BPSK to ASK Converter for RF Digital Communications

J. M. López-Villegas[1], J. G. Macias[1], J. Cabanillas[1], J. J. Sieiro[1], J. A. Osorio[1], J. Samitier[1], J. Bausells[2], J. Montserrat[2], E. Cabruja[2]

[1]Sistemes d'Instrumentació i Comunicacions, Dept. Electrònica, Universitat de Barcelona, Martí i Franquès 1, 08028 Barcelona, SPAIN.

[2]Centro Nacional de Microelectrónica (IMB-CSIC), Campus UAB, 08193 Bellaterra, SPAIN

Abstract **— This work presents a new circuit for the conversion of Binary Phase Shift Keying signals (BPSK) into Amplitude Shift Keying signals (ASK). The basic principles of the conversion method are the super harmonic injection of oscillator circuits and interference phenomena. The first one is used to synchronize the oscillators while the second is used to generate an amplitude interference pattern that reproduces the original phase modulation. When combined with an envelope detector, the proposed circuit allows the coherent demodulation of BPSK signals without need of carrier recovery system. Two prototypes of the converter have been implemented. The first one is a hybrid version working in the 300-400 MHz frequency range. The second has been implemented using Multi Chip Module (MCM) technology, and is intended for working in the range of 1.8-2.0 GHz. The time response of the converter to phase changes of the input signal is about 100 ns for the hybrid version and scales down to about 15 ns for the MCM version, giving upper limits for the modulation rate of about 5 Mbits/s and 30 Mbits/s, respectively.**

I. INTRODUCTION

The digital phase shift keying of a sinusoidal signal is one of the most efficient modulation techniques, both in terms of noise immunity and required bandwidth.. Coherent demodulation is the preferred procedure to demodulate PSK signals, especially when optimum error performance is of particular importance [1]. Coherent demodulation requires the availability of a local carrier having the same frequency and phase than the received modulated carrier. Frequency and/or phase deviations degrade the detection process and, consequently, the system performance. Local carrier synchronization is, then, a critical issue in most digital communication systems. Carrier recovery is accomplished by using synchronization loops [2],[3]. However, synchronization time is usually large, leading to loss of data at the beginning of a communication or malfunctioning in burst mode transmissions. Non-coherent demodulation of PSK signals can overcome this problem, however, noise immunity is worst and the bit period has to be known [1].

This work proposes an alternative for the demodulation of BPSK signals which is based on the use of a BPSK to ASK converter. The operation of the converter relies on two main principles: the super harmonic injection of two oscillators and interference phenomena. The former is used to lock the oscillators (in frequency and phase) with the incoming signal, while the second is used to generate an amplitude interference pattern that reproduces the original phase modulation.

To demonstrate the feasibility and performance of the conversion method two prototypes of the converter circuit have been implemented. The first one is a hybrid version working in the range of 300-400 MHz. The second one is a MCM version operating between 1.8 GHz and 2.0 GHz.

II. THEORETICAL FORMULATION

A. Injection Locked Oscillators

Injection is a usual way to synchronize an oscillator with an incident signal. When the injected signal is close to a harmonic of the oscillator free running frequency the ensemble is known as super harmonic Injection Locked Oscillator (ILO) [4]. In the locked state, super harmonic ILO's act as frequency dividers, being the dividing factor the harmonic order. The output of the locked oscillator could be in any of M possible phase states (being M the super harmonic order). This is due to the phase uncertainty introduced by the process of frequency division. For example, in the case of a 2^{nd} harmonic ILO the output frequency is half the frequency of the injected signal and phase uncertainty is equal to π.

