24 GHz Serrodyne Frequency Translator Using a 360° Analog CPW MMIC Phase Shifter

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***Abstract*— A 360° analog CPW MMIC phase shifter is presented for the first time. The compact MMIC employs eight multilayer 3 dB quadrature couplers and was fabricated using low cost GaAs foundry processing techniques. The phase shifter was required to implement a narrow band serrodyne frequency translator at 24 GHz. With an arbitrary, small-shift, frequency translation of +5 KHz, the measured results demonstrated a carrier suppression of 30 dB and an image sideband suppression of 13 dB. This was achieved with a simple linear sawtooth signal, providing 22% of under-modulation. In addition, a 0 dB conversion loss was achieved and almost no control power was required.**

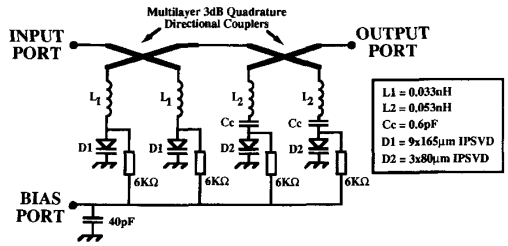

Fig. 1. Topology for a 90° CMRTPS stage.

I. Introduction

ULTRA-SMALL FREQUENCY translations are often required in modern microwave measurement, communication and radar systems,. Examples include: homodyne vector network analyzers [1]; multiple access communication systems [2]; frequency scanning antennas [3]; and velocity deception ECM systems [4].

With a conventional mixer the output filter must become unfeasibly selective when the relative frequency shift is very small. As a result, a nonmixing sinusoidal modulator, such as a balanced diode modulator [5] or I-Q vector modulator [6], can be employed to produce small-shift frequency translations. Alternatively, a serrodyne modulator can be used, in which a 360° phase shifter is modulated with a sawtooth waveform, such that one period of the sawtooth results in an induced phase shift which sweeps linearly through 360°. The amount of frequency translation is equal to the repetition rate of the sawtooth waveform and the direction of frequency translation can be changed by simply inverting the sawtooth profile.

A 14 GHz analog serrodyne modulator was recently reported which used 90° Cascaded-Match Reflection-Type Phase Shifters (CMRTPS's) [8], [9]. However, four discrete MMIC's were required, and the use of conventional microstrip techniques and Lange couplers resulted in a total chip area of 24 mm^2. In contrast, through the use of uniplanar techniques, the 24 GHz serrodyne modulator presented here has been implemented with a compact single-chip, having an total area of less than 9 mm^2.

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II. MMIC Realization

The 360° analog phase shifter consists of four identical 90° CMRTPS stages connected in cascade. The topology of one of these stages is shown in Fig. 1. The phase shifter was realized using a blend of CPW and multilayer technologies. In order to minimize the size of the MMIC, the eight 3 dB quadrature couplers required are implemented with CPW overlayed couplers, developed at King's College [10]. The varactor diodes are realised using standard foundry cell 0.5 μm MESFET's. These interdigitated planar Schottky varactor diodes (IPSVD's) [11] are directly compatible with CPW technology, since the drain/source (cathode) electrodes make direct electrical contact with the upper ground plane. Since the IPSVD's are either reversed biased or slightly forward biased, almost no control power is required. Finally, sixteen bias resistors and four large capacitors are included on-chip for RF decoupling.

The GEC–Marconi (Caswell) foundry was used to fabricate the GaAs MMIC—using their standard, low cost, F20 process. This process leaves a 3 μm thick metalization layer on the backface of the 200 μm thick semi-insulating substrate. Therefore, an additional chemical etching process was carried out to remove this unwanted backface metalization. A microphotograph of the MMIC, having dimensions of 3.4 ×2.6 mm^2 is shown in Fig. 2.

III. Measured Results

A Cascade Summit 9000 analytical probe station, HP8510B vector network analyzer, HP8341B synthesized frequency sweeper and HP8562A spectrum analyzer were used to perform the RF measurements. In order to suppress unwanted modes of propagation, low dielectric constant substrates were inserted between the CPW MMIC and the grounded stage

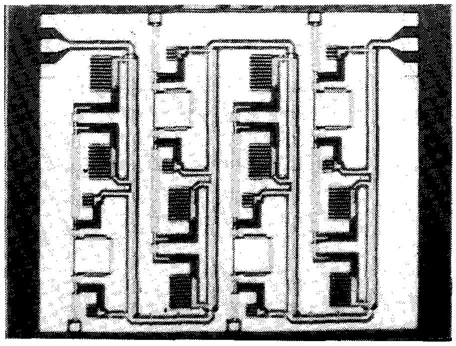

Fig. 2. Microphotograph of the 360° analog phase shifter MMIC.

of the probe station. An Exact-121 sweep function generator was used to provide the linear sawtooth modulating signal.

