A Novel Method for Closed-Loop Error Correction Microwave and Millimeter Wave QPSK Modulator

Asher Madjar**, Tamir Blum*, Moshe Namer*, Igor Itzkovic*, Boris Zusmanovic*

**RAFAEL, P. O. Box 2250 (code 87), Haifa, Israel. madjar@rafael.co.il
* Technion, Department of Electrical Engineering, Haifa, Israel.

ABSTRACT — **QPSK modulators at microwave and millimeter waves can be very useful for direct modulation communication links. The main problem with such modulators is the error in phase and amplitude balance, which is quite large at MM waves and degrades the performance of the modulator (carrier rejection, deviation from 90 degrees between states, etc). In this paper we introduce a novel approach featuring an error correction scheme, which is simple to implement both in hybrid and MMIC forms. A very important feature of the new method is the self-generated reference signal, which enables a simple (low cost) and self contained implementaion in a MMIC form of a high quality QPSK MM wave modulator.**

I. INTRODUCTION

Many millimeter wave digital communication links apply QPSK modulation. This is true for satelite communications as well as for various terrestrial communication links. The conventional approach to transmitter architecture employs frequency upconversion, namely, the modulation is performed at some low IF frequency and the modulated signal is upconverted to the desired RF frequency. This approach however yields a more complex and expensive transmitter. An approach which has been investigated for millimeter wave communication links employs a direct modulation of the carrier wave at the millimeter wave RF frequency. This approach has the potential of reducing the transmitter cost provided that a low cost high quality QPSK modulator at millimeter waves can be realized. Some work has been done following this approach during the nineties and even the eighties as evidenced by publications [1]-[6].

The main problem of millimeter wave QPSK modulators is their relatively poor quality in terms of carrier rejection, constellation integrity, etc. related mainly to balancing issues of the two channels of the modulator. In the laboratory at room temperature it is possible to tune the modulator and achieve good performance as evidenced in the above publications, however, a practical system must operate over a large range of temperatures and other environmental conditions. Under these conditions it is not practical to spec phase balance better than a few degrees and amplitude balance better than about 1 db for millimeter wave modulators.

A good and practical method to achieve high quality modulators is by employing a closed loop error correction scheme. However, in such case the modulator is usualy becoming a quite complicated and expensive sub-system. In this paper we present a new approach to the design of a closed loop error correction QPSK modulator, which is simple to implement even in the form of a MMIC chip. The important feature in this new approach is the self-generation of on-chip reference signals used for the closed loop. In that respect the chip can be self contained and does not need supply of external reference signals.

II. CONVENTIONAL QPSK MODULATOR

The most common implementation of a QPSK modulator is depicted in Fig. 1. It is a very similar structure to an Image Rejection Mixer (IRM). The modulator includes two balanced mixers, one 90 degrees splitter and one in-phase combiner. The carrier (or LO) signal is split equally by the 90 degrees hybrid and feeds the LO ports of the two balanced mixers. The two IF (or control) signals I, Q are feeding the IF ports of the two balanced mixers. The modulated signal is obtained by in-phase summation of the signals at the RF ports of the two mixers. When the circuit is used as an IRM the output signal contains only one sideband of the upconverted signal. When the circuit is used as a QPSK modulator each one of the I and Q signals is a digital signal having the value +1 or –1, and the output signal has the 4 phase states of the QPSK constellation. If the circuit in Fig. 1 is absolutely balanced an ideal QPSK signal is achieved. However, any unbalancing causes phase as well as amplitude errors. Because of these errors the QPSK constellation is not perfect and the carrier rejection is limited. It is possible to insert small tuning elements in each one of the modulator arms, and thus tune the phase and amplitude of each arm and equalize them. Under the practical assumption that the errors are small the tuning elements can be simple phase shifters (parallel varactor) and simple attenuators (parallel resistor). So in principle the modulator can be tuned to perform perfectly in the laboratory. Obviously some de-tuning occurs under environmental conditions, so this

0-7803-6540-2/01/$10.00 (C) 2001 IEEE

type of "open loop" modulator cannot be considered a high quality modulator in practical systems.

