A 0-to-40-GHz Direct-Coupled Distributed Baseband Amplifier IC with SCFL Interface

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***Abstract*—We have developed a distributed baseband amplifier IC with a distributed source-coupled FET logic (SCFL) level transformer. The amplifier and the SCFL level transformer are directly coupled by a distributed level-shift circuit. The amplifier incorporates our new loss-compensation circuit to improve high-frequency performance. The IC, which was fabricated using commercially-available GaAs MESFET's, has a gain of 5 dB and a 0-to-41-GHz bandwidth. It can also output a 40-Gbit/s pulse waveform on the SCFL logic level, so it can be directly coupled to an SCFL logic circuit. This is the highest performance among all reported GaAs MESFET baseband amplifiers with an SCFL interface.**

I. Introduction

The BIT RATE of optical-fiber transmission systems has been limited by the speed of electronic devices such as baseband amplifier IC's and decision IC's. The baseband amplifier IC's have adopted a distributed amplifier configuration to achieve a wider band than that of conventional lumped circuits. On the other hand, the lower limit frequency of baseband amplifiers is 8 kHz (as far as we know from experience, it is several tens of kHz) in synchronous digital hierarchy (SDH) standard systems. So, we designed distributed amplifier IC's as dc amplifiers using a frequency-dependent drain termination circuit [1] in which the termination impedance increases as the frequency decreases. This compensates for gain degradation caused by the parallel addition of the drain-to-source resistance of the transistors at low frequencies. A very flat gain response from 0 Hz is achieved compared with conventional resistor terminations.

These distributed baseband amplifier IC's, however, cannot be directly coupled to a source-coupled FET logic (SCFL) logic circuit [2] because of their high output dc level. For over-40-Gbit/s systems, we have developed two kinds of broadband dc transformer IC's [3] to avoid using chip capacitors. One is a distributed SCFL level transformer that can output the bit stream on the SCFL logic level, and the other is a distributed level-shift circuit that can directly couple the distributed amplifier and the distributed SCFL level transformer.

In this letter, we describe a direct-coupled distributed amplifier whose amplifier part adopts our new loss-compensation circuit [4] to achieve over-40-GHz bandwidth. We also show experimental results for an IC that incorporates these techniques and is built with commercially available GaAs MESFET's.

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II. Design Principle

The schematic circuit of our new direct-coupled distributed baseband amplifier is shown in Fig. 1. The amplifier part contains the loss compensation circuit [4], which is constructed with a cascode pair of transistors, and two additional transmission lines, L_{cg} and L_{sd}. L_{cg} increases the negative resistance of the cascode pair of transistors [5] and improves the gain at high frequencies. L_{sd} restores the instability caused by the L_{cg} and changes the frequency dependence of the negative resistance. The response of S_{21} is therefore flatter than that with only L_{cg}. We also use a frequency-dependent drain termination circuit [1] to achieve a flat gain starting from 0 Hz and active gate termination [1] to decrease the noise figure at low frequencies.

The distributed level-shift circuit is constructed in eight sections to reduce insertion loss. This circuit is basically a source follower circuit, so its output impedance is low. To improve this low output impedance at low frequencies, we omitted the output-line termination.

The distributed SCFL level transformer is constructed in four sections using a differential amplifier configuration to output SCFL logic levels. This circuit also uses the frequency-dependent drain termination.

III. Device Fabrication

The direct-coupled distributed amplifier IC was fabricated using 0.2-μm gate-length GaAs MESFET's [6] from NTT Electronics Technology Corporation. The MESFET's have an average f_T of 40 GHz and $f_{\max}$ of 80 GHz. The transmission lines are coplanar waveguides. A microphotograph of the direct-coupled distributed amplifier IC is shown in Fig. 2. The chip size is 3.5 $\times$ 4.0 mm.