The serrodyne modulator required a maximum bandwidth of 200 MHz, centred on 24 GHz. The measured relative phase shift performance of the MMIC is shown in Fig. 3(a) and the corresponding tuning characteristic is shown in Fig. 3(b). It can be seen from the tuning curve that this phase shifter is highly nonlinear. However, it has been previously demonstrated that a simple linear sawtooth function can still be used to implement a serrodyne modulator if there is an appropriate amount of under-modulation [7]. Across the desired bandwidth, the maximum rms phase error and amplitude error are ±3.5° and ± 3.5 dB, respectively. While the mean level of insertion loss and worst-case input return loss are 31 and 9 dB, respectively. The modulation waveform and the corresponding measured spectral response of the serrodyne modulator, for an arbitrary frequency translation of +5 KHz, are shown in Fig. 4(a) and Fig. 4(b), respectively, With reference to Fig. 3(b) and Fig. 4(a), it can be seen that there is approximately 22% under-modulation. The resulting levels of carrier suppression and image sideband suppression are 30 and 13 dB, respectively, while the other unwanted sideband suppression levels are better than 10 dB. This level of performance was achieved with both positive and negative frequency translations.

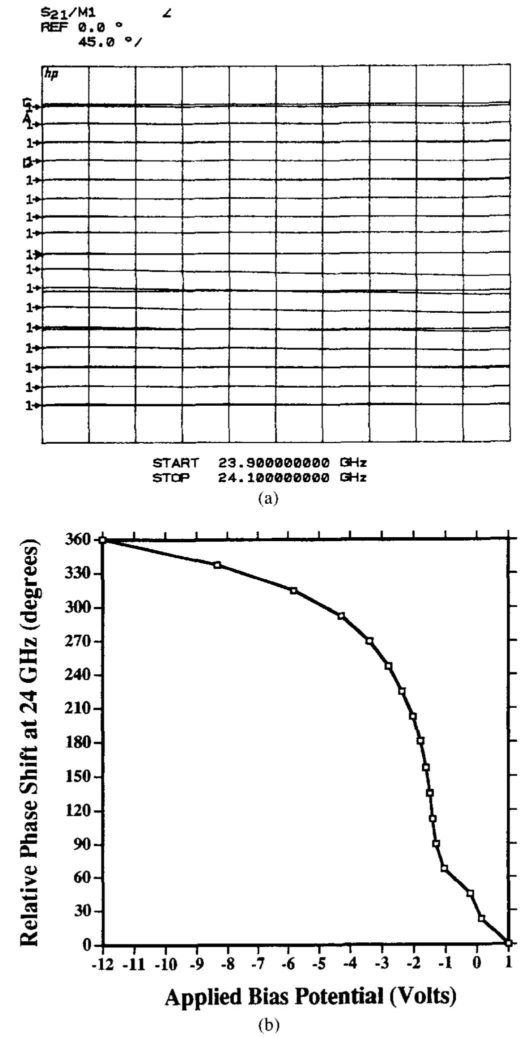

Fig. 3. Phase shifter: (a) frequency performance, (b) tuning characteristic.

the performance of the phase shifter and implementation of the serrodyne modulator has already been discussed in detail [7].

IV. Discussion

For the phase shifter, the high mean level of insertion loss was expected with the topology adopted. This is because the RF signal passes through eight overlayed couplers, which are lossy at high microwave frequencies. The other main contribution to the mean level of insertion loss is due to the IPSVD's, which are constrained by the use of standard MESFET processing and geometries.

One of the major factors which limits the levels of unwanted sideband suppression is the 10% flyback time in the generated linear sawtooth waveform. A linear sawtooth generator that is fully compatible with monolithic technology can have a flyback time of less than 1%. A range of techniques for improving

V. Conclusions

A 360° analog CPW MMIC phase shifter has been presented for the first time. The compact GaAs MMIC realization employs a blend of novel CPW and multilayer circuit components, while being fabricated using only standard, low cost, foundry processing techniques. The implementation of the phase shifter MMIC in a 24 GHz serrodyne modulator, requiring almost no control power, has been demonstrated. Since there is an inherent 0 dB conversion loss, this method of producing small-shift frequency translations is ideal for microwave and millimeter wave applications where filtering becomes impractical.

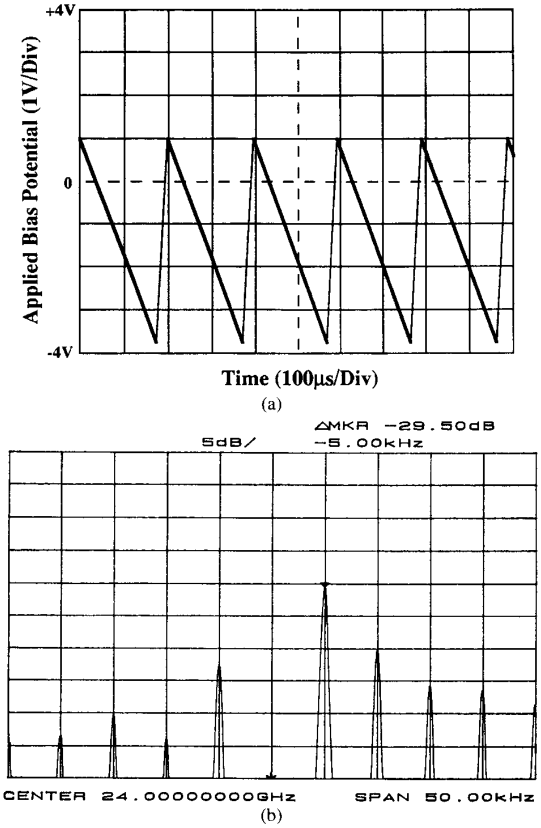

Fig. 4. Serrodyne modulator: (a) +5 KHz excitation, (b) 24 GHz spectral response.

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