A single chip C-band linear MMIC vector modulator on GaAs developed for an air-borne active phased-array synthetic aperture radar

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Abstract

The design, fabrication and performance results of a fully monolithic linear vector modulator are described. The circuit is designed for a 5.0 - 5.6 GHz frequency range.
The insertion loss of the device is typically 4 dB with input and output return losses better than 7 dB and 15 dB respectively. The RMS amplitude error is typical 0.4 dB and the RMS phase error typical 2.3 degrees over 255 states. These figures can be improved by correcting the systematic amplitude and phase errors of the device by a look-up table. The RMS amplitude error is reduced to 0.2 dB while the RMS phase error is less than 1.2 degrees.

Introduction

Small complex circuits, like vector modulators, are needed for implementation in active phased array radars.
This paper describes a vector modulator which is designed for transmit/receive modules used in a full polarimetric C-band air-borne phased-array synthetic aperture radar (SAR) called PHARUS [1]. The PHARUS design (acronym for PHased ARray Universal Sar) uses a dual polarised microstrip antenna with low cross-polarisation and has the possibility for accurate internal calibration.

The PHARUS system is currently manufactured and testing of the system will commence in the middle of 1994. This air-borne SAR will be used to image the earth's surface. Each of the 48 transmit/receive modules of the SAR is using two vector modulators. The vector modulators control the beam-forming of the radar, one for each polarisation. The bandwidth of the SAR is 40 MHz which is fully covered by the vector modulator. The SAR-system is upgradable to a bandwidth of 100 MHz.
Fig. 1, displayed at the end of the paper, shows a photograph of a transmit/receive module.

The technology in PHARUS resembles the architecture for future space borne SAR systems. In that sense the PHARUS project can be thought of as being a testbed for space borne SAR technology. The experience gained will help in developing the next generation of high performance space SAR systems.

Design

A simplified block diagram of the vector modulator is shown in Fig. 2. The active quadrature power splitter consists of a 2-stage amplifier with flat gain and relative low-noise figure. The quadrature phase relation is obtained by lumped element high-pass and low-pass filters [2], [3]. The biphase amplifiers consist of a differential amplifier and a push-pull amplifier [4]. The four output signals of the biphase amplifiers are then fed into the modulator-combiner which is realised with two interconnected double-balanced FET mixers. Summation takes place through the interconnection in the modulator-combiner.

Four orthogonal vectors are available at the outputs of the double balanced mixers. The amplitude of each vector is independently controllable. Thus, supplying the control signals:

$$I_x + I_{-x} = A_x \bullet \cos(\Theta) \qquad Q_y + Q_{-y} = A_y \bullet \sin(\Theta)$$

will result in a vector with the amplitude proportional to $\sqrt{\{A_x^2 + A_y^2\}}$ and an absolute insertion phase Θ at the output of the modulator-combiner. Any desired vector between 0 and 360 degrees can thus be obtained.

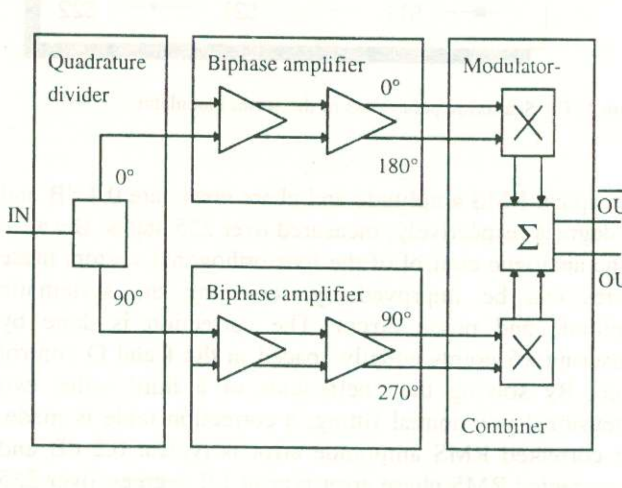

Figure 2: Simplified block diagram of the phase shifter

Measured performance

The vector modulators are on-wafer measured for DC performance. All 556 devices on two 2" wafers are automatically tested with a semi-automatic Alessi wafer prober.

The process used to fabricate the vector modulator does not support via-holes which implies that on-wafer measurements are not possible. The RF tests are done with the vector modulators mounted on a carrier. Through de-embedding, the RF performance of the vector modulator is derived. Although the device is intended for operation at 5.3 GHz with a bandwidth of 100 MHz, the measurements show that the bandwidth is at least 500 MHz.

Fig. 3 depicts the typical performance of the vector modulator. The slightly disappointing S_{11} is due to a critical component at the input of the circuit which shifted the resonance frequency. In the transmit/receive module a small microstrip line is used to compensate for this effect.

