

A Variable gain MMIC amplifier

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Abstract — A variable gain MMIC amplifier block is demonstrated. A maximum gain of 13 dB with a control range of 13 dB is obtained at 2.5GHz. The -3dB bandwidth is 5 GHz. The circuit consists of a cascade input stage with an active load followed by a source follower for impedance transformation. A GaAs pseudomorphic HEMT technology is used for the implementation. The active circuit area is less than 0.5 mm².

I. INTRODUCTION

A Variable gain amplifier is a versatile function block for radio communication and radar. It is used for controlling the transmitted signal power or adjusting the received signal amplitude in order to keep the signal to the detector constant. Some other applications include the temperature compensation in a satellite communication system, compensate for the loss of the phase shifter and for the improvement of the side lobe level in phased array antenna. Our purpose is to design a controllable gain stage in the IF block of a 60 GHz WLAN demonstrator by cascading several stages of VGAs following an LNA. There are usually two types of VGA. One is a discrete gain step with digital control signal [1] and the other is a continuously variable gain type [2-3] which is controlled by an analog signal. The latter type is preferred due to its capability of avoiding signal phase discontinuity. Variation of gain is achieved by controlling the channel resistance of a pHEMT.

II. BASIC THEORY

The low frequency small signal gain of a single ended amplifier is governed by the equation [4]:

$$G_n = - \frac{g_m R_d}{1 + g_{ds}(R_s + R_d) + g_m R_s} \quad (1)$$

where R_s is the source resistance, R_d is the drain resistance of the amplifier, g_m is the transconductance and g_{ds} is the output conductance of the transistor. If R_s is large and $g_{ds} \ll g_m$, equation (1) can be approximated:

$$G_n = - \frac{g_m R_d}{1 + g_m R_s} \approx - \frac{g_m R_d}{g_m R_s} = - \frac{R_d}{R_s} \quad (2)$$

By changing the source resistance, it is possible to control the gain of the amplifier in a practical way. We use the channel resistance of another HEMT, connected in parallel with R_s as voltage controlled resistor. The transistor used is a 2 fingers, 50 μ m, pHEMT whose model was developed at Chalmers [5]. Fig. 1 shows the variation of channel resistance against the gate voltage.

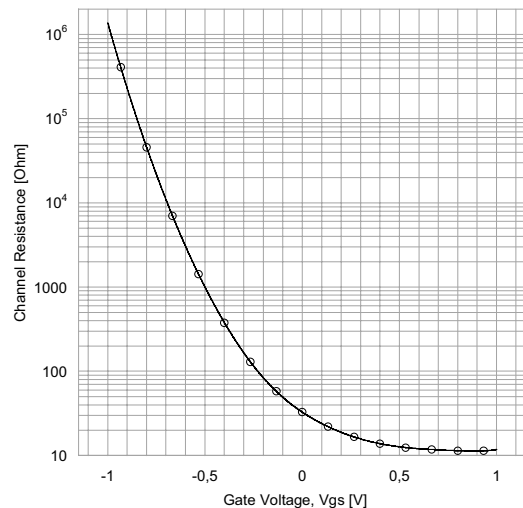


Fig. 1. Variation of channel resistance against the gate voltage of a 2 finger, 50 μ m OMMIC pHEMT for a drain-source voltage of 0.5 V.

III. DESIGN

The basic gain block of VGA is described in Fig. 2. In order to optimize the gain and bandwidth we use a cascode amplifier pair. In order to maximize the gain, R_d is replaced by a current generator which has a high equivalent resistance. A source follower has been used as an impedance transformer between the cascode output node and the output terminal. The source follower improves the bandwidth of the cascode due to a large

input impedance [6]. The value of circuit elements and the transistors sizes are summarized in Table 1. Figure 3 shows a photograph of the MMIC chip. The active area is approximately $0.6 \times 0.7 \text{ mm}^2$.

