COMPUTER AIDED DESIGN AND ANALYSIS OF a 2-4 GHz BROADBAND BALANCED MICROSTRIP AMPLIFIER

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Abstract: In this paper, a computer-aided design and analysis of a 2-4 GHz broadband balanced microstrip amplifier using a full computer simulation program developed by the author and others is presented. A short and efficient CAD procedure for broadband amplifier design is introduced. The first step is to design an initial narrow-band high gain microstrip amplifier at 3-GHz central frequency. The second step is to optimize the initial lengths and widths of the input and output microstrip-matching circuits to get the broadband amplifier over the range 2-4 GHz. The analysis of both narrow and broadband amplifiers is investigated. In addition, with the design and analysis of a low-pass microstrip filter, the paper introduces the design and analysis of a Lange coupler. The final AC schematic diagram of the designed amplifier with the lengths and widths of microstrip lines is presented.

Key Words: Computer-Aided Design and Analysis, Microstrip Amplifier, Microwave Amplifier.

1. INTRODUCTION

Presently the design of microwave solid-state amplifiers is performed using microwave bipolar junction transistor (BJT) as an active element. The BJT is usually implanted in a distributed passive network fabricated by microstrip line technology. Silicon BJT is widely used in microwave circuit design due to its excellent performance in the microwave range up to 4 GHz. In addition, with the good isolation between input and output, the device has a high gain, high power, and low noise figure when compared with other solid-state devices operating in the same frequency range.

The balanced amplifier has many advantages compared to the single device amplifier. These advantages are: 1) improved input and output impedance matching, gain flatness, and phase linearity, 2) possible design for amplifier, simultaneously for minimum noise figure and good input match, 3) gain compression and intermodulation characteristics are good, 4) high stability for short and open circuits, 5) the amplifier gain can be controlled over wide ranges by DC bias with little effect on gain flatness or impedance matching, 7) if one amplifier fails, the balanced amplifier unit will still operate with reduced gain, and 8) easiness to cascade the balanced amplifier to other units.

The designed microwave transistor amplifier is a balanced microstrip amplifier using two HXTR 3101 silicon BJTs as active elements. The associated passive microwave circuits such as amplifier matching circuits, low-pass filter, and hybrid couplers are designed using microstrip line technology. Teflon substrate is used with the following parameters: relative permittivity (ε_r) = 2.2, dielectric thickness (H) = 0.7874 mm, and conductor thickness (T) = 0.005 mm (skin depth–to-conductor thickness ratio $\cong$ 0.1).

2. DESIGN AND ANALYSIS OF 2-4 a GHz BROADBAND MICROSTRIP AMPLIFIER

The design of a broadband microstrip amplifier using HXTR 3101 BJT as an active element is performed using a full-scale computer simulation program developed by the author and others [1]. The program can perform complete analytical design of microstrip amplifiers.

2.1 Design Methodology

A short and efficient CAD procedure for the design of a broadband microstrip amplifier is performed. The design is based on the scattering-matrix parameters of the active element. The CAD procedure is composed mainly of two steps. The first step is to design an initial narrow-band high-gain amplifier operating at central frequency F_O = 3 GHz. The developed full-scale simulation program is used for stability consideration and for the design of the input and output matching circuits. The second step is to use an optimization program to adjust the initial designed lengths and widths of the input and output matching circuits to get a broadband over a frequency range 2-4 GHz [2-3].

2.2 Design of a Narrow Band 3 GHz Amplifier

In order for the amplifier to deliver maximum power to the load, it must be properly terminated at both input and output ports [4-9], hence the need for an input/output matching circuit arises. The scattering parameters of the HXTR 3101 BJT at 3 GHz and I_c=4 mA are:

S_{11}=0.57 $\angle$-173^o, S_{12}=0.043 $\angle$25^o,

S_{21}=2.2 $\angle$48^o, and S_{22}=0.77 $\angle$-58^o.

