A PHASE MODULATOR WITH GAIN FOR MICROWAVE MILLIMETER-WAVE SYSTEMS

R. S. Robertson

Hughes Aircraft Company, Missile Systems Group
Canoga Park, California

Abstract: This paper presents a method to achieve phase modulation directly at microwave and millimeter-wave frequencies with concurrent signal amplification. The modulation is achieved with a voltage controlled oscillator and circulator. The technique is demonstrated experimentally with the generation of a bi-phase coded signal at Ku-band with a signal gain of 10 dB.

Introduction:

Bi-phase coded microwave and millimeter-wave signals are widely used in high resolution radar [1] and/or spread spectrum applications. The conventional coding process for microwave and millimeter-wave systems is generally a two-step process. First, the digital data is encoded on an intermediate frequency (I.F.) signal via a PIN diode modulator, which attenuates the RF signal. Next, the signal is upconverted with a mixer and a phase locked local oscillator signal to the microwave/millimeter-wave frequency of interest and then filtered. Due to the associated losses in the modulation, mixing, and filter process, the signal must be put through multiple stages of amplification before sufficient signal strength is achieved to drive a transmitter. Another technique was described by Helmut Barth [2] for phase coding signals but this technique also has associated signal attenuation and the process occurs at the second harmonic of the fundamental signal frequency.

Phase Coding Procedure

The novelty of this technique is that: 1) the phase coding and signal amplification are accomplished in one step and directly at the fundamental frequency and 2) the procedure requires a single voltage controlled oscillator (VCO) operating over the frequency band of interest.

A VCO is normally operated as a voltage to frequency converter, i.e. the tuning voltage determines the operating frequency. The range of frequency excursion being a function of the reactance change available from the varactor diode and the circuit sensitivity. In this application, however, the VCO is made to operate as a voltage to phase shift converter. Figure 1 provides a pictorial illustration of the operation at a single frequency. The voltages V_1 to V_N correspond to the free running frequencies f_1 to f_N, respectively. An input signal, (f_{LOCK}), of lower signal strength than the free running power of the VCO, injection locks the oscillator by means of a circulator. The reflected output signal is amplified by the VCO and to first order is the sum of the locking signal and the free running power of the unlocked oscillator. The locking signal has a reference phase ϕ_1, which is related to the tuning voltage, V_1. Since the unit is injection locked, a new tuning voltage, V_2, imparts a new phase ϕ_2 on the output signal in lieu of changing the operating frequency. A judicious selection of V_1 and V_2 provides a phase change, $\Delta\phi = \phi_1 - \phi_2$, of 180^o. Selectively switching between V_1 and V_2 will both amplify and bi-phase code the locking signal frequency. An additional benefit is that the tuning voltage may be selected to provide continuous phase variation on the amplified locking signal.

One criteria must be satisfied in the implementation. Figure 1 illustrates an associated locking bandwidth for each tuning voltage, V_N, and input power level of the locking signal. A change in the tuning voltage results in a shift in the locking bandwidth. The input signal power and bandwidth shift must be selected such that f_{LOCK} remains within an overlapping bandwidth region common to tuning voltages V_1 and V_2 and yet still provide the desired phase shift. This criteria can be satisfied in practice.

Experimental Results

A ridged-waveguide, Gunn diode, voltage controlled oscillator was built using a modification of the circuit developed by Robertson and Eisenhart [3] [4]. The Gunn diode was of M-A/COM design with operational power levels of 200 mw. The varactor diode is a Varian design with a package capacitance of .11 pf. The chip capacitance was measured at Ku-band and found to vary from .36 to .20 pf over a bias range of -2v to -10v, respectively. The wire bond inductance was .24 nh.

During free running operation, a tuning voltage change of 0 - 10 volts resulted in a VCO bandwidth of 450 MHz at Ku-band. Tuning linearity was 15.9% and a nominal output power of 22 dBm.

A phase bridge was assembled and a series of static phase measurements were performed to characterize VCO performance. The VCO was tuned to provide 10 dB of gain when operated injection locked. The bias voltages were chosen to provide a 180° phase shift in the locking signal. The voltages were then switched as a square wave at rates from 100 KHz to 1 MHz. The maximum switching rate was limited by the square wave generator. The resultant spectrum and the detected video signal are shown in Figures 2(a) and (b), respectively. The suppressed carrier waveform is characteristic of a bi-phase coded spectrum. Carrier suppression of 18 dB was measured for the 1 MHz case. The detected video output corresponds to the bi-phase transitions. The results validated the phase modulation procedure.

