A DESIGN OF THE NOBLE VECTOR MODULATOR

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In this paper, vector modulator which controls magnitude and phase of input signals is proposed. The previous magnitude/phase controlling circuit which is composed of attenuator and phase shifter makes phase/gain cross-coupling. The proposed modulator which composed of low phase shifting attenuator and $0^{O}/180^{O}$ phase shifter can minimize phase/gain cross-coupling. So the Cartesian coordinate plane of the output signal space can be represented with vector modulator.

Introduction

For the efficient spectral resource use, QPSK modulation scheme is used in wireless communication basestation transmitting system. This scheme requires high linearity of power amplifier[1]. Now, linearizer which reduces the nonlinearity of amplifier is attached to wireless communication amplifier. The main circuits of linearizer are attenuator and phase shifter. These circuits are used to control magnitude and phase of signals.

Attenuator use PIN diode or GaAs MESFET and so forth that have electrically controlled resistor component and prefers PIN diode to other diveces because of convenience in general. PIN diode is operated as an attenuator by junction resistance(Rj) which is changed by bias current. But when PIN diode is operated as attenuator, PIN diode makes phase variation which is caused by other parasitic components of PIN diode besides junction resistance.

Phase shifter uses varactor diode in general. Junction capacitance of varactor diode is changed by reverse bias voltage and the phase of signal is changed according to junction capacitance. But when varactor diode is operated as phase shifter, phase shifter changes the magnitude of input signals which is also caused by other parasitic components of varactor diode besides junction capacitance.

When magnitude/phase controlling circuit is composed of attenuator and phase shifter, attenuator makes phase shifting besides attenuation and phase shifter makes insertion loss validation besides phase shifting. These phenomena make phase/gain cross-coupling, there is much tuning time to obtain the optimum attenuation and phase shift of the input signal. The phase/gain cross-coupling restricts to minimize the operation time for the optimum operation of SCPA(Single-Channel Power Amplifier) and MCPA(Multi-Channel Power Amplifier).

Design Theory

The magnitude/phase controlling of input signals with attenuator and phase shifter is that the output signal space plane is represented in the polar coordinate plane. The ouput signals are represented by magnitude and phase, so the overall points of the polar coordinate plane are the capable output signals as against the reference input signals. This output signal space plane is also represented by the Cartesian coordinate. The capable output signals can be represented by in-phase (X-axis) signal components and quadrature-phase (Y-axis) signal components.

The previous vector modulator is shown in Fig. 1[2]. The input signals are divided into in-phase and quadrature-phase components by 90^{O} hybrid. These signals are attenuated by the reflection-type PIN diode individually and the attenuated signals are combined by in-phase combiner. The signals of output port are points of the Cartesian coordinate in the output signal space plane. If the variation range of the junction resistance in PIN diode is $50 \sim \infty\Omega$, the vector modulator uses the 4th quadrature plane. But the variation range of the junction resistance in PIN diode is 0~50Ω , the vector modulator uses the 1st, 2nd, 3rd quadrature plane. The magnitude and phase of the output signals depend on the operation of in-phase and quadrature-phase attenuator. But the previous vector modulator ignores the phase shifting in addition of attenuation, so it can't represent the Cartesian coordinate properly. This phenomenon prevent from controlling the magnitude and phase properly.

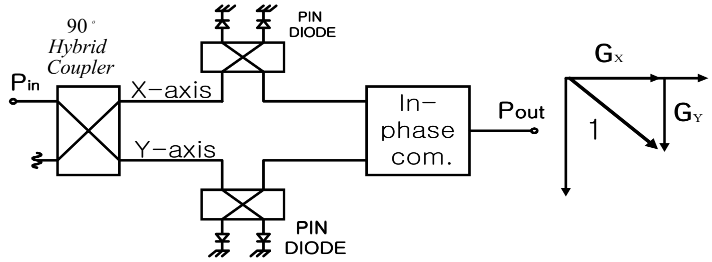
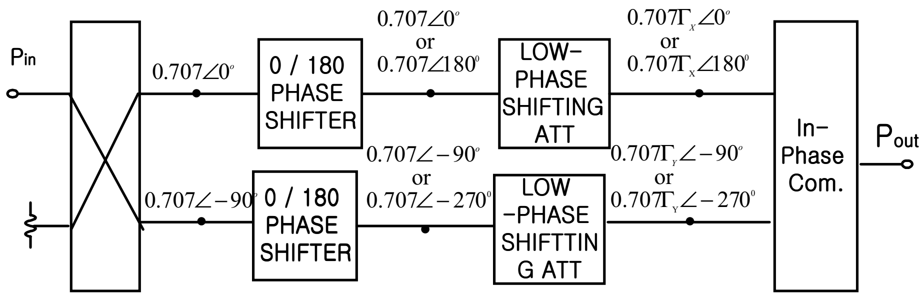


