EVEN HARMONIC QUADRATURE MODULATOR WITH LOW VECTOR MODULATION ERROR AND LOW DISTORTION FOR MICROWAVE DIGITAL RADIO

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ABSTRACT

An even harmonic quadrature modulator (EHQMOD) with a low vector modulation error (VME) and low distortion characteristics is presented for small sized digital radio transmitters in microwave. Relationships between modulation characteristics and circuit parameters in the EHQMOD are described by analytical and experimental approaches. In addition, this paper presents an improved configuration of the EHQMOD for a low VME and low distortion characteristics. Developed X-band EHQMOD with root cosine roll-off shaped $\pi/4$ DQPSK achieved 6% of VME without any adjustable circuits and -11dBm of output power with -50 dBc of leakage power at an adjacent channel. These experimental results verify the effectiveness of analyzed results. The EHQMOD technique indicated in this paper is effective for future high speed digital communications especially in millimeter wave band.

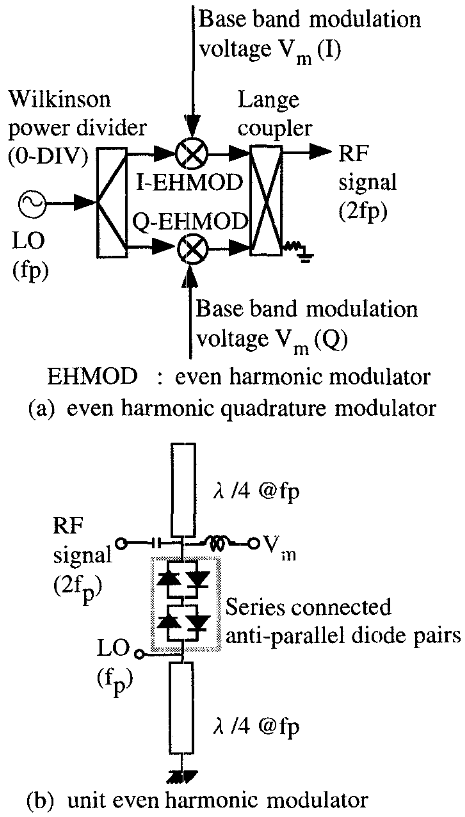
INTRODUCTION

A microwave quadrature modulation [1][2] is an effective technique for small sized digital radio transmitters used in mobile or satellite communication. Quadrature modulators require a low vector modulation error (VME) for low bit error rate and low distortion characteristics for a narrow bandwidth. An even harmonic quadrature modulator (EHQMOD) [3] with an anti-parallel diode pair (APDP) [4] has extremely low carrier leakage which is one of error components and also causes bit error. So the authors developed 40GHz band monolithic even harmonic mixer which employs a stub type diplexer, and achieved 70dB carrier (virtual LO leakage) suppression[5]. But there have been less discussions about EHQMOD possibility for digital radio systems.

This paper describes EHQMOD with a low VME and low distortion for digital radio systems. VME and output power of the EHQMOD are analyzed for revealing degrading factors of the digital modulation. As a result of the analysis, a VME degradation by interferences between two unit even harmonic modulators can be reduced by improving signal isolation of a local divider. Power leakage at an adjacent channel by third order distortion can be reduced by series connected two APDPs.

CONFIGURATION

Figure 1 shows a schematic diagram of the proposed EHQMOD which employs a stub type diplexer for LO (frequency fp) and RF signal (frequency 2fp)[5]. EHQMOD consists of two unit even harmonic modulators (EHMOD), a Wilkinson power divider for fp (0-DIV) and a Lange coupler for 2fp. Center frequency of the Wilkinson power divider is designed at 1.5fp to suppress 2fp interferences between I- and Q-EHMOD. Furthermore this EHQMOD employs series connected two GaAs monolithic APDPs for low distortion characteristics. The effectiveness of proposed configuration is described in the following discussions.



(a) even harmonic quadrature modulator

(b) unit even harmonic modulator

Fig.1 Schematic diagram of the proposed even harmonic quadrature modulator which employs a stub type diplexer for LO (frequency fp) and RF signal (frequency 2fp).

