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Bandwidth Analysis of Phase-Locked Loop(PLL) Frequency Modulation(FM) Modulator for Digital Data Transmission

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디지털 데이타 전송을 위한 PLL FM 변조기의 대역폭 분석

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ABSTRACT

In this paper the frequency bandwidth for two kinds of PLL FM modulator, which are Voltage Controlled Oscillator(VCO) PLL FM modulator and VCO-Reference PLL FM modulator, has been analyzed.

The VCO PLL FM modulator has high-pass filter characteristics. If digital data is injected into it, frequency components of that data below the 3 dB bandwidth will be rejected. But the VCO- Reference PLL FM modulator can pass low frequency components near DC. If the ratio of the reference oscillator gain to the VCO gain is equal to one with the damping factor=0.5, it would have uniform amplitude response and could be applied for digital data transmission.

要 約

본 논문에서는 두가지의 PLL 변조기, 즉 VCO PLL 변조기와 VCO Reference PLL FM 변조기에 대한 주파수 대역폭을 분석하였다. VCO PLL FM 변조기는 고주파 필터 특성을 갖는다. 이변조기에 디지털 신호를 인가하면 3 dB 대역폭 주파수 이하의 데이타 성분은 제거된다. 그러나 VCO Reference PLL FM 변조기는 DC 성분의 저주파 성분까지 통과시킬 수 있다. damping factor가 0.5 이고 기준 발진기 이득과 VCO 이득의 비가 1이면 일정한 진폭 응답 특성을 갖게 되어 디지털 전송에 응용될 수 있다.

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Ⅰ. Introduction

In VHF/UHF band, FM radio transceiver has been used for the purpose of military tactics, police group, business and leisure, etc.Recently FM radio transceiver has been mainly implemented by PLL synthesizer. And it is needed to send or receive both analog voice and digital voice signals.

There be two advantages if FM radio transceiver is able to send or receive the digital voice signal. First, users expect that data information service will be supported by using the existing radio sets. Secondly users expect that critical information could be protected from an unauthorized party. To protect user's voice information it is recommended that the encryption technique be used rather than the scrambling technique[1].

The conversion of an analog voice signal into a digital voice signal results in frequency bandwidth expansion.

The bandwidth of analog voice signal is normally from 300 Hz to 3,000 Hz, but the bandwidth of the digital voice signal is from DC to 1.5 times the sampling frequency of NRZ signal format. If the digital voice signal is transmitted by analog FM modulator and demodulated by the modulation analyzer, some data loss will happen for the data below 300 Hz. Therefore if the digital voice signal is transmitted, the FM modulator's bandwidth must be extended to meet the digital voice signal bandwidth.

There are two kinds of analog FM PLL modulators, which are VCO PLL FM modulator and VCO-Reference PLL FM modulator[2]. VCO PLL FM modulator is configured that the modulating signal is injected into VCO input, but VCO-Reference PLL FM modulator is configured that the modulating signal is injected into both VCO input and reference oscillator input. This paper discusses frequency characteristics of both VCO PLL FM modulator and VCO-Reference PLL FM modulator for the digital data transmission. If the ratio of the reference oscillator gain to the VCO gain in the PLL FM modulator is one and the damping factor is 0.5, it would have the ideal filter characteristics to send the digital signal.

Ⅱ. Frequency Characteristics of Digital Random Signal

An analog signal is converted into a digital signal through A/D converter, and the digital signal is added to the random digital source to generate the encrypted signal.

If the encrypted signal is NRZ data, then its power spectrum is shown in Figure 1. The power spectrum for the analog signal consists of frequency components from 300 Hz to 3,000 Hz. But power spectrum of the encrypted signal has the frequency components not only from 300 Hz to 3,000 Hz, but also from DC to 300 Hz. Hence, the bandwidth of the FM modulator must be extended to send the digital voice signal.

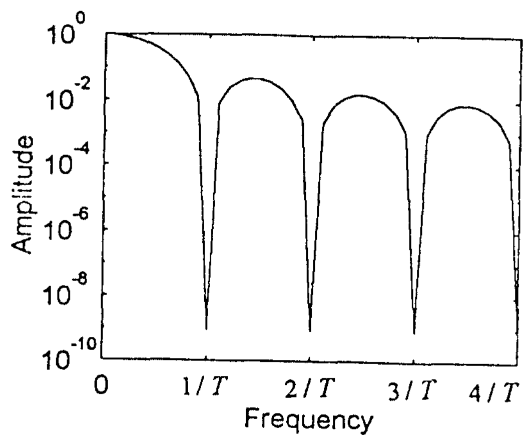


Fig. 1. Power Spectrum of NRZ Signal

Ⅲ. Bandwidth Analysis of VCO PLL FM Modulator

The VCO PLL FM modulator is widely used in the existing analog FM transceiver. Its block diagram is shown in Figure 2, which the modulating signal and the loop filter output signal are added and injected into VCO input. To analyze the bandwidth characteristics of the VCO PLL FM modulator, the following parameters are defined.

