Compact Ku-band GaAs Multifunction Chip for SATCOM Phased Arrays

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Abstract— **This paper presents a compact Ku-band GaAs multifunction chip using commercial GaAs pHEMT technologies for SATCOM applications. The multifunction chip consists of a 4-bit phase shifter and a 4-bit attenuator with a serial-to-parallel converter (SPC) but the size is less than 7.6 mm^2. Typical value of RMS attenuation error and RMS phase error are 0.5 dB and 3.5^o, respectively in the frequency range of 12-18 GHz. The SPC-integrated multifunction chip leads to a simplification in the control interface and a reduction in the cost of module assembly.**

Keywords—Multifunction chip, Ku-band, GaAs MMIC, phase shifter, attenuator, serial-to-parallel converter

I. INTRODUCTION

Phased array technologies have been increasingly applied to satellite communications and defense systems to implement high-performance antennas or radar systems. In phased array antennas, beam forming and steering functions are realized by controlling phase and amplitude of each radiator. However, since these increase the complexity and the cost of the system, commercial applications have been limited. Such problems can be solved by using the multifunction chip which includes many functions such as phase shifting, attenuation, and amplification.

In recent years several GaAs multifunction chips have been presented, and most of them operate in the X-band for radar T/R modules [1]-[2]. Research on Ku-band multifunction chips for mobile satellite telecommunications (SATCOM) is at an incipient stage through NATALIA project [3]-[4].

This paper presents a compact Ku-band GaAs multifunction chip using commercial GaAs pHEMT technologies for SATCOM applications. The multifunction chip consists of a 4-bit phase shifter, a 4-bit attenuator and a serial-to-parallel converter (SPC) under the size of 7.6 mm^2. Its control interface needs only five pads. This simple interface can be achieved by an integrated SPC, which we previously reported in [5] that presents S-band multifunction chips. The fabricated Ku-band multifunction chip shows RMS attenuation error of 0.5 dB and RMS phase error of 3.5^o over the frequency band of 12-18 GHz.

II. KU-BAND CORECHIP DESIGN AND FABRICATION

The Ku-band multifunction chip consists of a 4-bit phase shifter, a 4-bit attenuator and a serial-to-parallel converter for digital control. The functional block diagram of the multifunction chip is shown in Fig. 1. The 0.5 μm E/D mode GaAs pHEMT technology of WIN Semiconductors is selected to design the multifunction chip. The phase shifter and the attenuator of 'digital' type are designed for the immunity of noise and simplicity of the beam control circuit. The digital phase shifter and attenuator are controlled through the SPC. The SPC converts total 8 bits of serial control input into 8 bits of parallel control output. Thanks to the SPC, the number of pads for the control of the phase shifter and the attenuator can be reduced.

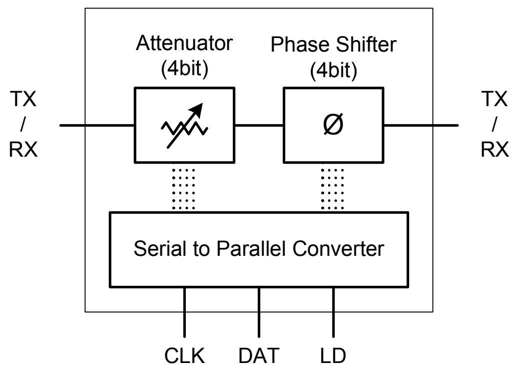

Fig. 1. Functional block diagram of Ku-band multifunction chip.

A. Attenuator

The 4-bit attenuator was composed of 0.5 dB, 1 dB, 2 dB, and 4 dB attenuation cells. Each attenuation cell was designed as switched-T configuration. The switched-T attenuator has advantages of low insertion loss and small size, since a single switch is used in series. The phase variation when attenuation status is changed must be minimized for precise control. The constant-phase digital attenuator can be implemented by the proper size of a switch FETs. Large signal model of the switch FET was used to design and simulate the attenuator [6].

