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AN EIGHT - PHASE BROADBAND SERRODYNE MODULATOR

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ABSTRACT

The design of a 6 to 18 GHz serrodyne modulator is described. It consists of a P-I-N diodes based all passive eight step phase shifter. The device is digitally controlled. Experimental data and a comparison with a conventional serrodyne TWT are presented.

INTRODUCTION

The serrodyne techniques have an important role in electronic systems. The most significant applications include frequency shifting in microwave relay systems, electrical scanning of antennas, doppler simulation for testing doppler radars. A typical serrodyne modulator is a TWT in which the helix or cathod voltage is properly modulated by a sawtooth.[1] The frequency shift of the incoming RF signal is equal to the sawtooth frequency. It is well known that the amplitude of the modulating sawtooth is frequency dependent and it is given by

$$\Delta V = 17.8 \cdot 10^{-2} \frac{V_h^{3/2}}{f_o l} \qquad (1)$$

were V_h is the helix voltage (V)

f_o is the input signal frequency (GHz)

l is the helix length (cm)

That frequency dependence makes the TWT modulator very expensive and complex while the serrodyne function is realized just in small portions of the TWT's bandwidth. The recent development of GaAs FET amplifier and the possibility of designing an integrated microstrip modulator makes very attractive the solid state serrodyne solution.

CONFIGURATION AND DESIGN CONCEPTS

The serrodyne frequency translation is theoretically obtained by a continuous phase modulation. It is possible to show that a continuously phase-modulated device can be replaced by a device that introduces quantized phase shifts[2]. To obtain a good approximation of the continuous case it is sufficient to use relatively few number of steps. In particular using an ideal eight step modulator the spurious frequencies due to the non continuous modulation are approximately 17 dB under the carrier. Note that a typical serrodyne TWT has spurious level 10 - 15 dB down. The spurious are due to the less than ideal linearity and non zero flyback time of modulating sawtooth. The eight step phase shifter, used as serrodyne modulator, acts as a complex weighting circuit[3] and its block diagram is shown in Fig. 1.
A 3 dB quadrature hybrid splits a signal of arbitrary phase and magnitude into its in-phase and quadrature components. The phase shifters can rotate the vectors 180° out of phase. Than each signal can be or not suppressed by the following nonreflective switch. The final power combiner acts as an adder for the signals.

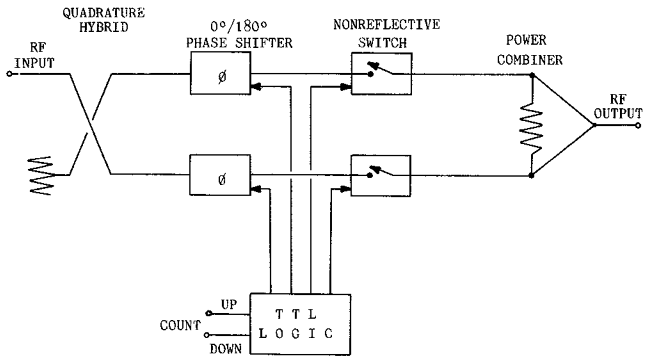

FIGURE 1. EIGHT-PHASE MODULATOR BLOCK DIAGRAM

Proper combination of one or two vectors gives the full range of vectors shown in Fig. 2.

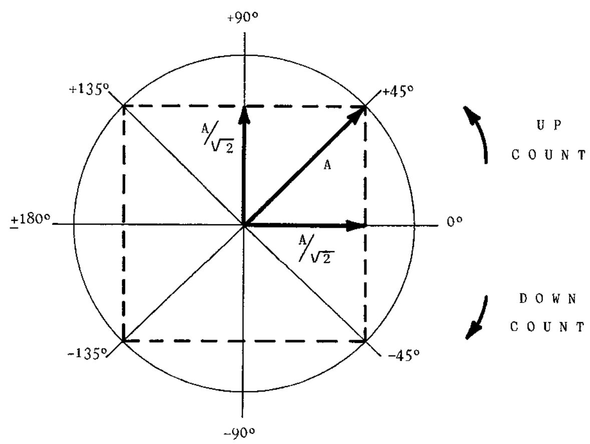

FIGURE 2. COMPLEX PLANE

Note that theoretically the amplitudes of the $(2n + 1)\frac{\pi}{4}$ vectors are 3 dB higher than the others

