IMPROVED INJECTION LOCKING OF MICROWAVE FM-OSCILLATORS

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Abstract

A system for injection locking by angle-modulated signals is presented in which both the locked oscillator and the locking source is angle-modulated by the same signal. This method provides increased locking gain and improved stability against oscillator drift with preserved signal performance. Intermodulation measurements on a low-Q Gunn-oscillator,angle-modulated by a weakly coupled varactor (0.5 dB loss) demonstrated the expected effects.

Introduction

Microwave solid-state active circuits are being introduced at present into various communications systems. As a RF-power generator in angle-modulated transmitters the circuit must fullfill the actual requirements concerning modulation quality, short- and long-term stability and efficiency.

First, the varactor-modulated, free-running oscillator was examined. Analysis and experiment showed, that this type of transmitter has very limited performance. Then the proposed injection-locked oscillator is discussed and compared to the usual locked amplifier. The principle is shown in Fig. 1, where the high-quality locking source (f_s, P_s) and the locked low-Q oscillator (f_o, P_o) are angle-modulated by the same modulating signal (video). Thereby the instantaneous frequency difference is greatly reduced and the locking performance improved. The locked source modulator (varactor) is weakly coupled and causes only small losses. The distorsion of this modulator and the angle-modulation noise of the locked low-Q oscillator are suppressed by the locking signal depending upon the relative locking level.

Varactor modulated free running oscillator

It is convenient to describe the frequency-modulation characteristic by means of the slope (S) of the $f(V_m)$ function. The nonlinearity is then defined as $(S_{max} - S_{min})/S_o$, where S_o refers to the bias point. Detailed calculations show[x], that this nonlinearity function is monotonously increasing with the following parameters:

- $\Delta f/f_o$: the relative frequency deviation,
- $1/n$: the reciprocal of the varactor-exponent
- C_{tot}/C_{vt}: the ratio between the total cavity capacitance and the transformed varactor capacitance.

The mean problem arises due to the low Q-values of commercial varactors, usually Q_v=20-40 in X-band. For low C_{tot}/C_{vt} ratios both the efficiency and the resulting Q drop drastically. Relating efficiency to output powers with, and without varactor, one gets approximately $\eta=Q_{rv}/Q_v$, where Q_{rv} is the resulting Q, and Q_r is the loaded cavity-Q without varactor-losses. With f_o=9,6GHz, Δf=4MHz, nonlin=0,01 (1%), and n=.5 we get C_{tot}/C_{vt}=2,51. With Q_r=100 and Q_v=30 we get η=0,43 and a resulting Q-value Q_{rv}=43. For the same case, but nonlin=0,15 we have calculated C_{tot}/C_{vt}=31, η=0,90 and Q_{rv}=90,3.

The low Q-values imply for present solid-state oscillators poor short-term and long-term stability. These calculations and the experiments show, that this type of FM-source has very limited field of application.

[x]To be published

Injection locked oscillator

For this case we start with an angle-modulated signal of the required quality which is to be amplified. Choosing an injection-locked oscillator as a "Locked Amplifier" the locking gain is substantially limited by group delay time and nonlinear effects.[1 2] These effects are increasing by increasing frequency deviation between the locking source and the free-running frequency of the locked source.

In the proposed system, described in the introduction and shown in Fig. 1 this deviation is considerably decreased. In a first approximation we assume that the angle modulation on both sources is performed with the same sign and deviation, and that thereby no locking transients exist. Analysis by a small perturbation of the frequencies f_s and f_o shows that the same suppression factor for the perturbating deviation is valid as in the stationary case.[3 4]

$$\text{Suppression factor} = \frac{1}{1+\left[\dfrac{(B_L/2)^2 - \Delta f_o^2}{f_m^2}\right]^{1/2}} \text{, where} \qquad (1)$$

B_L is the CW locking bandwidth, f_m the perturbating frequency and $\Delta f_o = f_s - f_o$.

The suppression of the FM intermodulation products caused by the varactor modulator have been calculated and plotted in Figs 4 to 6. Presumably, the same approximation is valid for the FM-noise components of the locked oscillator. This model makes no allowance for nonlinear dynamic effects. At this time no analytic theory is available for such cases.

Experimental model and the measuring system

In the experiment we used a simple low-Q cavity-oscillator tunable by a noncontacting cylindrical short. This Gunn-oscillator was modulated by a varactor-diode mounted in the centre of the short, and thus making a continously variable varactor-to cavity coupling possible. The reduction in output power was about 0.5 dB in our measurements. (See fig. 2.)

Intermodulation was measured by the two-tone method, and we studied the first intermodulating products, that is $(f_{m2}-f_{m1})$ and $(f_{m2}+f_{m1})$. The modulating signals were 300 kHz and 400 kHz resp. and the deviation was chosen to be 720 kHz.