B. *Phase Shifter*

The 4-bit phase shifter was composed of 22.5°, 45°, 90°, 180° cells. Modified bridged–T topology was adopted in the design of 22.5° cell to reduce the size. The 45° cell was made of two 22.5° cells. The 90° cell was designed with switched high-pass/low-pass topology. The 180° cell was designed with the structure proposed by Ayasli [7]. The amplitude variation when phase status is changed also must be minimized. The large signal model of the switch FET was also used to design the each phase shifter cell.

C. *Serial-to-Parallel Converter*

The serial-to-parallel converter consists of three transistor-transistor logic to direct-coupled FET logic (TTL-to-DCFL) converters, eight shift registers, and eight output drivers. The input control voltage levels are converted from the external TTL level to the internal DCFL level by the TTL-to-DCFL converters. A shift register is used to store data in the form of binary numbers and to shift the stored data to the next shift register once every clock cycle. The output drivers provide a sufficient switching voltage of -2.2 V to 0 V to switch FETs. Bias voltage and DC current are required to be -2.2 V and 60 mA, respectively [5].

Fig. 2 shows the microphotograph of the fabricated Ku-band multifunction chip. The chip size is 7.6 mm^2 (4 mm x 1.9 mm).

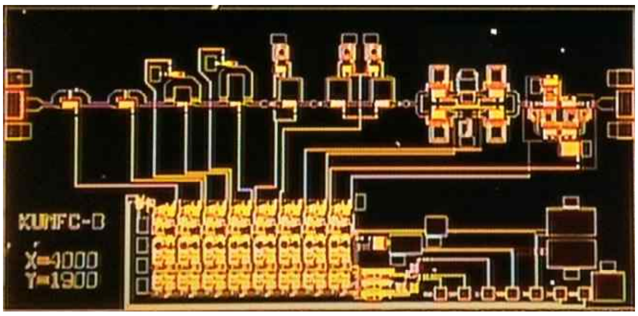

Fig. 2. Microphotograph of Ku-band multifunction chip.

III. MEASURED RESULTS

The multifunction chip was tested using an RF on-wafer probing system. The measured S21 and S11, S22 of the multifunction chip in a reference state are shown in Fig. 3. Fig. 4 through Fig. 9 show the measured attenuator and phase shifter performances. The measured relative attenuations versus frequency for all 16 states are shown in Fig. 4. The attenuation errors of the 2-dB cell and the 4-dB cell are 0.6 dB and 0.65 dB, respectively, so RMS attenuation error is increased. The RMS and the maximum/minimum attenuation error versus frequency are shown in Fig. 5. The measured RMS attenuation error is typically 0.5 dB over the frequency band of 12-18 GHz. Fig. 6 shows phase variation due to attenuator control in all 16 states. The phase varies from -5° to 5° when the all attenuation statuses are changed over the frequency band of 12-18 GHz.

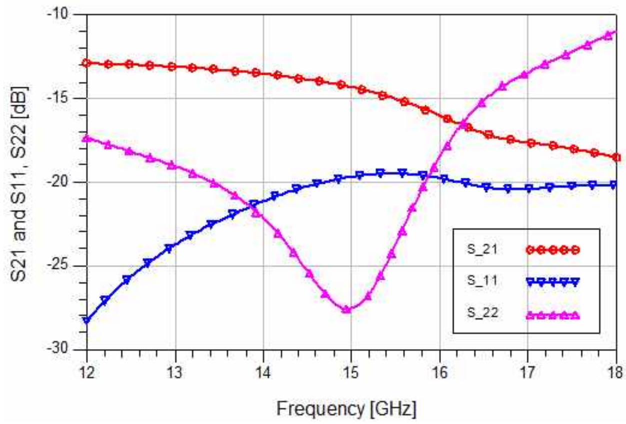

Fig. 3. Measureed S21 and S11, S22 of the Ku-band multifunction chip in a reference state.