IV. Circuit Performance

We measured the frequency response using on-wafer RF probes and a network analyzer. The measured scattering parameters are shown in Fig. 3. The IC has a gain of about 5 dB with a 41-GHz band. It also has a flat gain from 0 Hz and is suitable for baseband application without any off-chip components. The gain bandwidth product (GBWP) achieves 72.9 GHz. Our previously reported amplifier [3], whose drain

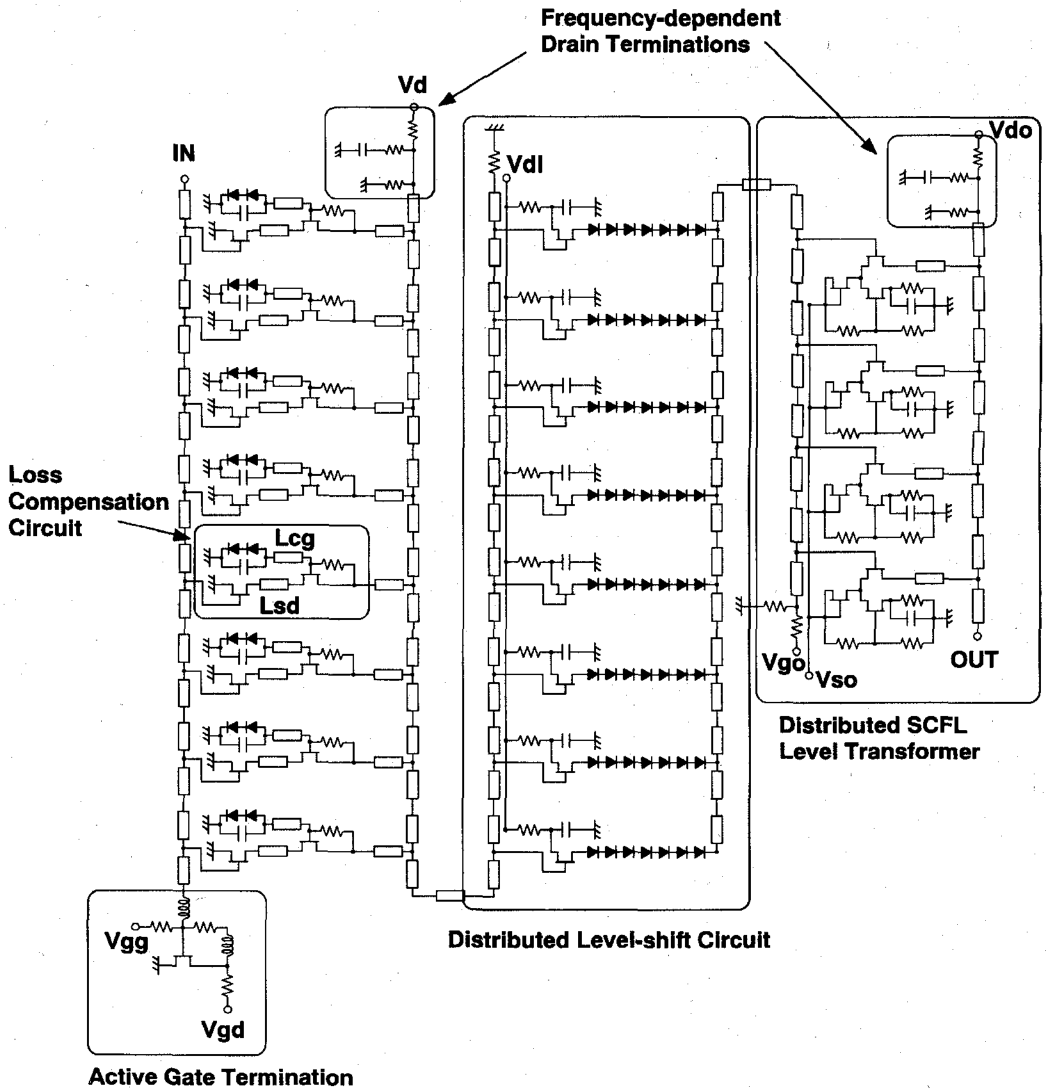

Fig. 1. Schematic circuit of the direct-coupled distributed baseband amplifier.