The stability of the transistor is first considered. The corresponding K and $|\Delta|$ are, respectively, 1.254 and 0.39. The transistor is thus unconditionally stable. For simultaneous conjugate match the source and load reflection coefficients are given by [10-12]:

$$\Gamma_{MS} = \frac{B_1 \pm \sqrt{B_1^{\,2} + 4|C_1|^2}}{2C_1} \tag{1}$$

$$\Gamma_{ML} = \frac{B_2 \pm \sqrt{B_2^{\,2} + 4|C_2|^2}}{2C_2} \tag{2}$$

$$B_1 = 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2 \tag{3}$$

$$B_2 = 1 + |S_{22}|^2 - |S_{11}|^2 - |\Delta|^2 \tag{4}$$

$$C_1 = S_{11} - \Delta S_{22} \tag{5}$$

$$C_2 = S_{22} - \Delta S_{11} \tag{6}$$

where Γ_{MS} and Γ_{ML} are the source and load reflection coefficients required for a simultaneous conjugate match

Fig. 1 $|S_{21}|$, $|S_{11}|$ and $|S_{22}|$ in dB versus frequency in GHz for the 3-GHz amplifier

Fig. 2 Schematic diagram of 3-GHz high-gain amplifier
A) Input matching circuit using open/balanced stub
B) Output matching circuit using open/balanced stub

2.3 Design of Broad Band 2-4 GHz Amplifier

The optimization process adjusts the circuit parameters (lengths and widths of microstrip input and output matching circuits given in Table 1) to achieve a flat gain over the range 2-4 GHz. It does this by minimizing an RMS error function defined as follows [12]:

$$\mathrm{E} = \frac{1}{nq}\sum_{q=1}^{Q}\sum_{n=1}^{N} W_n \Delta^2 n(f_q) \tag{14}$$

where f_q is the analysis frequency and Δ_n is the error in a parameter. For magnitude or other real quantities,

$$\Delta_n = P_{n,calc} - P_{n,goal} \tag{15}$$

Moreover, for phase angles the fractional error is used:

$$\Delta_n = \frac{\Theta_{n,calc} - \Theta_{n,goal}}{180} \tag{16}$$

P_n and θ_n are scalar parameters of the circuit at frequency f_q; P_n is the magnitude of S_{22}', θ_n is a phase angle of S_{22}', and W_n is a weighting coefficient. The optimizer terminates if the error function fails to decrease by a factor of 10^{-6} between two successive iteration.

As a result of the optimization process, the final lengths and widths of the input and output matching circuits for a 2-4 GHz broadband amplifier are given in Table 2.

Table 2 Input and output matching circuits for the 2-4 GHz broadband amplifier

Length/width of microstrip line	Input matching circuit	Output matching circuit
Length of series line	2.50 mm	9.54 mm
Length of open/ balanced shunt stub	4.38 mm	2.730 mm
Width of series line	1.00 mm	1.00 mm
Width of open/ balanced shunt stub	4.99 mm	4.99 mm

Figure 3 gives the variations of S_{21}, S_{11}, and S_{22}, all in dB, with frequency in GHz for a 2-4 GHz broadband amplifier.

Fig. 3 $|S_{21}|$, $|S_{11}|$ and $|S_{22}|$ in dB versus frequency in GHz for the 3-GHz amplifier

3. DESIGN oF a LANGE COUPLER

The balanced amplifier with coupled-line hybrid as input and output stages has mainly two problems. The first one is that the required even and odd mode characteristic impedances of the coupler are beyond the manufacturing capability, even on high permittivity substrate; this is because the required spacing between the lines is too small. The second problem is that the two outputs emerge on opposite sides of the isolated ports, so a symmetrical circuit layout is difficult to achieve.

A Lange coupler can be used to overcome these two problems [13]. The developed full-scale computer simulation program is used to design the Lange hybrid operated at central frequency F_o=3 GHz with four coupled lines and a coupling factor of 3 dB. As a result of the developed program, the parameters of the Lange hybrid are as follow:

Strip separation S = 0.142 mm, strip width W = 1.45 mm, even mode impedance Z_{oe} = 176.4 Ω, odd mode impedance Z_{oo} = 52.5384 Ω, Even mode W/H ratio = 1.1689, Odd mode W/H ratio = 7.29, and coupled line length L = 17.36 mm.

Figure 4 shows $|S_{21}|$, $|S_{31}|$, and $|S_{41}|$ versus frequency in GHz for a Lange coupler operated at 3-GHz central frequency. Figure 5 shows the configuration of the Lange coupler.

