Novel High Gain and Broadband GaAs MMIC Distributed Amplifiers with Traveling-Wave Gain Stages

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ABSTRACT — **Using the concept of traveling-wave gain stages, novel GaAs MMIC distributed amplifiers are designed to achieve high-gain over several octaves of bandwidth. The cascaded single-stage distributed amplifiers (CSSDAs) are used as traveling-wave gain stages to improve the gain performance of conventional distributed amplifier (CDA). By selecting the low pass filter (LPF) topology for the CDA and CSSDA and tuning the gain shape of CDA and CSSDA, a wide-band performance of the broadband amplifier, called CDA-CSSDA-2 is obtained. The CDA-CSSDA-2 achieves 22±1.5 dB small signal gain from 0.1 to 40 GHz with a chip size of 1.5x2 mm^2. This distributed amplifier produces gain-bandwidth product (GBW) of 503 which is the highest among all GaAs based distributed amplifiers. The flat group delay of the proposed distributed amplifier also proves the feasibility of this methodology for digital optical communications and broadband pulse applications.**

I. INTRODUCTION

The principles of the broadband capability of distributed amplifiers (DAs) are well known [1]-[3]. The advantages of uniform gain, flat group delay, and low VSWR over wide frequency ranges in DAs have also made it possible to implement the DA in a broadband millimeter-wave receiver for digital optical communications [4]-[5] and other pulse applications. However, the performances of these DAs are gain-bandwidth limited due to its optimum number of stages [2]. Those DAs fabricated on InP substrates [4]-[6] have achieved higher gain-bandwidth products than those fabricated on GaAs [7]-[13]. By adopting the proposed circuit topology on the GaAs substrates; a novel broadband MMIC DA is designed and demonstrates the gain-bandwidth product of 503 which is comparable with those amplifiers using InP designs.

There are several DA designs which tried to add gain stages to improve the gain/power capabilities, but most of their gain performances result in band-pass shape [14]-[16], not as the full-band shape in conventional DAs. Using the concept of traveling-wave gain stages to maintain DA's broadband performance, the cascaded single-stage distributed amplifiers (CSSDA) [17]-[18] are selected as broadband gain stages. This paper proposes a novel low pass filter (LPF) topology between the CDA and CSSDA to achieve the broadband performances. Two cascaded single-stage DA (2-CSSDA) and CDA with one/two CSSDAs (CDA-CSSDA-1 and CDA-CSSDA-2) have been fabricated for the proof of concept. These distributed amplifier configurations achieve wide bandwidth and high gain with ±1.5 dB ripple and flat group delay performance, which also proves the feasibility of this approach for broadband applications.

II. DEVICE CHRACTERISTICS AND MMIC FABRICATIONS

The MMIC distributed amplifiers were fabricated using GaAs-based pseudormorphic HEMT (PHEMT) MMIC foundry process provided by TRW [19]. The active device is a 0.15-μm gate-length PHEMT with a unit current gain frequency (f_T) and a maximum oscillation frequency f_{max} of 81 and 120 GHz. The peak of transconductance and maximum current at peak transconductance (I_{dsp}) are 400 mS/mm and 200 mA/mm, respectively. The passive components include GaAs thin film resistors, MIM capacitors, inductors, and via holes through a 100-μm GaAs substrate. The entire chip is also protected by silicon-nitride passivation for reliability concern.

III. CIRCUIT DESIGN AND ANALYSIS

A two-stage MMIC CSSDA is designed in Fig. 1(a). For the CSSDA designs, due to the second order low pass filter (LPF) configurations, the bandwidth of CSSDA is limited compared with CDA. Therefore, using CSSDA along, it is not easy to achieved high gain and wide bandwidth designs simultaneously for millimeter wave applications. Fig. 3(a) shows the measurement response of the 2-CSSDA, which has a limited bandwidth, below 22 GHz.

Therefore, the high-gain and broadband distributed amplifiers are proposed, in Fig 1(b) and 1(c), which combined CDA with CSSDA into new DAs. The first stage CDA is for wide bandwidth and the second stage CSSDAs are used as broadband gain stages to achieve high gain and over several octaves of bandwidth simultaneously. The forward available gain of the

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proposed distributed amplifier simply equal to the multiplication of the first and second amplifiers.

The novel broadband LPF topology between CDA and CSSDA is achieved through the transmission line between the CDA and CSSDA as a series inductor and the shunt capacitor C_{gs} of the first stage of the CSSDA. The series inductor value can be controlled by adjusting the length of the transmission line, and the shunt capacitor can be optimized through the device size selections. By tuning the gain shape of the CDA and CSSDA, the gain flatness can be extended to full-band of the proposed distributed amplifiers. Due to the matching advantages of the first stage CDA, the input VSWR of the proposed amplifier is minimized over a wide frequency range. There is also no in-stability problem as the frequency approaching the cut-off frequency of the gate or drain transmission line.