K_d : Phase Detector Gain [V/rad]

K_o : VCO Gain [rad/sec.V]

$F(s)$: Transfer Function of Loop Filter

V_d : Error Voltage

V_m : Modulating Signal

θ_i : Phase of Reference Oscillator

θ_o : Output Phase of VCO

$\Delta\omega_m$: Output Frequency of VCO

The VCO PLL FM modulator's characteristics is determined by analyzing the relationship between the external modulating signal and the VCO output signal. The VCO output frequency is represented by equation (1) and its Laplace transform is represented by equation (2).

$$\Delta\omega_m = \frac{d\theta_o}{dt} \tag{1}$$

$$\Delta\omega_m(s) = s.\theta_o(s) \tag{2}$$

Now suppose that the phase of reference oscillator is fixed and N value of N-divider might be one in Figure 2, then the output phase of VCO is given as the equation (3)

$$\theta_o(s) = \frac{K_o \cdot V_m(s)}{s + K_d \cdot K_o \cdot F(s)} \tag{3}$$

Since VCO gain and phase detector gain are constant the VCO output phase characteristics mainly depends on the loop filter transfer function F(s). Loop filter which is a low-pass filter can be implemented by RC circuit or operational amplifier. If loop filter in Figure 3 is used, the transfer function F(s) becomes

$$F(s) = \frac{s \cdot \tau_2 + 1}{s \cdot \tau_1} \tag{4}$$

where, $\tau_1 = R_1.C, \tau_2 = R_2.C$

By substituting equation (2) and (4) into equation (3) the transfer function of PLL modulator is given as follows

$$\frac{\Delta\omega_m}{V_m(s)} = \frac{K_o \cdot s^2}{s^2 + 2\cdot\delta\cdot\omega_n \cdot s + \omega_n^2} \tag{5}$$

where, $\delta = \frac{\tau_2}{2} \cdot \sqrt{\frac{K_o \cdot K_d}{\tau_1}}, w_n = \sqrt{\frac{K_o \cdot K_d}{\tau_1}}$

The transfer function of PLL FM Modulator is the second order closed loop system and its performance is determined by the damping factor and resonant frequency.

To determine the frequency response of PLL FM Modulator the amplitude response and 3 dB bandwidth should be anayzed.

Amplitude characteristics is given as equation (6) by substituting for complex number s in the equation (5) and calculating the absolute value. Also the 3dB bandwidth is

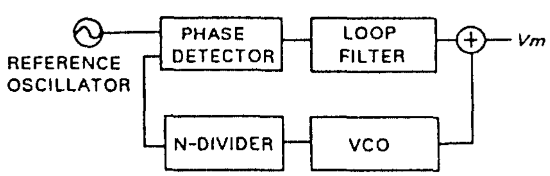


Fig. 2. Block Diagram of VCO PLL FM Modulator

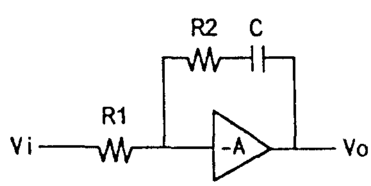


Fig. 3. Circuit Diagram of Loop Filter

given as equation (7) from the condition the square of amplitude is equal to 0.5.

$$H(\alpha)=\left|\frac{\Delta\omega_m(j\alpha)}{V_m(j\alpha)}\right|=\frac{K_o\cdot\alpha^2}{\sqrt{(1-\alpha^2)^2+(2\cdot\delta\cdot\alpha)^2}} \quad (6)$$

where, α is defined as the normalized frequency.

$$W(3dB)=\omega_n\cdot\sqrt{4\cdot\delta^2-1+\sqrt{2-8\cdot\delta^2+16\cdot\delta^4}} \quad (7)$$

As the normalized frequency and the damping factor varies the amplitude characteristics is shown in Figure 4. If the damping factor approaches to zero, the gain for the low frequency will be improved, but the locking time will be inversely proportional to the damping factor, therefore 3 dB bandwidth of VCO PLL FM modulator should be determinined by considering both the damping factor and the the locking time.The normalized 3dB bandwidth is shown in Figure 5 according to the damping factor.

From the figure the 3dB bandwidth will be proportional to the damping factor. Even though the damping factor approaches to zero the 3dB bandwidth does not converges to zero, that means the FM modulator can not pass the low frequency componenents near DC.

Ⅳ. Bandwidth Analysis of VCO-Reference PLL FM Modulator

If the modulating signal is injected into both the VCO and reference oscillator we call it VCO-Reference PLL FM modulator which is shown in Figure 6.

