A Ka-BAND 4-BIT MONOLITHIC PAHSE SHIFTER USING UNRESONATD FET SWITCHES

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Abstract

This paper presents a Ka-band 4-bit monolithic phase shifter incorporating novel unresonated FET switches which show broadband on/off characteristics up to 40 GHz without inductors. The developed switched-line phase shifter MMIC demonstrated an overall phase deviation of 3.3° rms and an insertion loss deviation of 0.9 dB rms at 34.5 GHz. Over a relatively wide frequency range from 33 to 36 GHz, the phase deviation was less than 7° rms. The chip size of the MMIC is 2.5 mm x 2.2 mm.

Introduction

Phase shifters are key components for phased-array antenna systems. Monolithic implementation is necessary for low cost and high producibility. Several phase shifter MMIC's have been reported at Ka- and Q-bands [1]-[3]. In these frequency bands, switched-line configuration has advantages of applicable phase shift characteristics to the above systems and a small chip size due to simple circuit and layout designs.

A conventional switched-line phase shifter employs resonated switches which consist of FET's and spiral inductors [1][2]. In the circuit design, precise model or well-established data base for the inductors is needed at the operating frequency. Moreover, in case of using resonated switches, the switch isolation characteristic is sensitive to the change in off-state FET capacitance due to the process variation.

In this paper, we propose a switched-line phase shifter incorporating ***unresonated*** switches based on ohmic electrode sharing technology (OEST), that one of the authors has developed [4]. The fabricated Ka-band monolithic phase shifter using OEST-switches showed good phase shift characteristics with high design feasibility.

Circuit Design

The OEST-switch, which is employed in the phase shifter, reduces parasitic capacitance by arraying the series FET and shunt FET with a common electrode between them instead of intentionally wiring, as shown in Fig. 1. This results in broadband characteristics up to millimeter-wave range without inductors. An insertion loss less than 1.7 dB and an isolation better than 20 dB are obtained from dc to 40 GHz. The OEST-switch occupies small area, thus, it is suitable for switched-line phase shifters.

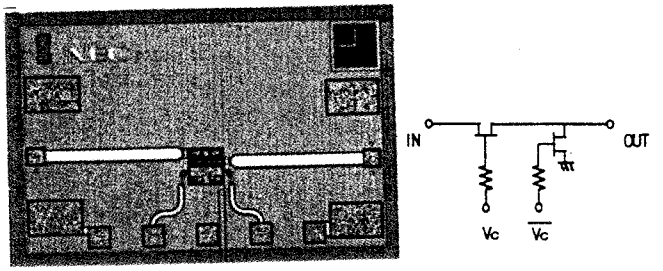

Fig.1. Microphotograph of the OEST-switch with circuit topology.

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The switched-line phase shifter is composed of the OEST-switches, reference lines and delay lines as shown in Fig. 2. The off-state switches appear to be capacitances between the lines and the ground. When 50 Ω lines are used as reference and delay lines, mismatch occurs. Therefore, a special design technique is necessary.

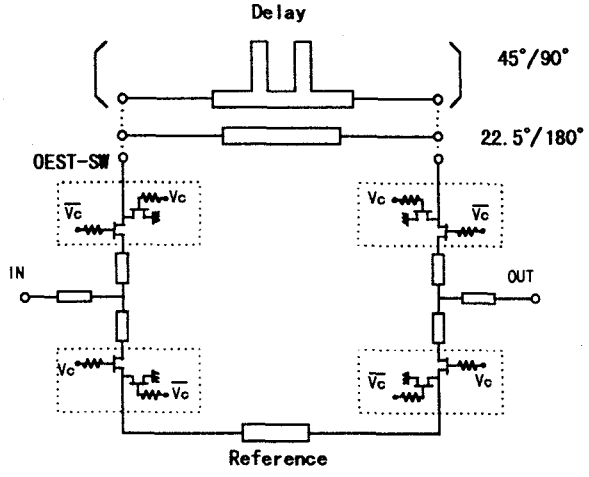

Fig.2. Circuit topology for the phase shifters incorporating the OEST-switches.

A design circuit scheme for the reference and delay lines is shown in Fig. 3. To realize good matching characteristics, reflection coefficient viewing from the center of the line to the input port (Γci) should be real value. Since Γci is identical to that viewing from the center of the line to the output port (Γco) due to symmetry design, it satisfies: $\Gamma ci = \Gamma^{*} co$ for reference and delay lines. In addition, at the center of the line, the phase should delay half of desired phase shift compared to that of the reference line.

