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X-Band 5-bit MMIC Digital Attenuator with Low Phase Shift

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Abstract

This paper presents the x-band 5-bit MMIC digital attenuator with low phase shift. Phase compensation techniques were used in the MMIC design to reduce the phase shift. This attenuator is fabricated with 0.2μm GaAs PHEMT process. Measurement results of the developed MMIC chips in the x-band show that the 5-bit MMIC digital attenuator has 0.5dB resolution and 15.5dB dynamic attenuation range, input return losses was less than 10dB and output return losses was less than 13dB for all attenuation states, RMS is less than 0.2dB; insertion loss is less than 3.8dB; phase shift error is less than 5°for 35 attenuation states; The MMIC chip size is 1.58 mm×2.95 mm×0.1mm.

***Keywords**: X-band, 5-bit, digital attenuator, low phase shift*

1. Introduction

MMIC variable attenuators are required in many communication systems such as cellular-phones to control the signal level and adjust the system power budget. An attenuator specially is a key device of the module used in cellular-phones because the attenuator is to control of the amplitude [1-4].

The attenuator has two types of control method, analog attenuator and digital attenuator. Digital attenuators offer better linearity, high power handling, and easy and accurate control of attenuation, So MMIC digital attenuators have gained lots of interest in recent years [5].

The requirements of the MMIC digital attenuators to be designed are as following: small size, high attenuation accuracy, low insertion phase shift, high reliability and low cost [6].

In this paper, we describes an MMIC digital attenuator with low phase shift in X-band. The 5-bit digital attenuator has obtained excellent performances and implements in 0.2um GaAs PHEMT MMIC.

2. Circuit Design

Published literature on MMIC digital attenuators mainly rely on three basic types of topologies: i) Tee attenuator; ii) Bridged-Tee attenuator; iii) Pi attenuator. All of them relay on a signal through either a bypass line or an attenuation cell with RF switches [7, 8]. Figure 1, Figure 2 and Figure 3 show the topologies of Tee attenuator, Bridged-Tee attenuator and Pi attenuator.

Referring to FIG.5. the schematic of the x-band MMIC digital attenuator with low phase shift is shown. To achieve good performance, the circuit configuration as well as the process conditions, should be selected properly.

The digital attenuator consists of switched PHEMTs, capacitors, resistors, and microstrip lines. When PHEMT is ON-state,a small resistance R_{ON}, ideally zeroed, appears between source and drain ports; when PHEMT is OFF-state, the simplified equivalent model shows a high resistance R_{OFF} and a Parallel capacitor C_{OFF} between source and drain ports;The switched PHEMTs in the circuit are controlled through 8kΩ resistors of the gate poles, which provide enough radio frequency isolation between the gate of each switched PHEMT and the control sources. And the low value resistors are used to form the topologies for attenuators [9].

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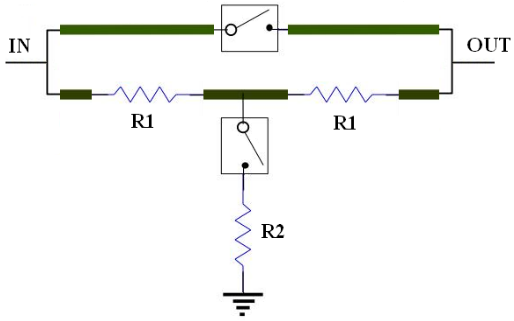