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VME ANALYSIS OF THE EVEN HARMONIC QUADRATURE MODULATOR

Figure 2 shows the VME model of EHQMOD. In this model, scattering parameters of each component are defined at fp and 2fp. A conversion gain from fp to 2fp is defined in EHMOD blocks. A vector of an output signal V_o is expressed approximately as :

$$V_o \approx \left[\{(1+\Gamma_t)T_I + X_t \cdot T_Q\} + U_A \cdot e^{j(\frac{\pi}{2}+U_\phi)} \{(1+\Gamma_t)T_Q + X_t \cdot T_I\} \right] \cdot V_p$$
$$\Gamma_t = (T_{\mathrm{mod}})^2 \cdot \Gamma_{div} \quad , X_t = (T_{\mathrm{mod}})^2 \cdot T_{div} \tag{1}$$

where V_p is LO voltage, T_I and T_Q are conversion gains of I- and Q-EHMOD, U_A and U_ϕ are amplitude and phase imbalances between I and Q channel respectively. T_{mod} is an isolation between fp port and 2fp port of EHMOD at 2fp, Γ_{div} is a reflection coefficient of 0-DIV at 2fp and T_{div} is an isolation of 0-DIV at 2fp. The VME is calculated from vector error defined as the difference between an ideal space diagram and an actual diagram V_o. From equation (1), the maximum VME (VME_{max}) is given as follows:

$$VME_{\max} = \frac{1}{\sqrt{2}} \{ (1+U_A{}^2)(|\Gamma_t|^2 + |X_t|^2) + 4U_A|\Gamma_t||X_t|\sin U_\phi + 1 + U_A{}^2 - 2U_A \cdot \cos U_\phi + \sqrt{E_1^2 + E_2^2} \}^{0.5}$$
$$E_1 = 2|X_t| - 2U_A|X_t|\cos U_\phi + 2U_A|\Gamma_t|\sin U_\phi$$
$$E_2 = 2U_A|X_t|\sin U_\phi + 2U_A{}^2|\Gamma_t| - 2U_A|\Gamma_t|\cos U_\phi \quad . \tag{2}$$

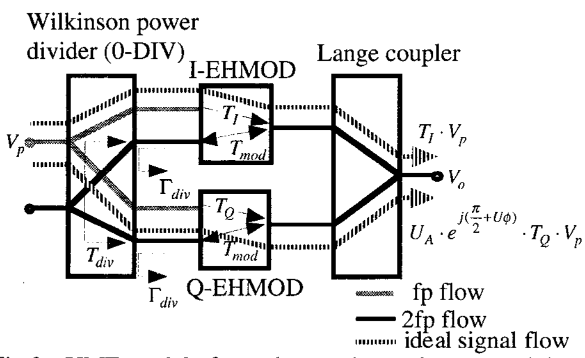


Fig.2 VME model of even harmonic quadrature modulator.

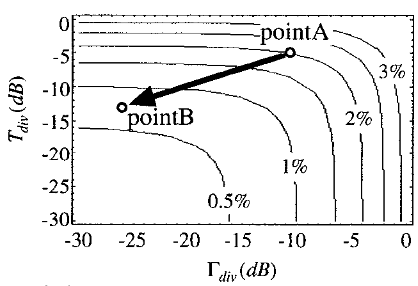


Fig.3 Calculated contour plot of the VME_{max} with a condition of U_A=0 dB, U_ϕ=0 degree and T_{mod}=-15 dB (point A : Wilkinson power divider designed in fp point B : Wilkinson power divider designed in 1.5fp).

Equation (2) represents the relationship between the VME and scattering parameters of each component. In these equations, X_t and Γ_t are degradation factors caused by the 0-DIV and are not negligibly small especially in case of the EHQMOD, because 0-DIV designed at fp has poor isolation and VSWR at 2fp. So 0-DIV of a developed EHQMOD is designed at 1.5fp. Figure 3 shows calculated contour plot of the VME_{max} under the condition of U_A=0 dB, U_ϕ=0 degree and T_{mod}=-15 dB. In this figure, point A that employs 0-DIV designed at fp is located at the VME_{max} of 2%, and point B that employs 0-DIV designed at 1.5fp is located at VME_{max} of 0.7%. As a result of this analysis, design conditions of each component which satisfy required VME can be given.

OUTPUT POWER ANALYSIS OF THE EVEN HARMONIC MODULATOR

Figure 4 shows a calculation model for output power of unit EHMOD. In this analysis, Shottky barrier diode (SBD) for APDP is considered as a switch with resistance R_s. By this model, the second order Fourier coefficient A_{2p} of diode current Ij modulated by V_m is given as follpws:

$$A_{2p} = \frac{2V_p}{3\pi \cdot (R_0 + R_s)} \{ (1-p^2)^{1.5} - (1-q^2)^{1.5} \}$$
$$\approx -\frac{4}{\pi \cdot (R_0 + R_s)} \cdot \frac{V_t}{V_p} \left\{ \left(1 - \frac{V_t^2}{2V_p{}^2}\right) V_m - \frac{1}{2V_p{}^2} V_m{}^3 \right\}$$
$$p = (V_m + V_t)/V_p \quad , \quad q = (V_m - V_t)/V_p \tag{3}$$

where V_t is built-in voltage of SBD and R_0 is an internal resistance of generator. It is assumed that $|p| \leqq 1$ and $|q| \leqq 1$. Equation (3) indicates that there are only odd order harmonics of V_m in A_{2p}, because even order harmonics are suppressed in APDP. In case of higher V_p, equation (3) can be approximated to

$$A_{2p} \approx -\frac{4}{\pi \cdot (R_0 + R_s)} \cdot \frac{V_t}{V_p} \cdot V_m \quad . \tag{4}$$

