A 10-14 GHz LINEAR MMIC VECTOR MODULATOR WITH LESS THAN 0.1 dB AND 0.8° AMPLITUDE AND PHASE ERROR

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ABSTRACT

The design, fabrication and performance of a GaAs monolithic linear vector modulator in the 10-14 GHz band is described. The circuit exhibits side band and carrier rejections of more than 45 dB with third order intermodulation signals at -40 dBc. Such performance has never been obtained previously in neither hybrid nor monolithic technology.

INTRODUCTION

Direct linear vector modulation is a very important function in microwave systems such as : analog phase shifters in phased-array radars, QAM modulators in digital radio links and false-doppler return signals in ECM systems. Up to now, direct vector modulators fabricated in a hybrid technology have demonstrated average performance (1) (side band and carrier rejection of 25-30 dB which correspnds to an amplitude and phase error of 1 dB and 6° respectively). This performance is not good enough to replace the classical heterodyne solution for 16 QAM modulation in digital radio systems for example, although direct modulation offers considerable system simplification (2).

Advanced phase-array radars with a limited number of elements and very low side lobes require phase shifters with at least a 7-bit phase resolution. This phase resolution is very difficult to obtain in the conventional approach which uses digital phase shifters in hybrid technology or on GaAs substrates because of the accumulating phase errors. Continuous variable phase shifters are an attractive alternative. GaAs monolithic direct linear vector modulators are potentially capable of providing these phase shifters and QAM functions at microwave frequencies due to their excellent amplitude and phase balance over a wide band. In order to demonstrate this feature and take full advantage of the very low parameter variations of active and passive components in an MMIC circuit (typically ≤ 1 %) we based the design on symmetrical circuits. A MMIC BPSK modulator, which is one of the key components of a vector modulator, exhibiting amplitude and phase balance better than 0.1 dB and 0.7° respectively in the 10-14 GHz band is described in (3). In this paper we present a 10-14 GHz vector modulator made up of two of the above MMIC BPSK modultors associated to a high performance MMIC quadrature power divider and a Wilkinson power combiner.

DESIGN OF VECTOR MODULATOR

The block diagram of the vector modulator is given figure 1. The function realised by the vector modulator is illustrated by the vectorial representation figure 2. The four basic vectors (0°, 180°, 90°, 270°) are generated by the quadrature power splitter and differential amplifiers. Each pair of basic vectors (0°, 180°) and (90°, 270°) is then combined linearly by a double balanced mixer function of the input modulation (I, $\bar{I}$) and (Q, $\bar{Q}$) respectively. The outputs are then summed to generate any vector, amplitude and phase, function of the modulation level (1).

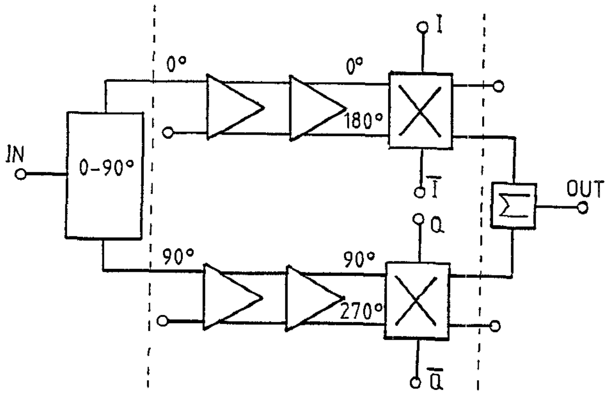

Figure 1
Block diagram of vector modulator

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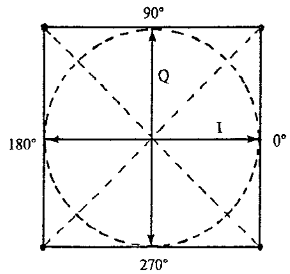

Figure 2
Vectorial representation of the function

The quadrature power splitter consists of a Wilkinson power divider followed by a high pass and low pass filter on each channel. Their cut-off frequencies are optimised so that the output signals are quadrature balanced signals in the 10-14 GHz frequency range (see figure 3).

