FM DISTORTION IN SINGLE AND CASCADED INJECTION LOCKED DIODE OSCILLATORS

T. Berceli

Research Institute for Telecommunication
1026 Budapest, Gábor Áron-u 65, Hungary

Abstract

FM distortion in injection locked diode oscillators is investigated both theoretically and experimentally. At the lower frequency end of the locking band, the distortion is rather high. Hence the distortion is decreased with increasing frequency and a minimum is achieved at a frequency higher than the band center.

Introduction

Single and cascaded injection locked diode oscillators are widely used in microwave transmitters for power amplification of frequency or phase modulated signals. In these applications, the FM distortion is an important property. The injection locked diode oscillators have already been treated in many papers[1,2]. However, less attention was drawn to the distortion properties of these oscillators. In the present paper, the FM distortion in injection locked diode oscillators is investigated both theoretically and experimentally. The distortion is primarily determined by the group delay time, AM-PM conversion and AM compression. In the theory, a large signal model is used to describe the device behaviour. In the experiments, circuits with Gunn and IMPATT diodes have been investigated.

Analysis

The analysis of injection locked diode oscillators is based on the equivalent circuit shown in Fig.1. The diode is represented by a nonlinear conductance G_d and a nonlinear capacitance C_d. The level dependence of these elements is approximated by a function of second power of the voltage across the diode terminals:

$$Y_d = -1 + \frac{1}{2} V^2 + j \frac{2\pi f C_{do}}{G_o} + j b_n V^2 \qquad /1/$$

The admittance is normalized to G_o which is the negative value of the small signal diode conductance. The voltage is normalized to the voltage of free running oscillator giving maximum power. Further f is the signal frequency, C_{do} is the small signal diode capacitance, b_n is a factor characterizing the diode susceptance nonlinearity. The latter may be determined by measurements in the stable amplifier mode of diode operation[3].

The circuit comprising the diode is substituted by a parallel resonant circuit L_p-C_p. Input and output are separated by a circulator. The oscillator is analysed in the steady-state condition when only a single frequency voltage component is present across the diode terminals. In this case, the sum of the left side and right side admittances at terminals x-x should be zero[4]. Thus the relationship between the input and output signals is given by the following nonlinear equations:

$$\left.\begin{aligned} 1 - \frac{1}{2} V^2 &= G_L \frac{1}{V^2} (V_o^2 - V_i^2) \\ 2Q_o\delta + b_n V^2 &= 2G_L \frac{1}{V^2} V_o V_i \sin\theta \\ V^2 &= V_o^2 + V_i^2 + 2V_o V_i \cos\theta \end{aligned}\right\} \qquad /2/$$

where:

$$\left.\begin{aligned} \delta &= (f - f_o)/f_o \\ Q_o &= 2\pi f_o (C_p + C_{do})/G_o \end{aligned}\right\} \qquad /3/$$

Here f_o is the small signal resonant frequency, δ is the relative frequency deviation, Q_o is the small signal quality factor of the circuit, θ is the phase difference between input and output signals.

The powers are expressed by the voltages as follows:

$$P_o = 2G_L V_o^2 \quad , \quad P_i = 2G_L V_i^2 \qquad /4/$$

Powers are normalized to the maximum free running oscillator power.

The output power P_o and the phase θ are obtained by solving the set of nonlinear equations /2/ and taking into account Eqs. /4/. An iteration method is used for this purpose.

Single injection locked diode oscillator

In the transmission of frequency or phase modulated signals, the distortion is primarily determined by the derivated characteristics: group delay time, AM-PM conversion and AM compression. These characteristics are derived by numerical methods and shown in diagrams.

The quantity $\tau 2\pi f_o/Q_o$ proportional to the group delay time is shown in Fig.2 as a function of $Q_o\delta$ for different input powers. Higher input power introduces less group delay time and less fluctuation in a given band. The unsymmetry of the curves is the result of the susceptance nonlinearity.

AM-PM conversion is plotted in Fig.3 for different susceptance nonlinearity factors. Susceptance nonlinearity results in a shift to lower frequencies and higher conversions and in appearance of unsymmetry. In the case of $b_n \neq 0$, zero conversion occurs not in the locking band center but at higher frequencies, and the zero conversion point is shifted to higher frequencies than the band center with increasing susceptance nonlinearity.