Figure 1. Tee Attenuator

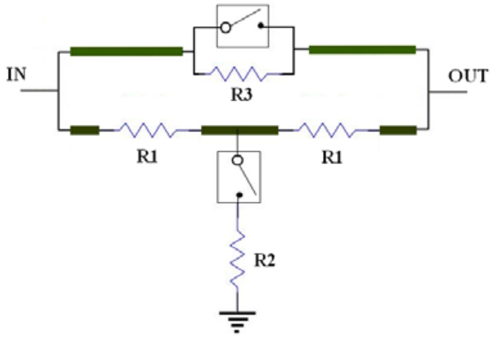

Figure 2. Bridged-Tee Attenuator

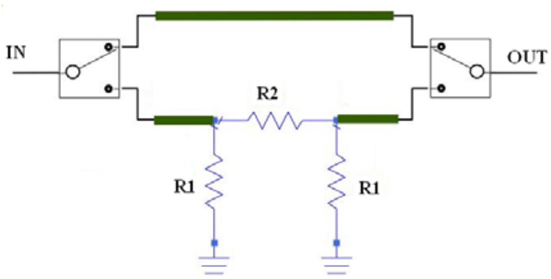

Figure 3. Pi Attenuator

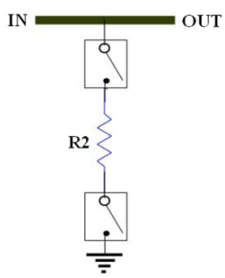

Figure 4. Simple Tee Attenuator

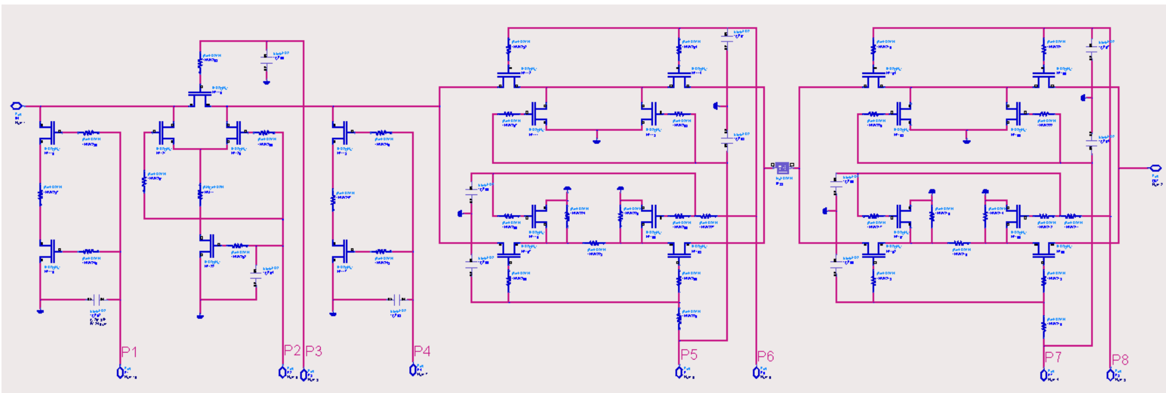

Figure 5. Schematic of the Digital Attenuator

The five required attenuation bits are the 0.5dB, 1dB, 2dB, 4dB and 8dB, providing a dynamic range from 0.5dB to 15.5dB. Tee attenuator (Figure 1) is selected for 0.5dB-bit, 1dB-bit and 2dB-bit attenuator, Tee attenuator is chosen because of its good performance in insertion loss, input/output VSWR and has better attenuate precision than other. The Tee attenuator used in 0.5dB-bit and 1dB-bit is Simple Tee attenuator (Figure 4), compare to typical Tee attenuator, the Simple Tee attenuator without R1 and parallel PHEMT switch, the attenuator cell is represented only by R2 to the ground. The Tee attenuator used in 2dB-bit neglect the R1, microstrip lines lengths are used to have no phase shift between the two states. The 4dB-bit and 8dB-bit is acquired by using Pi attenuator (Figure 3), because of two switches, Pi attenuator has more insertion loss, but Pi attenuator is robust to the temperature variation and process. because the difference between parasitic components casused by the ON-state and OFF-state operations of the switching PHEMTs of the digital Attenuator causes the difference between the pass phases. 0.5dB-bit, 1dB-bit and 2dB-bit attenuator have little impact on the phase shift error, through the optimization of the circuit, satisfactory results are obtained. a phase correction unit connected in parallel with the 4dB-bit and 8dB-bit attenuation circuit unit. Beside the R2 the phase correction unit structure is the same with Pi attenuator. In perfect case, microstrip lines lengths between ON and OFF states is zero, In reality, Lengths are also used to have no phase shift between the two states, and use the same configuration in two channel [10, 11].

The digital attenuator uses 8 voltage control port to feed the PHEMTs' gate poles. In this case, when the control voltages are set at -5V, which is the negative pinch-off voltage of switched PHEMT, the switched PHEMT will work at its "off" state (high resistance). When the control voltages are set at 0V, The switched PHEMT will work at its "on" state. So the required attenuation can be obtained by switching the control voltages at the port.

The digital attenuator is at the minimum attenuation state, when the control voltages P3, P6 and P8 are 0 V, P1, P2, P4, P5 and P7 are -5 V. In this case, the attenuator has a minimum insertion loss. The attenuator is at the maximum attenuation state, when the control voltages P1, P2, P4, P5 and P7 are 0 V, and P3, P6 and P8 are -5V.

The above description is equally available for the other states. The control signal with the value of 0 V is taken as "1" and the control signal with the value of -5 V is taken as "0." The truth table of the digitally-controlled main attenuation states shows in Table 1, which is referred to in Figure 4.

