because our measurement did not have an orthogonal arrangement of waveguide-input probes. S31 showed a sharp rise of about 1 dB around 26 GHz, and this rise was not observed in the circuit simulation that did not include the line coupling effect. This rise is probably an effect of the CPW lines on the output 2 side being closer together than those on the output 1 side. The saturation output voltage measured at 40 GHz was about 0.5 Vpp. The gain and saturation power will be improved by increasing the unit section of the distributed configuration.

V. Conclusion

A feature of a dc-to-100-GHz 1 : 2 distributor IC is a distributed differential circuit for obtaining a wideband performance. IC's were fabricated using a 0.1-μm-gate-length InAlAs/InGaAs/InP HEMT with a coplanar-waveguide technology. The IC has a 3-dB bandwidth of 100 GHz and a low-frequency gain of -2.5 dB. The return loss and isolation are better than -10 dB and -20 dB up to 100 GHz. The impressive wideband performance of the IC will allow it to have a considerable impact on future very-high-speed optical communication systems.

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