Conclusion: A novel procedure has been described and demonstrated for simultaneously amplifying and phase coding microwave and millimeter-wave signals. The procedure uses a voltage controlled oscillator and circulator. Continuous phase variability with gain is available. By cascading multiple VCO's in an injection locked chain, additional gain and continuous phase variability are possible. Finally, a reduction in microwave hardware may be realized in phase coding system applications.

[1] R. S. Robertson, E. L. Holzman, R. L. Bowen, "A Ka-Band Solid State Transmitter for a Synthetic Aperture Radar," Proceedings, Tenth DARPA/Tri Service Millimeter-Wave Symposium, 1986, pp. 249-258.

[2] Helmut Barth, "A 94 GHz Synchronized Oscillator-Chain for Fast, Continuous 360° Phase Modulation," 1987 IEEE MTT-S International Microwave Symposium Digest, vol. 1, pp. 433-436.

[3] R. S. Robertson and R. L. Eisenhart, "Coaxially Coupled Ridge Waveguide Tunable Oscillator," 1981 IEEE MTT-S International Microwave Symposium Digest, pp. 235-237.

[4] R. S. Robertson and R. L. Eisenhart, "Coaxially Coupled Tunable Oscillator Using a Ridge Waveguide," U.S. Patent No. 4,429,287, January 31, 1984.

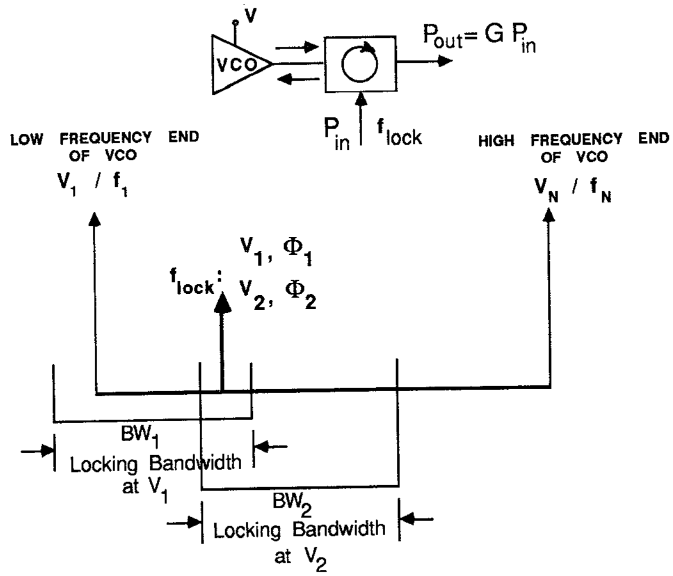
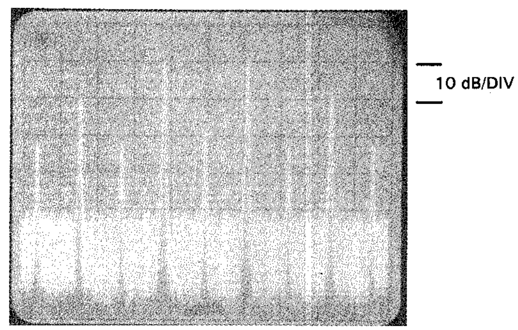
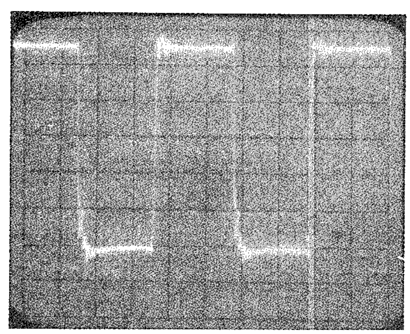


Figure 1: Phase Modulator's Functional Block Diagram



SCALE: 1 MHz/DIV

(a)



SCALE: 0.20 μsec/DIV

(b)

Figure 2. Bi-phase Modulation at 15.7 GHz and a modulation rate of 1 MHz.
(a) Suppressed carrier waveform.
(b) Phase transitions on video signal.