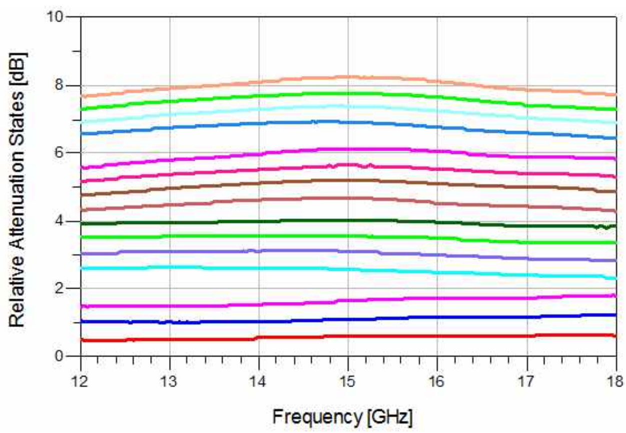

Fig. 4. Measureed all relative attenuation states.

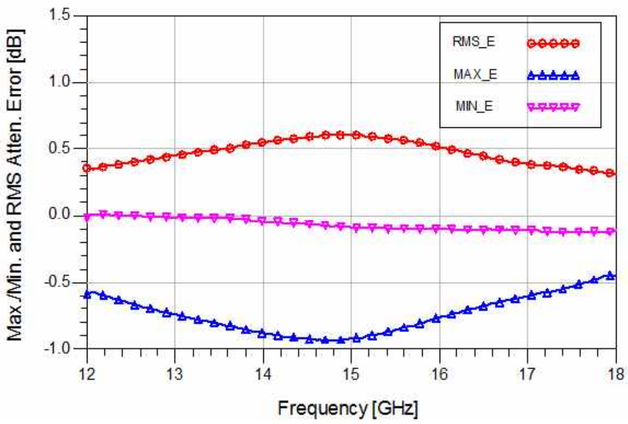

Fig. 5. Maximum, minimum and RMS Attenuation errors

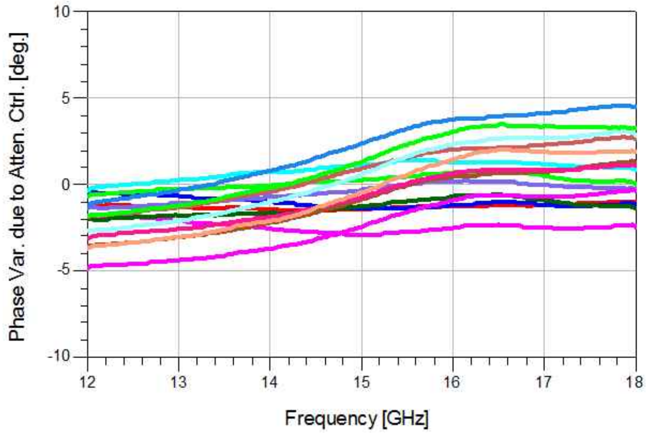

Fig. 6. Phase variation due to attenuator control.

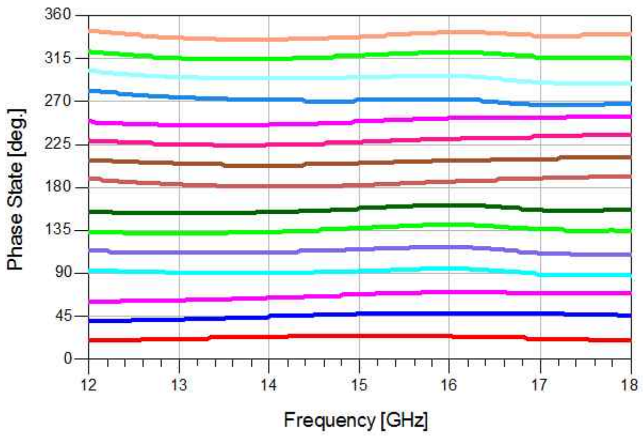

Fig. 7. Measureed all phase states.