A possible implementation of 2^{nd} harmonic ILO is shown on Fig.1. The circuit is a cross pair oscillator, whose resonant tank consists of an inverter transformer and a pair of varactor diodes. The 2^{nd} harmonic is injected at the center tab of the transformer. Ideally, under common mode excitation the transformer acts as a short circuit, so that the injected signal is found without

0-7803-7694-3/03/$17.00 © 2003 IEEE

distortion at the varactors terminals. There, due to the non linear behavior of the stored charge and the applied voltage, the injected signal at frequency 2f mixes with the oscillator signal at frequency close to f. As a consequence, a new current component appears which modifies the characteristics of the resonant tank. First order harmonic balance analysis gives for the fundamental current, $\langle I|1\rangle$, passing through the varactor diodes:

$$\langle I|1\rangle = \left(C_o - \alpha \frac{A_2}{2} \sin\theta(t)\right)\frac{d\langle V|1\rangle}{dt} + \alpha A_2 \pi f \cos\theta(t) \langle V|1\rangle \tag{1}$$

Co and α are, respectively, the varactor capacitance and its derivative with respect to the applied voltage, both at the bias point. The fundamental component of the oscillator voltage, $\langle V|1\rangle$, and the injected signal, $\langle V|2\rangle$, are given by:

$$\langle V|1\rangle = A_1 \cos(2\pi f t + \Phi(t)) \tag{2}$$

$$\langle V|2\rangle = A_2 \cos(4\pi f t + \psi) \tag{3}$$

Being A_1 and A_2 their amplitudes and $\phi(t)$ and ψ the corresponding phases. Note that phase $\phi(t)$ takes account of possible deviations of the oscillator frequency from the fundamental frequency, f. Finally, angle $\theta(t)$ relates phases $\phi(t)$ and ψ, as follows:

$$\theta(t) = 2\Phi(t) - \psi - \pi/2 \tag{4}$$

According to (1), the varactor capacitance (term between brackets) changes depending on the Amplitude of the injected signal and angle $\theta(t)$. This implies changes in the oscillator frequency, which are reflected in $\phi(t)$ and, through (4), also in $\theta(t)$. Provided $|d\phi(t)/dt| < 2\pi f$, the dynamics of this process is governed by the following differential equation:

$$\frac{d\theta(t)}{dt} = 4\pi(f_r - f) - \pi f_r \frac{\alpha A_2}{C_o} \sin\theta(t) \tag{5}$$

Where, f_r, indicates the free running frequency of the oscillator.

The oscillator is locked when $d\theta(t)/dt = 0$. There is only one possible value of angle θ_s which verify this condition and is stable. It is given by:

$$\theta_s = \arcsin\left(\frac{C_o}{\alpha A_i}\,\frac{f_r - f}{f_r}\right) \tag{6}$$

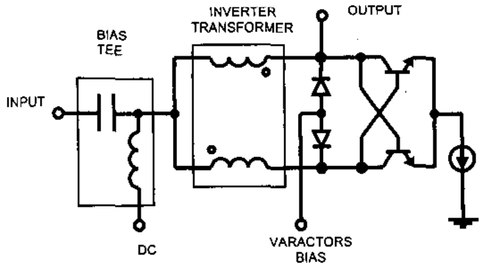

Fig. 1. Circuit schematic of a 2[nd] harmonic Injection Locked Oscillator ILO. (cross pair bias circuit omitted).

B. Binary PSK to ASK Conversion

Let us consider a 2nd harmonic ILO which is injected with a BPSK signal. Assuming that the ILO is in the locked state, when phase, ψ, changes in π, according to (4) angle θ changes from its equilibrium value θs to $\theta s-\pi$. Substituting this value in (5) we found two different dynamic behaviors:

a) If $fr > f$ then $d\theta(t)/dt > 0$ and it will remain positive until the equilibrium is reached again. The overall change of θ will be $\Delta\theta = \pi$, and from (4) $\Delta\phi = \pi/2$.

b) On the contrary, if $fr < f$ then $d\theta(t)/dt < 0$ during the whole process back to equilibrium. In this case change of θ will be $\Delta\theta = -\pi$, and from (4) $\Delta\phi = -\pi/2$.