III. THE CLOSED-LOOP ERROR CORRECTION METHOD

The new architecture of the modulator proposed here is depicted in Fig. 2. As can be seen, the differences between the new structure and the conventional one (Fig. 1) are:

1) Variable phase shifter and attenuator are added in one arm and fixed attenuator and delay line in the second arm in such a way that they can be used to equalize the phase and amplitude of the two channels.
2) A "magic T" is used at the output to generate the sum (Σ) and difference (Δ) signals (in practice a hybrid ring can be used).
3) The variable attenuator is closed-loop controlled by the analog product of the sum and difference signals (realized in practice by a balanced mixer).
4) The variable phase shifter is closed-loop controlled by the amplitude difference between the sum and difference signals (realized in practice by a couple of detectors and a differential amplifier).
5) The modulator output is taken from the Σ port.

The principle of operation of this error correction scheme is based on the following observations:

1) In case of a perfect amplitude balance between the two channels the phase difference between Σ and Δ signals for all four constellation states is exactly 90 degrees (in other words Σ and Δ are orthogonal and their scalar product, realized by the mixer, is zero).
2) In case of a perfect phase balanced between the channels (90 degrees phase difference) the amplitudes of the Σ and Δ signals are exactly equal.

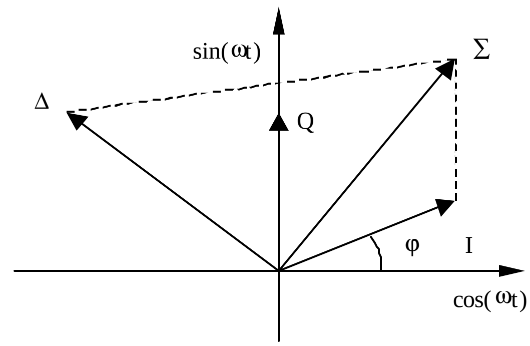
The validity of the above observations can be easily shown by deriving the expressions for the Σ and Δ signals. From Fig. 2 assuming perfect phase and amplitude balancing:

$$\Sigma = I\cos(wt) + Q\sin(wt)$$
$$\Delta = I\cos(wt) - Q\sin(wt)$$

The cofffiicients I, Q can have the value either +1 or –1. In the table below, the four constellation states are listed along with the phase for Σ and Δ:

I	1	1	-1	-1
Q	1	-1	-1	1
Σ phase	45	135	225	315
Δ phase	135	45	315	225
Phase difference	90	90	90	90

From this table it is clear that observation (1) above is indeed valid.
Denote the phase error between the two channels by φ. The phasor diagram describing the Σ and Δ signals is



shown below:
Using trigonometric relations:

$$\left|\Sigma\right|^2 = I^2 + Q^2 - 2IQ\cos(90 - j) =$$
$$= I^2 + Q^2 - 2IQ\sin(j)$$
$$\left|\Delta\right|^2 = I^2 + Q^2 - 2IQ\cos(90 + j) =$$
$$= I^2 + Q^2 + 2IQ\sin(j)$$

It is clear from the above expressions that the amplitudes of Σ and Δ are equal only if the phase error is zero. This proves the validity of observation (2) above.
The mudulator scheme in Fig. 2 has been simulated by the communications software SPW and it was shown that indeed this type of error correction loop is effective. A phase and amplitude error was purposely introduced, and it was shown (in time domain) that the loop corrects the error and balances the circuit.
The advantage of the modulator presented here is that it generates its own reference signals used for nulling the error. Another practical advantage is that this type of modulator can be easily implemented in MMIC form by use of a GaAs Schottky process, even in the millimeter band. The only element which is not on-chip is the low frequency differential amplifier, which is a very low cost silicon chip. Therefore this approach can yield a low cost

MMIC high quality QPSK modulator, which can be used for millimeter wave direct modulation transmitters.

An experimental demonstration of this new method was performed at 14 GHz by constructing the above modulator in a hybrid form on a duroid substrate. The circuit performed well and was able to correct the phase and amplitude errors. More details of the circuit and performance will be presented at the symposium. We are now in a stage of implementing this approach to 30 GHz QPSK modulators for the sattelite communication band.

IV. References

[1] W. Philibert, R. Verbiest, "A Subharmonically Pumped I/Q Vector Modulator MMIC for Ka Band Satellite Communications", 2000 IEEE Radio Frequency Integrated Circuits Symposium Digest, June 11-13, Boston, USA, pp. 183-186.

[2] G. B. Gajda, C. J. Verver, "Millimeter Wave QPSK modulator in fin line", 1986 IEEE International Microwave Symposium Digest, Baltimore, USA, pp. 233-236.

[3] A. Grote, K. Chang, "60 GHz Integrated circuit quadriphase exciter and modulator", 1984 IEEE MTT-S International Microwave Symposium Digest, San Francisco, USA, pp. 445-447.

