K-3

A 94 GHz SYNCHRONIZED OSCILLATOR-CHAIN FOR FAST, CONTINUOUS 360° PHASE MODULATION

Helmut Barth

AEG Aktiengesellschaft Ulm
W.-Germany

Abstract

A continuous phase shift of 0 to 360° has been achieved at 94 GHz by injection locking a 2nd harmonic mode Gunn-oscillator at its fundamental frequency. Phase shifting is achieved by varactor tuning the free running fundamental frequency within the locking range. The resulting phase shift between reference signal and the VCO output signal is ±90 degrees at the fundamental frequency and doubled to ±180 degrees at the 2nd harmonic frequency. The phase shifted signal as well as the reference signal each have output powers of more than 20 mW at 94 GHz.

Introduction

Fast electronically and continuously tunable mm-wave phase shifters are difficult to realize because PIN-diode phase shifters are only suited to digital operation and in addition they are lossy devices. Since PIN-diodes have to be driven with relatively high current (e.g. 30 mA for a 94 GHz-device) their switching speeds are lower compared with varactor phase shifters which can be driven with virtually no power consumption.

The latter have the advantage of being capable of either switching or continuous tuning. However to achieve a tuning range of ±180 degrees complex circuits (e.g. staggered tuned resonant circuits) and a large degree of constructional effort are required.

The basic concept described in this paper takes advantage of the phase difference that occurs between a synchronizing signal and the output signal of a locked (slave) oscillator to provide active phase shifting. For this purpose the free running frequency of the slave oscillator is made tunable by a varactor within its locking range. In this way, a phase shift of ±90 degrees can be achieved. By extracting the n'th harmonic power of both (master and slave) oscillators, this phase shift is correspondingly multiplied by n. Tuning speed is mainly restricted by the form of bias-circuitry. However, the VCO described in the following sections is suited for modulation frequencies up to 16 GHz.

Design Aspects

The design and performance of a new mm-wave phase shifter will now be described. It consists of two 2nd harmonic mode oscillators having output ports for their fundamental as well as their second harmonic waves [1], cf. block diagram Fig. 1.

One of the oscillators (the slave) is varactor tuned and injection locked at its fundamental frequency by the other, fixed tuned master oscillator. Mutual coupling is avoided by inserting one or two isolators (25 to 50 dB isolation) between master and slave oscillator .

The phase difference between the two fundamental waves is given [2] as

$$\Delta\phi_{fund.} \approx \sin^{-1}\left(Q_s \cdot \frac{f_m - f_s}{f_m}\sqrt{\frac{P_s}{P_m}}\right) \qquad (1)$$

where f_m and f_s are the fundamental or harmonic frequencies of the master and slave oscillators respectively, Q_s is the external quality factor of the slave at the fundamental frequency. P_m and P_s are the fundamental output powers, f_m-f_s is the locking range and P_s/P_m the locking gain.

The total phase shift at the n'th harmonic frequency is given by

$$\Delta\phi_{harm} \quad n\cdot\Delta\phi_{fund} \tag{2}$$

Because $\Delta\phi_{fund}$ covers a range of ±90 degrees [2], a phase shift of ±180 degrees can be achieved at the 2nd harmonic frequency. However, for a 4 PSK-system a maximum phase shift of only ±135 degrees (or ±67,5 degrees at the fundamental frequency) is required. This provides a sufficient margin to the locking edges and therefore an operation free of distortion.

Construction Details

The mechanical arrangement of the master oscillator is shown in Fig. 2. The waveguide of the Gunn-diode mount 2 supports both the fundamental and 2nd harmonic waves. The W-Band (75-110 GHz) waveguide reflects the fundamental signal and acts as a backshort to tune the frequencies fm and 2fm. The U-Band (40-60 GHz) waveguide 7 at the opposite side supports the fundamental as well as the harmonic wave. To optimize the harmonic output power a resonant iris 6 is inserted at a certain distance from the diode which is adjusted by a U-Band spacer 5 shown in Fig. 2. This iris [3] reflects the harmonic wave almost completely while the fundamental wave is passed without loss.

The VCO shown in Fig. 3 is similar in construction, but a varactor holder is added at a distance that is optimized by spacer 10 to achieve a wide tuning range.