As both the phase shifters and the nonreflective switches are digitally controlled, using a simple TTL logic it is possible to incrementally change the phase of an incoming RF signal, step by step, 45° each, or clockwise or in the reverse way. If f_c is the frequency of the applied TTL clock the RF signal will be shifted for an amount equal to $f_c/8$. The frequency translation

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will be up or down the unmodulated carrier according to the sign of the incremental 45° step.
The design of the serrodyne modulator is therefore referred to the design of the single blocks of Fig. 1.

1) At the input a Lange interdigital hybrid is used to split the RF signal into its components. The typical octave bandwidth of the Lange couplers was increased by a computer optimization.
2) The same Lange hybrid is used on the following 0/180° hybrid phase shifters[4]. The RF schematic is in Fig. 3A.
3) The nonreflective switches have the configuration shown in Fig. 3B. This structure inherently has a very wide bandwidth. An isolation greater than 35 dB and a V.S.W.R. better than 1,5 : 1, both states, are achievable.
4) A three sections wide-band Wilkinson combiner used as final vectors' adder.

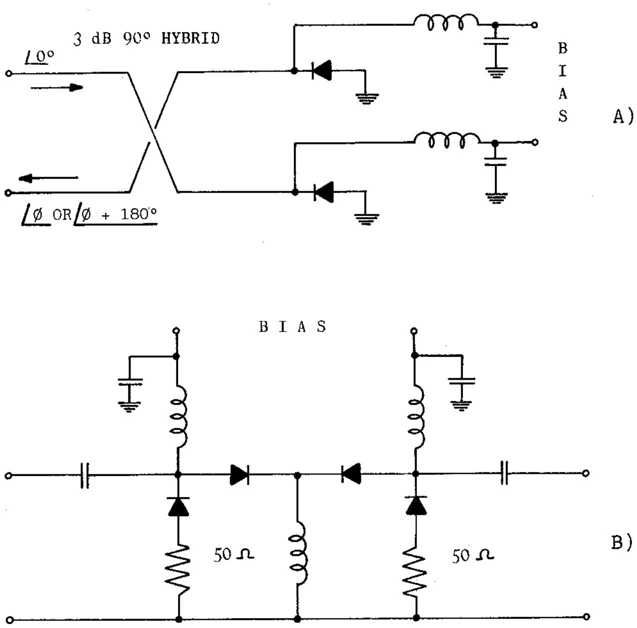


FIGURE 3. RF SCHEMATICS
A) 0°/180° PHASE SHIFTER
B) NONREFLECTIVE SWITCH

EXPERIMENTAL RESULTS

A picture of the serrodyne modulator is shown in Fig.4. The typical performances are summarized in Table I.

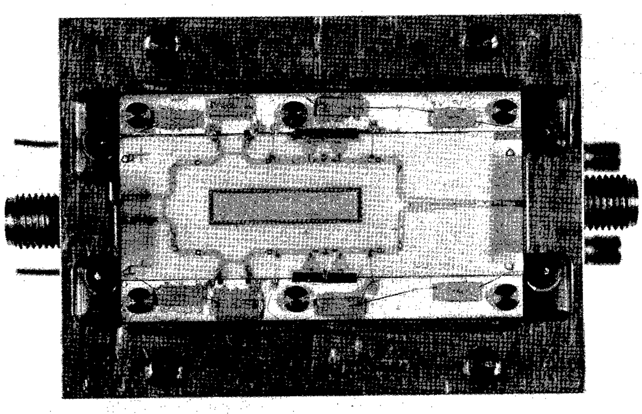


FIGURE 4. EIGHT-PHASE SERRODYNE MODULATOR

TABLE I

EIGHT-PHASE SERRODYNE MODULATOR PERFORMANCES

Bandwidth	6 - 18 GHz
Insertion loss	10 dB for $\emptyset = (2n+1)\frac{\pi}{4}$
	13 dB for $\emptyset = n\frac{\pi}{2}$
V.S.W.R.	1.8 : 1 all states
Incremental phase change	45° ± 7°
Frequency translation range	0 - 3 MHz