Keeping this in mind, let us consider two ILO's injected with the same BPSK signal (i.e. using a power divider), one of them having a free running frequency slightly above the locking frequency, f, and the other slightly below. In the locking state both oscillators will have the same frequency, f, and their relative phase could be either 0 or π. According to the above discussion when phase, ψ, changes in π, the phase of the output signals of one of the ILO's changes in $\pi/2$ while the other changes in $-\pi/2$. That is, if the relative phase was 0 it will become π, or vice versa. BPSK to ASK is then accomplished just adding the outputs of both ILO's (i.e. using a power combiner). The resulting interference pattern reproduces the phase changes of the injected signal.

III. Converter Design

The hybrid version of the converter circuit has been implemented using lumped components on a printed circuit board. Special care has been taken over the transformers design. These components have been printed directly on board as interleaved square spirals. Electromagnetic simulations tools have been used to optimize their geometry in order to achieve good performance in both, common mode and differential mode of operation.

The MCM version has been implemented using a substrate carrier fabricated on 100 mm diameter glass wafers (Pyrex 7740). Two metal levels (Al /0.5%Cu/ 0.75%Si) with a thickness of 1.5 μm are used as interconnects and to perform the required integrated transformers. Polyimide, 4.5μm thick, is used as intermetal dielectric and passivation layer. RFIC's dies including the active part of the oscillators have been fabricated using 0.35 μm CMOS technology. These dies have been mounted by Flip-Chip on the carrier substrate using Pb/Sn solder bumps over pads with a previous Ti/Ni/Au metallization. The resulting assembly is shown on Fig. 2. The two ILO's are located left and right. The attached RFIC's dies containing active circuitry can be seen in the lower left and lower right corners. Finally, the power divider and the power combiner are located top and bottom, respectively. Two surface mount resistors (center) have been used to assure a good isolation between ports of the power divider and combiner.

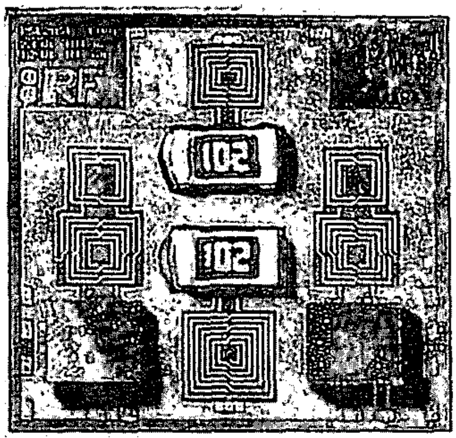

Fig. 2. Photograph of the MCM version of BPSK to ASK Converter. The overall dimensions are 7x7 mm2.

IV. Results

The output spectrum of the free running MCM converter is shown on Fig.3. This figure also shows the converter's output spectrum when it is injected with a 2 GHz input signal. Arrows on the figure indicate the frequency shift of both oscillators from the free running state to the locked state. Note the presence of intermodulation products at both sides of the main peaks f1 and f2 due to the finite isolation of the power divider and combiner and electromagnetic coupling. It is important to remark that the interval [f1,f2] defines the conversion channel. BPSK signals outside this frequency range will not be converted because both ILO's will increase or decrease their phases simultaneously and no interference pattern will be produced at the converter's output. Moreover, the wider the conversion channel the higher the injected power required to lock the converter will be. Thus, it appears a tradeoff between modulation bandwidth and sensitivity of the converter.

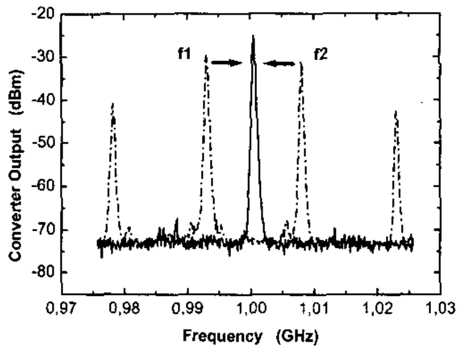

Fig. 3. Output spectra of the MCM version of BPSK to ASK Converter. The dashed line corresponds to the unlocked (free running) state and the continuous line to the locked state.

