L-band Phase Shifter with Switching FET's for Phased Array Antenna

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Abstract

An L-band 3-bit phase shifter has been developed with switching GaAs MESFET's. To get simple and low loss phase shifter, the switching performance of the FET is improved. The FET has an on-state resistance of 1.5ohms by optimizing device structures. By using the phase shift circuit consisting of the FET and a short stub, a phase shifter insertion loss becomes 1.7±0.2dB over the range of 1540 - 1660MHz. A phased array antenna is also developed with the phase shifter.

Introduction

Phased array antennas are one of the promising antennas for mobile satellite communications because of advantages such as low profile and beam agility. Therefore several types of phased array antennas have been developed[1,2]. Toyota Central R&D Labs. have already developed the phased array antenna with PIN diode phase shifters to get high electrical performance[3].

Phased array antennas for cars are required to be as simple and thin as possible. Power consumption and cost are also the major factors. Phase shifters with switching FET's should be appropriate for these purposes because the FET has following advantages.

1) The FET is a three-terminal device and it is easy to isolate the DC bias from RF signal. Therefore the phase shifter becomes simple and small.

2) Switching power of the FET is very low. Phased array antennas with the FET's spend less driving power.

However a switching loss of the FET should be reduced for minimizing the insertion loss of the phase shifter. Moreover phase shifters should be designed considering the switching performances of the FET. In this paper, we discuss about reducing the loss of the FET and developed phase shifter with the FET's. We also discuss about a phased array antenna.

GaAs MESFET for switching application

Layers for the GaAs MESFET are grown by molecular beam epitaxy. The MESFET is fabricated by a mesa etched isolation and a recessed gate process as shown in fig. 1. To reduce the on-state resistance, the FET has following features. (1)It has the thick cap layer with a thickness of 1500A and a carrier concentration of $3\times10^{18}cm^{-3}$. It is decided from the consideration for a channel resistance[4]. A manufacturing process is developed to have a good interconnection across the mesa edges. (2)A gate is 0.5 μm in length. (3)The current I_{dss} of about 300mA/mm is decided so as to get small on-state resistance when the voltage applied to the gate is zero. As a result, the on-state resistance of 2.4ohms/mm is obtained.

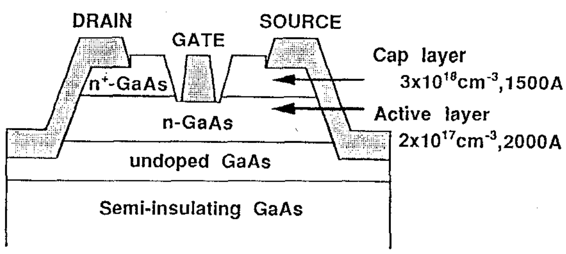

Figure 1. Schematic cross-section of developed FET.

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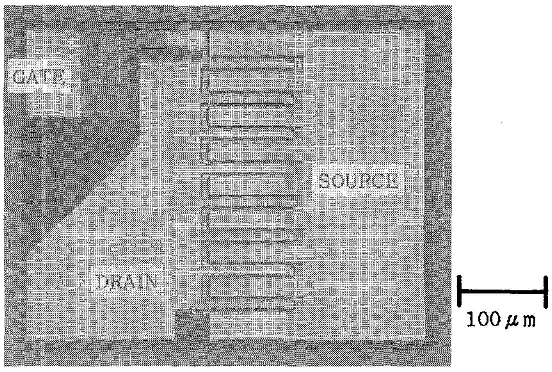

Figure 2. Photograph of FET chip.

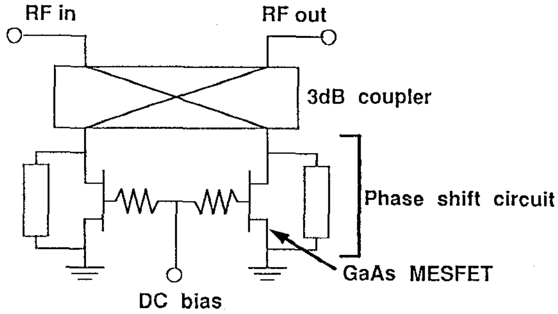

Figure 3. Configuration of phase shifter.