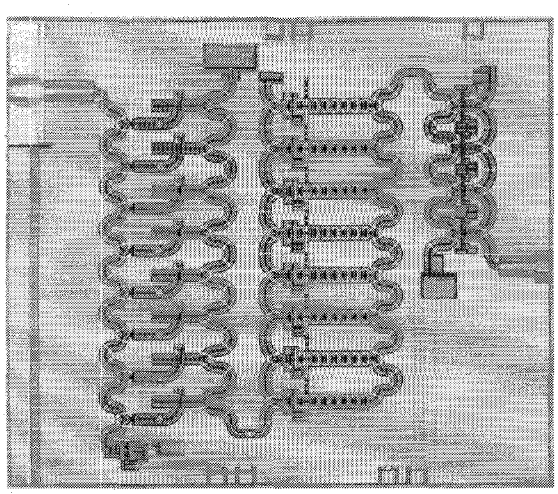

Fig. 2. Microphotograph of the direct-coupled distributed baseband amplifier IC.

line loss was not compensated, had a gain of 7 dB with a 30-GHz band, thus the GBWP was 67.2 GHz. So, our new IC has the widest band and the highest GBWP among all

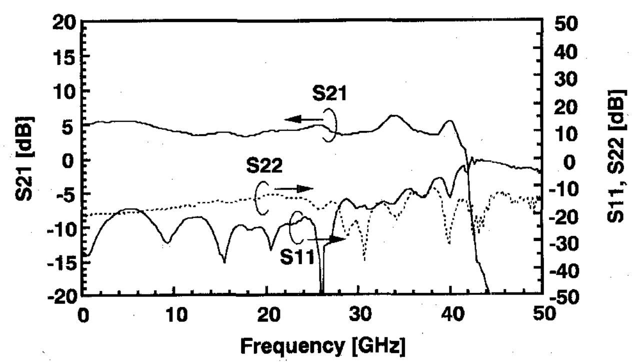

Fig. 3. Measured S-parameters of the direct-coupled distributed baseband amplifier IC.

reported GaAs MESFET baseband amplifier IC's with the SCFL interface. The operating voltages are $V_d = 17.0$ V, $V_{gg} = -3.9$ V, $V_{gd} = 9.6$ V, $V_{dl} = 8.8$ V, $V_{do} = 6.9$ V, $V_{go} = -16.5$ V, and $V_{so} = -4.5$ V. The power dissipation is about 6.9 W. This IC is stable when $V_d < 18.2$ V, but the bandwidth of the circuit decreases below 40 GHz when $V_d < 16.0$ V. The yield is 31% on a 3-in. wafer.

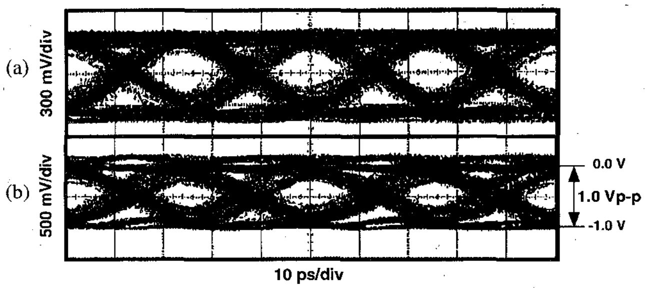

Fig. 4. Measured 40-Gbit/s pulse waveformes (word length $= 2^7 - 1$). (a) Input waveform (measured waveform with THRU on an impedance standard substrate). (b) Output waveform of the direct-coupled distributed baseband amplifier IC.

We also measured the 40-Gbit/s pulse waveform of the IC. We used on-wafer RF probes and our MUX modules [7], [8]. The measured input and output waveforms (word length $= 2^7 - 1$) are shown in Fig. 4. The output eye openings are very wide on the SCFL logic levels.

V. Conclusion

In summary, advanced design techniques and a GaAs MESFET direct-coupled distributed baseband amplifier IC built with these techniques have been described. The new loss-compensation circuit increases the bandwidth and the distributed dc transformers shift the output dc level to the SCFL logic level. The amplifier IC has a flat gain of 5 dB from 0 to 41.0 GHz, so the gain bandwidth product is 72.9 GHz. To our knowledge, this is the widest band and highest GBWP among all reported GaAs MESFET baseband amplifier IC's with an SCFL interface. Moreover, the output waveform of the IC has good eye-opening characteristics on the SCFL logic levels.

These innovative design techniques make it possible to build 40-Gbit/s-class baseband amplifier IC's with commercially-available GaAs MESFET's. We believe these new techniques will break through the speed limitation of high-speed optical communication systems.

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