A Miniature High Gain and Broadband MMIC Distributed Amplifier

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ABSTRACT — A new miniature MMIC distributed amplifier, which combines conventional distributed amplifier (CDA) to extend wider bandwidth and a single-stage cascode amplifier (SSCA) as a gain stage for high gain over several octaves of bandwidth (called CDA-SSCA) is presented in this paper. The low pass filter (LPF) configuration is adopted between the CDA and SSCA while resistive terminations are used in the biasing circuitry to provide broadband matching. The measured small signal gain is 22 ± 1.5 dB from 0.5 to 27 GHz with a chip size of 1.5×1 mm². Another two broadband distributed amplifiers are also designed for comparison and with the same chip size. One is cascaded the two single-stage distributed amplifiers, called two-cascaded single-stage distributed amplifier (2-CSSDA), and the other is a CDA cascaded with a CSSDA, called (CDA-CSSDA). This CDA-SSCA produces a significantly higher gain than the other two designs 2-CSSDA and CDA-CSSDA within the same bandwidth. The flat group delay of this design also proves the feasibility for digital optical communication applications.

I. INTRODUCTION

The broad bandwidth property of conventional distributed amplifier (DA) is well known [1]-[2]. The recent improvements in GaAs hybrid [3]-[4] and monolithic circuit [5] technologies demonstrated a modern prospect in multi-octave wideband amplification. Recent applications have been derived for development of extremely high performance, compact, wideband, low cost and highly reliable microwave distributed amplification. The distributed configuration is suitable for multi-octave band applications, such as amplifiers, mixers, doublers, and switches. The great advantages of uniform gain, flat group delay, and low VSWR performances over very wide bandwidth have made it possible to achieve a broadband millimeter-wave receiver for digital optical communication and other pulse applications.

This paper, for the first time, demonstrates the concept of combining the conventional DA (CDA) used to extend wider bandwidth performance and a single-stage cascode amplifier (SSCA) as a gain stage, called (CDA-SSCA), to achieve wide bandwidth and high gain simultaneously. The low pass filter (LPF) configuration is adopted

between the CDA and SSCA and resistive terminations are used in the biasing circuitry to provide broadband match. By designing the gain frequency response of CDA and SSCA separately, both broadband and high gain characteristics, which feature 22 ± 1.5 dB gain from 0.5 to 27 GHz, are obtained in this attempt. For comparison, two different distributed amplifiers are also designed and presented. One is cascaded the two single-stage distributed amplifiers, called two-cascaded single-stage distributed amplifier (2-CSSDA), and the other is a CDA cascaded with a CSSDA, called (CDA-CSSDA). All of the three designs have a common chip size of 1.5×1 mm². The CDA-SSCA configuration achieves wide bandwidth and high gain within ± 1.5 dB gain ripple and flat group delays, which are better than those of the 2-CSSDA and CDA-CSSDA.

II. DEVICE CHARACTERISTICS AND MMIC FABRICATION

The MMIC distributed amplifier were fabricated using GaAs-based pseudomorphic HEMT (PHEMT) MMIC foundry process provided by Philips Microwave Limeil [6]. The active device is a $0.2\text{-}\mu\text{m}$ gate-length PHEMT with a unit current gain frequency (f_T) and a maximum oscillation frequency f_{max} of 53 and 80 GHz. The peak of transconductance and maximum current at peak transconductance (I_{dsp}) are 220 mS/mm and 180 mA/mm, respectively. The passive components include GaAs thin film resistor, MIM capacitor, inductor, and via hole through $100\text{-}\mu\text{m}$ GaAs substrate. The entire chip is also protected by silicon-nitride passivation for reliability concern.

III. CIRCUIT DESIGN AND ANALYSIS

A. Two-Cascaded Single-Stage Distributed Amplifier (2-CSSDA)

The schematic diagram of two-cascaded single-stage distributed amplifier (2-CSSDA) is shown in Fig. 1(a). Each CSSDA utilizes the artificial transmission line in conjunction with active devices, which consist of second order LPF. The resistive termination is used in the bias circuit to reduce the external circuit sensitivity and provide a broadband impedance matching. This broadband

amplifier design omits the idle drain/gate terminations in the inter-stage of the CSSDA, and thus the power gain can be significantly improved due to the voltage swing across the gate of the cascaded active device being doubled.

The RF signal will be boosted and terminated by properly matched resistive load at each stage. The Phase velocity equalization is unnecessary for this configuration due to the total output current is independent of the phase coherence of the individual current generators. The only requirement is to equalize the characteristic impedance of the input gate and output drain ports of the active devices involved at each stage. This can be done by adding an extra capacitor to the output capacitor C_{ds} in order to equalize the input capacitor C_{gs} , as suggest in [4].

B. Conventional DA Cascaded with a Cascaded Single-Stage DA (CDA-CSSDA)

This distributed amplifier used a conventional distributed amplifier (CDA) to extend wider bandwidth in the first stage and followed by a cascaded single-stage distributed amplifier (CSSDA) as a gain stage. This approach was proposed to operate high gain and over several octaves of bandwidth simultaneously [7].

The circuit schematic diagram is illustrated in Fig. 1(b). Due to the CDA as the input stage, the input VSWR of the overall CDA-CSSDA is low over very wide band. Also, the in-stability problem can be resolved by selecting transmission line length between the CDA and CSSDA and the input capacitor C_{gs} of the CSSDA, as the frequency approaching the cut-off frequency of the gate or drain transmission line. The gain frequency response of the overall CDA-CSSDA can be controlled by adjusting those of the CDA and CSSDA to achieve flat gain even at very low frequency.