4. DESIGN OF A LOW-PASS FILTER

The low-pass filter is used for passing only the DC bias voltage to the bases and collectors of the two transistors and suppressing the unwanted AC signals. The designed low-pass filter is made by using distributed microstrip lines with teflon substrate. A maximally flat low-pass prototype filter is used to design the low-pass filter. The full simulation program developed by the author and others [1] is used to design the maximally flat low-pass filter taking into consideration the effects of step discontinuities and the equivalent end effect lengths. The program calculates all parameters of the low-pass filter for the given characteristic impedance of the distributed inductance Z_{OL} = 90 Ω, characteristic impedance of the distributed capacitance Z_{OC} = 20 Ω, number of sections N = 1, pass-band frequency F_P = 0.75 GHz, and stop-band F_S = 1.5 GHz. As a result of the developed program: The length and width of the inductive microstrip line are 23.52 mm and 0.8312 mm, respectively.

The length and width of the capacitive microstrip line are 29.94 mm and 7.82 mm, respectively.

The lumped inductance and capacitance of the designed low-pass filter are 0.4579 x 10^{-12} H, and 0.7132 x 10^{-11} F, respectively.

Fig. 4 $|S_{21}|$, $|S_{31}|$ and $|S_{41}|$ versus frequency in GHz for a Lange coupler operated at 3 G Hz

Figure 6 shows $|S_{11}|$ and $|S_{21}|$ versus the frequency in GHz for the designed low-pass filter. Figure 7 shows the distributed and lumped one-section maximally flat low-pass filter.

Fig 5 Configuration of Lange coupler: (1) Input port, (2) Coupled port, (3) Directed port and (4) Isolated port

Fig. 6 $|S_{11}|$ and $|S_{21}|$ versus the frequency in GHz for the designed low-pass filter.

Fig. 7 Schematic of the designed distributed low-pass filter and the corresponding lumped circuit

5. FINAL AC SCHEMATIC OF THE DESIGNED BALANCED MICROSTRIP AMPLIFIER

Figure 8 shows the schematic of the broadband 2-4 GHz balanced microstrip amplifier, where:

Fig. 8 AC microstrip schematic of the broadband 2-4 GHz balanced amplifier

A) Input Lange coupler

B) Output Lange coupler

C) Input matching circuit of the first amplifier

D) Input matching circuit of the second amplifier

E) Output matching circuit of the first amplifier

F) Output matching circuit of the second amplifier

Q1) The transistor for the first amplifier

Q2) The transistor for the second amplifier

1) Input port of the balanced amplifier

2) Output port of the balanced amplifier

3) Isolated port at the output of the balanced amplifier

4) Isolated port at the input of the balanced amplifier

5) Input of the first amplifier

6) Input of the second amplifier

7) Output of the first amplifier

8) Output of the second amplifier

6. APPLICATIONS

The designed broadband microstrip amplifier could have many applications including sensors, pulse Doppler communications, airborne radar, traffic control radar, satellite communications, etc.

7. CONCLUSIONS

This paper introduces a computer-aided design and analysis of a broadband 2-4 GHz microstrip amplifier using silicon BJT HXTR 3101 as an active element. The associated microwave circuits comprise matching circuits, 3-dB Lange couplers, and low-pass filters. A short and efficient CAD procedure for the design of broadband amplifier is introduced. An initial narrow-band, high gain amplifier is designed. The analytical design procedure approach of the narrow-band high gain amplifier is presented. An optimization program is used to adjust the initial lengths and widths of the input and output matching circuits to get the broadband amplifier over the range 2-4 GHz. A full-scale computer simulation program developed by the author and others is used to get the complete design of input and output matching circuits, Lange couplers, and low-pass filters. Analyses of the individual parts of the balanced amplifier are performed. The final AC schematic of the designed broadband microstrip amplifier is illustrated.

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BIOGRAPHY

Dr. Said Hassan Ibrahim was born in Cairo, Egypt (Aug. 6, 1960). He got both his B.Sc. and M.Sc. Degrees in Electrical Engineering from Military Technical College, Cairo, Egypt, respectively, in July 1983 and Jan. 1991 and his Ph.D. Degree in Electrical Engineering from Faculty of Engineering, Ain-shams Univ., Cairo, Egypt in Oct. 1996. He has worked in education, research, and industry. Now he is working as an assistant professor at the Faculty of Computers and Information, Mansura Univ., Mansoura, Egypt. He has published more than 30 papers in international and national conferences.