The time domain output of the hybrid converted in the locked state is shown on Fig. 4. The observed amplitude changes are the converter response to two consecutive phase shifts of 180° of the input signal. The carrier frequency is 300 MHz and the time between phase changes is 2 μs. Data indicate that the time response of the converter to a phase shift is about 100 ns. This figure scales down to about 15 ns for the MCM converter. Accordingly, the upper limits for the BPSK modulation rates would be about 5 Mbits/s and 30 Mbits/s, respectively. However, factors like the required injected power could prevent reaching these limits.

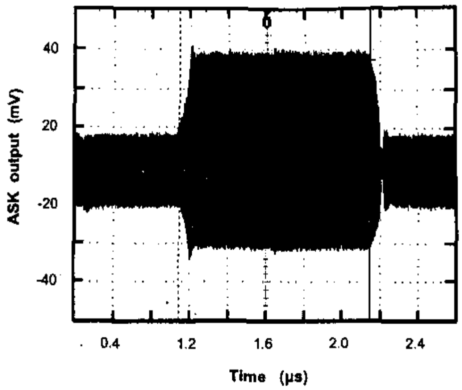

Fig. 4. Time domain ASK output of the hybrid version of BPSK to ASK Converter in response to two consecutive phase changes of the BPSK signal.

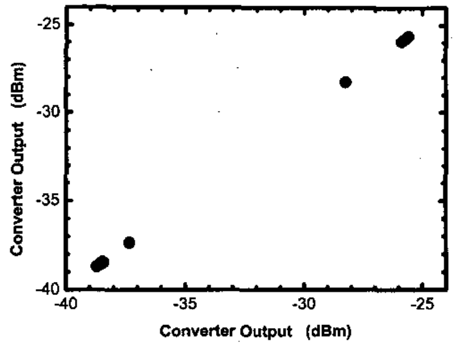

Fig. 5. Constellationlike diagram of the MCM version of the PSK to ASK converter, showing low and high amplitude levels of the ASK output signal.

Finally, Fig. 5. shows a sort of constellation diagram obtained by plotting the peak amplitude of the MCM converter's output versus itself, when it is injected with a 2 GHz BPSK signal. Low and high amplitude levels of the ASK output signal are clearly observe, as well as two sample points corresponding to the transition between them.

V. CONCLUSION

This work demonstrates the feasibility of BPSK to ASK converter using super harmonic injection locked oscillators. Two circuit prototypes have been fabricated using hybrid and MCM technologies. The obtained results for the converter time response indicate that BPSK signals with modulation rates up to few tens of Mbits/s could effectively be converted to ASK signals. Further improvement of the converter circuit would allow the development of new BPSK receiver architectures.

ACKNOWLEDGEMENT

This work was supported by Spanish Science and Technology Commission under projects TIC2001-2947-C02-01 and TIC2001-2947-C02-02

REFERENCES

[1] B. Sklar, *Digital Communication Fundamentals and Applications*, Upper Saddle River, NJ: Prentice-Hall International, Inc., 1988.

[2] S. Mirabbasi, S. Gazor and K. Martin "A Wideband Carrier-Recovery System for Multilevel QAM Signals," *2000 IEEE Int. Symp. On Circuits and Systems, ISCAS 2000. Proceedings*, pp IV-661, IV-664.

[3] H. Sari and S. Moridi "New Phase and Frequency Detectors for Carrier Recovery in PSK and QAM Systems," *IEEE Trans. Commun.*, vol. 36, pp 1035-1043, Sep. 1988.

[4] H.R. Rateg and T.H. Lee "Superharmonic Injection-Locked Frequency Dividers," *IEEE J. Solid-State Circuits*, vol 34, pp 813-821, June 1999.