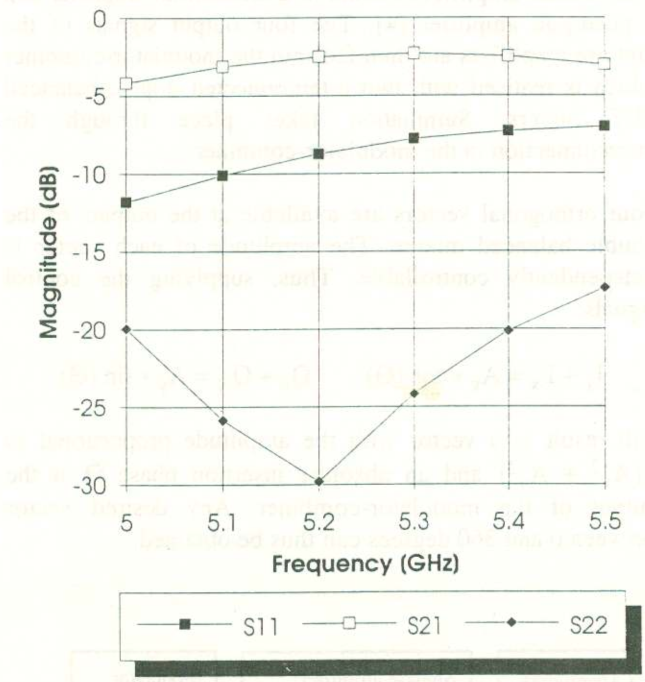

Figure 3: The Scattering parameters of the vector modulator.

The typical RMS amplitude and phase errors are 0.4 dB and 2.3 degrees respectively, measured over 255 states. Because of the analogue control of the four orthogonal vectors these figures can be improved by correcting the systematic amplitude and phase errors. The correction is done by measuring 16 points equally spaced in the I and Q control range. By solving the coefficients of a third order two dimensional polynomial fitting, a correction table is made. The corrected RMS amplitude error is typical 0.2 dB and the corrected RMS phase error typical 1.2 degrees, over 255 states. Fig. 4 shows a polar plot measured on an HP8720B network analyser. The measurements are done in fully operational transmit/receive modules with integrated correction tables. The outer parallelogram shaped measurement (•) shows the uncorrected vector modulator at maximum gain over 360 degrees. The sixteen numbered circles are measured after correcting the vector modulator. It is clearly seen that the vector modulator now describes circles with equally spaced amplitude intervals.

The 1dB power compression point at the output of the device is better than 3 dBm. DC dissipation is less than 1.8 watt.

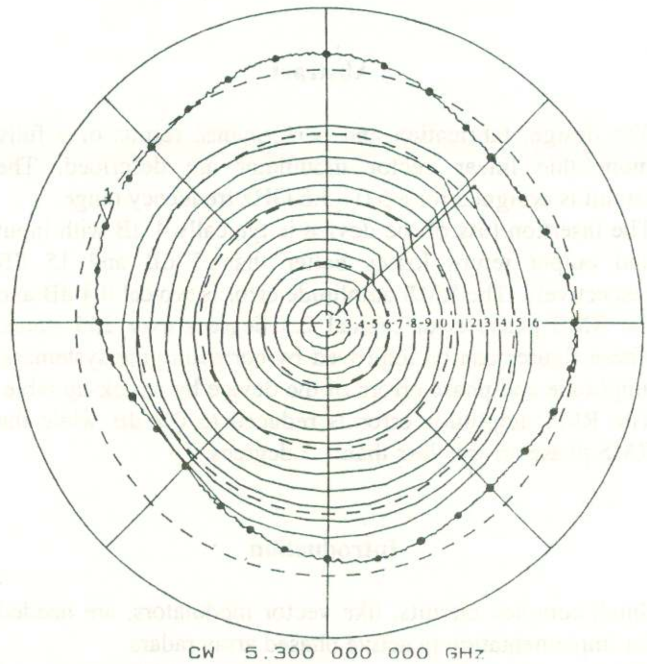

Figure 4: Measured polar plot of the vector modulator showing maximum uncorrected gain over 360 degrees (•) and 16 corrected gain circles.

Manufacturing and circuit layout

The vector modulator was fabricated using the standard D07A process at the GaAs foundry of Philips Microwave Limeil. This process includes 0.7µm MESFETs, implanted GaAs resistors, MIM capacitors, spiral inductors and bridges. Via-holes are not supported in this process which made the design at C-band quite a challenge. The D07A process offers a good quality versus price ratio. The quality is expressed in the total DC and RF yield of 73% which, considered the complexity of the circuit, is excellent.

The size of the vector modulator chip is very small (1.9x2.9 mm^2) and holds up to 42 MESFETs. A photograph is shown in Fig. 5. Most parts of the layout are symmetrical to ensure equalisation of the insertion phase and amplitude. DC blocking and RF decoupling are fully done on chip. Only 3 DC supplies (8 volt, 5 volt and -5 volt) are needed to bias the circuit. On-chip resistive dividers and self-biasing techniques are used to bias the FETs.

