TECHNICAL FEATURE

DESIGN OF A NOVEL VECTOR MODULATOR

A vector modulator that controls magnitude and phase of an input signal is proposed in this article. The previous magnitude and phase-controlling circuits, composed of an attenuator and a phase shifter, permit phase and gain cross-coupling. The proposed modulator, which is comprised of low phase-shifting attenuators and 0°/180° phase shifters, can minimize the phase and gain cross-coupling, so the loci of the output signals of the vector modulator can be displayed in Cartesian coordinates.

The quadrature phase shift keying (QPSK) modulation scheme is used in wireless communication basestation transmitting systems for efficient spectral resource use. This scheme requires highly linear power amplifiers.[1] In order to meet this requirement, linearizers are used to reduce the nonlinearity of the amplifiers for wireless communications. The main circuit of a linearizer is composed of an attenuator and a phase shifter in order to control the magnitude and phase of the signals.

The attenuator may use PIN diodes or GaAs MESFETs that have an electrically controlled resistive component and, in general, PIN diodes are preferred over other devices for convenience. A PIN diode is operated as an attenuator by varying its junction resistance (R_j) with a bias current. However, when PIN diodes are operated as attenuators, they also show a phase variation that is caused by parasitic components besides the junction resistance.

In general, phase shifters use varactor diodes. The junction capacitance of a varactor diode is changed with its reverse bias voltage and the phase of the signal is changed according to the junction capacitance. However, when the varactor diode is operated as a phase shifter, it changes the magnitude of the input signals, which is also caused by parasitic components of the diode besides its junction capacitance.

When magnitude and phase-controlling circuits are composed of attenuators and phase shifters, the attenuator produces a phase shift in addition to attenuation and the phase shifter's insertion loss changes while phase shifting. These phenomena produce phase and gain cross-coupling, leading to extensive tuning time to obtain the optimum attenuation and phase shift of the input signals. The phase and gain cross-coupling is an impediment to the optimum operation of single-channel power amplifiers (SCPA) and multichannel power amplifiers (MCPA).

DESIGN THEORY

The magnitude and phase control of an input signal with an attenuator and a phase shifter produce an output signal that can be represented in polar coordinates. It is represented by a vector (magnitude and phase), so all the points in the polar coordinate plane can be a representation of the output signal as referred to the input signal. The output signal can also be represented in Cartesian coordinates. The available output signal is represented by an in-phase (X-axis) signal component and a quadrature-phase (Y-axis) signal component.

