THE INJECTION-LOCKED-OSCILLATOR AS A MICROWAVE AMPLIFIER OF MSK MODULATED SIGNALS - PART II

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ABSTRACT

Because of its phase continuous nature a Minimum-Shift-Keying (MSK) type of digitally modulated microwave signal may be amplified with an Injection-Locked-Oscillator Phase-Locked-Amplifier (ILO-PLA) Experimental bit-error-rate results for an ILO-PLA are presented in this paper for MSK modulated signals. The results show that for MSK signals an ILO-PLA does not display the large performance degradation previously reported for QPSK signals. Further a two sided locking bandwidth equal to 1.8 times the input signal bit-rate results in about .3 dB degradation in the bit-error-rate performance due to the ILO-PLA. A positive or negative frequency offset of about ten per cent of the locking bandwidth causes negligible further degradation of the performance.

I. Introduction

For digital and analog angle modulated signals, (i.e., phase or frequency modulation), the information is contained in the instantaneous phase, and therefore a high power microwave phase-locked-oscillator which is phase locked to the weak input modulated signal may be used as a high gain microwave amplifier[1,2,3,4]. Such an amplifier is commonly referred to as the Phase-Locked-Amplifier (PLA). The two versions of the first order phase-locked-oscillator that may be used in such applications are the ILO-PLA and the Voltage-Tuned-Oscillator Phase-Locked-Amplifier (VTO-PLA). For digitally modulated signals the performance of a PLA is limited by the 90^o and 180^o phase transients at the interbit switching instants[3,4,5]. The previously reported results[4] show that for QPSK signals the bit-error-rate at high E_b/N_o (bit energy to noise spectral density) ratios does not follow the ideal-channel PSK performance curve and that an ILO-PLA introduces an error floor.

Minimum shift keying is a digital modulation technique which is free of any phase transients. The 90^o phase shift in a bit interval is obtained by a linear variation of the phase and the phase continuity is maintained at the interbit switching instants. This suggests that MSK modulated signals will be compatible with an ILO-PLA for high gain amplification. In a previous paper[5] we presented spectrum-spreading results for the amplification of filtered MSK signal with an ILO-PLA. In this paper we describe the measured bit-error-rate results obtained when amplifying MSK modulated signals with an ILO-PLA. The experimental bit-error-rate results are presented in Section II. A discussion of the results and conclusions are presented in Section III.

II The Bit-Error-Rate Performance Results

The bit-error rate performance of a digital system is determined by the bit energy to additive Gaussian noise power-spectral-density ratio (E_b/N_o) required to achieve a certain probability of bit-error. The degradation in the bit-error-rate is measured with respect to the performance achievable for an ideal channel. The bit-error-degradation of a given subassembly of the system may be determined by the additional degradation which may occur as a result of introducing that particular subassembly in the system. The bit-error-rate performance was measured for a 5 M Bits/sec MSK signal using the test arrangement of Fig. 1.

The locking bandwidth of an ILO is inversely proportional to the square root of the power gain. The degradation in bit-error-rate performance will determine the required locking bandwidth. The degradation will increase as the locking bandwidth decreases for a higher gain values. Thus a trade-off between the achievable gain and the performance degradation is possible. This trade-off is experimentally determined in this paper. In determining this trade-off it is also shown that because of the phase continuous nature of MSK, an ILO-PLA does not exhibit a large performance degradation as for QPSK.

The parameters of the microwave oscillators used in the bit-error-rate experiment are shown in Table 1.

Table 1. Oscillators Used in ILO-PLA Bit-Error-Rate Performance Testing.

OSC.No.	Configuration	Power Out (Milliwatts)	Freq. (GHz)	External Q
1	Microstrip IMPATT	10	6	126.5
2	Waveguide IMPATT	410	8.555	60.1
3	Waveguide IMPATT	200	9.187	40.6

The external Q in the last column of Table 1 was calculated from the measured locking bandwidth by using Adler's equation[6] given below.

$$B_L = \frac{2f_o}{Q_e}\sqrt{\frac{P_i}{P_o}}$$

where

B_L = Two sided locking bandwidth

f_o = Input signal carrier freq.