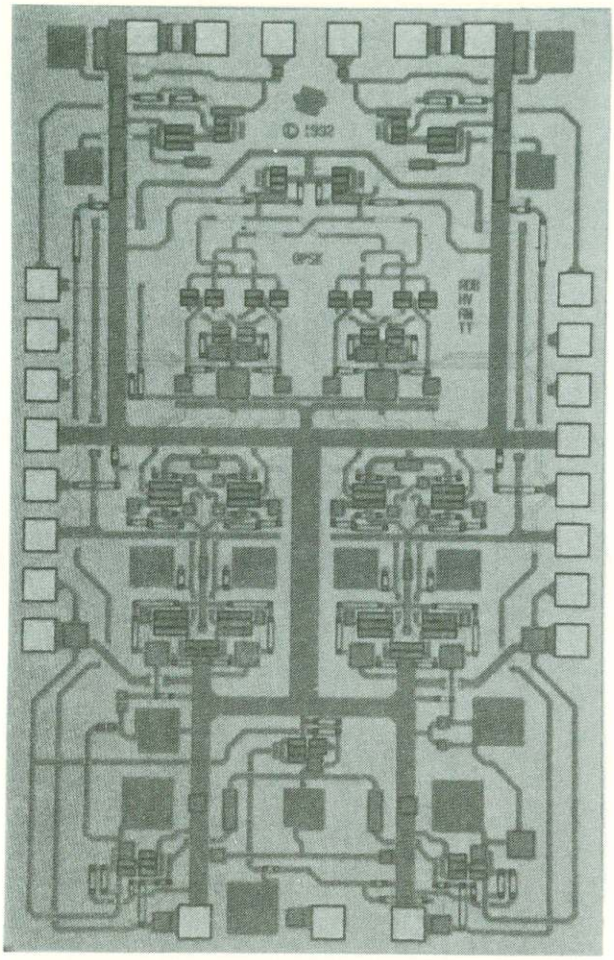

Figure 5: The realised vector modulator (1.9x2.9 mm^2).

Conclusion

A single chip C-band linear vector modulator realised on GaAs has been designed. The chip size is only 1.9x2.9 mm^2. The good RMS amplitude and RMS phase error of 0.4 dB and 2.3 degrees respectively can be improved by correcting the systematic amplitude and phase errors to 0.2 dB and 1.2 degrees, measured over 255 states. The good performance and excellent yield of 73% makes the vector modulator a key component of the successfully developed air-borne active phased-array synthetic aperture radar transmit/receive modules.

Acknowledgement

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References

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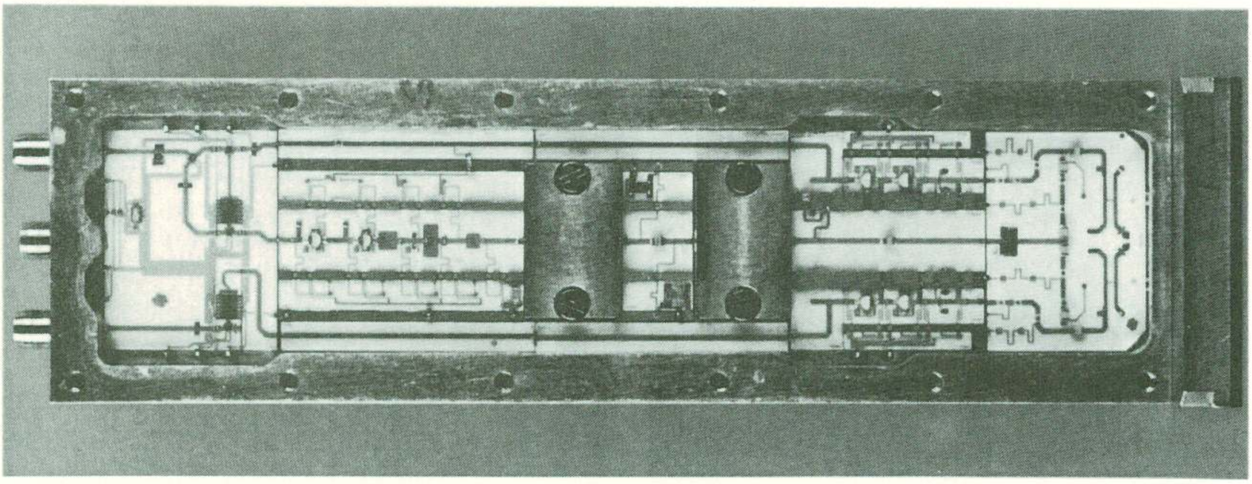

Figure 1: The assembled PHARUS C-band transmit/receive module (16.0x4.4x4.0 cm^3).