In the phase shifter design, the characteristic impedance of each line is lower than 50 Ω. For 45°- and 90°-bit phase shifters, additional open-circuited lines have been incorporated in the delay lines (Fig. 2). With this circuit topology, the MMIC layout is simple, which is an advantage of the switched-line configuration.

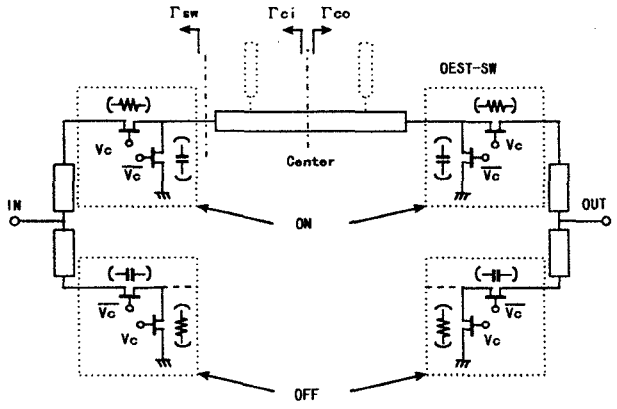

Fig.3. Circuit scheme for the phase shifter design.

As a result of optimization, return loss better than 18 dB was designed for each-bit phase shifter over a frequency range from 33 to 36 GHz. For the 4-bit phase shifter, the maximum phase deviation to the desired relative phase would be 6.8° rms for 16 states over the entire frequency range, which is almost determined by a linear phase-frequency relation for the delay lines.

FET Characteristics

The employed MMIC process features a double-doped double heterojunction FET (HJFET), which has been developed for millimeter-wave high power applications [5]. The active part of the epitaxial structure for the HJFET consists of an InGaAs channel layer sandwiched between Si-doped AlGaAs layers. The HJFET has a T-shaped gate with 0.15 μm length. The device exhibited a typical transconductance of 380 mS/mm and an fmax of 200 GHz with a reverse gate-drain breakdown voltage of 10 V. For the OEST-switches, gate fingers with 100 μm length were employed.

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MMIC Performance

The chip photograph for the fabricated 4-bit monolithic phase shifter is shown in Fig. 4. The chip size is 2.5 mm x 2.2 mm x 0.04 mm.

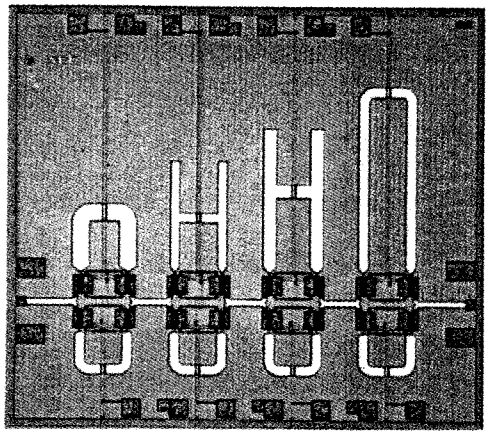

Fig.4. Chip photograph for the fabricated Ka-band four-bit monolithic phase shifter (2.5 mm x 2.2 mm).

MMIC chips were tested using RF probes. Control voltages of 0 and -5 V were applied to the OEST-switches. The designed and measured phase shift characteristics for all 16 states were in good agreement with the theoretical designed values, as shown in Fig. 5. The phase deviation to the desired relative phase was less than 7° rms from 33 to 36 GHz (Fig. 6). At the center frequency of 34.5 GHz, a phase deviation of 3.3° rms was obtained.

The measured insertion loss is shown in Fig. 7. An insertion loss deviation of 0.9 dB rms with an average insertion loss of 15 dB was obtained for 16 states. The input VSWR for all states from 33 to 36 GHz is shown in Fig. 8. The input and output VSWR's were better than 1.5 and 2.0 at 34.5 GHz. These results were obtained at the first design and fabrication.