P_i = Locking signal power

P_o = The locked oscillator output power

Q_e = The oscillator external Q.

The measured bit-error-rate results with the oscillator 1 ILO-PLA are shown in Fig. 2 for the 5 M Bits/Sec. MSK modulated input. As may be seen from this figure very little additional degradation ($\leq$ .15 dB at a BER of $1x10^{-6}$) was introduced by the ILO-PLA for a gain of 14 dB. The degradation increased to .3 dB at a BER of $1x10^{-6}$ as the gain was increased to 20 dB. A rapid degradation in performance (20 dB at a BER of $1x10^{-6}$) can be noticed as the gain was further increased to 26 dB. It may be seen that the bit-error rate curves for MSK do not exhibit the anomalous behaviour previous reported[4] for amplification of QPSK signals with an ILO-PLA. Further, a two sided locking bandwidth of only 9 MHz (corresponding to a gain of 19 dB for oscillator 1) results in less than .3 dB degradation in the performance. This bandwidth is only 1.8 times the bit rate of 5 M Bits/Sec.

A further insight into ILO-PLA behaviour is provided by the I-Q channel eye diagrams shown in Fig.3 as the ILO-PLA gain was increased from 16 dB to 31 dB. Increasing the gain from 16 to 21 dB causes only a marginal closure of the eye. A rapid closure of the eye can be noticed as the gain was increased from 21 dB to 26 dB. It is interesting to note that even at a gain of 31 dB, where the two sided locking bandwidth is only 2.5 MHz (= .5 times the bit rate) the eye is still not completely closed indicating that the system is still usable although with a very high degradation of the bit-error-rate performance.

As may be seen from the last column of Table 1,oscillators 2 and 3 had external Q's of 60.1 and 40.64 respectively compared to an external Q value of 126.5 for oscillator 1. The measured bit-error-rate results for oscillators 2 and 3 of Table 1 are given as Figures 4 and 5 respectively. As expected a higher gain can be obtained for approximately the same performance degradation by lowering the external Q of the oscillator. In practice a lower limit on the external Q will be imposed by the frequency instability of the oscillator and by the noise, both of which increase as Q is lowered. The Q will be thus designed to make a compromise between the frequency stability and noise on the one hand and the gain on the other hand.The frequency instability of the oscillator will in effect result in frequency offset between the ILO free-running frequency and the input signal nominal carrier frequency. The effect of this frequency offset was measured for the oscillator No. 1 of Table 1. The measured results are presented as Fig.6 for an ILO-PLA gain of 20 dB with the frequency offset as the parameter. As may be seen from this figure a frequency offset of 1 MHz results in only a minimal degradation (<.1 dB) of the performance. However, increasing the frequency offset to 2 MHz causes a rapid degradation (1-1.5 dB). It may be noted that a frequency offset of 2 MHz at a gain of 20 dB for the oscillator 1 represents 22.2 percent of the two sided locking bandwidth at this gain.

III Conclusions

Based on the experimental bit-error-rate results, it may be concluded that an ILO-PLA for MSK modulated signals does not display the anomalous behaviour previously reported[4] for QPSK signals, namely a large and erratic bit-error-rate at high E_b/N_o ratios. Further it requires a two sided locking bandwidth of only twice the MSK modulated signal bit-rate to maintain the degradation in the performance due to the ILO-PLA to a small value, of the order of .3 dB. A high gain single stage amplifier for MSK signals may, therfore, be realized using an ILO-PLA. A positive or negative frequency offset of about ten percent of the two sided locking bandwidth causes little further degradation in the performance, while a frequency offset of about twenty-five percent results in a rapid degradation of the performance.