The linear modulation by V_m can be obtained with conditions of $V_p >> V_t$ and $V_p >> V_m$. Maximum value A_{max} of A_{2p} with respect to V_m can be approximated from equation (3) to

$$A_{\max} \approx -\frac{8\sqrt{2}}{3\sqrt{3}\pi} \cdot \frac{V_t}{R_0 + R_s} \left(1 - \frac{V_t^2}{2V_p{}^2}\right)^{1.5} . \tag{5}$$

Moreover, A_{max} converges with increasing V_p to a value A_{lim}.

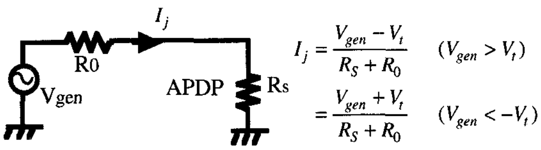
$$A_{\lim} = -\frac{8\sqrt{2}}{3\sqrt{3}\pi} \cdot \frac{V_t}{R_0 + R_s} \cdot \tag{6}$$

Figure 5 shows analytical and simulated output power of unit EHMOD employing a single APDP with parameters shown in Table 1. Analytical results agree well with simulated ones by the harmonic balance method except lower local power case, because of the approximation of DC characteristics. From the analysis mentioned above, low distortion conditions of EHQMOD are given as follows:

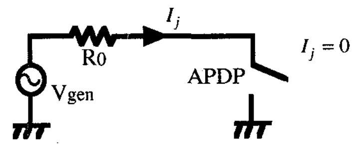
(a) Linear modulation by V_m can be achieved by increasing V_p as shown in equation (3).
(b) Limits of output power A_{lim} can be increased by employing SBD with higher V_t as shown in equation (6). So series connected two APDPs that have $2V_t$ is an effective approach to improve output power, and it means that linear modulation can be achieved easily.

Table 1 parameter summary of GaAs APDP (Sanyo:SBL-803(A))

parameter	Value
Saturation current Is (used in simulation)	0.087pA
Ideality factor n (used in simulation)	1.17
Junction capacitance Cjo (used in simulation)	0.04pF
Series resistance Rs (used in analysis and simulation)	5Ω
Built-in voltage Vt (used in simulation)	0.85V



(a) APDP in on state(Vgen<-Vt,Vgen>Vt)



(b) APDP in off state (-Vt<Vgen<Vt)

Fig.4 The calculation model for output power of unit even harmonic modulator.

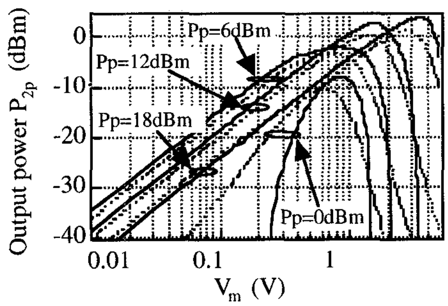


Fig.5 Analyzed and simulated output power of the unit even harmonic modulator (fp:1GHz, solid lines: analyzed results by eq.(3), dashed lines: simulated results by harmonic balance method).

X-BAND EVEN HARMONIC QUADRATURE MODULATOR

Figure 6 shows a photograph of an integrated X-band EHQMOD fabricated on an alumina substrate with the size of 16.5mm×10.3mm×0.38mm. For this X-band experiment, we employed π/4DQPSK with symbol rate 192ksymbol/sec and roll-off rate 0.5 which are defined in the Japanese digital cordless telephone "PHS". Figure 7 shows a signal locus of the EHQMOD with 8 symbols of π/4DQPSK. Figure 8 shows measured and predicted VME of the X-band EHQMOD. In the figure, the solid line indicates measured values, and dashed line indicates VME_{max} by equation (3). VME is below 6% in 8% bandwidth. PHS requires 12.5% VME for example, so this value is low enough for digital radio systems.