The oscillator was locked by a microwave generator with low intermodulation and it was possible to frequency-modulate the generator and/or the oscillator. The deviation of the locking-source was kept constant, while it was possible to vary the varactor deviation whitin several megahertz. With constant output power (P_o), the locking power (P_s) was varied and measured with a stabile power meter whose output was fed to a

X-Y-recorder.

Frequency difference between the locking source and the oscillator (Δf_o) was accomplished by varying the oscillator short while the output-spectrum was studied on a spectrum analyzer.

The output signal from the oscillator was detected in a high quality microwave FM-receiver and the resulting video spectrum was shown on a display with 100 dB dynamic range and also recorded on the X-Y-recorder. The presented curves (fig. 4 to 6) consequently show the intermodulating products for various cases as a function of the locking power. In order to get a stabile and reliable measuring setup 4 isolators were used.

By setting the variable attenuator to maximum the oscillator could be studied as a free-running FM-source.

The total residual intermodulation of the measuring system was kept below -70 dB, and the measurements were repeatable within $\pm$ 1 dB.

Results and discussion

Some important data for the measurement setup (Fig. 3) and for the plotted curves (Figs 4-6) are collected in Table 1.

Now we summarize the experimental results and compare them with our assumptions. (In Fig. 5 and in several other measurements we have noticed sharp distortion minima at low levels for the de-tuned cases ($\Delta f \neq 0$). This was probably due to compensating effects of different phase characteristics in the system.)

The relative locking level is increased about 8-10dB for the same distortion compared with P_o/P_1=13-15 dB, the typical gain in previously published locked amplifiers for FM systems (Fig. 6).

It is seem from Figs 4-6 that stabile locking exists down to and below 30 dB relative locking level with excellent distortion characteristics even under de-tuned conditions ($\pm$ 1 MHz).

According to the assumptions concerning noise suppression in our locked oscillator, the resulting intermodulation from the varactor has been calculated using equ.(1) and compared with the measurements. The ⊖-marked points in Figs 4-6 are theoretical values and refer to the case when both sources are modulated and Δf_o=0. These points show good agreement with the experimental values for P_o/P_1<30 dB.

An optimum value for the deviation of the locked oscillator with respect to intermodulation has been observed. This deviation is not necessarily the same as the source deviation, but it is depending upon signal characteristics and circuit parameters (Fig. 6).

Further theoretical investigations are being conducted concerning nonlinear effects and optimization parameters.

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Table I

Video-mod:
Frequencies: f_{m1} = 300 kHz, f_{m2} = 400 kHz
Peak deviation: Δf = 720 kHz
Measured products: $f_{m2}-f_{m1}$ = 100 kHz, $f_{m2}+f_{m1}$ = 700 kHz

Locked oscillator: f_o = 9,66 GHz, P_o = 15 mW
Varactor loss: = 0,5 dB

Figures 4 and 5: Q_{ex} = 140, V_d = -7,3 V

Figure 6: Varactor coupling changed
Intermodulation: "0"-level = -31 dB, "S"-level = -65 dB

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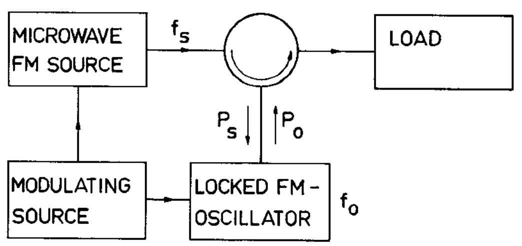