References

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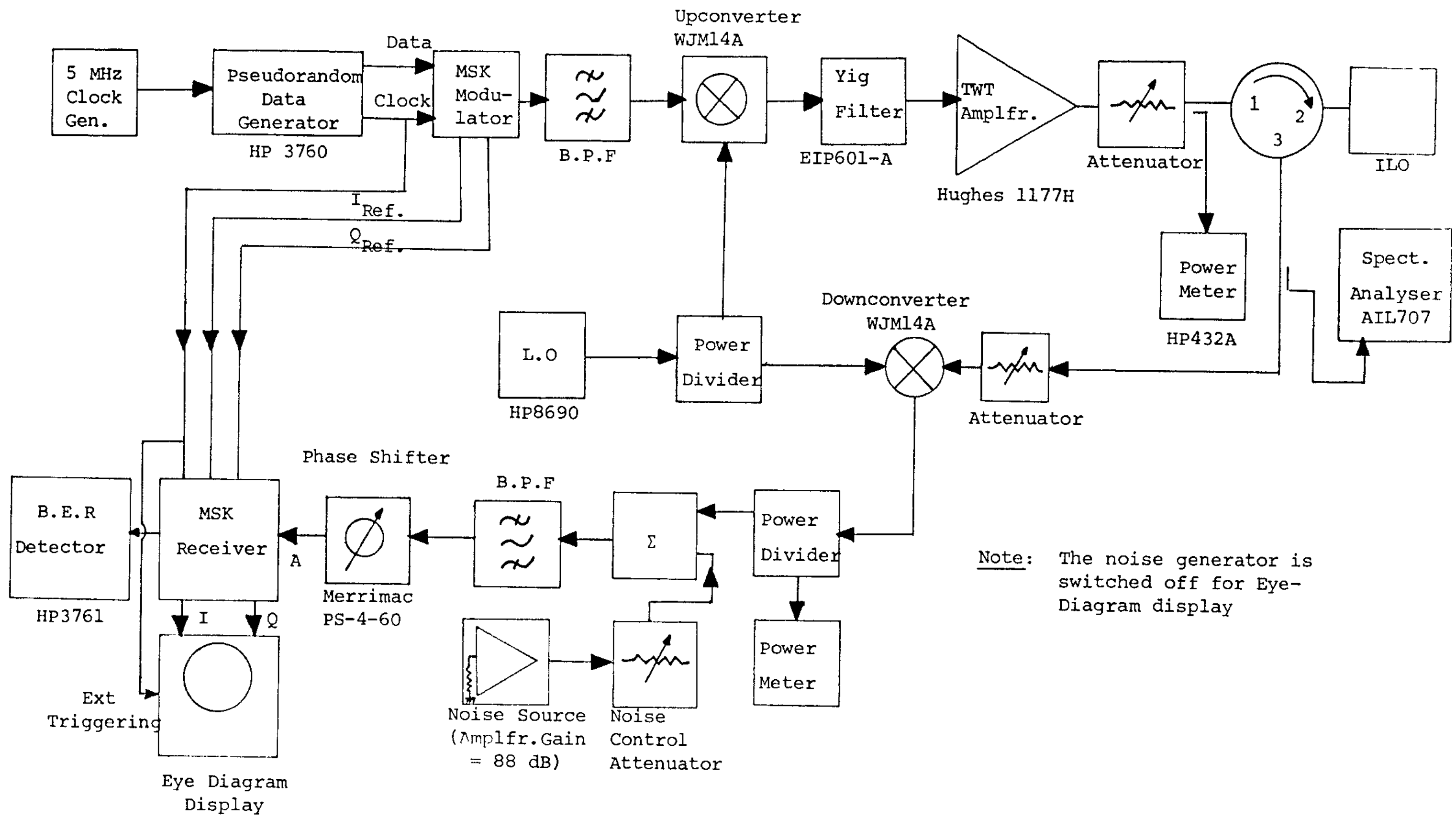