[4] H. Ogawa, M. Aikawa, M. Akaike, "Integrated Balanced BPSK and QPSK modulators for the Ka-Band", IEEE Transactions on Microwave Theory and Techniques, MTT-30, March 1982, pp. 227-234.

[5] G. S. Des-Brisay, D. F. Horwood, G. E. Lee, "Two Gbsp QPSK modem", 1979 IEEE MTT-S International Microwave Symposium Digest, Orlando, USA, pp. 522-524.

[6] M. V. Schneider, R. Trambarulo, A. Gnauck, M. J. Gans, "High Speed Millimeter Wave Modulator/Demodulator", 1990 IEEE MTT-S International Microwave Symposium Digest, Dallas, USA, pp. 611-614.
.

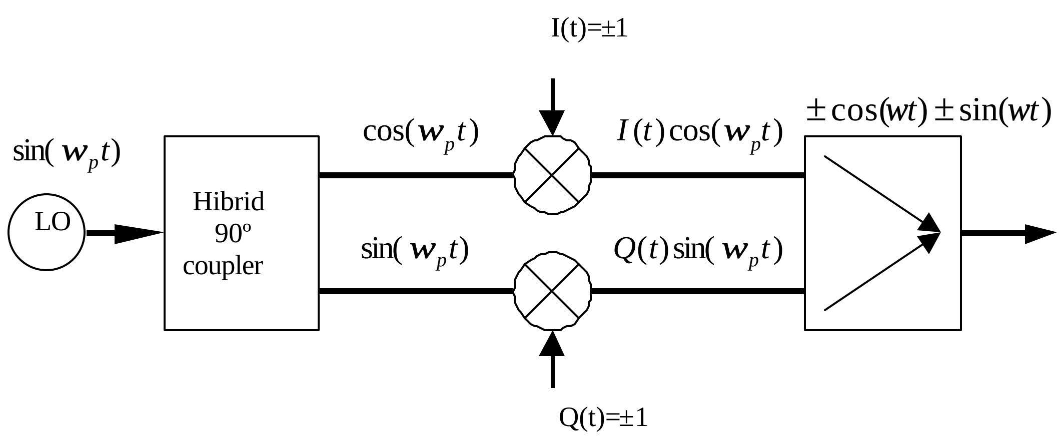


Fig. 1 Mixer Based QPSK Modulator

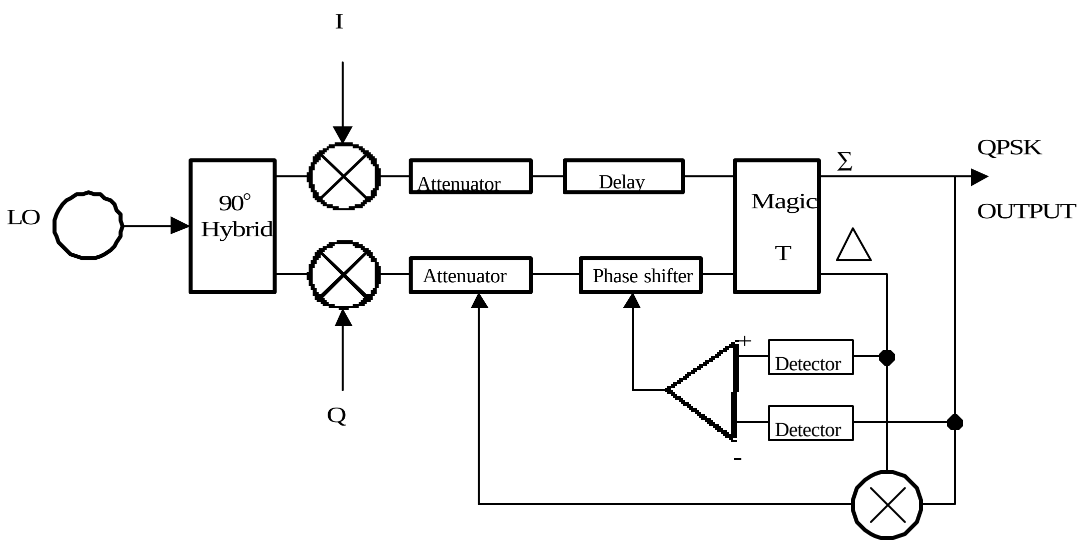


Fig. 2 Closed Loop Error Correction Mixer Based QPSK Modulator