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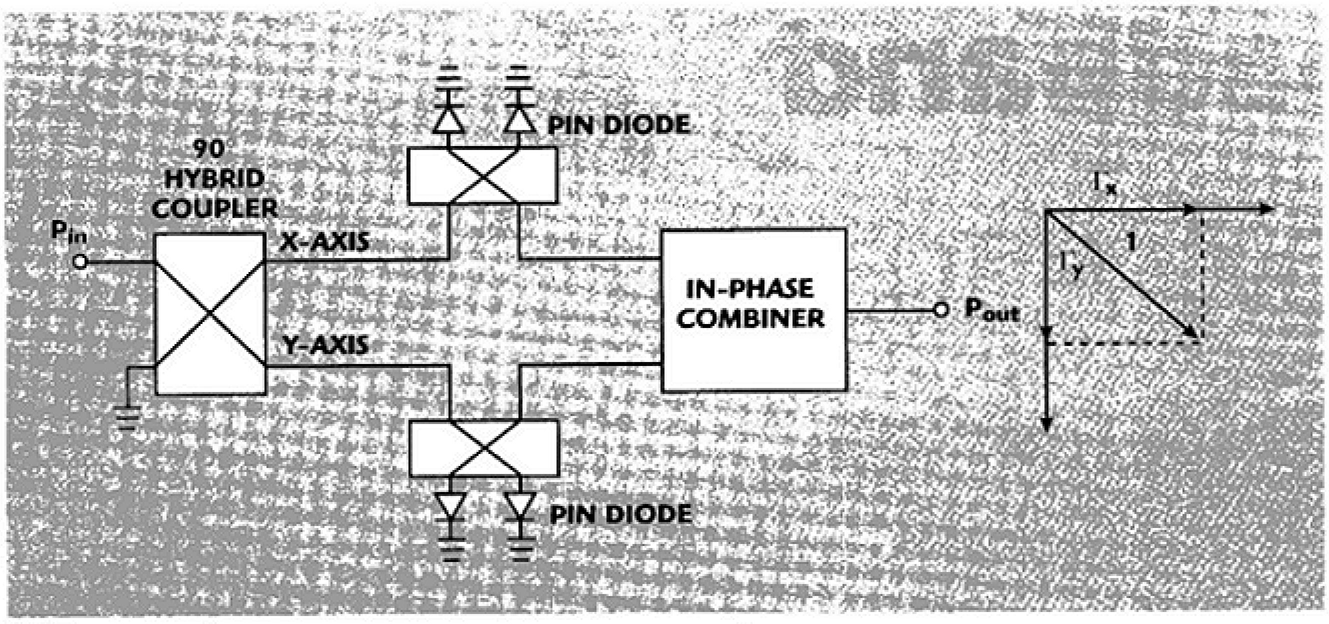
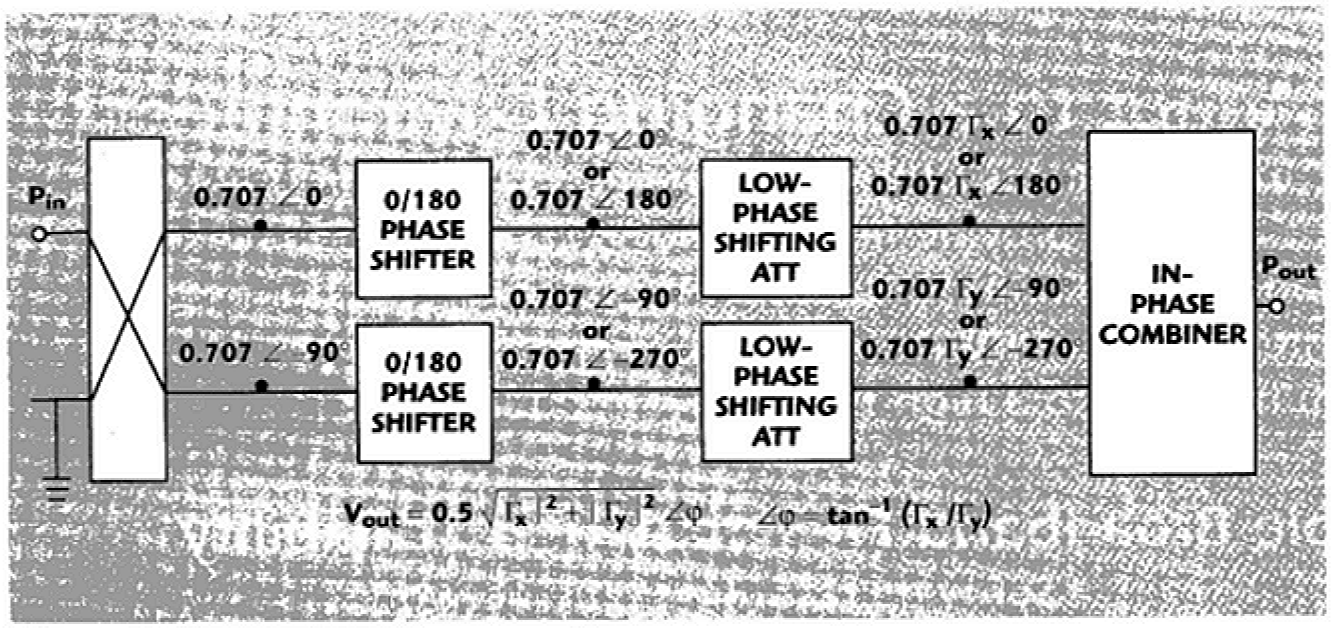
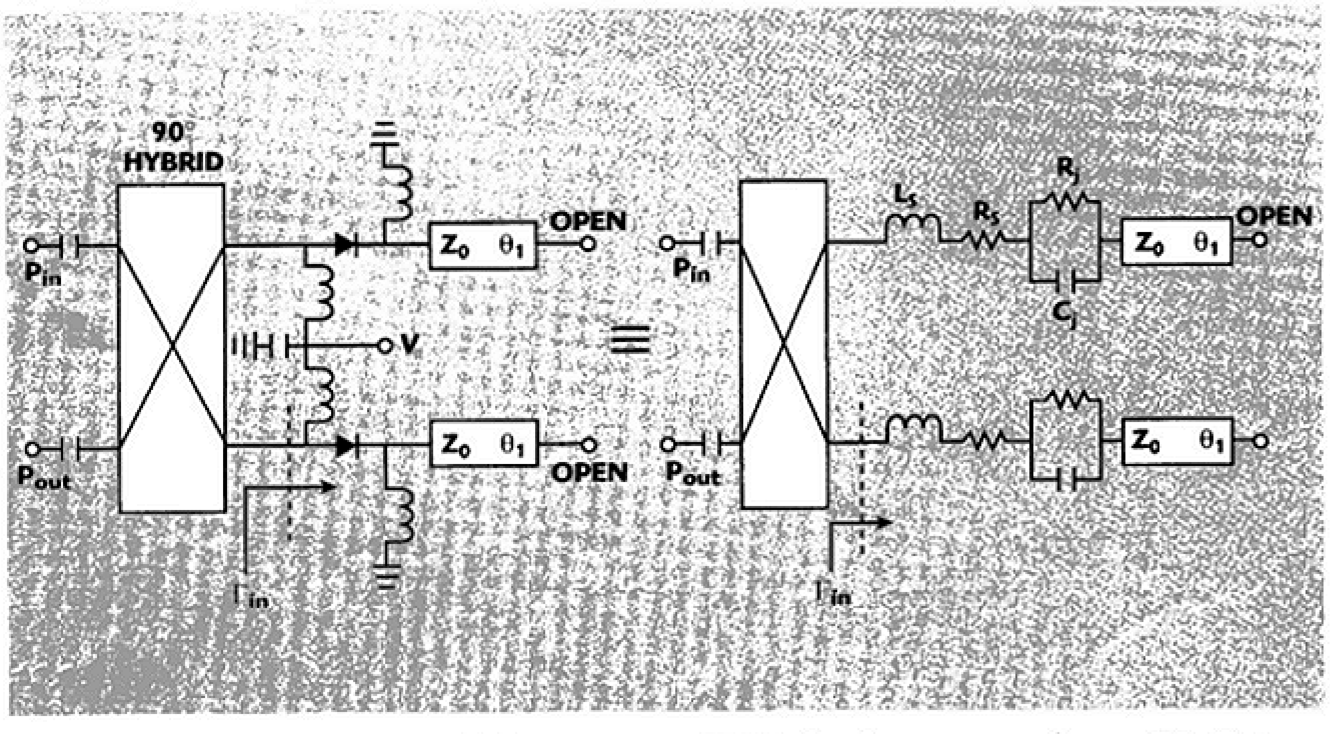