Fig. 1 The Test Set-up Used for the BER Measurements

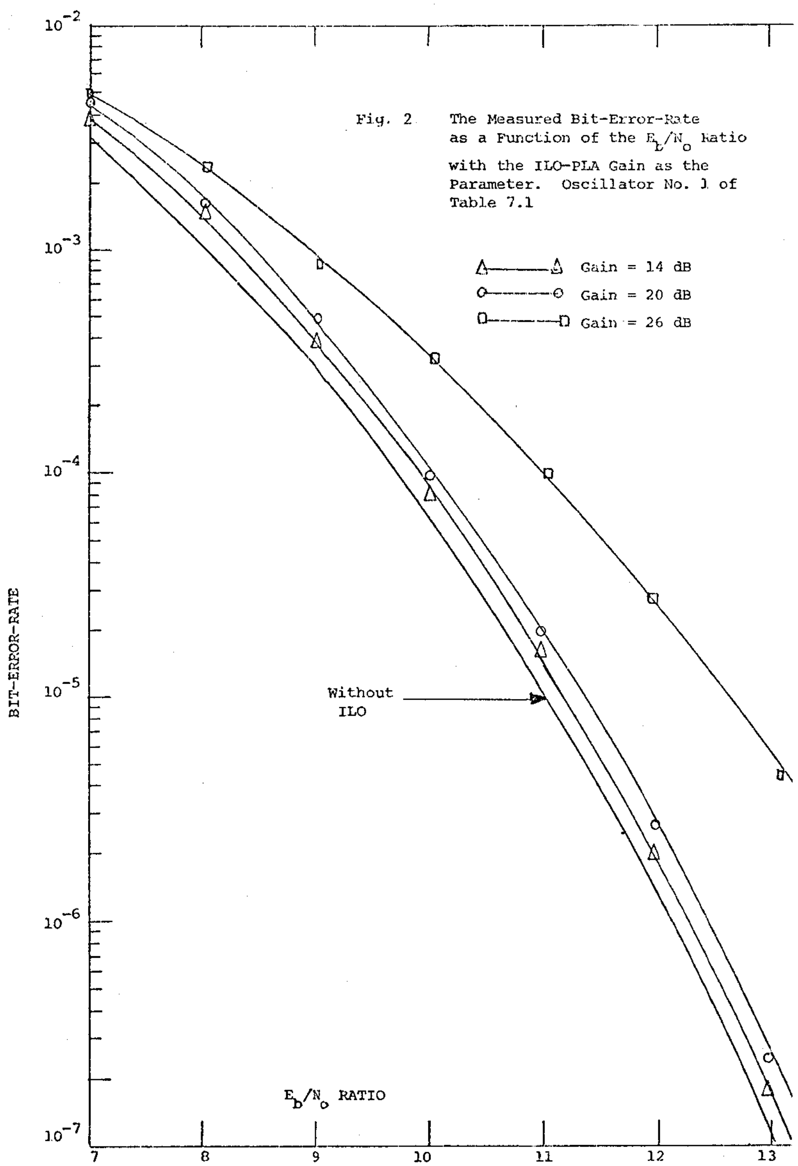
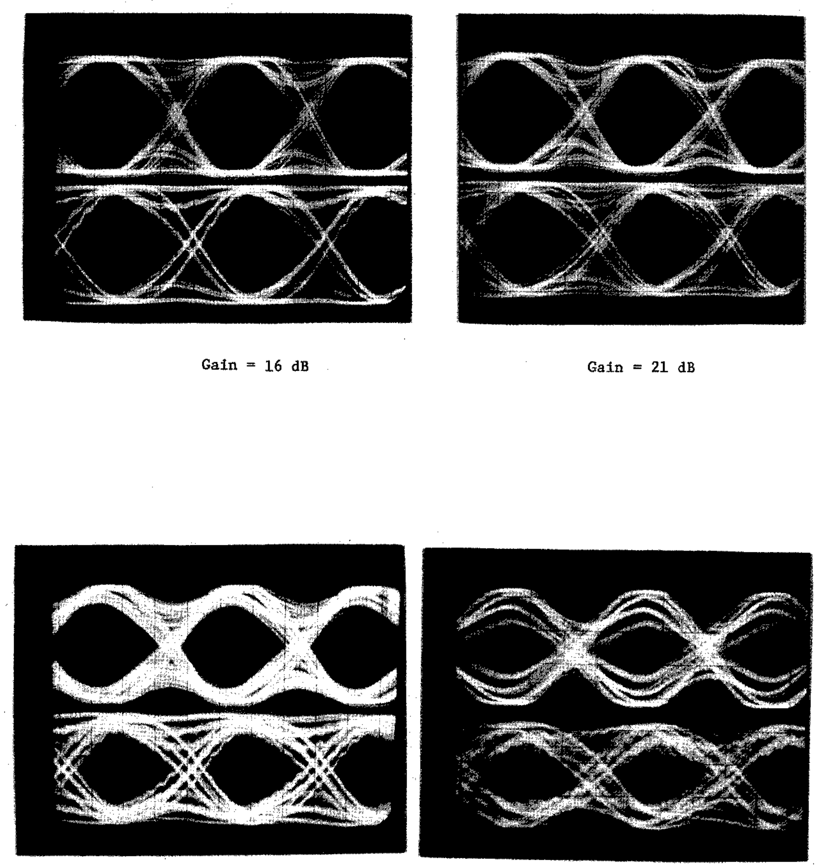