Measured Results

The performance characteristics of each oscillator are summarized in the following:

Master oscillator

fund. frequency	fm = 47 GHz
harm. frequency	2fm = 94 GHz
fund. power	50 mW
harm. power	20 mW
external Q-factor (at fund. frequency)	400

Slave oscillator

fund. frequency	fs = 47 ± 0.6 GHz
harm. frequency	2fs = 94 ± 1,2 GHz
fund. power	150 mW
harm. power	20 mW
external Q-factor (at fund. frequency)	50

The phase behaviour of the synchronized slave oscillator is measured using the test equipment shown in the block diagram Fig 4. A single balanced mixer is used for phase detection, hence, the output voltage of this mixer is either

$$V = A\cdot\cos\left(2\cdot\Delta\phi_{fund}\right) = A\cdot\cos\left[2\cdot\sin^{-1}\left(\frac{\Delta f}{\Delta f_{max}}\right)\right] \tag{3}$$

or

$$V = A\sin\left(2\Delta\phi_{fund}\right) = A\sin\left[2\cdot\sin^{-1}\left(\frac{\Delta f}{\Delta f_{max}}\right)\right] \tag{4}$$

In the case of a narrow locking range $2\cdot\Delta f_{max}$ and high locking gain, the frequency deviation Δf is proportional to the deviation of the varactor voltage ΔV_V. Equations (3) and (4) then can be written as.

$$V = A\cos\left[2\cdot\sin^{-1}\left(\Delta V_V/\Delta V_{Vmax}\right)\right] \tag{5}$$

and

$$V = A\sin\left[2\cdot\sin^{-1}\left(\Delta V_V/\Delta V_{Vmax}\right)\right] \tag{6}$$

Equations (3) and (5) are only valid for a certain adjustment of the line extender (shown in Fig. 4) setting the phase φ. For additional 90 degrees (4) and (6) must be used.

The display photos in Fig. 5a and b show the phasedependent output voltages (vertical scale: A = 3 div) of the mixer as a function of the varactor voltage (horizontal scale: $\Delta V_{v\,max}$ = 4.6 div). Based on this display-calibrations the mixer output voltage can be calculated from (5) or (6) as:

$$V = 3 \cdot \cos\left[2 \cdot \sin^{-1}(hor.div/4.6)\right]$$

or

$$V = 3 \cdot \sin\left[2 \cdot \sin^{-1}(hor.div/4.6)\right]$$

The calculated functions fit the measured curves within the width of the display trace.

The final Fig. 6 shows a photograph of the hardware. Although no minimization of the outside dimensions has been done, the entire unit does not exceed a volume of 2,5" x 2,5" x 1". It should be pointed out, that temperature changes will affect the accuracy of the phase shifter; therefore, oven or PROM control is required.

Conclusion

A novel type of phase shifter especially suited for the mm-wave range has been described. It provides 20 mW power at both reference and signal output ports. Because the phase is controlled by a varactor, without the use of power very fast phase tuning is possible. The total phase shift covers a range of $\pm$180 degrees at the 2nd harmonic frequency. This range can be easily extended by using higher harmonics.

The phase shifter can be made frequency tunable by varactor tuning both the master and the slave oscillator. As in the case of fixed tuning the frequency offset between both signals determines the phase.

Acknowledgement

The author gratefully acknowledges the helpful discussions with Dr. John Ondria.

References

[1] H. Barth, "A Fundamental Wave Injection Locked 2nd Harmonic Gunn-Oscillator at 94 GHz," IEEE MTT-S Digest, 1984.

[2] K. Kurokawa, "Injection Locking of Microwave Solid-State Oscillators," Proc. IEEE, Vol. 61, No. 10, October 1973.

[3] H. Barth, " A High Q Cavity Stabilized Gunn-Oscillator at 94 GHz," IEEE MTT-S Digest, 1986.

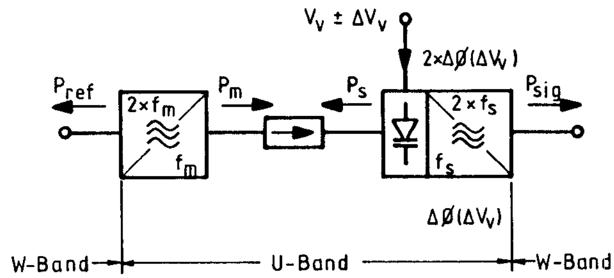


Fig. 1 Block diagram of the phase modulator

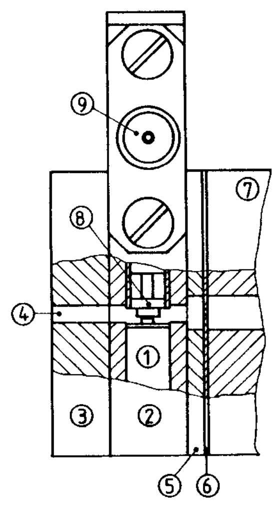


Fig.2 94 GHz master oscillator

1 Gunn-diode
2 Oscillator mount
3 W-Band flange
4 Harmonic wave output
5 U-Band spacer
6 Resonant iris
7 Isolator
8 Coaxial bias filter, teflon coated
9 OSM-conn. for biasing