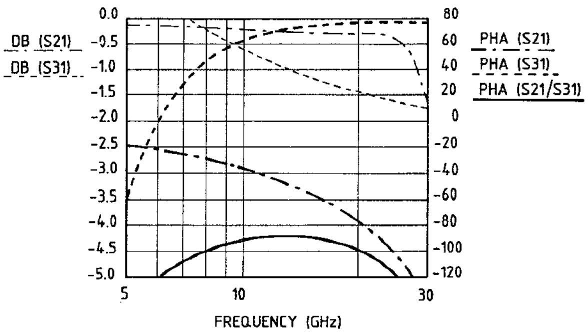

Figure 3
Simulated performance of quadrature power splitter with identical 50 ohm loads

This quadrature power splitter performs extremely well, provided it is loaded by identical 50 Ω loads. However the phase balance degrades rapidly if the loads contain a reactive component and even more if they are different. As active MMICs (amplifiers) cannot offer more than 10 dB input return loss over a wide band we have designed a novel wide band active isolator to mask the input mismatch of the BPSK modulators (3). It consists of a feed-back amplifier whose input and output ports have been inverted (4). This wide band MMIC active isolator exhibits more than 20 dB input return loss, 18 dB output return loss, 20 dB reverse loss and less than 9 dB loss in the 1-20 GHz frequency range. The block diagram of the quadrature power splitter is given figure 4.

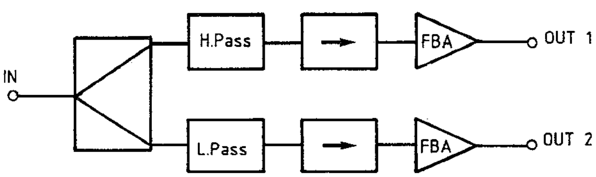

Figure 4
Block diagram of quadrature power splitter

A feed-back amplifier has been added on each channel to compensate the loss of the front stages. The BPSK modulator has been described in reference (3) and will not be described here. It exhibits a carrier rejection of more than 40 dB in the 10-14 GHz band without any tuning (see figure 5). The third order intermodulation signals, which characterises the linearity of the modulator, have been measured at -40 dBc for an output power of more than 0 dBm.

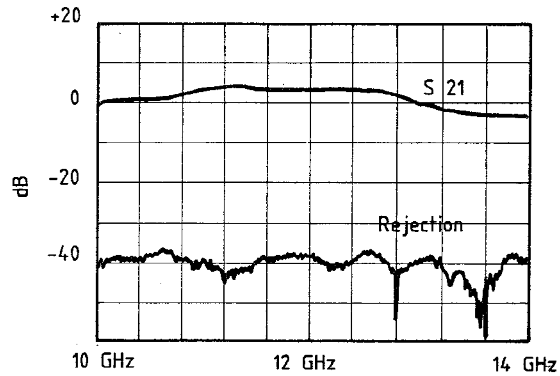

Figure 5
Measured gain and residual even mode signal of BPSK modulator using the scalar analyser

CIRCUIT LAY-OUT AND FABRICATION

To achieve excellent amplitude and phase balance of the vector modulators, we have taken great care during lay-out to preserve the symmetry of the circuits. This is very important for the BPSK modulators (3) and quadrature power splitter and can be achieved only with an MMIC technology.

The circuits have been processed at the PHILIPS MICROWAVE LIMEIL (PML) Foundry with its standard D05ML process. It includes 0.5 µm gate MESFETs, implanted resistors, MIM capacitors, via holes and air bridges. A photograph of the vector modulator mounted in its test fixture is presented figure 6.

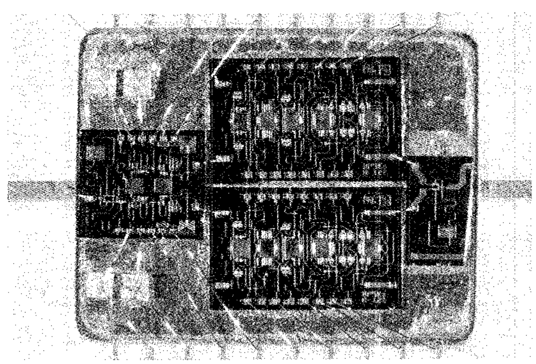

Figure 6
Photograph of vector modulator in its test fixture

EXPERIMENTAL RESULTS OF THE LINEAR VECTOR MODULATOR

The vector modulator which consists of four MMIC chips (quadrature power splitter, two BPSK modulators and a Wilkinson power combiner) has been mounted in a microwave test fixture with more than 60 dB input/output isolation. This requirement is essential since any residual signal transmitted from input to output would degrade the amplitude balance and phase precision of the vector modulator. The total area occupied by the four MMIC chips is less than 11 mm^2 while the total power consumption is less than 1.6 Watts.

