Temperature Compensation Circuit for Linear Microwave Amplifiers

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***Abstract*—A hybrid circuit, integrated in a double-stage microwave amplifier, able to compensate for gain variations in the −54.75 °C temperature range and 6.18-GHz frequency band, has been designed, realized, and measured. Analytical studies show that cascode configuration for the amplifiers is the best one to solve the problem. Measured results are in good agreement with the analysis.**

I. Introduction

MODERN radar and electronic warfare systems need high a receiver sensitivity value and dynamic range, and these characteristics must also be assured in a wide range of temperatures. GaAs FET amplifiers are seriously affected by temperature variations, resulting in gain spread of many dB for amplifier. In the present letter, we recall the temperature-dependent physical mechanism and voltage solutions used in GaAs FET amplifiers. Then, we have realized a circuit that compensates for the effect of temperature and gain variations for GaAs FET monolithic amplifiers, resulting in a quite stable gain value between −54–75 °C. Electrical measurements of compensation circuit plus monolithic amplifiers are given.

II. Device Temperature Fundamentals

The causes for gain variation due to absolute temperature T changes are mainly due to the variation of transconductance $g_m(T, V_g)$ [3]–[5]

$$g_m(T, V_g) = V_s(T)\left\{\frac{eN\varepsilon}{2[V_g - V_0(T)]}\right\}^{1/2} \tag{1}$$

where

- $V_s(T)$ carrier speed versus temperature, following a relationship proportional to $1/T^{1.5}$
- $V_0(T)$ built-in potential versus temperature, following a relationship proportional to T
- e electron charge
- N channel doping
- ε permittivity
- V_g gate potential.

We now want to search a relationship between V_g and the temperature that, when applied, will realize a gain-temperature compensation.

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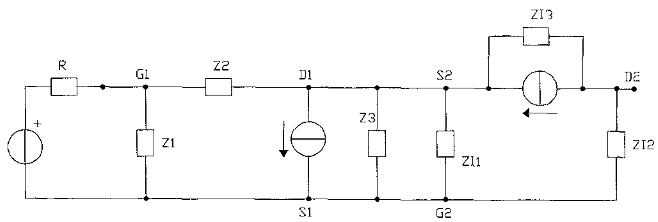
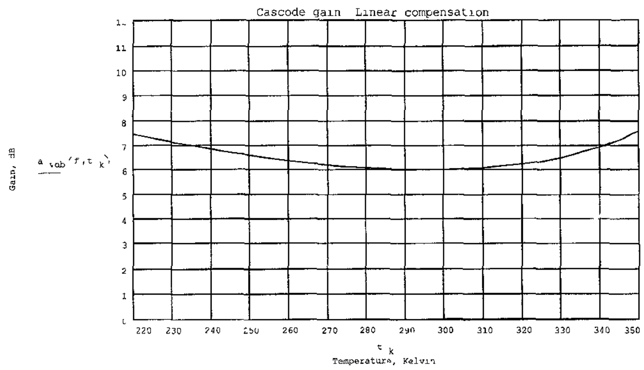


(a)



(b)

Fig. 1.

III. Transconductance Versus Temperature for a FET

Let us calculate the differential dg of e above. We have

$$dg = \frac{\delta g}{\delta T}\,dT + \frac{\delta g}{\delta Vg}\,dVg. \tag{2}$$

Executing the partial derivative at the second member of (2) and setting $dg = 0$ we have

$$\frac{dV_g}{V_g} \approx \frac{dT}{T}. \tag{3}$$

The previous equation shows us that when the temperature increases, we also need to increase the gate voltage if we want to have a constant FET transconductance. Note that (3) is valid locally and consequently cannot be used for extended temperature ranges since the $g_m(T, V_g)$ does not vary linearly with T. Under this condition, in order to compensate for the amplifier change of gain a linear variation of temperature must be followed by a linear variation of gate voltage. Another limitation is due to the fact that the variation of bias voltage in MESFET amplifiers makes the input capacitance to change, so the input matching network can't realize the initial condition