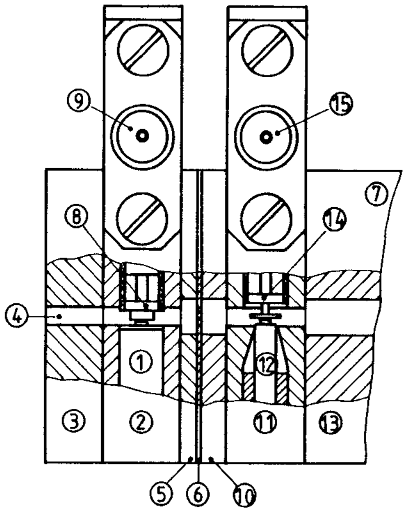
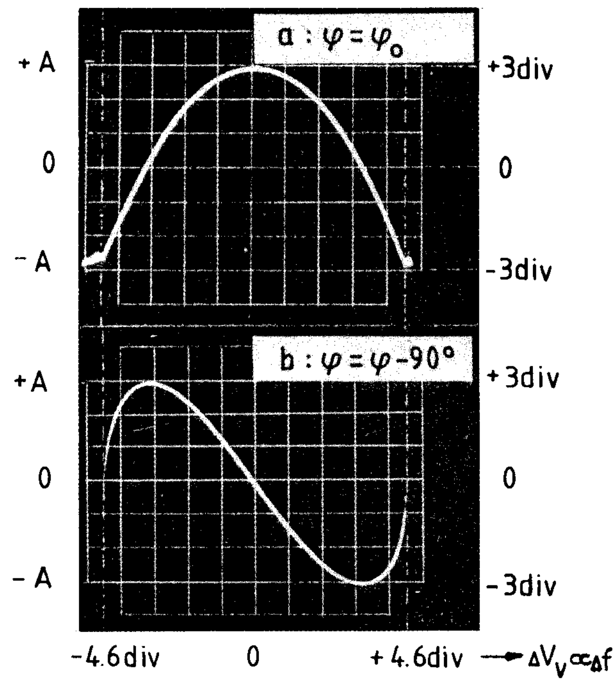


Fig.3 94 GHz varactor tunable slave-oscillator

7 Isolator output
10 U-Band spacer, optimizing tuning range
11 Varactor mount
12 Varactor diode on its mounting post
13 Collet
14 coaxial bias filter
15 SMA Connector for varactor voltage
For numbers 1 to 9 please refere to Fig.2.



Figs.5 Phase detector output voltage

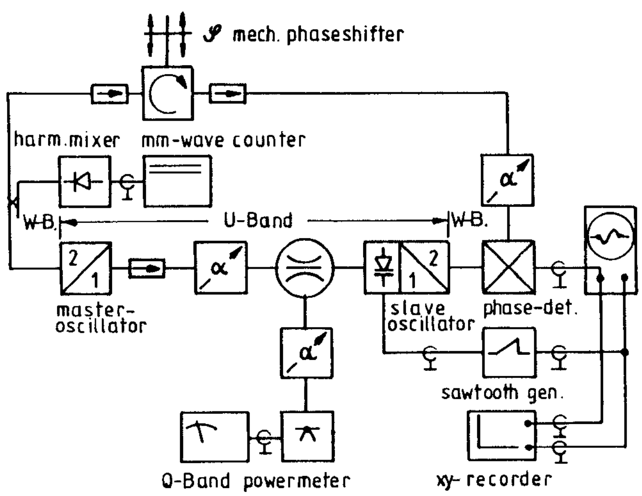


Fig.4 Phase bridge measurement system

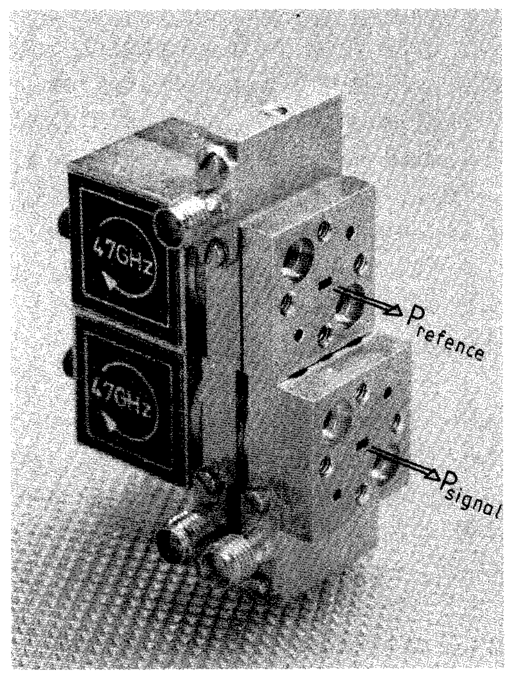


Fig.6 94 GHz synchronized oscillator-chain for fast, continuous 360° phase modulation