The amplitude and phase precision expected from the vector modulator is too high to be detected by the network analyser. Instead we have used the carrier and side band rejection method (5) which consists in using modulating signals (I and Q) which are 90° out of phase. This results in a phase rotation of the RF output signal at the angular velocity (Ω) of the modulating signal. The spectrum of the output modulated signal contains a signal at frequency (RF + $\Omega/2\pi$) a residual carrier signal at (RF) and rejected side band at RF - $\Omega/2\pi$). The carrier rejection characterises the precision of the 180° signals and the side band rejection that of the 90° signals. The maximum overall amplitude and phase error are related to the side band and carrier rejection by the relations :

Digital (I,Q) modulation	Analog (I,Q) modulation
$(Crej)_{dBc} = (Pc/Ps)_{dB} - 0.9\ dB$	$(Crej)_{dBc} = (Pc/Ps)_{dB} - 3\ dB$
$(Brej)_{dBc} = (Pb/Ps)_{dB}$	$(Brej)_{dBc} = (Pb/Ps)_{dB}$

$$\text{Amplitude error } (\delta A) < 20 * \text{Log}(1 + (Crej) + \sqrt{2} * (Brej))$$

$$\text{Phase error } (\delta\theta) < \text{Arctan}((Crej) + \sqrt{2} * (Brej))$$

where :
Pc = Carrier level, Ps = Signal level,
Pb = Suppressed side band level,
Crej = Carrier referenced to the unmodulated carrier
Brej = Side band referenced to the unmodulated carrier

The amplitude error (ΔA) and phase error ($\Delta\theta$) corresponding to Carrier and Band rejection of 40 dBc and 50 dBc are given below as example.
Crej = Breij = -40 dBc, $\Delta A \leqslant .21$ dB, $\Delta\theta \leqslant 1.4°$
Crej = Breij = -50 dBc, $\Delta A \leqslant .07$ dB, $\Delta\theta \leqslant 0.5°$

We have characterised the vector modulator by the side band and carrier rejection method using digital modulating signals. More than 45 dB carrier and side band rejection have been achieved in the 10-14 GHz frequency range while the output power is 2 ± 1 dBm for + 5 dBm input power (see figure 7). An example of the spectrum of the modulated RF signal is given figure 8. The input carrier frequency is 11 GHz (+ 5 dBm) and the digital modulating signals at 3 MHz with modulation levels set to 0 and -1 Volt. The carrier and side band rejection is more than 50 dB with an output power of - 2 dBm (including losses in cables and couplers). This corresponds to a maximum amplitude and phase precisio of 0.07 dB and 0.5° respectively. This result represents a real technical breakthrough since direct vector modulation with this amplitude and phase precision at X-Ku band has never been achieved before neither in MMIC nor hybrid technology. Furthermore this performance is even better than what is achieved by classical heterodyne solutions in actual digital radio links which will certainly be replaced by direct vector modulators very soon (2), (6).

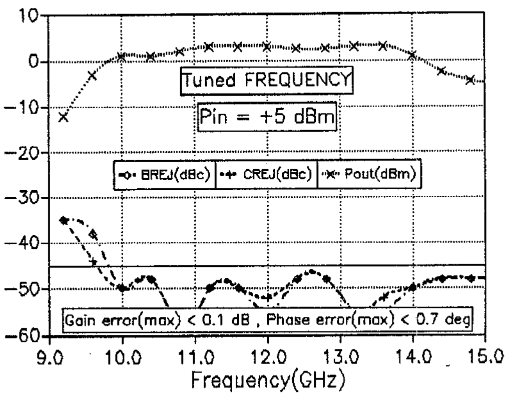

Figure 7
Measured output power, carrier and side band rejection function of frequency

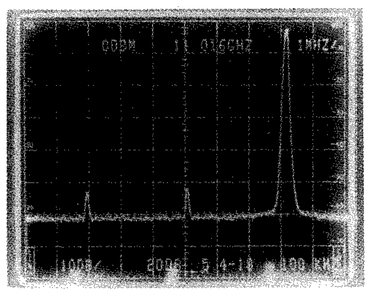

Figure 8
Photo of the spectrum of the modulated microwave signal at 11 GHz

CONCLUSION

We have demonstrated Direct Linear Vector Modulators at X-Ku band having unrivaled amplitude and phase balance of better than 0.1 dB and 0.8° respectively, that is, more than 45 dB carrier and side band rejection in the 10-14 GHz frequency range. This vector modulator has been achieved thanks to the state-of-the-art 0.5 µm MMIC process provided by Philips Microwave Limeil (PML) Foundry associated to a novel active MMIC isolator and a new design method of symmetrical circuits. This method used to design vector modulators is not limited to Ku band. With the appearance of HEMTs the same method can be used to design HEMT vector modulators at Ka band and above. The only limiting factor being the cut-off frequency of the active device just as for classical microwave amplifiers.

This Linear Vector Modulator is ideal for direct 16 QAM modulation in X-Ku band digital radio links and Satellite communications. Thanks to its linearity, amplitude and phase precision it has numerous applications such as analog phase shifter for phased array antennae or SSB up convertor.

ACKNOWLEDGEMENT

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