Table 1. Truth Table of Main Attenuation States Shows ("1"as 0V.0"AS -5V)

	0.5dB	1dB	2dB		4dB		8dB	
	P1	P4	P2	P3	P5	P6	P7	P8
MIN	0	0	0	1	0	1	0	1
0.5dB	1	0	0	1	0	1	0	1
1 dB	0	1	0	1	0	1	0	1
2 dB	0	0	1	0	0	1	0	1
4 dB	0	0	0	1	1	0	0	1
8 dB	0	0	0	1	0	1	1	0
MAX	1	1	1	0	1	0	1	0

Using the new configuration, a digital attenuator has been realized by 0.2um GaAs process. The simulation of our digital attenuator have been presented based on the ADS2008.Broadband and low phase shift performance was achieved by optimization of the transmission line parameters and the resistor values.

The Monte Carlo analysis were also utilized in the attenuator design, the results predicted that the design has stability against the process variations. The layout of x-band MMIC digital attenuator with low phase shift as shown in Figure 6. RF input and output are at the either end with complementary pairs of the control lines along one edge. The chip size was 1.58mm×2.95mm.

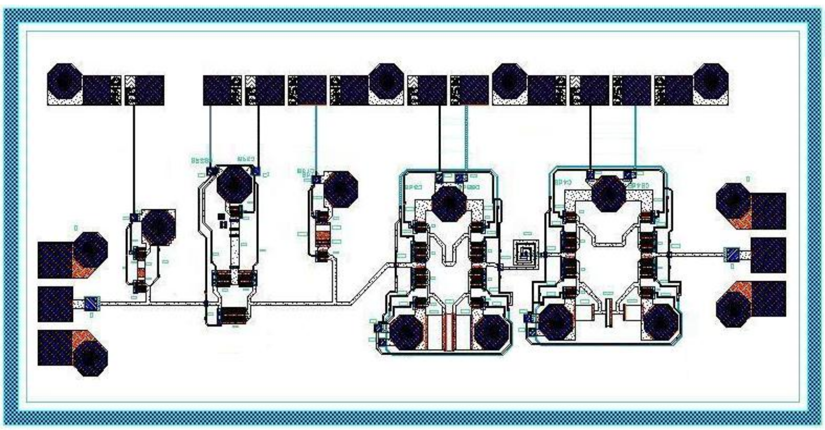

Figure 6. The Layout of x-band MMIC Digital Attenuator with Low Phase Shift

3. Measured Results

The circuit measurement was completed by using a computer controlled test system, Which consists of computer platform, GPIB interface, Agilent PNA-X network analyzer and data acquisition card. Input and output inductance of 0.5nH included. Circuit parameters measurement was conducted for all 35 attenuation states. The eight control voltages of the attenuator were using Truth table.