Denoting reference oscillator gain and the reference oscillator output phase, the VCO output phase is given as equation (8).

$$\theta_o(s)=\frac{K_o\cdot V_m(s)+K_o\cdot K_d\cdot K_f\cdot F(s)}{s+K_o\cdot K_d\cdot F(s)} \quad (8)$$

By substituting equation (2) and (4) into equation (8), the transfer function of VCO-Reference PLL modulator is given as equation (9).

$$\frac{\Delta\omega_m(s)}{V_m(s)}=\frac{K_o\cdot s^2+K_f\cdot(2\cdot\delta\cdot\omega_n\cdot s+\omega_n^2)}{s^2+2\cdot\delta\cdot\omega_n\cdot s+\omega_n^2} \quad (9)$$

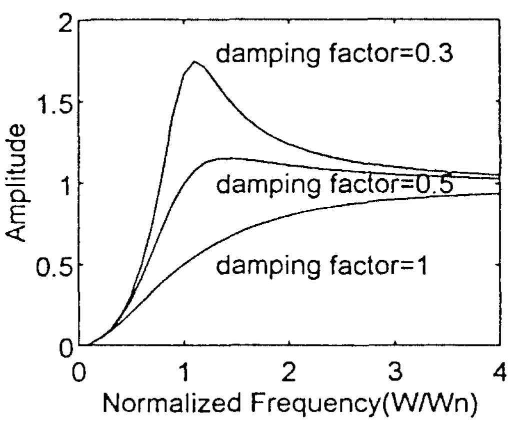


Fig. 4. Amplitude Response of VCO PLL FM Modulator

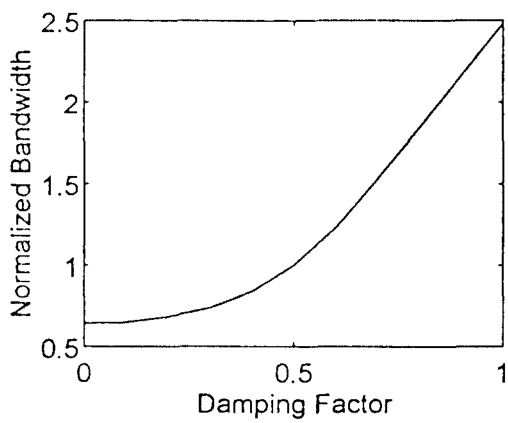


Fig.5. 3 dB Bandwidth of VCO PLL FM Modulator

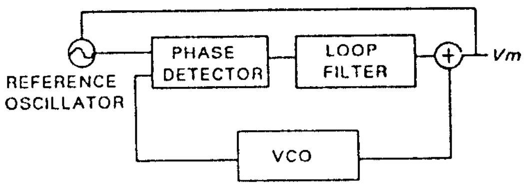


Fig. 6. Block Diagram of VCO-Reference PLL FM Modulator

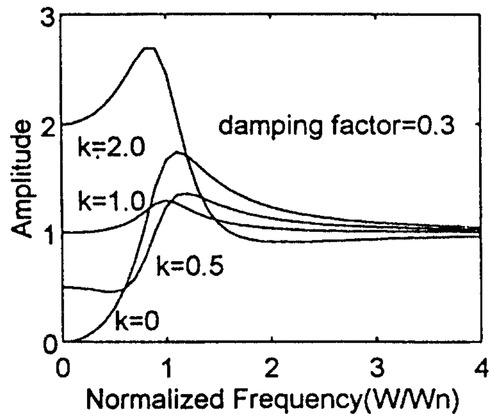


Fig. 7. Amplitude Response of VCO-Reference PLL FM Modulator for ζ = 0.3

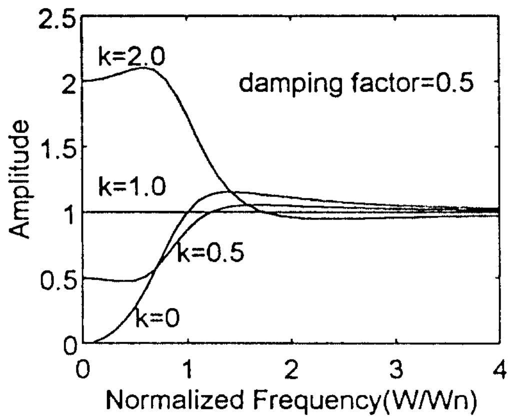


Fig. 8. Amplitude Response of VCO-Reference PLL FM Modulator for ζ = 0.5

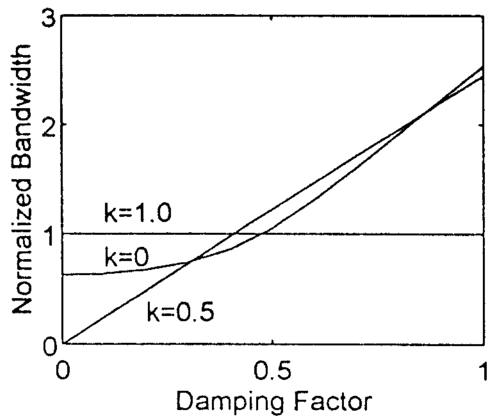


Fig. 9. Amplitude Response of VCO-Reference PLL FM Modulator for ζ = 1.0

Amplitude characteristics is given as equation (10) by substituting for complex number s in the equation (9) and calculating the absolute value. Also the 3dB bandwidth is given as equation (11) from the condition the square of amplitude is equal to 0.5.