At large signals, the main source of FM distortion is the AM-PM conversion. Thus the distortion properties of injection locked diode oscillators can be evaluated from Fig.3. At the lower frequency end of the locking band, the distortion is rather high. Hence the distortion is decreased with increasing frequency and a minimum is achieved at a frequency higher than the band center. Further on, to reache at a low distortion, a small susceptance nonlinearity factor is also needed which is only determined by the diode parameters at a given frequency.

The dependence of AM-PM conversion on the load is given in Fig.4. With increasing load the locking bandwidth is increased, and the AM-PM conversion around the band center is decreased.

The theoretical results have been checked by experiments. Injection locked Gunn and IMPATT diode oscillators have been built at 8 GHz[5]. The measurement results obtained with an IMPATT diode oscillator of 500 mW output power are presented here.

The AM-PM conversion and AM compression have been measured by a special instrument and measurement set up developed for this purpose. It contains a generator producing a 70 MHz signal modulated in amplitude. This signal is up-converted into the microwave band and provided to the input of the measured circuit. The signal modulation is modified by the AM-PM conversion and AM compression. The modified signal is down--converted to 70 MHz and detected by AM and FM detectors of high precision. The AM-PM conversion of the measurement set-up is 0,3 °/dB and its AM compression is 1 dB.

The AM-PM conversion is shown in Fig.5 as a function of carrier frequency for two input powers. The band center was adjusted to 8350 MHz in both cases, with a simultaneous adjustment of output power to the maximum. With increasing input power, the magnitude of conversion is generally decreased, and the locking bandwidth is increased.

The dependence of AM compression on modulation frequency is given in Fig.6. The parameter of curves is the deviation of carrier frequency from band center. With increasing modulation frequency, AM compression is significantly diminished. The reduction in AM compression is greater when the deviation of carrier frequency is higher.

Cascaded injection locked diode oscillators

A three stage injection locked diode oscillator chain has been developed for FM signal transmission at 8 GHz. The block diagram of the oscillator chain is shown in Fig.7. The input power is 3 mW and the output power is 1 W. In the first two stages, Gunn diodes are applied, and in the third stage, an IMPATT diode is used.

AM-PM conversion of the injection locked oscillator chain is plotted in Fig.8 as a function of carrier frequency. The AM-PM conversion of the first stage and that of the cascaded first two stages is closely of the same value as shown in Fig.8 for three stages.

AM compression is given in Fig.9 as a function of carrier frequency. The AM compression of the first stage is very high. The contribution of the second stage to the AM compression is significant while that of the third stage is already small.

The measurement results of AM-PM conversion can be explained on the basis of Fig.9. Due to the high AM compression, the amplitude modulation at the second and third stages is rather small and therefore the contribution of these stages to the AM-PM conversion of the chain is negligible.

The measurements carried out on the three stage injection locked diode oscillator chain have shown that the overall transmission characteristics are influenced in a different degree by the stages. The amplitude characteristic is mainly determined by the last stage, AM-PM conversion by the first one, while the group delay time and AM compression are dependent on every stages. Further the ends of the locking band are always determined by the worst case.

Conclusion

In the transmission of frequency or phase modulated signals, the distortion is primarily determined by the group delay time fluctuation, AM-PM conversion and AM compression of the circuit. These characteristics have been shown in diagrams for different parameters. For example, susceptance nonlinearity results in a shift to lower frequencies and higher conversions, and in appearance of unsymmetry.

At large signals, the main source of FM distortion is the AM-PM conversion. Thus the distortion properties can be evaluated from the AM-PM conversion diagrams. At the lower frequency end of the locking band, the distortion is rather high. Hence the distortion is decreased with increasing frequency and a minimum is achieved at a frequency higher than the band center.

The overall transmission characteristics of cascaded injection locked diode oscillators are influenced in a different degree by the stages. The amplitude frequency characteristic is mainly determined by the last stage, AM-PM conversion by the first one, while the group delay time and AM compression are dependent on every stage.

References

1. A. Tveit, "Gunn and IMPATT Diode Applications in Radio Link Equipment," Proceedings of 1971 European Microwave Conference, Stockholm, Paper C12/1, August, 1971.

2. P. Brand and H. Keinath, "A Comparison between Reflection-Type and Phase-Locked Amplifiers for FM-Signals with Gunn- and IMPATT-Diodes," Proceedings of the Fifth Colloquium on Microwave Communication, Budapest, Vol. IV, pp. MT/121-130, June, 1974.