The linear PHEMT model used in the simulation is provided by the foundry and is implemented in the commercial CAD software (LIBRA™ from HP-EESOF). Three types of distributed amplifiers are designed. Based on the linear simulations, the port return losses of these amplifiers are better than −8 dB and small signal gains are 20±1, 19±1, 21±1 dB in the desire frequency band. Fig.2 shows the photos of the MMIC chips, with die size of 1.5 x 1 mm^2, 1.5 x 1 mm^2, and 1.5x2 mm^2, respectively.

IV. CIRCUIT PERFORMANCE

The proposed broadband MMIC two-cascaded single-stage distributed amplifier (2-CSSDA) and combined conventional distributed amplifier and one- and two-cascaded single-stage distributed amplifiers (CDA-CSSDA-1 and CDA-CSSDA-2) were measured via on wafer probing. The small signal characteristics, P_{1dB}, and group delay were evaluated for the proposed broadband MMIC distributed amplifiers. Fig. 3(a) shows gain of 20 dB with flatness ±1 dB and port return losses better than −5 dB for the 2-CSSDA in the frequency range of 0.5-22 GHz. For the CDA-CSSDA-1, the measured gain is 19±1 dB and port return losses are better than −8 dB in the frequency range of 0.5-27 GHz as shown in Fig. 3(b). For the CDA-CSSDA-2, the measured available gain is 22±1.5 dB and port return losses are better than −5 dB in the frequency range of 0.5-40 GHz as shown in Fig. 3(c) with total dc power consumption 480 mW. It is important to note that the gain roll-off of these amplifiers are very gradual, which is important for digital applications, as the sharp gain roll-off often seen in distributed amplifiers will lead to excessive group delay peaking and a deteriorated eye diagram [5]. Fig. 4 shows the average group delay 30±10 ps of the CDA-CSSDA-2. The flat group delay of the proposed distributed amplifier is very important for digital optical communications. The P_{1dB} of the proposed distributed amplifier are shown in Fig. (5), which has 14 dBm output 1-dB compression point at 30 GHz.

Table I summarized the features and performances of the previously published distributed amplifiers and this work. Compared with the previously published results [4]-[9], this MMIC CDA-CSSDA-2 demonstrated the highest GaAs based Gain-Bandwidth product (GBW) performance.

V. CONCLUSION

This paper presented the novel high gain and broadband distributed amplifiers, which combined conventional distributed amplifiers and cascaded single stage distributed amplifiers. The distributed amplifier produces gain-bandwidth product (GBW) of 503, which is significantly higher than GaAs based distributed amplifiers. By selecting the low pass filter (LPF) topology between the CDA and CSSDA and by tuning the gain shape of CDA and CSSDA, the broadband performances are obtained. The flat group delay performance also proves the feasibility of this approach, which is suitable for digital optical communication and broadband pulse applications.

ACKNOWLEDGEMENT

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Table I

Summary of the previously published distributed amplifiers and this work

Ref.	Freq. (GHz)	S_{21} (dB)	GBW (GHz)	Design Features	Chip size (mm^2)
[4]	1-50	24	792	InP 0.1 μm HEMT, cascade, CPW design, 4 stages	
[5]	0.1-70	17	495	InP D-HBT, attenuation compensation, CPW design, 7 stages	0.6x1.8
[5]	0.1-92	12.5	387	InP S-HBT, cascode, CPW design, 5 stages	1.6x0.4
[6]	0.1-70	17	495	InP 0.1 μm HEMT, cascade, CPW design, 3 stages	
[7]	0.1-54	15	303	GaAs 0.15 μm HEMT, cascade, GCPW design, 8 stages	2.7x2.2
[8]	0.1-46	20	460	GaAs 0.15 μm PHEMT, twin cascode, CPW design, 8 stages	1.5x4
[9]	0.1-65	14.5	345	GaAs 0.15 μm MHEMT, cascode, ML design, 7 stages	1.4x1.2
This work	0.1-40	22	503	GaAs 0.15 μm PHEMT, ML design, (CDA-CSSDA-2)	1.5x2

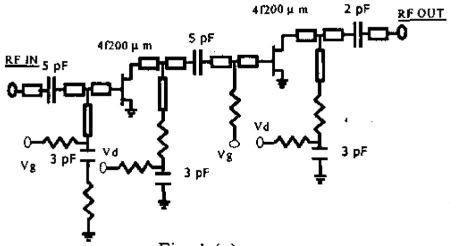

Fig. 1 (a)

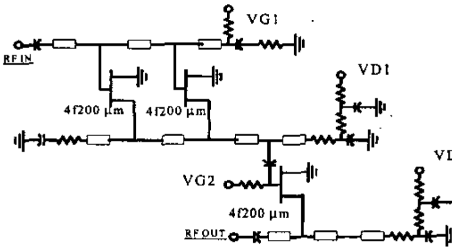

Fig. 1 (b)