▲ *Fig. 1 Standard vector modulator and its vector diagram.*



▲ *Fig. 2 The proposed vector modulator.*

▼ *Fig. 3 Reflection type 0°/180° phase shifter and its equivalent circuit.*



A standard vector modulator is shown in ***Figure 1***.[2] The input signal is divided into in-phase and quadrature-phase components by a 90° hybrid coupler. Each signal is attenuated by a reflection-type PIN diode attenuator and then combined with an in-phase combiner. The signals at the output port can be represented by their Cartesian coordinates in the output signal space plane. If the variation of the junction resistance of the PIN diode ranges from 50 Ω to a large value, the vector modulator uses the 4th quadrant. The magnitude and phase of the output signal depend on the operation of the in-phase and quadrature-phase attenuators. The vector modulator ignores the phase shifting associated with attenuation and cannot represent a pure phase shift. This phenomenon prevents it from controlling the magnitude and phase properly.

In this article, a new type of vector modulator is proposed and shown in ***Figure 2***. Its operation is described below. The input signal is divided by a 90° hybrid coupler, and the in-phase and quadrature-phase output signals are connected to 0°/180° phase shifters, which change the phase by 0° or 180° according to the control voltage. If the 0°/180° phase shifters are set to 0°, the phase of the output signals is not changed and is then connected to a low phase-shifting attenuator, which minimizes the phase variation while attenuating. The attenuated in-phase and quadrature-phase signals are connected to an in-phase combiner, where they are combined. The output signal of the modulator is located in the 4th quadrant; however, if the 0°/180° phase shifters change the phase by 180°, then the output signal can be located in the 1st, 2nd or 3rd quadrature plane.

Figure 3 shows the 0°/180° phase shifter and its equivalent circuit. When R_j reaches its maximum value, the incident wave is reflected at R_j. But when $R_j = 0\ \Omega$, the incident wave is reflected at the end of an open stub. Thus, if the two output waves have the same magnitude and are out-of-phase, this device is operated as a 0°/180° phase shifter. The impedances at the input port of the PIN diode in the case of a high junction resistance and a small junction resistance are

$$Z_{in,large} = R_s + j\omega L_s + \frac{1}{\frac{1}{R_j} + j\omega C_j} + Z_{OC}\Big|_{R_j=large} = R_s + \frac{R_j}{1 + j\omega R_j C_j} + j\left(\omega L_s - Z_0 \cot\theta_1\right)\Big|_{R_j=large} \qquad (1)$$