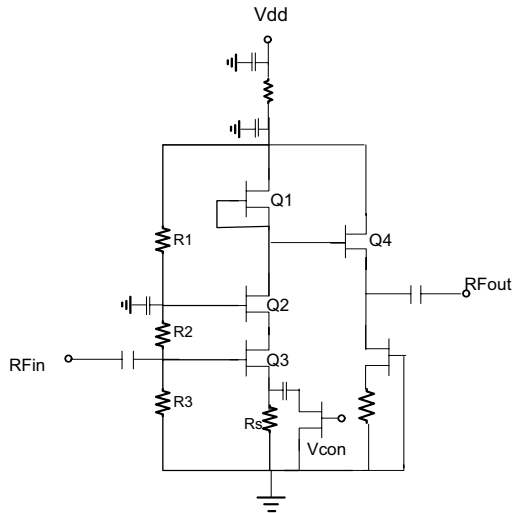


Fig.2. Single ended variable gain amplifier.

TABLE 1

Circuit Element	$n \times W_g /$ Dimension	Numerical Value
Q ₁	2X15 μm	
Q ₂	4X25 μm	
Q ₃	4X25 μm	
Q ₄	6X15 μm	
Q ₅	2X15 μm	
Q _{control}	2X50 μm	
R ₁	140X8 μm^2	2.2 K Ω
R ₂	116X12.5 μm^2	1 K Ω
R ₃	116X12.5 μm^2	1 K Ω
R _s	61X28 μm^2	200 Ω
R _{cs}	86X17.5 μm^2	500 Ω

IV. DEVICE TECHNOLOGY

The commercial foundry process offered by OMMIC [www.ommic.com], France, has been used for the MMIC design implementation. The process is a double delta doped high-electron mobility transistor (pHEMT) utilizing a high drain current density (700 mA/mm) with high breakdown voltage of 8 V. The transistors used have a mushroomed gate with a length of $0.15 \mu\text{m}$ in order to reduce gate resistance. f_t is found in the vicinity of 95 GHz.

V. MEASUREMENTS AND RESULT

The S-parameter, output power characteristics and the noise figure were measured. An HP8510C was used to

measure the S-parameter whereas an Agilent 4419B power meter was used to measure the compression characteristics. The measured transmission co-efficient, $|S_{21}|$, for various control voltage is shown in Fig. 4a. In Fig. 4b, the simulated and measured results were compared.

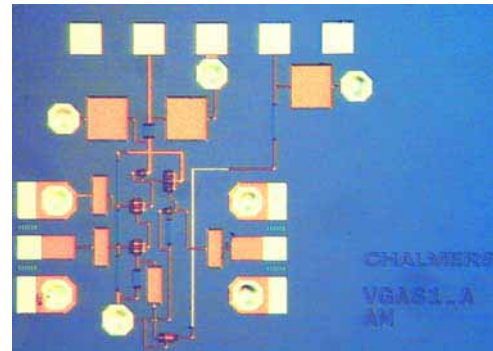


Fig.3. Microphotograph of MMIC VGA

The gain ($|S_{21}|$) is plotted for sweeping control voltage at 2.5 GHz. A maximum gain variation of more than 13 dB is achieved.

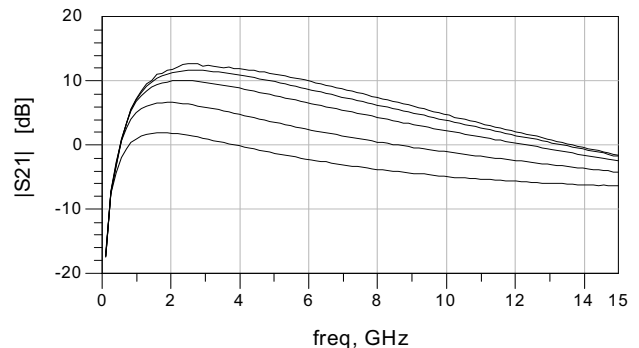


Fig. 4a. Measured $|S_{21}|$ for the gate (control) voltage, $V_{con} = -0.00 \text{ V}, -0.3 \text{ V}, -0.4 \text{ V}, -0.5 \text{ V}, -0.6 \text{ V}$.