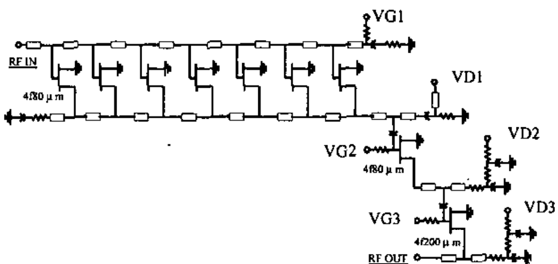

Fig. 1 (c)

Fig. 1. The schematic diagram of these new broadband MMIC distributed amplifiers. (a) 2-CSSDA, (b) CDA-CSSDA-1, and (c) CDA-CSSDA-2.

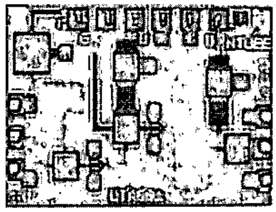

Fig. 2 (a)

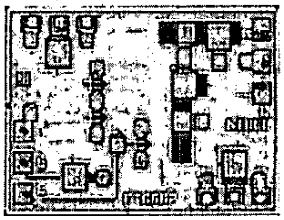

Fig. 2 (b)

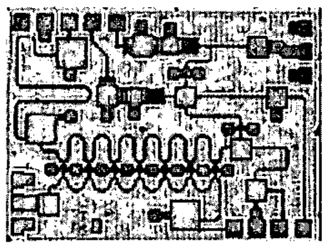

Fig. 2 (c)

Fig. 2. The chip photo of the broadband (a) 2-CSSDA (b) CDA-CSSDA-1, and (c) CDA-CSSDA-2 with die size of 1.5 x 1 mm^2, 1.5 x 1 mm^2 and 1.5x2 mm^2 respectively.

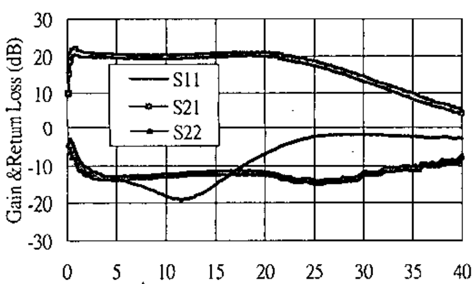

Fig. 3 (a)

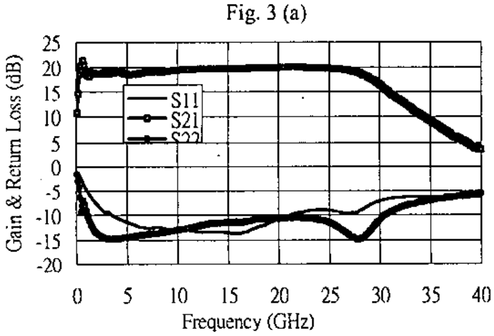

Fig. 3(b)

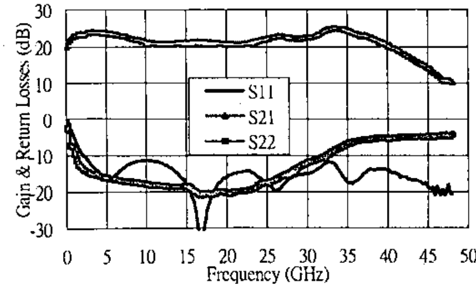

Fig. 3 (c)

Fig. 3. Measured the small signal performance of the novel broadband MMIC distributed amplifiers. (a) 2-CSSDA, (b) CDA-CSSDA-1, and (c) CDA-CSSDA-2.

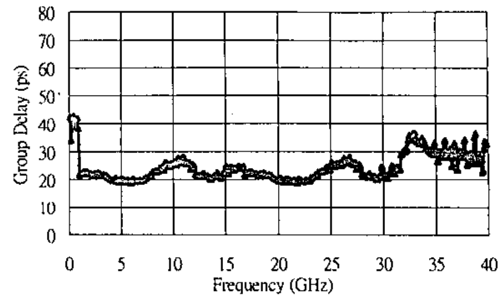

Fig. 4. Measured group delay of the proposed broadband MMIC distributed amplifier (CDA-CSSDA-2).

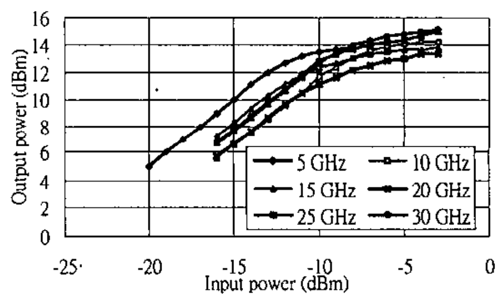

Fig. 5. Measured the nonlinear performance of the novel broadband MMIC distributed amplifiers (CDA-CSSDA-2)