$$Z_{in,small} = R_s + \frac{R_j}{1 + j\omega R_j C_j} + j\left(\omega L_s - Z_0 \cot\theta_1\right)\Big|_{R_j=small} \qquad (2)$$

and the reflection coefficient is

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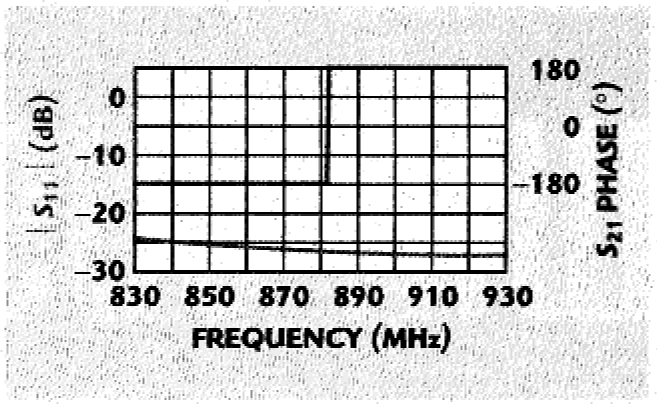
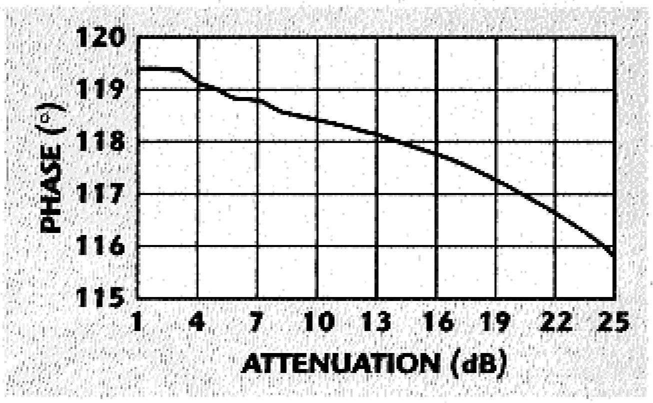
$$\Gamma_{in,j} = \left|\Gamma_{in,j}\right| e^{\phi j} = \left.\frac{Z_{in,j} - Z_0}{Z_{in,j} + Z_0}\right|_{j=\text{large or small}}$$

$$= \left.\frac{R_s - Z_0 + \dfrac{R_j}{1+\left(\omega R_j C_j\right)^2} + j\left(\omega L_s - Z_0 \cot\theta_i - \dfrac{\omega R_j^2 C_j}{1+\left(\omega R_j C_j\right)^2}\right)}{R_s + Z_0 + \dfrac{R_j}{1+\left(\omega R_j C_j\right)^2} + j\left(\omega L_s - Z_0 \cot\theta_i - \dfrac{\omega R_j^2 C_j}{1+\left(\omega R_j C_j\right)^2}\right)}\right|_{R_j=\text{large or small}} \quad (3)$$

$$\phi_j = \tan^{-1}\left[\frac{\omega L_s - Z_0 \cot\theta_i - \dfrac{\omega R_j^2 C_j}{1+\left(\omega R_j C_j\right)^2}}{R_s - Z_0 + \dfrac{R_j}{1+\left(\omega R_j C_j\right)^2}}\right] - \tan^{-1}\left.\left[\frac{\omega L_s - Z_0 \cot\theta_i - \dfrac{\omega R_j^2 C_j}{1+\left(\omega R_j C_j\right)^2}}{R_s + Z_0 + \dfrac{R_j}{1+\left(\omega R_j C_j\right)^2}}\right]\right|_{R_j=\text{large or small}} \quad (4)$$



▲ *Fig. 4 Measured results for the reflective type 0°/180° phase shifter.*



▲ *Fig. 5 Phase variation of the reflection type attenuator.*

From the definition of the 0°/180° phase shifter, the electrical length θ_1 can be derived.

$$F_1(\phi_1) = \Gamma_{in,large} + \Gamma_{in,small} \approx 0 \quad (5)$$

In the case of the low phase-shifting attenuator, even though its attenuation varies as the junction resistance changes, the phase variation of the attenuator must be as small as possible. If the phase at high attenuation ($R_j = 50\ \Omega$) is the same as for low attenuation ($R_j = 0\ \Omega$ or max. Ω), low phase-shifting attenuator characteristics are obtained. Let $\phi_{Rj} = 50\ \Omega$ be the phase at high attenuation ($R_j = 50\ \Omega$) and ϕ_{Rj} = max. the phase at low attenuation (Rj = max.). From the definition of a low phase-shifting attenuator, the electrical length ϕ_2 can be derived.[3]

