OCTAVE-BAND HIGH PRECISION BALANCED MODULATOR

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ABSTRACT

This paper describes an octave bandwidth component that closely approximates an ideal bi-phase linear modulator at microwave frequencies. PIN diodes in a balanced configuration of hybrid couplers were combined to realize the component in a microstrip circuit. Phase errors of 2 degrees or less were achieved over an octave band for a bi-phase modulator application. The modulator was also used to form a frequency translator with a minimum carrier suppression of 30dB and sideband suppression of 20dB over the 4-10GHz frequency band.

1. INTRODUCTION

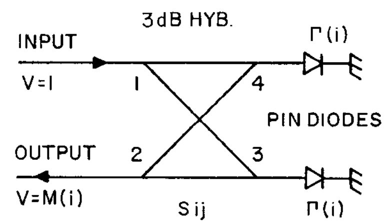
An ideal bi-phase linear modulator performs the mathematical operation of multiplication between a modulating signal and an RF carrier; it thus functions as a basic RF signal processing component with a wide range of applications. Both phase and amplitude modulation are possible, and, by changing the phase at a steady rate, frequency translation can also be achieved. This paper describes a balanced modulator which closely approximates ideal performance over more than an octave bandwidth. Experimental results are reported for a bi-phase modulator and a frequency translator.

A single-ended modulator, of the type shown in figure 1, consists of a 3dB quadrature coupler with two of its ports terminated by PIN diodes. The diodes produce a variable reflection coefficient determined by their current controlled resistance. The modulator transfer function (M) can be expressed in terms of the S-parameters (Sij) of the coupler and the reflection coefficient (Γ) of the diodes:

$$M(i) = S_{21}+S_{24}\Gamma(i)S_{41}+S_{23}\Gamma(i)S_{31}$$

$$= S_{21}+2S_{24}S_{41}\Gamma(i)$$

Here i=-1 to 1 has been used to designate the input control signal, a current or digital word for example, that selects the various modulator states.

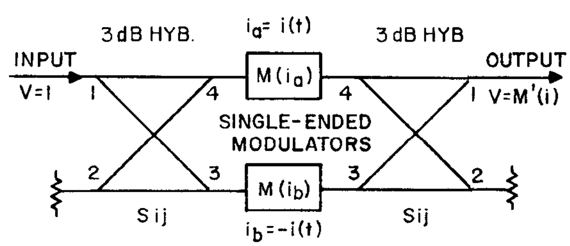


$$M(i) = S_{21}+S_{24}\Gamma(i)S_{41}+S_{23}\Gamma(i)S_{31}$$

FIG. 1 SINGLE-ENDED DIODE MODULATOR

2. BALANCED MODULATORS

Single-ended modulators are usually limited in performance by diode parasitics ($\Gamma(i)\neq-\Gamma(-i)$), and by the directivity of the hybrid coupler ($S_{21}\neq0$). These limitations become quite severe for octave bandwidth components. A balanced configuration provides a simple but very effective means for reducing these effects. Figure 2 illustrates a balanced PIN diode modulator which is



$$M'(i)=S_{14}M(i_a)S_{41}+S_{13}M(i_b)S_{31}$$

FIG. 2 BALANCED TWO-PORT MODULATOR

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driven in a push-pull fashion. It consists of two single-ended modulators, with transfer functions $M(i_a)$ and $M(i_b)$, combined by a pair of hybrid couplers. The transfer function for the balanced modulator can be expressed as follows:

$$M' = S_{14}M(i_a)S_{41} + S_{13}M(i_b)S_{31}$$

$$= S_{14}^2(M(i_a) - M(i_b))$$

where use has been made of the 3dB quadrature property, $S_{31} = jS_{41}$. With a push-pull drive, $i_a = -i_b = i$, the modulation function becomes:

$$M'(i) = S_{14}^2(M(i) - M(-i))$$

The bi-phase condition $(M'(-i) = -M'(i))$ is then clearly attained in spite of the limitations on the single-ended components. Of special significance are the relations $M'(-1) = -M'(1)$ and $M'(0) = 0$. Attainment of this performance depends on the existence of hybrid couplers which rely on geometric symmetry for their precise quadrature property. Geometric symmetry is readily obtained by using a two-wire construction, rather than an interdigital coupler which has an intrinsic phase error(1). An example of the former type is the broadband Hopfer coupler(2).