Fig. 1 The previous vector modulator and vector diagram

In this paper, the new type vector modulator is proposed. The operation of this vector modulator is below. The input signals are divided by 90^{O} hybrid and the divided in-phase and quadrature-phase signals are connected $0^{O}/180^{O}$ phase shifters which change the phase of input signals into $0^{O}/180^{O}$ according to control voltage. If $0^{O}/180^{O}$ phase shifters are setted to 0^{O}, the phase of output signals in $0^{O}/180^{O}$ phase shifter is not changed and then connected to low phase shifting attenuator which minimizes the phase variation on attenuating. The attenuated in-phase and quadrature-phase signals are connected to in-phase combiner, so in-phase and quadrature-phase signals are vectors combined. The final output signals are located in the 4th quadrature plane, but if $0^{O}/180^{O}$ phase shifter changes the phase to 180^{O}, then the final output signals can be located in the 1st, 2nd, 3rd quadrature plane. The proposed vector modulator is shown in Fig. 2.



$$V_{out} = 0.5\sqrt{|\Gamma_X|^2 + |\Gamma_Y|^2}\angle\phi \qquad \phi = \tan^{-1}(\Gamma_X/\Gamma_Y)$$

Fig. 2 The proposed vector modulator

Fig. 3 shows $0^{O}/180^{O}$ phase shifter and the equivalent circuit. When R_j=Max Ω , the incident wave is reflected at R_j. But when R_j=0 Ω , the incident wave is reflected at the end of open stub. So if two output waves have the same reflection magnitude and out-of-phase property, this device is operated as

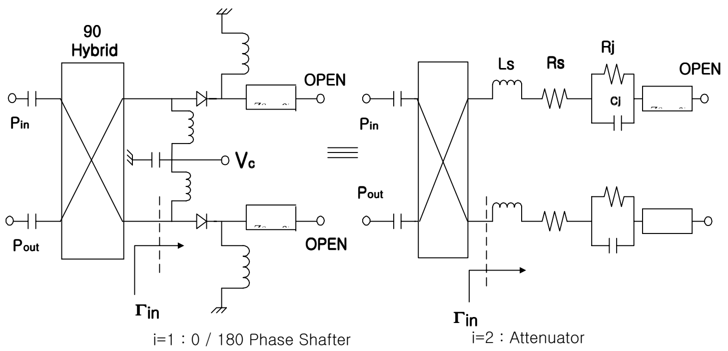


Fig. 3 Reflection-type $0^{O}/180^{O}$ phase shifter(i=1)/low phase shift attenuator(i=2) and the equivalent circuit

$0^{O}/180^{O}$ phase shifter. The input impedance at the input port of PIN diode is below.

$$Z_{in,\text{large}} = R_s + j\omega L_s + \frac{1}{\frac{1}{R_j} + j\omega C_j} + Z_{O.C} \Big|_{R_j=\text{large}} = R_s + \frac{R_j}{1 + j\omega R_j C_j} + j(\omega L_s - Z_o \cot\theta_1) \Big|_{R_j=\text{large}} \quad (1)$$

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

The reflection coefficient is below.

$$\Gamma_{in,j} = \left|\Gamma_{in,j}\right| e^{\varphi_j} = \left.\frac{Z_{in,j} - Z_o}{Z_{in,j} + Z_o}\right|_{j=\text{large } or \ small}$$
$$= \left.\frac{R_s - Z_o + \frac{R_j}{1+(\omega R_j C_j)^2} + j(\omega L_s - Z_o \cot\theta_i - \frac{\omega R_j^2 C_j}{1+(\omega R_j C_j)^2})}{R_s + Z_o + \frac{R_j}{1+(\omega R_j C_j)^2} + j(\omega L_s - Z_o \cot\theta_i - \frac{\omega R_j^2 C_j}{1+(\omega R_j C_j)^2})}\right|_{R_j=\text{large } or \ small} \quad (3)$$

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

By the definition of $0^{O}/180^{O}$ phase shifter, the electrical length Θ_1 is derived.

$$F_1(\theta_1) = \Gamma_{in,\text{large}} + \Gamma_{in,small} \approx 0 \quad (5)$$

In case of low phase shifting attenuator, even though the attenuator has different attenuation value as junction resistance changes, the phase variation of attenuator must have as small as possible. If the phase of high attenation (Rj=50 Ω) is the same phase of low attenuation (Rj=0 Ω or Max. Ω around), the low phase shifting attenuator characteristics are obtained. Let $\varphi_{R_j=50}$ be as phase of high attenuation (Rj=50 Ω) and $\varphi_{R_j=Max}$ as phase of low attenuation (Rj =Max. Ω). By the definition of low phase shifting attenuator, the electrical length Θ 2 is derived[3].

$$F_2(\theta_2) = \varphi_{R_j=50} - \varphi_{R_j=Max} \approx 0 \quad (6)$$

Measurement

The proposed vector modulator has been designed at 869~894 MHz. The used PIN diode is HSMP-4810(HP). The equivalent circuit of PIN diode is obtained with Deloach method and the extracted parameters are R_S=3.342Ω , L_S=1.748nH, Cj=0.2034pF[4]. The electrical lengths of $0^{O}/180^{O}$ phase shifter and low phase shifting attenuator are $\Theta_1=86.4^{O}$, $\Theta_2=84.4^{O}$. The design results are simulated by Mathcad v.7. The junction resistance variation range of PIN diode is 50 ~ Max. Ω for low power consumption. The used PCB is 31mil epoxy (ε_r=4.3) and 90^{O} hybrid is S03A888N1 of RF Power Inc. and in-phase combiner is realized with Wilkinson combiner.