FIG. I THE PRINCIPLE OF THE LOCKED SYSTEM

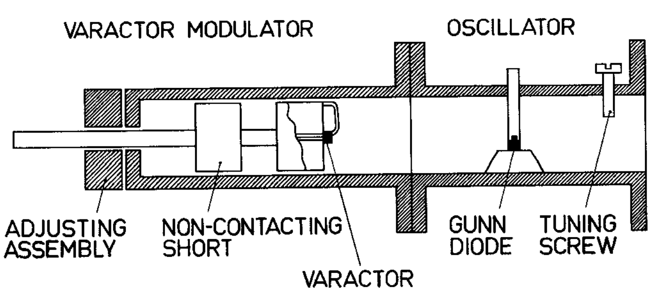

FIG. 2 THE FREQUENCY-MODULATED GUNN OSCILLATOR

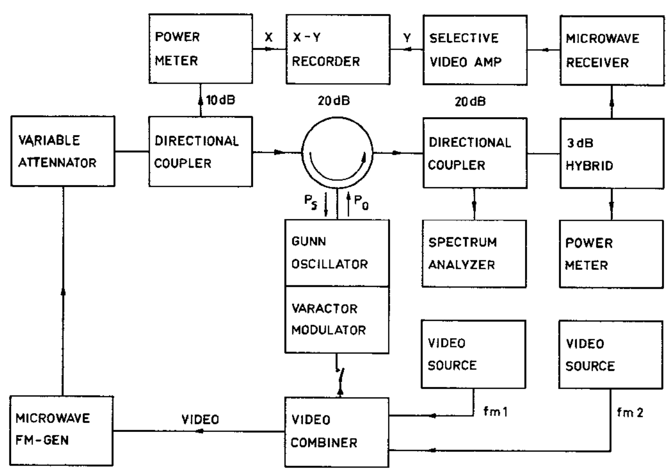

FIG. 3 THE MEASURING SETUP

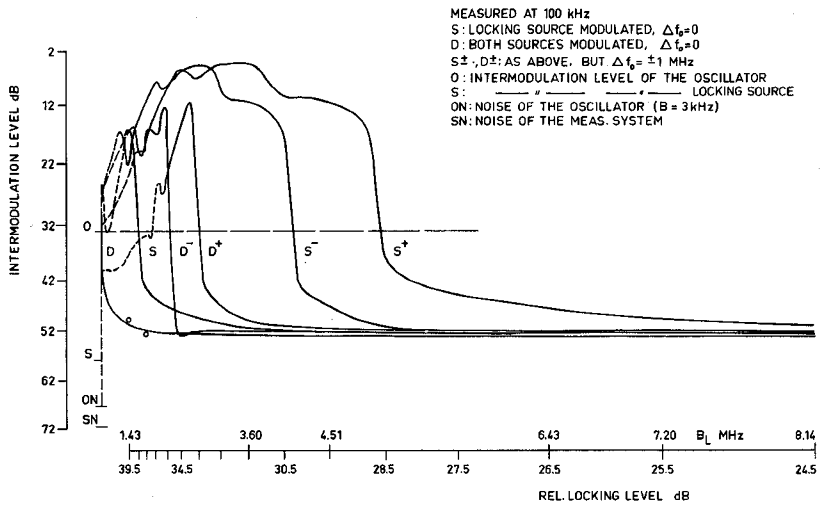

FIG. 4 MEASURED INTERMODULATION LEVEL AT 100 KHZ AS A FUNCTION OF THE LOCKING LEVEL

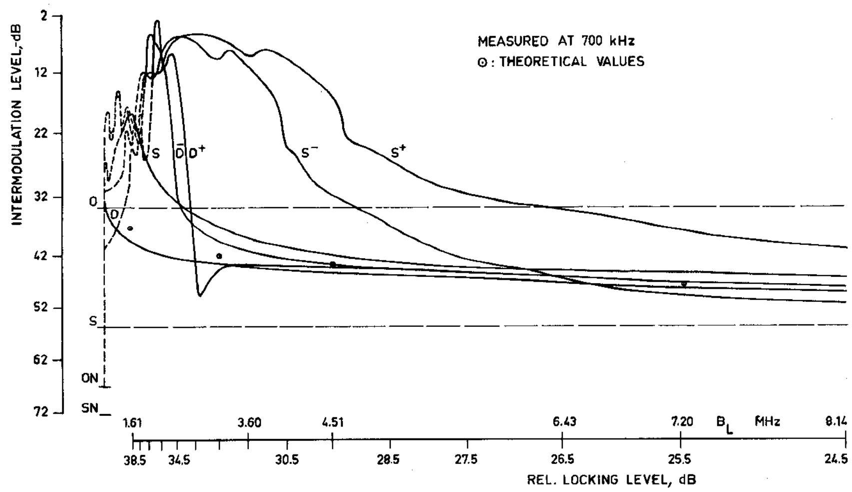

FIG. 5 MEASURED INTERMODULATION LEVEL AT 700 KHZ AS A FUNCTION OF THE LOCKING LEVEL

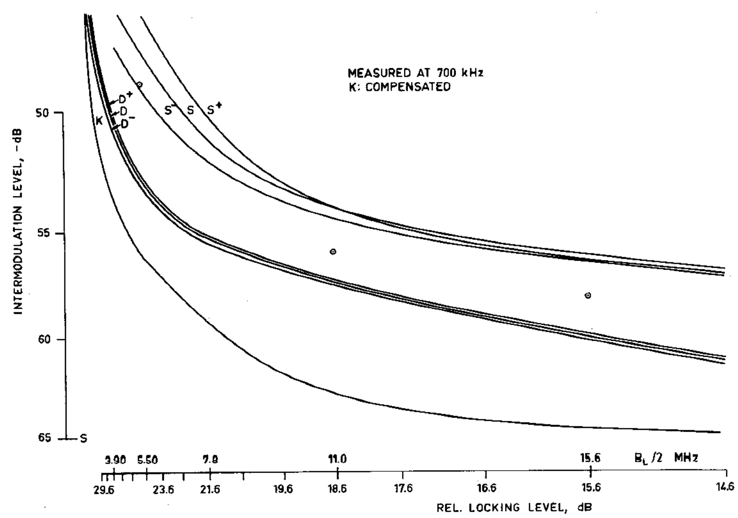

FIG. 6 THE SAME AS IN FIG. 5, BUT WITH CHANGED VARACTOR COUPLING