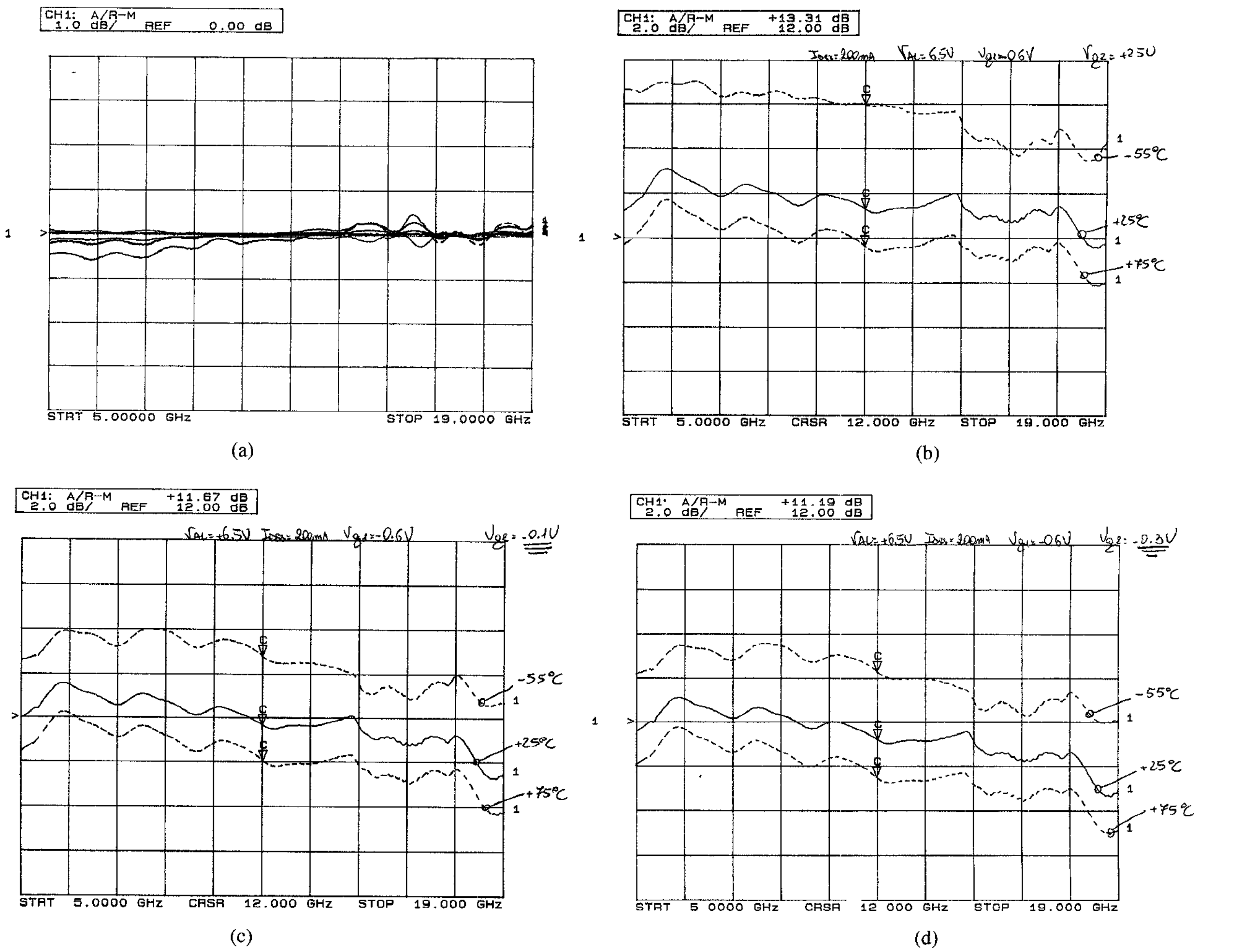


Fig. 2.

of return loss. This fact damages the performances of wide-band amplifiers. Also note that (3) has been defined for one FET only.

IV. Temperature Analysis of a Cascode Circuit

An analytical study of a cascode circuit is presented using the equivalent circuits with elements function of temperature. The temperature dependence is as previously indicated.

With the equivalent circuit indicated in Fig . 1, its voltage gain $Av(f, tk)$ is

$$Av(f, tk) = \frac{\{Z_1(f)a(f, tk) + [Z_1(f) + Z_2(f)]b(f, tk)\}Z_{i2}(f)}{|c(f, tk)|}. \quad (4)$$

In the previous equation we have

$$\begin{aligned}
Y_1(f) &= j\Omega C_1 \\
Y_2(f) &= j\Omega C_2 \\
Z_{i2}(f) &= \frac{R_1}{1 + j\Omega R_1 C_{zi2}} \\
a(f, tk) &= [1 + g_1(tk)Z_1(f)] \\
&\quad \cdot [Z(f) - g_2(tk, v_2)Z(f)Z_{i3}(f)] \\
b(f, tk) &= Z(f)g_1(tk)Z_1(f) \\
&\quad \cdot [g_2(tk, v_2)Z_{i3}(f) - 1] \\
Z(f) &= \frac{Z_3(f)Z_{i1}(f)}{Z_3(f) + Z_{i1}(f)} \\
Y_{i1}(f) &= j\Omega C_{zi1} \\
Y_3(f) &= j\Omega C_3 \\
Y_{i3}(f) &= j\Omega C_{zi3}
\end{aligned}$$

and where $|c(f, tk)|$ is the determinant of the coefficient matrix of the system equation of the network in Fig. 1(a).

After determining the gain of the stage, we have applied a gate voltage following a linear relationship with temperature with an adjustable slope so that the best result can be found [indicated in Fig 1(b)].