Thus far, only two-port modulators have been considered. As a one-port reflective device, the balanced modulator takes the particularly simple form similar to a single-ended modulator. The difference is that the diodes are driven out of phase so that power is reflected to the input port. The need for a high directivity circulator to convert this component into a two-port device severely limits its bandwidth. Alternately, two reflective modulators can be combined with a hybrid coupler(3); however, as with a single-ended configuration, the performance depends on the directivity of the coupler.

3. BI-PHASE MODULATOR RESULTS

Basic performance of the balanced modulator was demonstrated by constructing bi-phase modulators operating in the 5-10GHz and 6-18GHz frequency ranges. The 6-18GHz modulator shown in figure 3 consists of a Duroid microstrip circuit containing four PIN diodes combined with four Hopfer couplers. The complete unit, including a built-in driver, measured 1.2x1.2x0.4 inches. Performance curves for this unit are shown in figure 4.

There is a maximum phase error of 5 degrees and a peak amplitude imbalance of 0.75dB between the 0 and 180 degree states. Data for the 5-10GHz unit show a maximum phase error of 2 degrees and a peak amplitude imbalance of 0.6dB. Comparable performance has been reported(4) for a reflection type modulator, but only for half-octave bandwidth.

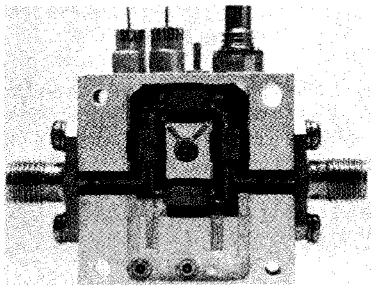


FIG. 3 MICROSTRIP CIRCUIT OF 6-18GHz BALANCED MODULATOR

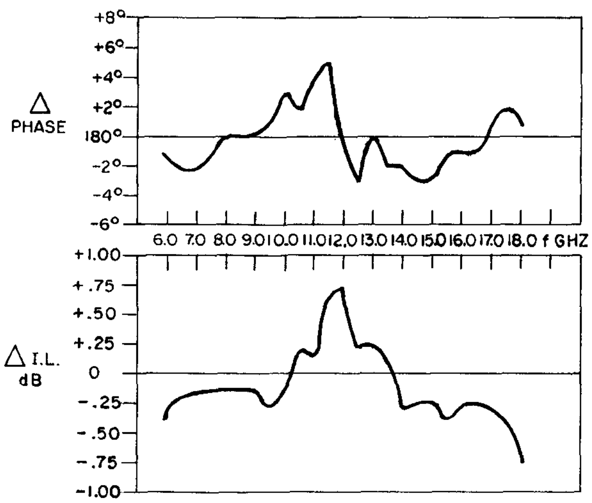


FIG. 4 BALANCED BI-PHASE MODULATOR PERFORMANCE CURVES

In such wide-band applications, a variation of the hybrid coupling factor results in a modulation error, which can be defined by $E' = M'(-1)/M'(1) + 1$. However, for a balanced modulator the error is reduced by a factor (N) relative to a single-ended modulator: $E' = N * E$.

$$N = (S_{14}^2 + S_{13}^2)/(S_{14}^2 - S_{13}^2 + S_{12}^2 E)$$

$$\cong (a - jb)/(1 - E/2)$$

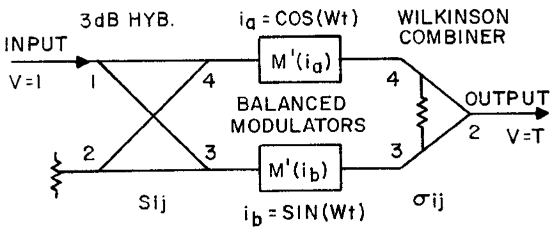
where $a = |S_{14}|^2 - |S_{13}|^2$ measures the amplitude imbalance of the hybrids and b is the deviation from quadrature. In the case of a single section coupler operating over an octave bandwidth (a=0.11 and b=0) the error is reduced by 19dB.