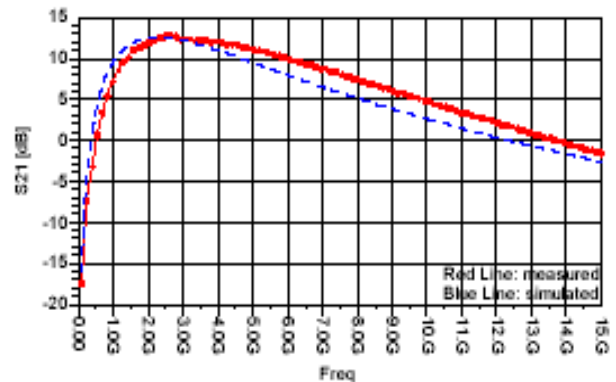


Fig. 4b. Measured and simulated $|S_{21}|$ for highest gain

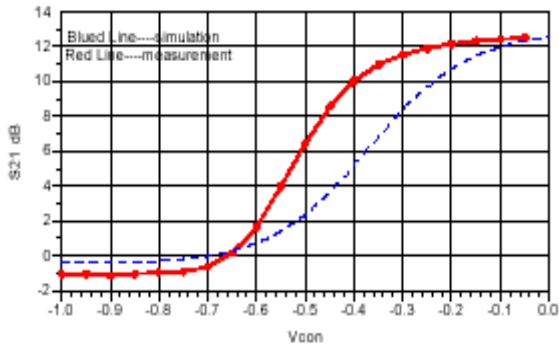


Fig. 5. Measured and simulated gain variation

The rate of gain variation is drawn against the control voltage in Fig. 6. The curve follows the expected shape as evident from equation (1) and (2). We see a maximum rate of variation around -0.5 to -0.6 volts. Fig. 7 shows the measured output versus input power for various values of the control voltage. The -1 dB compression point is not sensitive to the gain and of the order of -15 dBm to -14 dBm in the whole control range.

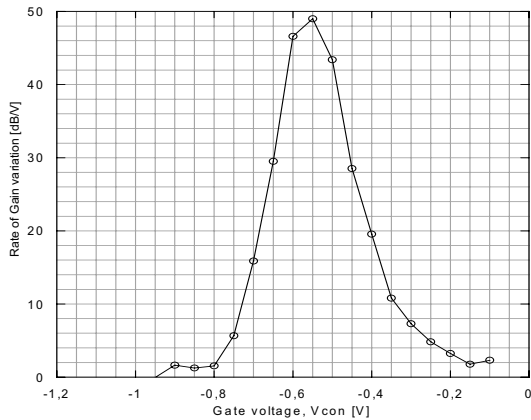


Fig. 6. Rate of change of gain w.r.t. the gate voltage.

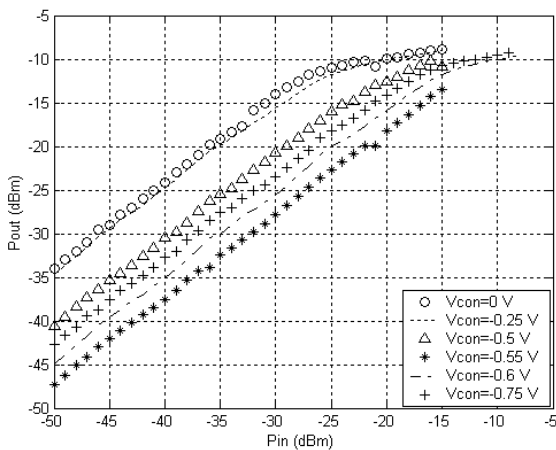


Fig. 7. Measured output power for sweeping input RF power.

The noise figure (NF) was measured using Agilent 8974A noise figure meter. Fig. 8a shows the NF at $V_{con}=0$ V and the same is plotted in fig. 8b for sweeping control voltage. NF varies from 1.83 dB to 9.6 dB with the control voltage swept from 0 to -1 V. This VGA design is however not optimized for low noise figure. It will be a part of a high-gain IF block consisting of a low noise amplifier by 3 VGA blocks. The measured reflection coefficients are drawn in the smith chart of Fig. 9a. The linear scale representation is shown in figure 10a and 10b for sweeping control voltage and frequency.