Fig. 2 The Measured Bit-Error-Rate as a Function of the E_b/N_o Ratio with the ILO-PLA Gain as the Parameter. Oscillator No. 1 of Table 7.1



Gain = 16 dB

Gain = 21 dB

Gain = 26 dB

Gain = 31 dB

Fig. 3 The I and Q Channel Eye Diagrams with Different Values of the ILO-PLA Gains for the Oscillator No. 1 of Table 1.

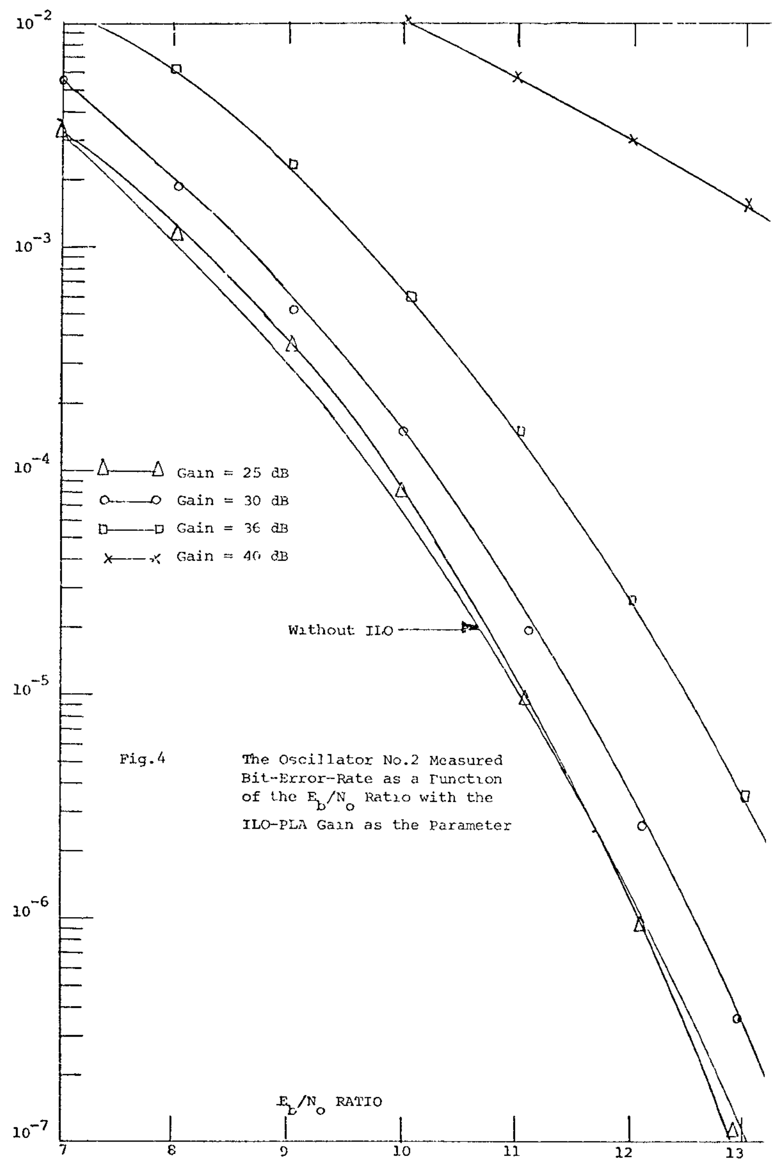


Fig.4 The Oscillator No.2 Measured Bit-Error-Rate as a Function of the E_b/N_o Ratio with the ILO-PLA Gain as the Parameter

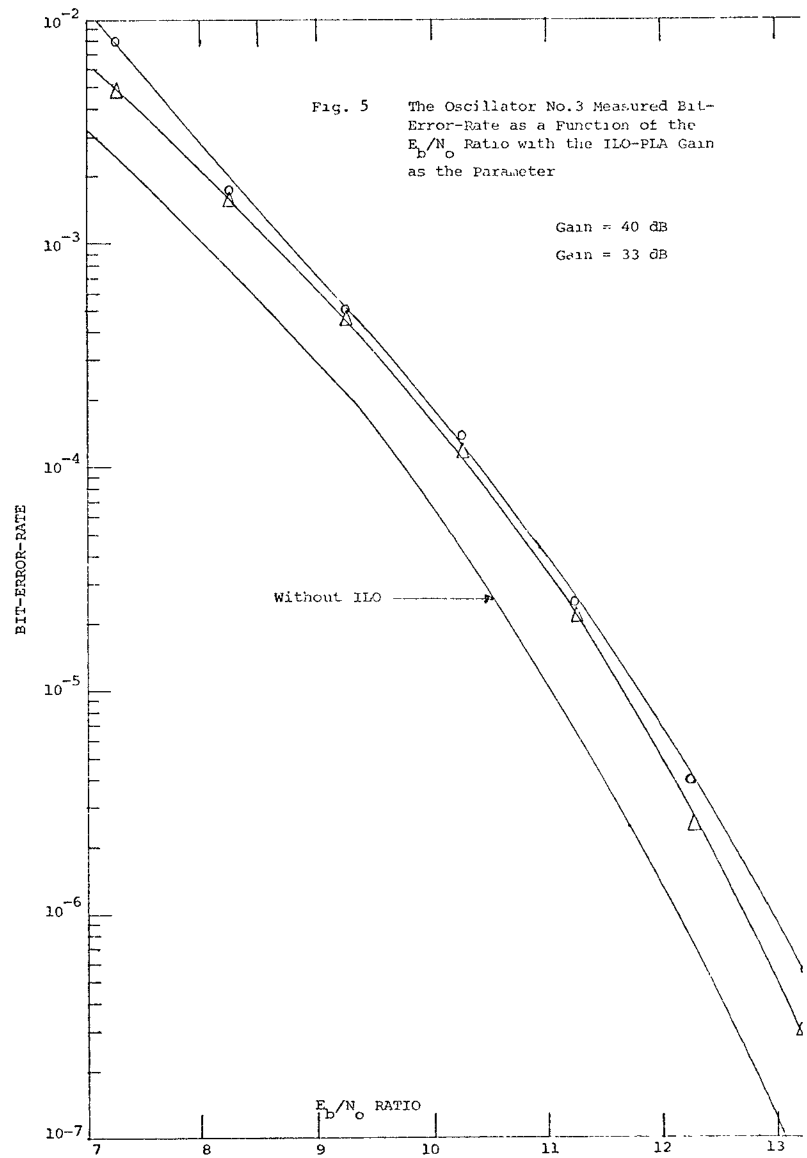


Fig. 5 The Oscillator No.3 Measured Bit-Error-Rate as a Function of the E_b/N_o Ratio with the ILO-PLA Gain as the Parameter