Figure 9 shows measured virtual carrier leakage. Figure 10 shows output power and leakage power at an adjacent channel. The measured virtual carrier leakage is extremely lower than output power. By increasing P_p, measured leakage power by the third order distortion is reduced as shown in the analyzed result. Output power -11dBm with -35dBc virtual carrier leakage and -50 dBc leakage power at an adjacent channel are achieved in P_p of 16dBm. Figure 11 indicates output spectrum of the X-band modulator. In a case of higher Pp, bandwidth is decreased. The effectiveness of proposed configuration and analytical results are verified in the above experimental results.

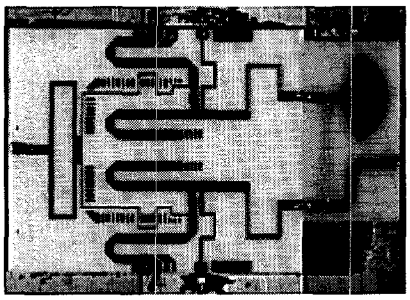


Fig.6 Photograph of integrated the X-band even harmonic quadrature modulator fabricated on an alumina substrate with 0.38mm thickness (Size : 16.5mm×10.3mm) .

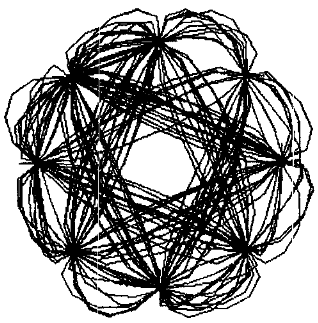


Fig.7 Signal locus of the even harmonic quadrature modulator with 8 symbols of π/4DQPSK (symbol rate : 192ksymbol/sec, roll-off rate : 0.5).

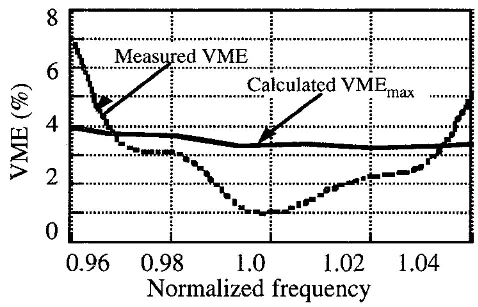


Fig.8 Measured VME and calculated VME_{max} of the X-band even harmonic quadrature modulator.

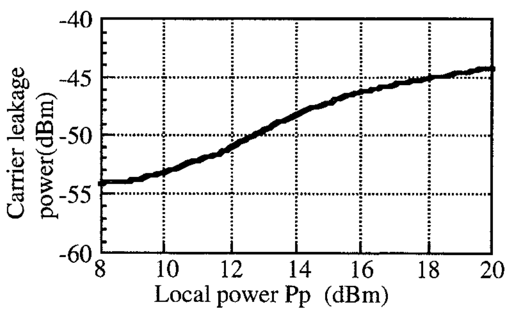


Fig.9 Measured virtual carrier leakage of the X-band even harmonic quadrature modulator.

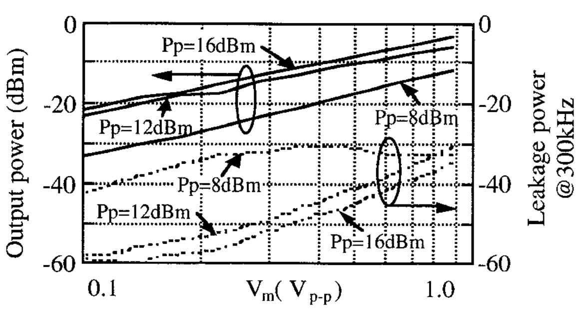


Fig.10 Output power and leakage power at an adjacent ch nnel of the X-band even harmonic quadrature modulator.(solid line: output power, dashed line: leakage power, modulation : π/4DQPSK, Roll-off rate: 0.5, symbol rate: 192ksymbol/sec).

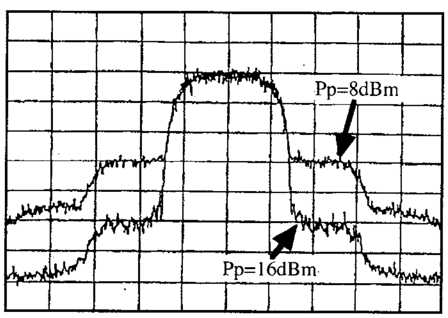


Fig.11 Output spectrum of the X-band even harmonic quadrature modulator (V_m=0.29V, Vertical: 10dB/div, Horizontal: 100kHz/div).

CONCLUSION

The EHQMOD with a low VME and low distortion characteristics has been presented for digital radio systems. Modulation characteristics of the proposed EHQMOD were described in analytical and experimental approaches. The X-band EHQMOD achieved 6% VME in 8% bandwidth without any adjustable circuits and -11dBm output power with -50dBc leakage power at an adjacent channel. The effectiveness of analysis has been experimentally verified.

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