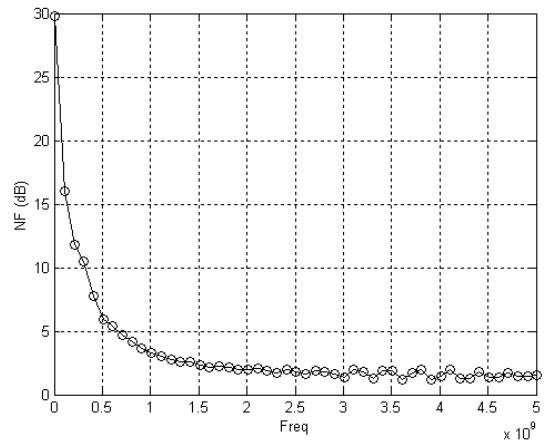


Fig. 8. Measured noise figure for $V_{con}=0$ V.

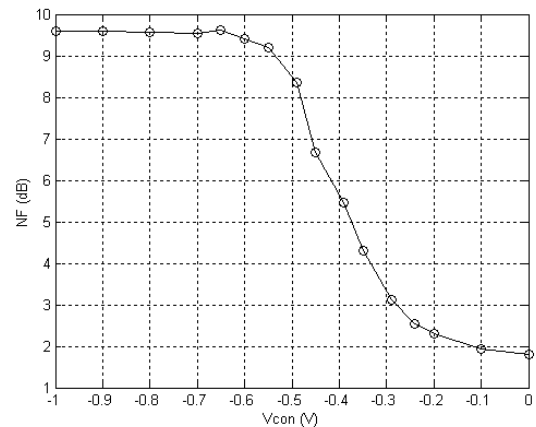


Fig. 9. Measured noise figure for sweeping control voltage

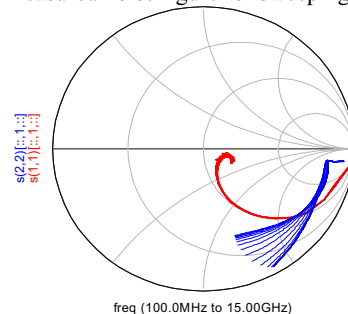


Fig. 10. Reflection co-efficient ($|S_{11}|$ & $|S_{22}|$) in the smith chart

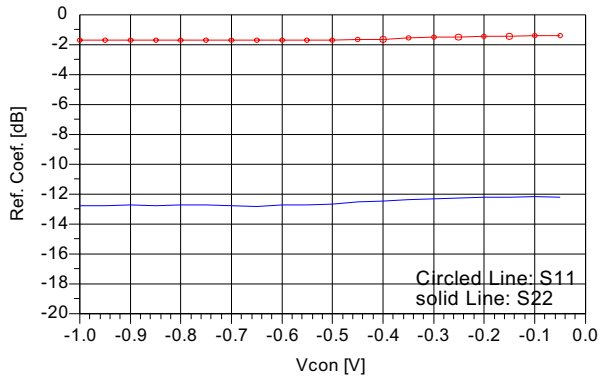


Fig. 11a. Reflection co-efficient ($|S_{11}|$ & $|S_{22}|$) for sweeping control voltage

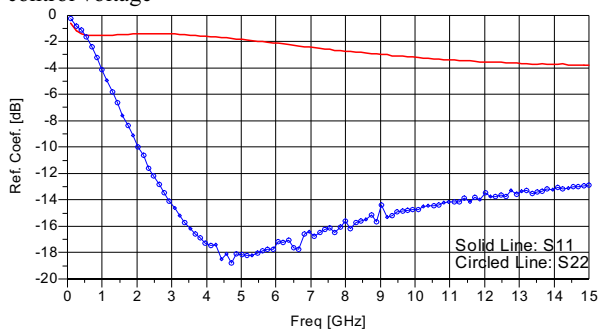


Fig. 11a. Measured reflection co-efficient ($|S_{11}|$ & $|S_{22}|$) for sweeping frequency

VI. DISCUSSION AND CONCLUSION

A compact VGA-block based on a cascade topology and variable resistive source series feedback is designed, fabricated and verified experimentally. The gain at 2.5 GHz can be controlled from -1 dB to 12 dB as the control voltage is changed from -0.7 V to 0 V. The linearity of the amplifier was found to be independent of gain i.e. the compression point of the amplifier is constant with control voltage in contrast to VGAs based on gain variation obtained by just controlling the gate bias. As far as linearity, stability and gain variation are concerned, the design gives the result expected from the simulation analysis.

VII. ACKNOWLEDGEMENT

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