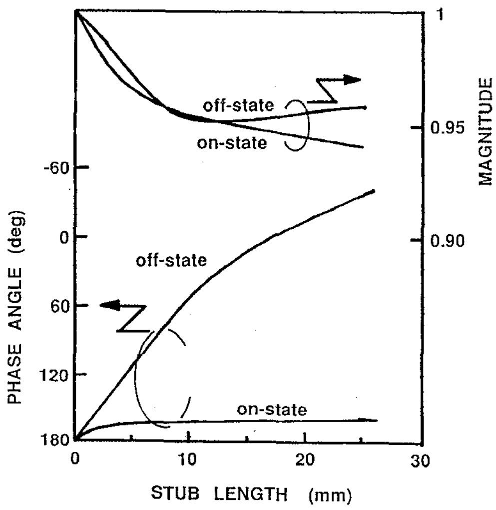

Figure 4. Calcurated reflection coefficient of phase shift circuit.

Table 1. Reflection coefficients of FET.

	Reflection coefficient
on-state (V_{GS}= 0V)	0.94∠159°
off-state (V_{GS}=-4V)	0.98∠-43°

The width of the gate is decided by considering both the on-state resistance and off-state capacitance. By widening the gate, the on-state resistance is decreased but the change in the phase angles of the reflection coefficient (as seen at the drain of the FET which is grounded at the source) between two states is smaller due to large off-state capacitance. The width is decided to be 1.6mm to get appropriate phase angles.

The photograph of the FET is shown in fig. 2. A 10kohm resistance is connected at the gate in series to isolate the DC bias from RF. The reflection coefficients of the FET are described in table 1. The magnitude is very close to unity but different between on- and off-states. The phase shifter should be designed to be equal insertion loss between two phase states.

L-band 3bit phase shifter

A 3-bit phase shifter is composed with developed FET's. The reflection type[5] with a conventional Lange coupler[6] is chosen for all bits of the phase shifter to minimize size.

Fig. 3 shows the configuration of the phase shifter for single bit. Phase shift circuits are designed to yield a prescribed change in the phase angle of the reflection coefficient, while maintaining constancy of the magnitude of it. A phase shift circuit composed with the FET and a short stub connected in shunt[7] with the FET complies with these requirements. The reflection coefficients of the phase shift circuits are shown in fig. 4. Any change in phase angle is realized by changing the stub length. The magnitude fluctuation between two phase states is small in any stub length.

Phase shifters for 45, 90 and 180 degrees bits are composed with the phase shift circuits. The photograph of the 3-bit phase shifter (including feeding circuit) is shown in fig. 5. As shown in the figure, the phase shift circuits are made compact. The ceramic-PTFE composite is used as the substrates whose relative dielectric constant is 10.2 and thickness is 1.27mm. The size is 6cm x 5cm.

The average insertion loss is 1.7dB with a variation of ±0.2dB. The return loss is less than -15dB. The phase error is less than 10 degrees over the frequency range of 1540 - 1660 MHz. These results are summarized in figs. 6, 7 and 8.

Phased array antenna

A phased array antenna with developed phase shifters has been developed as well as PIN diode type phased array antenna[3]. Fig. 9 shows antenna gains as the function of the beam steering angle at 1550MHz and 1650MHz. A value of θ_0 indicates the elevation angle from horizon. A little drop of gain is observed for the antenna with FET phase shifters compared with PIN diode phase shifter type. This is caused by larger insertion loss of phase shifters and power divider/combiner. The photograph of feeding network of the antenna is shown in fig. 10. All of the circuits of feeding network, i.e. feeding circuits, phase shifters and power divider/ combiner are assembled into the same plane. The antenna with developed phase shifter has such simple configuration and low profile.

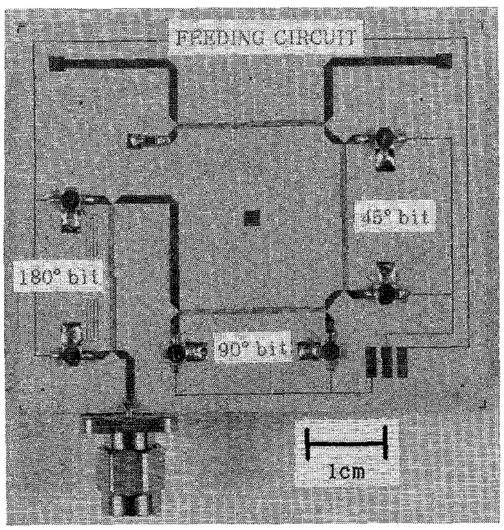

Figure 5. Photograph of 3-bit phase shifter including feeding circuit.