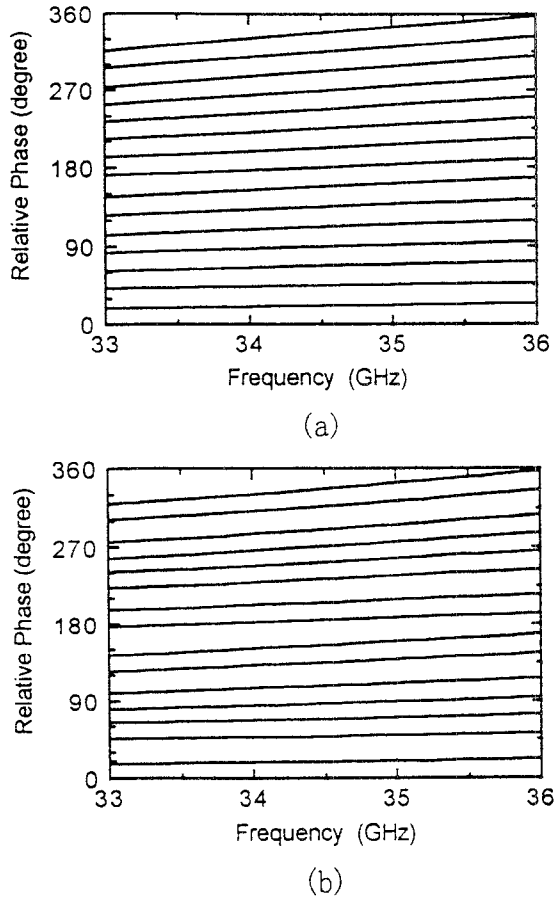

Fig.5. Relative phase shift of the 4-bit phase shifter. (a) Designed (b) Measured

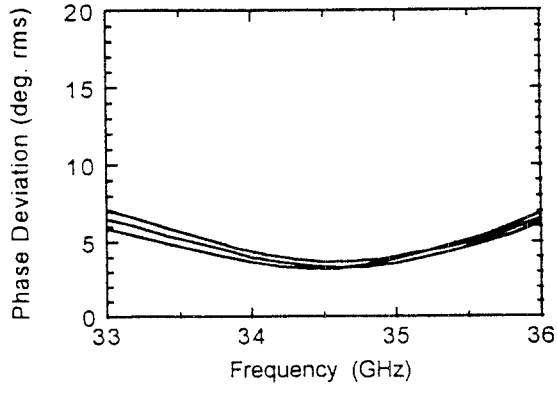

Fig.6. Measured root-mean-square phase shift deviation of 16 states for three MMIC's.

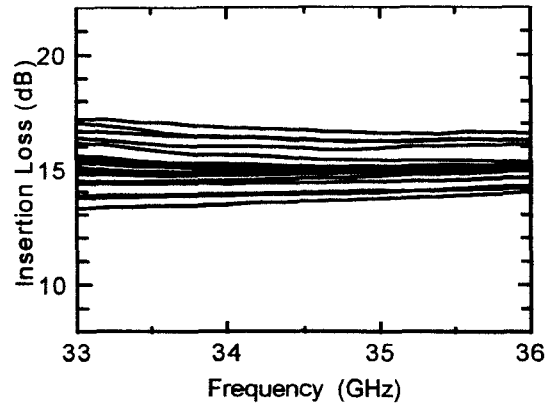

Fig.7. Measured insertion losses of 16 states for 4-bit phase shifter.

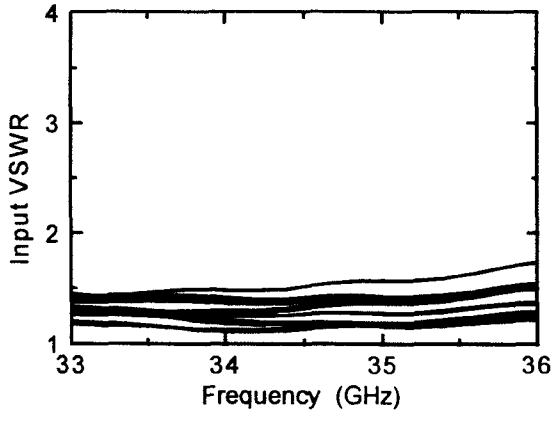

Fig.8. Measured input VSWR of 16 states for the 4-bit phase shifter.

Summary

We have developed a Ka-band 4-bit monolithic phase shifter using unresonated OEST-switches. The switched-line phase shifter MMIC demonstrated an overall phase deviation of 3.3° rms and an insertion loss deviation of 0.9 dB rms at 34.5 GHz. Over a relatively wide frequency range from 33 to 36 GHz, the phase deviation was less than 7° rms. The developed phase shifter featuring a small chip size and good phase shift characteristics promises great applicability to Ka-band phased array antenna systems.

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