$$F_2(\theta_2) = \phi_{Rj=50} - \phi_{Rj=max} \approx 0 \quad (6)$$

MEASUREMENT

The proposed vector modulator has been designed for the 869 to 894 MHz band. The PIN diode used is an Agilent HSMP-4810. The equivalent circuit of the PIN diode was obtained by the Deloach method[4] and the extracted parameters are $R_S = 3.342\ \Omega$, $L_S = 1.748$ nH, $Cj = 0.2034$ pF. The electrical lengths of the stubs of the 0°/180° phase shifter and low phase-shifting attenuator are $\theta_1 = 86.4°$ and $\theta_2 = 84.4°$, respectively. The design results were simulated with Mathcad v.7. The junction resistance variation range of the PIN diode is from 50 Ω to a maximum value for low power consumption. The PCB board used is made of 31 mil thick epoxy ($\varepsilon_r = 4.3$) and the 90° hybrid coupler is model S03A888N1 of RF Power Inc. The in-phase combiner is a Wilkinson combiner.

Figure 4 shows the measured characteristics of the 0°/180° phase shifter. The relative phase conversion characteristic is 179.9° ±1.4° for the 869 to 894 MHz frequency band. ***Figure 5*** shows the measured phase characteris-

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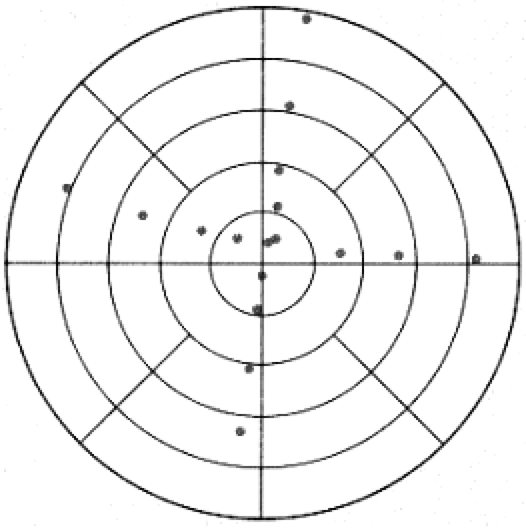

▲ *Fig. 6 Standard vector modulator response at 881 MHz.*

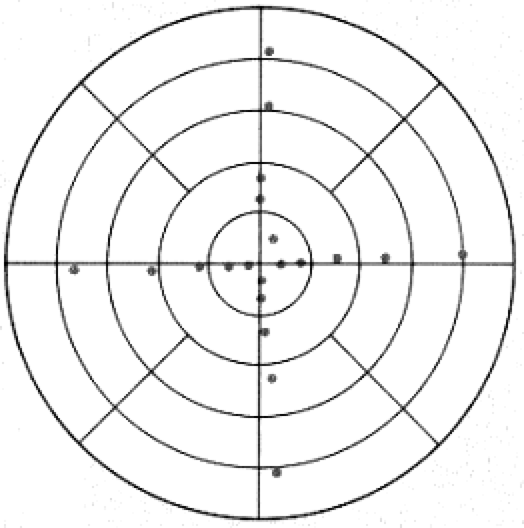

Fig. 7 The proposed vector modulator response at 881 MHz. ▲

tics of the low phase-shifting attenuator. The phase variation is 3.6° for 25 dB attenuation range at 881 MHz.

When the in-phase and quadrature-phase signals are attenuated –1, –5, –10, –15, –20 dB, using the attenuator, ***Figure 6*** shows the measured characteristics of the standard vector modulator and ***Figure 7*** shows those of the proposed vector modulator. The results are normalized with an insertion loss of 4.2 dB and a delay of approximately 45° for comparison of measurements which are aligned with the X- and Y-axis. The characteristics of the standard vector modulator show that its locus is not on a straight line. The center point is located in the 1st quadrant and does not represent the Cartesian coordinate plane correctly. The characteristics of the proposed vector modulator show that its locus is almost a straight line and the center point is located near zero, and thus represent the Cartesian coordinate plane correctly.

CONCLUSION

A vector modulator that controls the magnitude and phase of an input signal, but rejects phase and gain cross-coupling, is presented. The vector modulator is simulated and realized for the 869 to 894 MHz frequency band to show its validity. The 0°/180° phase shifter and low phase-shifting attenuator which are used in the vector modulator show 0° to 180° phase conversion and 3.6° phase variation for 25 dB attenuation at 881 MHz, respectively. The realized vector modulator shows that the Cartesian coordinates can be realized and output signals with arbitrary magnitudes and phases can be obtained. ■

References

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