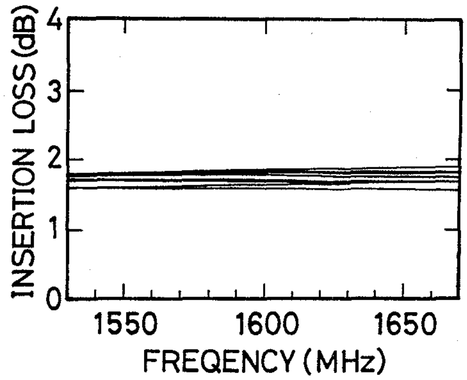

Figure 6. Insertion loss of 3-bit phase shifter.

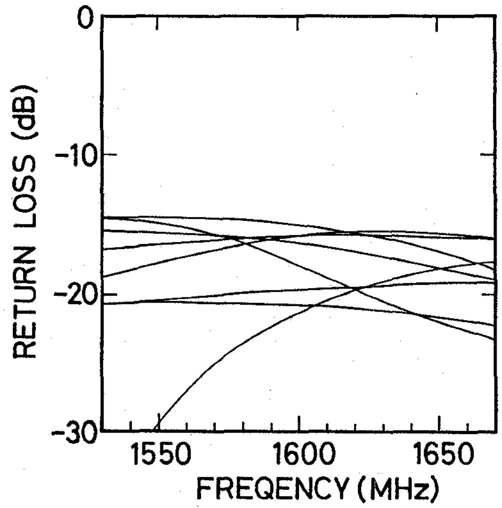

Figure 7. Return loss of 3-bit phase shifter.

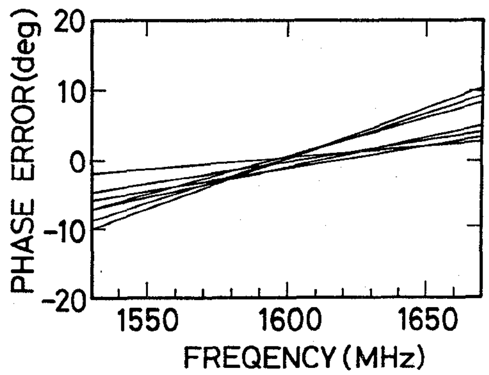

Figure 8. Phase error of 3-bit phase shifter.

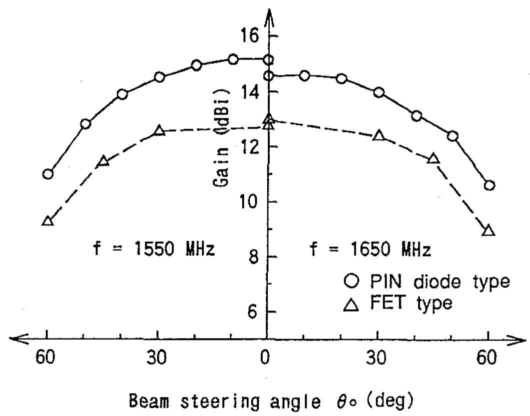

Figure 9. Antenna gain as a function of beam steering angle.

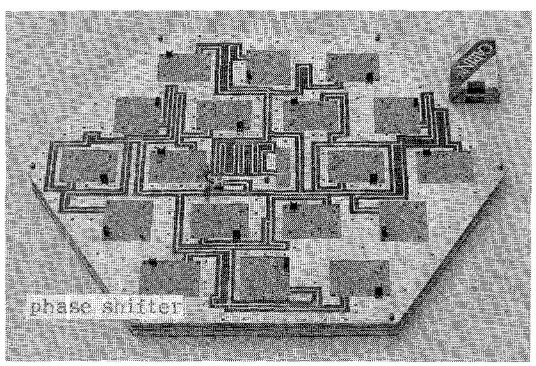

Figure 10. Photograph of feeding network for phased array antenna (Upper ground plate of power divider/combiner is removed).

Conclusions

FET phase shifters for a phased array antenna have advantages such as simple, small and low driving power. To improve the switching performance of FET's, the device structure is optimized. A small on-state resistance of 1.5ohms is obtained by a thick cap layer.

The compact phase shifter has developed by using the phase shift circuits consisting of the FET and a short stub. An insertion loss of the phase shifter averages 1.7dB with a variation of 0.2dB and a return loss is less than -15dB. A phase error is 10 degrees maximum over the frequency range of 1540 - 1660MHz.

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