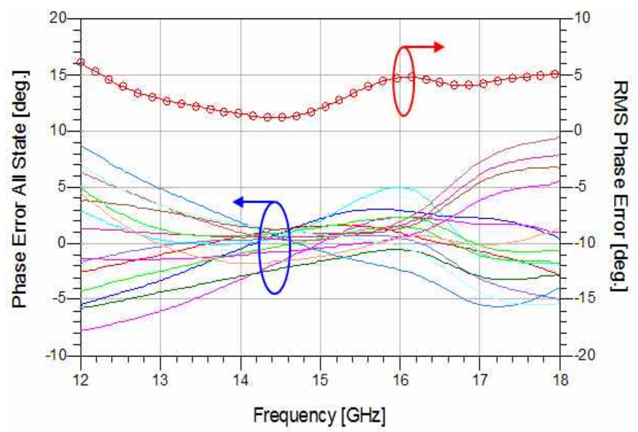

Fig. 8. RMS and all state phase errors.

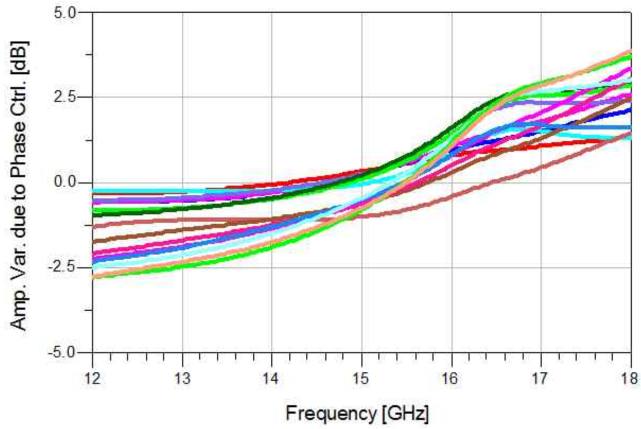

Fig. 9. Amplitude variation due to phase shifter control.

Fig. 7 shows all 16 states of the measured relative phase. The phase error of all states and RMS phase error are shown in Fig. 8. The RMS phase error is typically 4° over the frequency band of 12-18 GHz. Fig. 9 shows amplitude variation due to phase shifter control in all 16 states. The amplitude varies from -2.5 dB to 3 dB when the all phase shifter statuses are changed over the frequency range of 12-18 GHz.

Finally, the main measured performance of multifunction chip is summarized in Table 1.

TABLE I. SUMMARY OF KU-BAND MULTIFUNCTION CHIP PERFORMANCE

Parameter	Value	Unit	Notes
Operating Frequency	12 ~ 18	GHz	
Area	4.0 x 1.9	mm^2	
Atten. dynamic range	7.5	dB	
Phase dynamic range	360	deg.	
Bits for attenuation	4	bit	LSB = 0.5 dB
Bits for phase	4	bit	LSB = 22.5°
RMS attenuation error	0.5 (0.6)	dB	Typ. (Max.)
RMS phase error	3.5 (6)	deg.	Typ. (Max.)
Insertion loss (S21)	-15 (-18.5)	dB	Typ. (Min.), @Ref.
Input return loss (S11)	-21 (-19.5)	dB	Typ. (Max.) , @Ref.
Output return loss	-20 (-11)	dB	Typ. (Max.) , @Ref.
DC cur. consumption	60	mA	Vc = -2.2 V

IV. CONCLUSION

A compact Ku-band multifunction chip was designed and fabricated with 0.5 μm GaAs pHEMT technologies. The multifunction chip provides digital 4-bit attenuation and phase shifting with wideband performance and a small chip size. The

SPC-integrated multifunction chip leads to a simplification in the control interface and a reduction in the cost of module assembly. It is anticipated that this multifunction MMIC will be a good candidate for a Ku-band SATCOM phased arrays.

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