4. FREQUENCY TRANSLATOR RESULTS

A high-precision modulator is the critical component in a single-sideband frequency translator of the type shown in figure 5. This translator consists of a quadrature hybrid feeding two balanced modulators that are driven in quadrature, and a Wilkinson combiner at the output port. The transfer function (T) for translation frequency (W) is given by

$$T(t)=S_{14}(M'(\cos Wt)+jM'(\sin Wt))/\sqrt{2}$$

If the modulator were ideal ($M'(i)=i$), this would be a perfect translator ($T(t) \propto \exp(jWt)$).



$$T(t)=\sigma_{24}M'(i_a)S_{41}+\sigma_{23}M'(i_b)S_{31}$$

FIG. 5 SINGLE-SIDEBAND FREQUENCY TRANSLATOR

A balanced modulator eliminates all even harmonies, including the carrier. This result can be derived by expanding the transfer function for a single-ended modulator in a Fourier series:

$$M(i(t))=\sum_{n} Mn*\exp(jnWt)$$

Then with $i_b(t)=i_a(t+\pi/W)$, the balanced modulator has the following representation:

$$M'(i(t))=S_{14}{}^2\sum_{n} Mn*\exp(jnWt)(1-\exp(jn\pi))$$
$$=2*S_{14}{}^2\sum_{n(odd)} Mn*\exp(jnWt)$$

The doubly-balanced translator configuration removes additional terms with n=4k-1 (k=integer). That is,

$$T(t)=2*S_{14}{}^3\sum_{n(odd)} Mn*\exp(jnWt)$$
$$(1+j*\exp(jn\pi/4))/\sqrt{2}$$
$$=4*S_{14}{}^3\sum_{n=2k+1} Mn*\exp(jnWt)/\sqrt{2}$$

so that image sidebands are also suppressed.

Experimental confirmation of these conclusions has been obtained. A translator, based on the 5-10GHz modulator described above, was constructed and tested. Figure 6 shows a plot of the carrier and sideband levels of this unit relative to

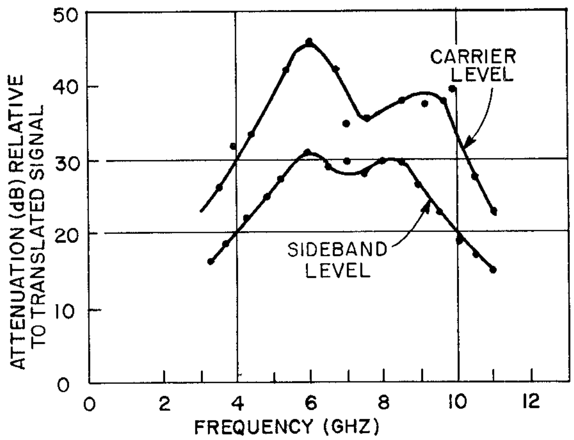


FIG. 6 PERFORMANCE CURVES FOR FREQUENCY TRANSLATOR TRANSLATION FREQUENCY: 0-60KHz

the translated signal. From 4 to 10GHz, the carrier is suppressed by more than 30dB, and the sideband is down by more than 20dB. Carrier suppression depends solely on the "null' and "bi-phase" property of the balanced modulator while the sideband suppression is a result of the double-balanced arrangement. These results demonstrate the superior performance achievable with a properly designed balanced modulator.

ACKNOWLEDGMENTS

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