3. T. Berceli, "Nonlinear Effects in IMPATT-Diode Amplifiers," Conference Prodeedings of the 5th European Microwave Conference/Microwave 75, Hamburg, pp. 705-709, September, 1975.

4. T. Berceli, "Large Signal Properties of Injection Locked Diode Oscillators," Acta Technica Sci, Hung., Budapest, 1977.

5. T. Berceli, "Distortion Properties of Injection Locked Oscillators and Reflection Amplifiers," IEEE Workshop on "Solid--State Transmitter Technology for Terrestrial Radio-Relay Systems" San Diego, June, 1977.

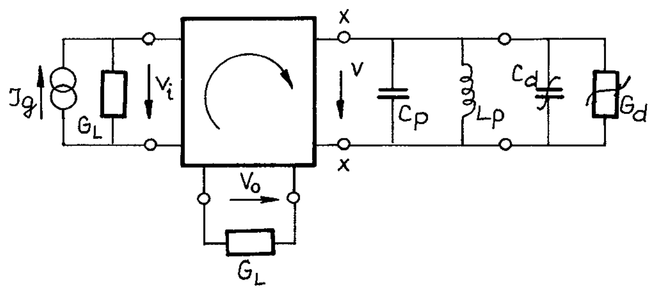

Fig. 1. Equivalent circuit

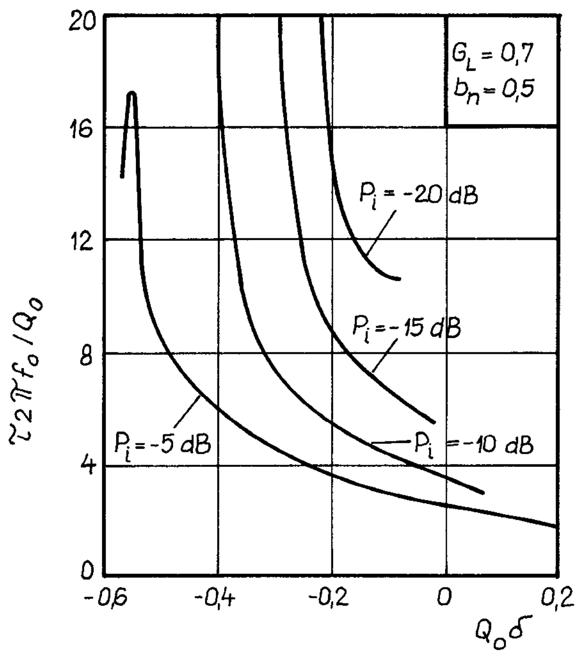