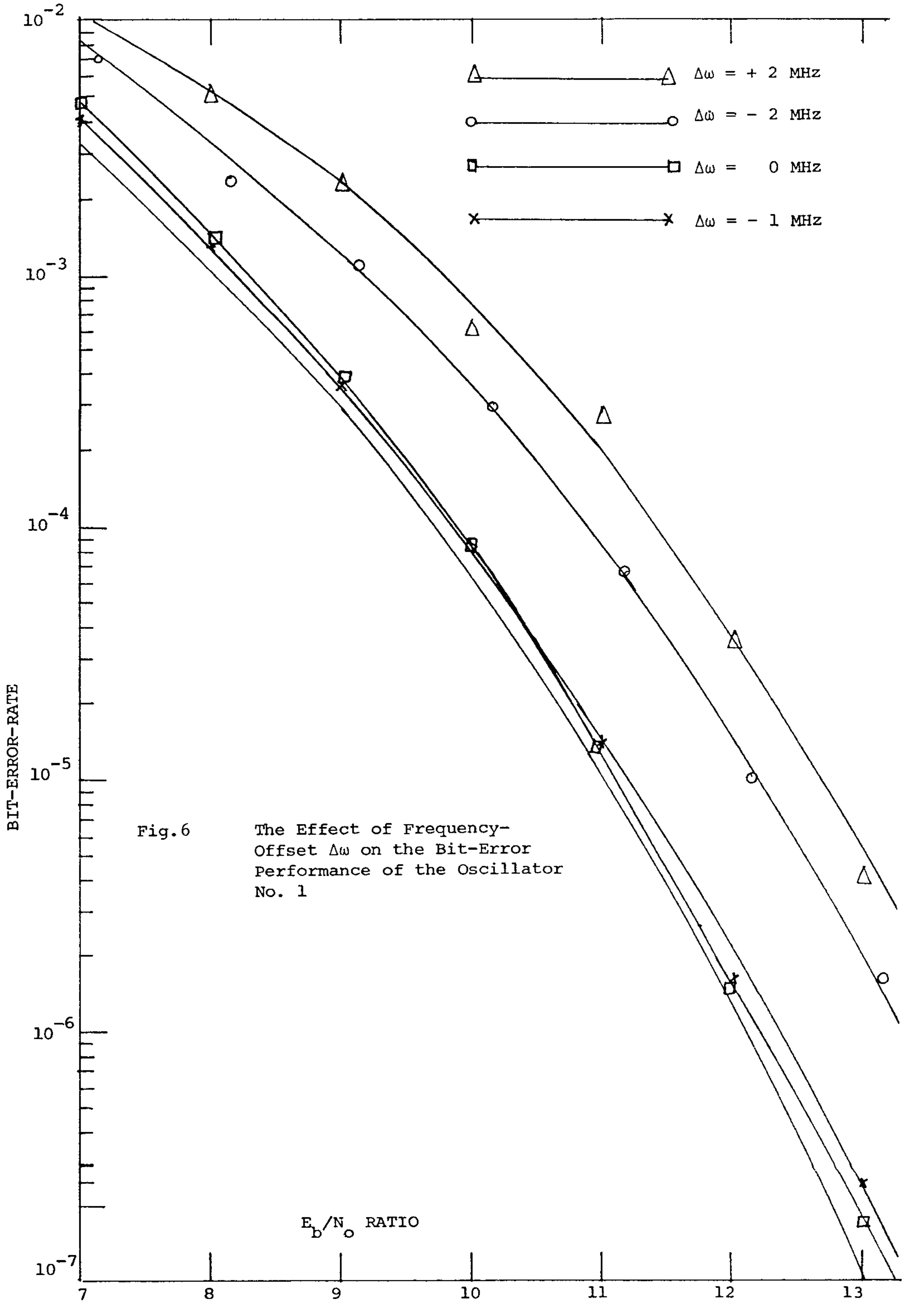


Fig. 6 The Effect of Frequency-Offset $\Delta\omega$ on the Bit-Error Performance of the Oscillator No. 1