Fig. 4 shows the measured characteristics of $0^{O}/180^{O}$ phase shifter. The relative phase conversion characteristics is 179.9 ± 1.4^{O} on 869~894 MHz. Fig. 5 shows the measured characteristics of low phase shifting attenuator. The phase variation is 3.6^{O} for 25dB attenuation at 881 MHz. When in-phase and quadrature-phase signals are attenuated -1, -5, -10, -15, -20 dB using attenuator,

Fig. 6 shows the measured characteristics of the previous vector modulator and Fig. 7 shows the measured characteristics of the proposed vector modulator. The above results are normalized with the insertion loss 4.2dB and electrical delayed around 45^{O} for comparison. The characteristics of the previous vector modulator show that the locus is not straight line and the center point is located in the 1st quadrature plane and don't represent the Cartesian coordinate plane correctly. But the characteristics of the proposed vector modulator show that the locus is almost straight line and the center point is located near zero and represent the Cartesian coordinate plane correctly.

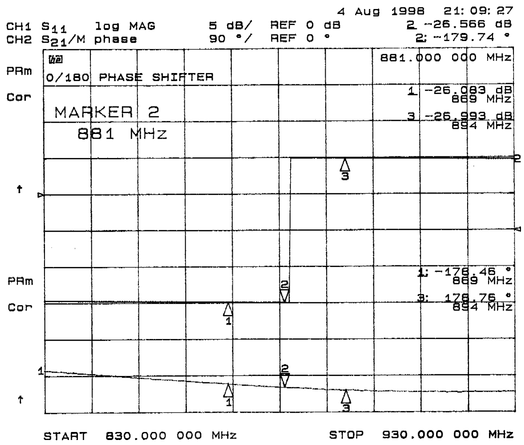


Fig 4. The measurement result of reflection-Type $0^O/180^O$ phase shifter

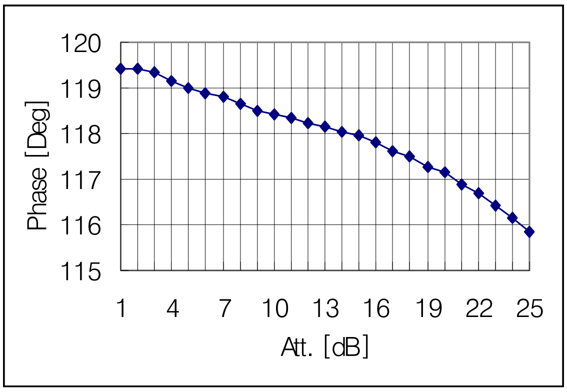


Fig. 5 The phase variation characteristics for the attenuation of reflection-type attenuator

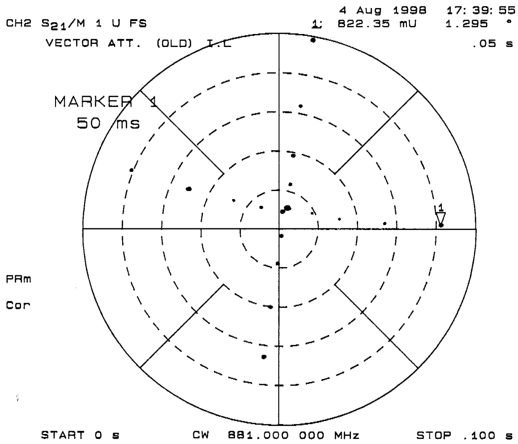


Fig. 6 The previous vector modulator response

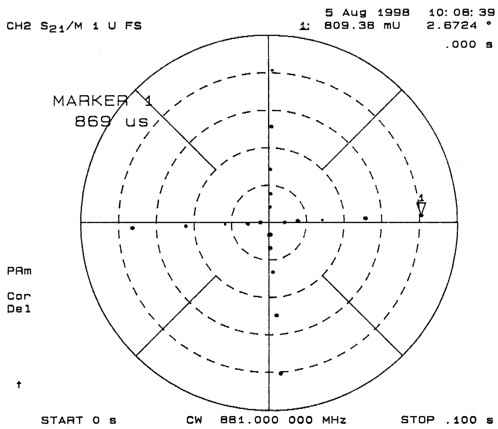


Fig. 7 The proposed vector modulator response

Conclusion

The vector modulator which controls the magnitude and the phase of input signals but rejects phase/gain cross-coupling phenomenon is presented. The vector modulator is simulated and realized at 869~894MHz to show the validity. The $0^O/180^O$ phase shifter and low phase shifting attenuator which consist in the vector modulator show $0^O/180^O$ phase conversion and 3.6^O phase variation for 25 dB attenuation at 881MHz. The realized vector modulator shows that the Cartesian coordinates can be realized and the output signals which have the arbitrary magnitudes and phases can be realized.

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