A Variable gain MMIC amplifier

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Abstract — A variable gain single ended MMIC amplifier is demonstrated. A maximum gain of 13 dB with a control range of 13 dB is obtained at 2.5 GHz. The -3 dB bandwidth is 5 GHz. The circuit consists of a cascode 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 1 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 VGA 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 it 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, 11]:

\[ G_n = \frac{g_m R_d}{1 + g_m (R_s + R_d) + g_m R_s} \]  \hspace{1cm} (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 \( g_{ds} < g_m \), equation (1) can be approximated:

\[ G_n \approx -\frac{g_m R_d}{1 + g_m R_s} - \frac{R_d}{R_s} \]  \hspace{1cm} (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 two fingers, 50µm, 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, 50µm OMMIC pHEMT for a drain-source voltage of 0.5 V.](image)

III. DESIGN

The basic gain block 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 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 0.6x0.7 mm².

**Fig. 3. Microphotograph of MMIC VGA**

**TABLE 1**

<table>
<thead>
<tr>
<th>Circuit Element</th>
<th>n x Wg / Dimension</th>
<th>Numerical Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>2X15 µm</td>
<td></td>
</tr>
<tr>
<td>Q2</td>
<td>4X25 µm</td>
<td></td>
</tr>
<tr>
<td>Q3</td>
<td>4X25 µm</td>
<td></td>
</tr>
<tr>
<td>Q4</td>
<td>6X15 µm</td>
<td></td>
</tr>
<tr>
<td>Q5</td>
<td>2X15 µm</td>
<td></td>
</tr>
<tr>
<td>Qcontrol</td>
<td>2X50 µm</td>
<td></td>
</tr>
<tr>
<td>R1</td>
<td>140X8 µm²</td>
<td>2.2 KΩ</td>
</tr>
<tr>
<td>R2</td>
<td>116X12.5 µm²</td>
<td>1 KΩ</td>
</tr>
<tr>
<td>R3</td>
<td>116X12.5 µm²</td>
<td>1 KΩ</td>
</tr>
<tr>
<td>R4</td>
<td>61X28 µm²</td>
<td>200 Ω</td>
</tr>
<tr>
<td>Rcs</td>
<td>86X17.5 µm²</td>
<td>500 Ω</td>
</tr>
</tbody>
</table>

**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 µm 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 and the noise figure were measured. An HP 8510C 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. 4(a). The simulated and the measured results were compared for the control voltage of $V_{con}$= 0 V and is shown in Fig. 4(b) and Fig. 5. A maximum gain variation of more than 13 dB is achieved.

**Fig. 4(a). Measured $|S_{21}|$ for the gate (control) voltage, $V_{con}$= -.05V, -0.3 V, -0.4 V, -0.5 V, -0.6 V.**

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

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
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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.

2.5 GHz. The VGA however, is not optimized for low noise figure. It will be a part of high-gain IF block consisting of a low noise amplifier by 3 VGA block. The measured reflection coefficients are drawn in the smith chart of Fig. 9. Linear scale representation is shown in figure 10(a) & 10(b) respectively.

The noise figure (NF) was measured using Agilent 8974A noise figure meter. Fig. 8a shows the noise figure for sweeping frequency at V_{con}= 0 V whereas Fig. 8b shows the same for the sweeping control voltage at frequency of

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**Fig. 5.** Measured and simulated gain variation.

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

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

**Fig. 8 (a).** Noise Figure for sweeping frequency.

**Fig. 8 (b).** Noise Figure for sweeping frequency.

**Fig. 9.** Reflection coefficients (|S_{11}| & |S_{22}|).
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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 to 0 volts. 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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REFERENCES