C. Conventional DA Cascaded with a Single-Stage Cascode Amplifier (CDA-SSCA)

Compared with the CDA-CSSDA described in III-B, a single-stage cascode amplifier (SSCA) as a gain stage was adopted in this amplifier to achieve higher gain than that of a CSSDA, as shown in the schematic diagram of Fig. 1(c). Using cascode cell in the second stage of the amplifier has the features of (i) higher output shunt resistance reduces loading of drain line and also reduced the transmission line loss of the output stage, and (ii) lower gate-to-drain capacitance reduces negative feedback at high end. The gain of CDA-SSCA is an ideal lossless m -stages of CDA and n -stages of SSCA is given by (1) as

$$G_{av} = \frac{m^2 g_m^2 Z_{od1} Z_{og1}}{p^2} \cdot \frac{g_m^{4n} Z_{o_{int}}^{2(n-1)} Z_{o_{ext}}^2}{4} \quad (1)$$

The gain of CDA-SSCA in (1) is higher than that of the CDA-CSSDA [7], [8].

The linear PHEMT model used in the simulations for all three DAs is provided by the foundry and is implemented in the commercial CAD software (LIBRA^{TM} from HP-EESOF). The simulated small signal gains are

15±1, 17±1, 23±1 dB for three amplifiers, respectively and input/output port return losses are all better than 8 dB in the desire frequency band. Fig. 2 shows the photographs of the three fabricated MMIC chips, with a common chip size of 1.5 x 1 mm².

IV. CIRCUIT PERFORMANCE

All the three miniature MMIC DA chips were measured via on wafer probing. The small signal characteristics, P_{1dB} , and group delays were evaluated for these amplifiers. Fig. 3(a) shows small signal gain of 15 dB with flatness of ±1 dB and input/output return losses better than 8 dB with total dc power consumption 0.1 W for the 2-CSSDA in the frequency range of 0.5-27 GHz. For the CDA-CSSDA, the measured gain is 18±1.5 dB and input/output return losses are better than 8 dB in the frequency range of 0.5-27 GHz with total dc power consumption 0.13 W as shown in Fig. 3(b). For the CDA-SSCA, the measured small signal gain is 22±1.5 dB and input/output port return losses are better than 5 dB in the frequency range of 0.5-27 GHz with total dc power consumption 0.21 W as shown in Fig. 3(c). The measured small signal gain frequency responses demonstrate the validity of the design approach of cascading a CDA and a SSCA with a LPF structure. It is important to note that the gain roll off of these amplifiers are very gradual, which is important for digital optical communication applications, as the sharp gain roll off often seen in distributed amplifiers will lead to excessive group delay peaking and a deteriorated eye diagram [4]. Fig. 5 shows the group delay of 15, 15, and 20 ps of the three distributed amplifiers, respectively. The flat group delay of these distributed amplifiers also indicates that they are suitable for digital optical communication and pulse applications. The output 1-dB compression point of the CDA-SSCA is 12.5 dBm from 2-25 GHz.

Table I summarized the performances of all the three distributed amplifiers described in this paper. Compared with 2-CSSDA and CDA-CSSDA, the CDA-SSCA can provide a higher gain, and thus higher gain bandwidth product (GBW), than the other two amplifiers.

V. CONCLUSION

A new miniature high gain and broadband MMIC distributed amplifier, which cascades a conventional distributed amplifier (CDA) and a single-stage cascode amplifier methodology (SSCA) to achieve high gain and of wide bandwidth of several octaves simultaneously, is demonstrated in this paper. It is observed that this CDA-SSCA produces significantly higher gain and GBW than the 2-CSSDA, CDA-CSSDA. The flat group delays of these distributed amplifiers also make them suitable for digital optical communication and pulse applications.

ACKNOWLEDGEMENT

This work is supported in part by National Science Council of Taiwan, ROC (Project no. NSC 90-2219-E-002-007, and NSC 89-2213-E-002-178) and the Research Excellence Program funded by Ministry of Education, ROC (ME 89-E-FA06-2-4). The MMIC foundry service is provided by PHILIPS Microwave Limeil through the Communication Research Center (CRC) of Canada. The authors would like to thank Miss. Glaser of CRC for the foundry service coordinate effort.

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Table I

Summary the measured results of the three different distributed amplifiers

Chip Name	Freq. (GHz)	Gain (dB)	GBW (GHz)	P _{DC} (W)	Number of Devices	Chip Size (mm ²)	Gain/Chip Size (dB/mm ²)
2-CSSDA	0.5-27	15	152	0.10	2	1.5x1	10
CDA-CSSDA	0.5-27	18	214	0.13	3	1.5x1	12
CDA-SSCA	0.5-27	22	340	0.21	4	1.5x1	14.7

Fig. 1 The circuit schematic diagrams of the three broadband MMIC distributed amplifiers. (a) 2-CSSDA, (b) CDA-CSSDA, and (c) CDA-SSCA.

(a)

(b)

(c)

Fig. 2 The photographs of the three broadband MMIC distributed amplifiers. (a) 2-CSSDA, (b) CDA-CSSDA, and (c) CDA-SSCA, with a common chip size of $1.5 \times 1 \text{ mm}^2$.

(a)

(b)

(c)

Fig. 3 The measured small signal gain and input/output return losses of the three broadband MMIC distributed amplifiers. (a) 2-CSSDA, (b) CDA-CSSDA, and (c) CDA-SSCA.

Fig. 4 The measured group delays of the three broadband MMIC distributed amplifiers.