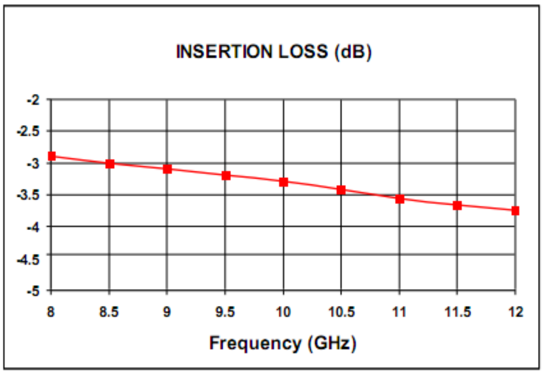

Figure 7. Insertion Loss

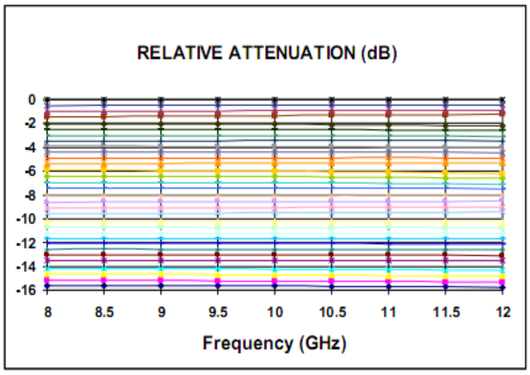

Figure 8. Relative Attenuation

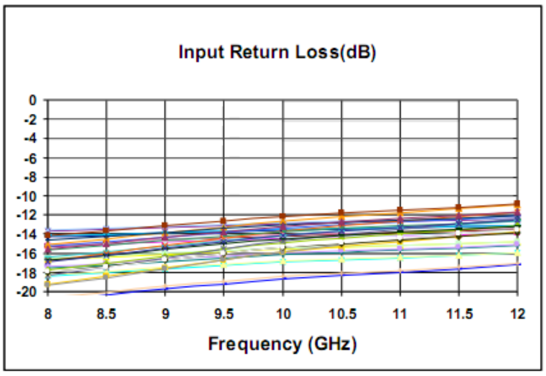

Figure 9. Input Return Loss

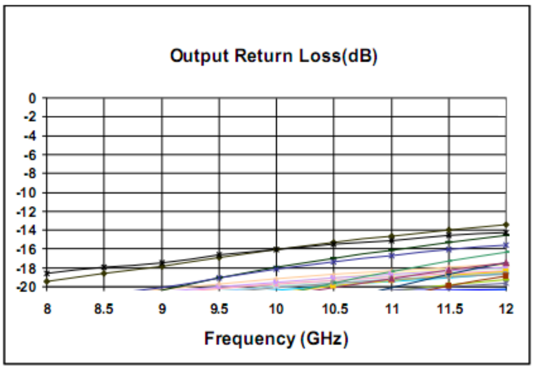

Figure 10. Output Return Loss

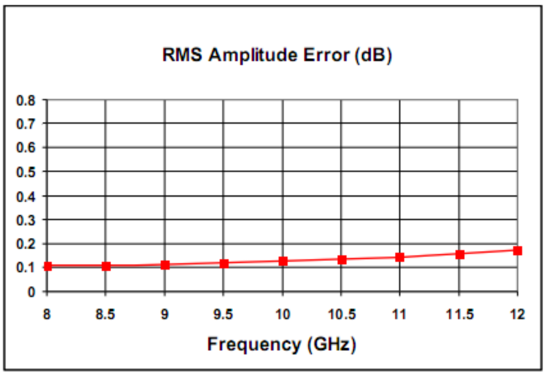

Figure 11. RMS Amplitude Error

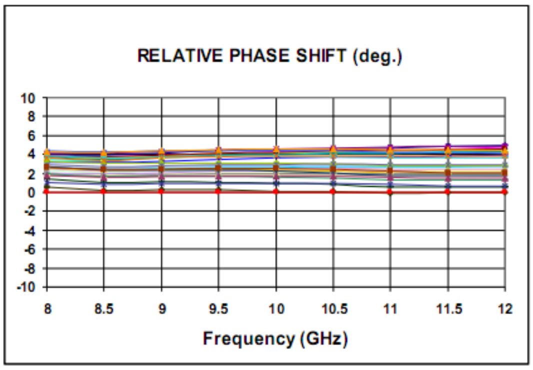

Figure 12. Relative Phase Shift

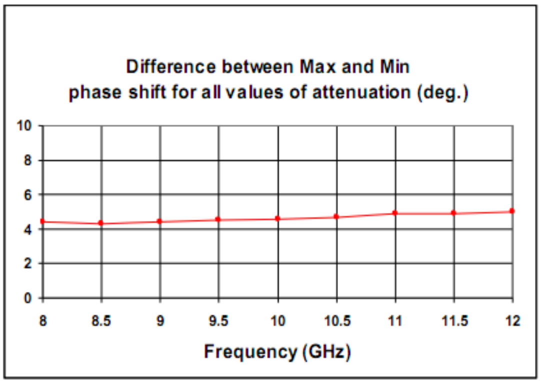

Figure 13. Difference between Max and Min Phase Shift

The measured insertion loss is shown in Figure 7. The attenuator achieved a minimum insertion loss of 2.9~3.8dB in the entire x-band. Referring to Figure 8, It can be seen that each curve in the figure represents a different attenuation setting in a roughly 0.5dB step with over 15.5dB dynamic range, for which a proper combination of the control voltages was chosen. Figure 9 and Figure 10 show the measured input and output return losses for 35 attenuation states. The input return loss was always less than 10dB and the output return loss was always less than 13dB at any attenuation setting from x-band. RMS amplitude error is shown in Figure 11, which was below 0.2dB. Figure 12, and Figure 13 show the Relative Phase Shift, Difference between Max and Min Phase Shift. phase shift error is very low, Difference between max and min phase shift for all values of attenuation, the value is less than 5° for 35 attenuation states.

4. Conclusion

The theory, design, and measurement of a the x-band 5-bit MMIC digital attenuator with low phase shift are presented. Phase compensation techniques were used in the MMIC design to reduce the phase shift. To ensure high yield, Performance redundancy optimization strategy is used in design. the results of the developed MMIC chips in the x-band show that the 5-bit MMIC digital attenuator has 0.5dB resolution and 15.5dB dynamic attenuation range, input return losses was less than 10dB and output return losses was less than 13dB for all attenuation states, RMS is less than 0.2dB; insertion loss is less than 3.8dB; phase shift error is less than 5°for 35 attenuation states. The MMIC chip size is 1.58 mm×2.95 mm×0.1mm. This proposed MMIC has shown excellent performance covering x-band for digital attenuator.

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