V. Experimental Results for a Cascode MMIC Amplifier

The analytical results of the previous paragraphs show us that for a single FET amplifier, a linear relationship between gate voltage and temperature can compensate the gain variation only in a restricted temperature and frequency range, while for a cascode configuration the previously mentioned relationship is quite linear in a broader temperature range. To verify the cascode analytical results, we show the experimental results for a manual gain compensation versus temperature of a traveling cascode amplifier, made by Hewlett-Packard. The temperature range is between −60–85 °C. In this figure we

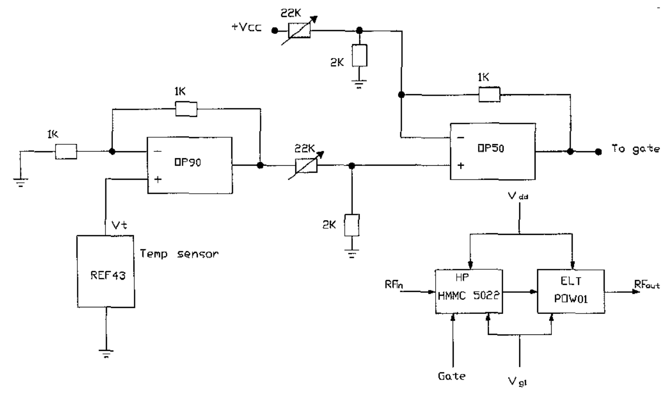


Fig. 3.

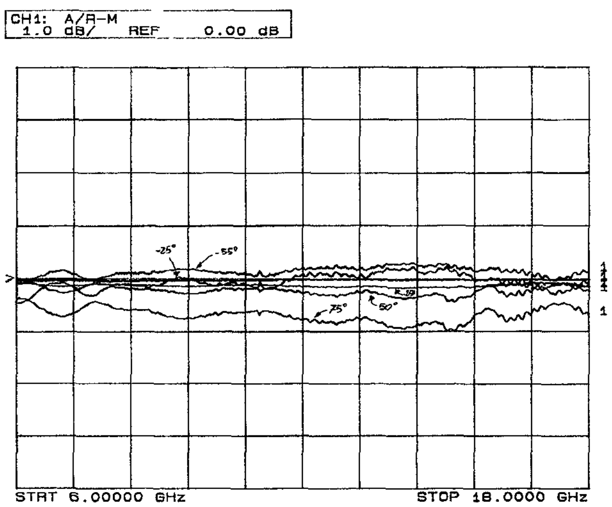


Fig. 4.

have depicted the required dc voltage to be applied to the gate of the common gate (CG) FET to maintain the gain as constant as possible.

The gain versus temperature, normalized to that obtained at 25 °C, is shown in Fig. 2(a) for different gate voltages in the 5.19-GHz frequency range. Fig. 2(b) shows the uncompensated gain versus frequency at room and extreme temperatures.

It is important to remark as the linear dependence between temperature and gate voltage is a function of the first gate voltage.

Fig. 2(c) and (d) shows the uncompensated gains versus frequency, at room and extreme temperatures, for two gate-bias voltages. (All of the figures have markers at 12 GHz.)

VI. The Temperature-Compensation Circuit

With the results of the previous analysis and trials, we have realized a temperature compensation circuit that uses only active components for temperature sensing and compensing. The schematic circuit is given in Fig. 3, together with the block diagram showing the microwave assembly under compensation. In fact, with this circuit we have compensated two monolithic microwave integrated circuit (MMIC) amplifiers in tandem, the first one the H.P. traveling cascode model HMMC5022 as input and a traveling power MMIC-type POW01, produced by Elettronica–ROMA, as output.

As it is seen, the temperature-sensing element is a REF-43, produced by Siliconix. This element has an output whose voltage is linearly function of temperature and is sent to a buffer, the OP90. The output of this buffer can be attenuated using a trimmer resistor. In this way, we may regulate the slope of the curve temperature-voltage. This voltage is sent to the positive input of a second buffer OP50, where at the negative input is present a voltage regulated by a second trimmer resistor. Finally, at the output of the OP50 is present a voltage whose slope and offset may be changed by the two trimmers.

We have applied a constant dc voltage at the first gate of the cascode, while at the auxiliary gate we have connected the output of the temperature-compensation circuit shown in Fig 3. The gate of the output MMIC are at the same potential of the first gate of the cascode. The overall gain to be maintained in the temperature range between −54–75 °C has been chosen to be 11 dB.

In Fig. 4, we have the results of this temperature compensation, where the gain variation normalized to the gain at 25 °C are shown. Note as the measured values are very similar to that shown in Fig. 2(a)–(d).

VII. Conclusion

In the present letter, we have shown that for little temperature variations near a defined value, the gain of a MESFET amplifier can be held constant if its dc gate bias is changed linearly with temperature.

Theoretical analysis has been presented that shows that a MESFET amplifier in CASCODE configuration can give a constant gain in a broad temperature range if the dc bias of the auxiliary gate is changed linearly with temperature.

A temperature-compensation circuit, driving the series of a traveling monolithic cascode amplifier and a traveling monolithic amplifier, has been realized. It can control very efficaciously the gain variations of these amplifiers in the −54.75 °C temperature.

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