$$H_R(\alpha)=\frac{K_o\cdot\sqrt{(K-\alpha^2)^2+(2\cdot K\cdot\delta\cdot\alpha^2)}}{\sqrt{(1-\alpha^2)^2+(2\cdot\delta\cdot\alpha)^2}} \qquad (10)$$

$$W_R(3dB)=\omega_n\cdot\sqrt{a+\sqrt{a^2+1-2\cdot K}} \qquad (11)$$

where, $a=4\cdot\delta^2(1-K^2)+2K-1, K=\frac{K_f}{K_o}$

α is the normalized frequency and K is the ratio of the reference oscillator gain to the VCO gain.

As the damping factor and the ratio of reference oscillator gain to VCO gain varies, the amplitude characteristics also varies as shown in Figure 7, 8, 9 for the damping factor 0.3, 0.5, 1.0 respectively. As K value approaches to one, the amplitude response of VCO-

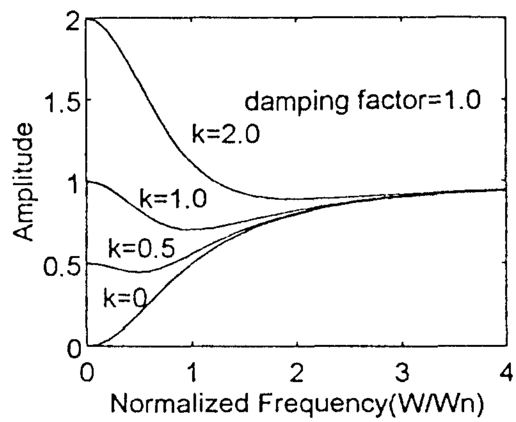


Fig.10. 3 dB Bandwidth of VCO-Reference PLL FM Modulator

Reference PLL FM modulator has the uniform amplitude and it is mainly effected by K value rather than the damping factor, also it has an ideal filter characteristics for K=1 and ζ =0.5. The normalized 3 dB bandwidth is shown in Figure 10 according to K value. From the figure the 3 dB bandwidth will be constant for K=1.0. Consequently, as K value approches to 1.0, the 3 dB bandwidth does converge to zero, which means the FM modulator can pass the low frequency components near DC.

Ⅴ. Conclusions

The FM modulator which can transmit the digital signal must be designed to have more bandwidth than the bandwidth of the modulating signal. Now existing VCO PLL modulator has the high-pass filter characteristics. For transmission of a digital signal the damping factor of the PLL modulator must approach to zero, but this results in longer locking time and unstable PLL opreation.

Therefore VCO PLL modulator get some data loss below the 3 dB bandwidth. The characteristics of the VCO-Reference PLL FM modulator mainly depends on the ratio of the reference oscillator gain to the VCO gain and the damping factor. If the ratio of the reference oscillator gain to the VCO gain is equal to one for the various value of damping factor, the modulator can pass low frequency components near DC.

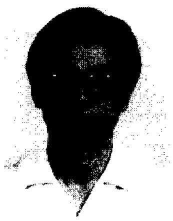
The amplitude characteritics changes due to the damping factor. if the damping factor is equal to 0.5, it has uniform amplitude for the normaized frequency.

Since the resistor and the capacitor components are used in the FM modulator design and there is tester's performance limitation to measure frequency component near DC, it is difficult to design the modulator which can modulate the digital signal without any loss in practice.

Thus the VCO-Reference PLL modulator is an alternative method for the digital data transmission by the simple circuit modification.

References

1. Henry J. Beker, Fred C. Piper, Secure Communications, Academic Press, 1985.
2. Farron L. Ducas, Design and Optimization of Frequency Modulated Phase Locked Loop, RF Synthesizer, March, 1992.
3. Floyd M.Gardner, Phaselock Techniques, John Wiley & Sons, Inc., 1979.
4. Chak M. Chie, William C. Linsey, "Phased-Locked Loops, Applications, Performance Measures, and Summary of Analytical Results," Phased-Locked Loops, IEEE Press, pp.3~25, 1986.
5. Benjamin C. Kuo, Automatic Control Systems, Prentice-Hall, Inc, 1975.



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