Fig. 2. Group delay time

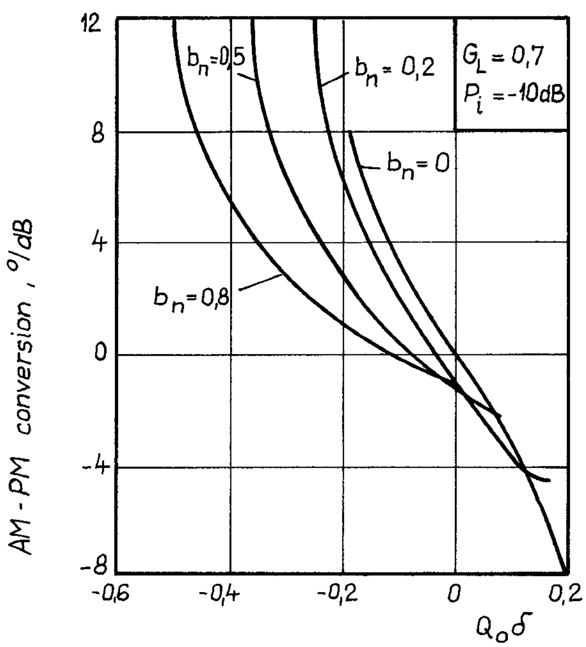

Fig. 3. AM-PM conversion for different susceptance nonlinearities

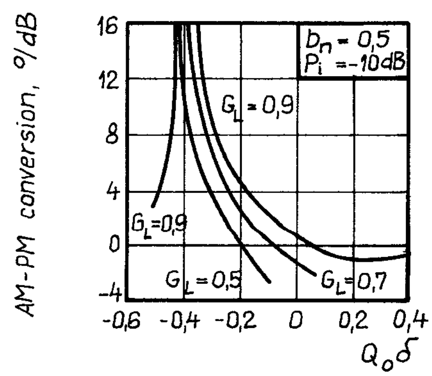

Fig. 4. AM-PM conversion for different loads

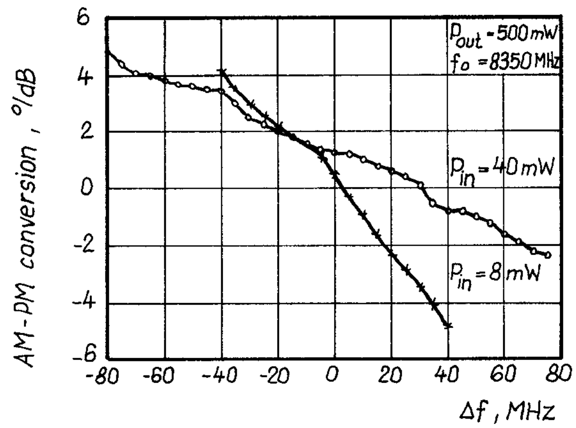

Fig. 5. AM-PM conversion versus carrier frequency

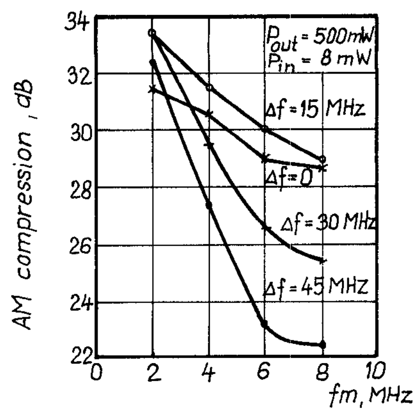

Fig. 6. AM compression versus modulation frequency

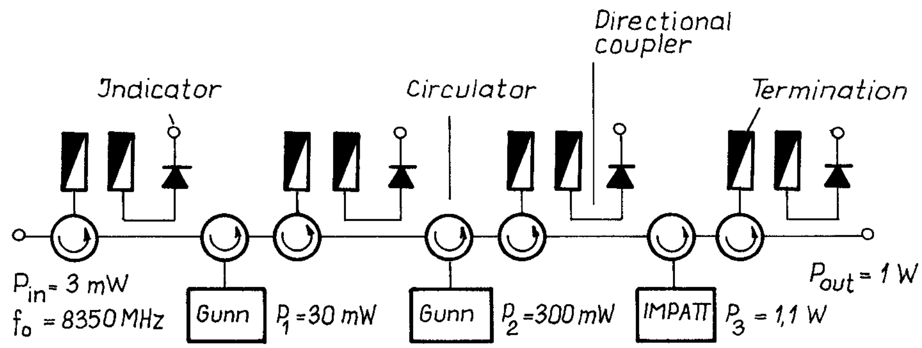

Fig. 7. Oscillator chain

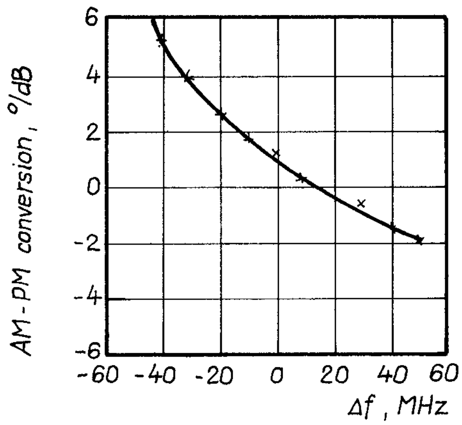

Fig. 8. AM-PM conversion of oscillator chain

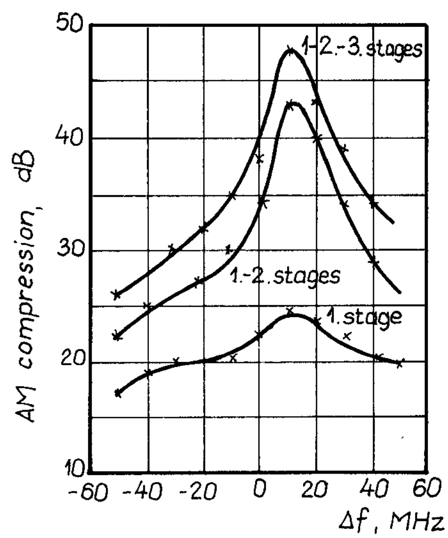

Fig. 9. AM compression of oscillator chain