The serrodyne signal, based on a generalized sinusoid, can be expressed as:

$$f(t) = \frac{A}{\sqrt{2}}\left\{\frac{(1+\sqrt{2})}{2} + \frac{(1-\sqrt{2})}{2}\cos\left[\pi \cdot \mathrm{Int}\left(\frac{4\omega_s t}{\pi}\right)\right]\right\} \cdot \sin\left[\omega_o t \pm \frac{\pi}{4}\mathrm{Int}\left(\frac{4\omega_s t}{\pi}\right)\right]$$

were Int (x) is the integer part function
$\omega_o = 2\pi f_o$ is the input signal frequency
$\omega_s = 2\pi f_s$ is the modulating signal frequency

A theoretical evaluation of the spectral response was done and a computer analysis is shown in Fig.5. It results that the spurious level is ≃17 dB down.
Note that the odd components are due to the 3 dB amplitude modulation. In Fig. 5 is shown also the spectral response of a signal when the amplitude is not modulated.

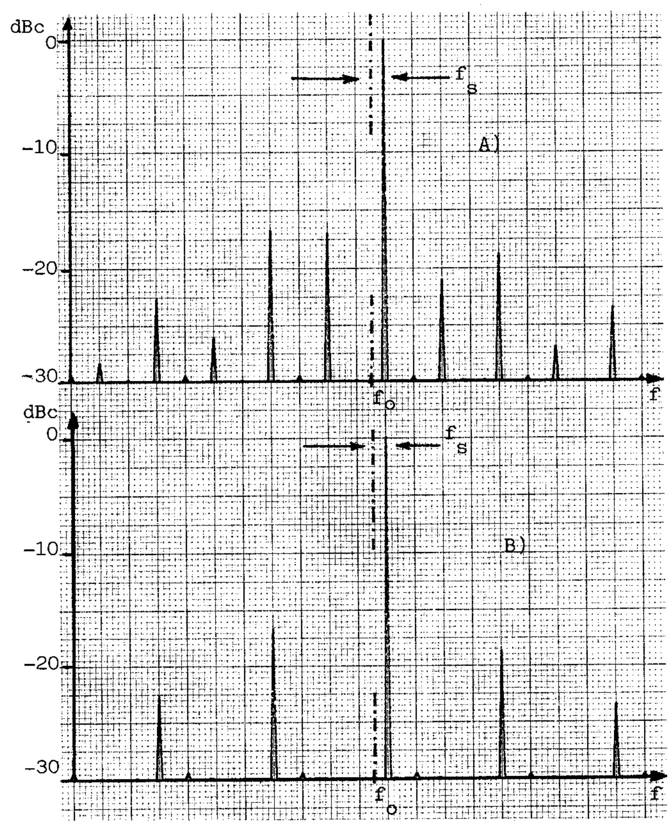


FIGURE 5. THEORETICAL EVALUATION OF THE SPECTRAL RESPONSE FOR AN EIGHT STEP PHASE MODULATED SIGNAL:
A) 3 dB amplitude modulation
B) No-amplitude modulation

As for the serrodyne technique applications the most important spurious is the input signal residual, theoretically absent, that means that the 3 dB modulation does not heavily affects the performances of the device. In Fig. 6 is shown a Spectrum Analyzer picture of the actual modulator's performances.It results that a spurious is present at the frequency of the unmodulated carrier. This spurious is due to the not ideal 45° phase steps. Its level is typically 20 dB down or more.

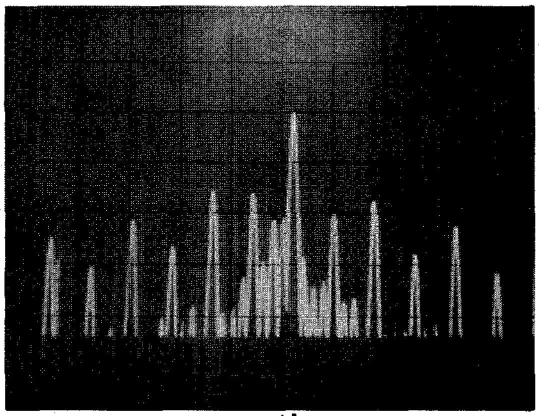
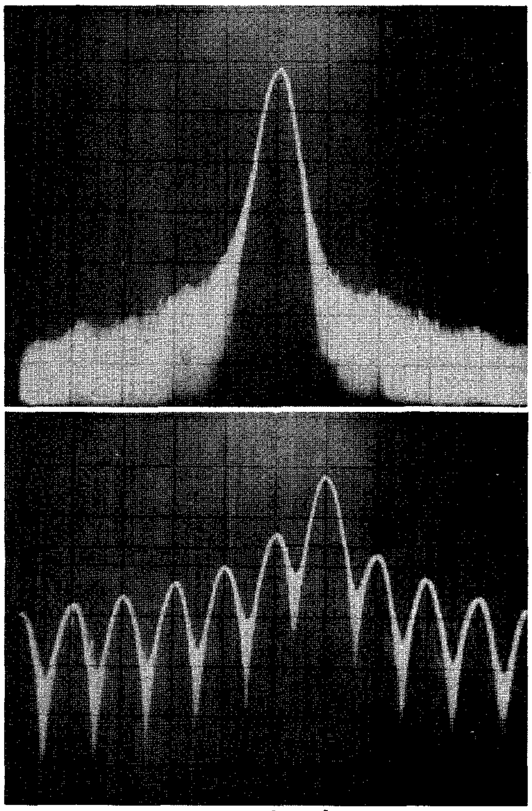


FIGURE 6. ACTUAL SPECTRAL RESPONSE

In Fig. 7 is pictured the serrodyne modulation on an input signal (Fig. 7A) using a TWT (Fig. 7B) and the described modulator (Fig. 7C). The frequency shift was 10 KHz. That means 80 KHz TTL clock for the eight phase modulator. Note that the achievable spurious suppresion in a TWT is typically 15 dB (Fig. 7B).



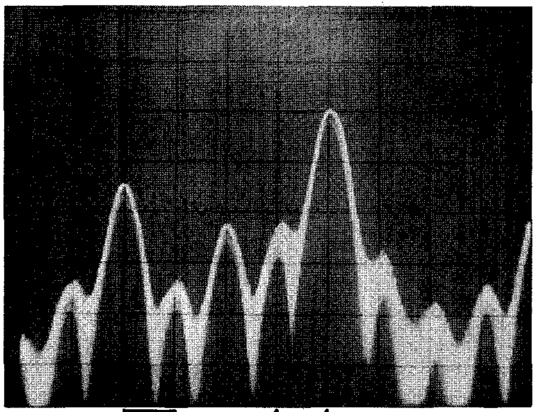


FIGURE 7. SPECTRAL RESPONSES
f_s = 10 KHz
Vertical axis = 10 dB/Div,
Horizontal axis = 10 KHz div
A) Unmodulated carrier
B) Serrodyne TWT
C) Eight - phase modulator

CONCLUSIONS

An eight-phase modulator has been designed for wide band serrodyne applications. Its small size and consequently its integrability into a S.S.A., its TTL control, its higher performances and lower cost make this phase modulator an interesting competitor of the conventional serrodyne TWT's, and on some applications, also of the more expensive, dual-gate GaAs FET based, analog phase shifters.

ACKNOWLEDGMENTS

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