FM NOISE OF TRANSMISSION-TYPE INJECTION-LOCKED GaAsFET OSCILLATORS AND AMPLIFIERS

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Abstract

FM noise performance of transmission-type injection locking was investigated using GaAsFET oscillators. Lower off-carrier FM noise for transmission-type than for reflection-type was observed when the injection power was kept equal for both types.

Introduction

In our previous paper(1), the transmission-type injection locking technique was introduced in which an oscillator equipped with two output ports with a large directivity between them was used and obtained high gain within a locking frequency range which was wider than that of conventional reflection-types. In order to apply transmission-type injection to FM amplifying systems, FM noise performance of the locked oscillator is an important factor to consider in the design of a system. Investigation of FM noise for transmission-type injection was carried out in comparison with reflection-type using GaAsFET oscillators. Lower off-carrier FM noise was observed for transmission-type than reflection-type when the injection power was kept equal for the both types.

Transmission-type Injection Locking

Injection locking experiments were performed using GaAsFETs with 1 μm gate length and 300 μm gate width. GaAsFETs were used rather than bipolar transistors because of their higher maximum stable gain at microwave frequencies. A GaAsFET chip was mounted on a chip carrier and placed between two alumina substrates (Fig. 1). Gate and drain electrodes were connected by lead wires to microstrip lines on the alumina substrates, while source contacts were bonded to the chip carrier. Between the two striplines, a feed back circuit was fabricated using a microchip capacitor (1.5 pF) and a 25 μm$^\phi$ gold wire.

The gate port, port 1, was terminated by a 50 ohm load. A matching circuit at the drain was designed to transform the optimum device admittance for oscillation to another 50 ohm load. Thus a two-port oscillator was constructed at 8.1 GHz with an output power of 4.5 mW at port 1, P_{01}, and 18.3 mW at port 2, P_{02}, respectively. The temperature coefficient of the oscillation frequency was about 1.4 MHz/°C.

Both transmission- and reflection-type injection locking experiments were performed by injecting signals, P_i, into gate and drain ports respectively. The relation between locking gain (P_{02}/P_i) and locking range is shown in Fig. 2. Wider locking range was obtained with transmission-type than reflection-type by a factor of 1.5. The equivalent external Q for injection at ports 1 and 2, Q_{ext1} and Q_{ext2}, was found to be 10.5 and 15.3 respectively.

FM Noise Measurement

When injection locking is applied to the amplification of FM signals, the signal-to-noise ratio of the output signal becomes one of the important factors determining the required input signal level, and thus the maximum locking gain of injection. Here, FM noise characteristics of transmission-type injection locked oscillators used as FM amplifiers are investigated and compared with reflection-type.

Fig. 3 shows the block diagram of a noise measuring system. An output signal of a UHF low-noise synthesizer, up-converted by a mixer with a local oscillator, was used as an injection source. A Gunn oscillator was used as the local oscillator with its oscillating frequency stabilized by a high Q resonator at 7.6 GHz with root mean square FM noise deviation (Δfrms) of less than 0.15 Hz/$\sqrt{\text{Hz}}$. The up-converted signal was injected into the gate port (port 1) of the two-port FET oscillator being tested when the injection was transmission-type and into the drain port (port 2) when it was reflection-type. Synchronized output from the drain port was down-converted by another mixer using half of the power from the same local oscillator used with the first mixer. Injection signal power was monitored by a spectrum analyzer (SA). The down-converted signal was frequency demodulated by a UHF high-sensitivity FM linear detector (FLD), and the demodulated signal level was measured by a wave analyzer. Baseband frequency range of the FM linear detector was 0 to 200 KHz and residual FM noise was less than 0.02 Hz/$\sqrt{\text{Hz}}$. The wave analyzer was calibrated by measuring the voltage amplitude of the frequency demodulated FM signal, having peak frequency deviation of 1 KHz.

FM noise of the GaAsFET oscillator at free running operation is shown in Fig. 4. Off-carrier frequency range in this experiment falls in the 1/f noise and generation-recombination noise region of GaAsFETs; the value of the noise depends mainly on the material and fabrication process of GaAsFETs. The measured value is essentially the same as results reported(2),(3) for GaAsFET oscillators, taking into account the difference in external Q's.

FM noise of the synchronized output is compared for transmission-types and reflection-types in Fig. 5. The bottom solid line (x) shows the FM noise level for the UHF synthesizer.

When the injection signal level is small and the locking gain is high, the FM noise of synchronized output degrades from that of the injected signal.(5) This degradation was studied by Kurokawa(4) for conventional reflection-type injection and was described as a function of locking range when the oscillator and injection sources were set. In our experiment, the degradation of FM noise of transmission-types and reflection-types was compared, Fig. 5. It is clear from the figure that the degradation of FM noise is less for the transmission-type, when the injection power is the same for the both types or even smaller, 2-3 dB lower, for the transmission-type.

Discussion

A two-port oscillator can be described by a noise-free oscillation circuit, Y, with an equivalent noise current source at each port, i_{n1} and i_{n2}, and each port connected to a load conductance Y_S and Y_L, respectively, as shown in Fig. 6(a). With respect to the output power at each port, the circuit is equivalent to a one-port oscillator which is expressed by a parallel circuit of an admittance and an equivalent noise source, Y_T and $n_1(t)$, or Y_U and $n_2(t)$, according to the port concerned, as is shown in Fig. 6(a) and (c). Y_T and Y_U are functions of (ω,A) and (ω,B), respectively, where A and B are voltage amplitudes at port 1 and port 2. Injection signal source, i_{s1} is connected to port 1, when the circuit is for transmission-type injection, and injection source, i_{s2}, to port 2 for reflection-type. Here, signal sources i_{s1} and i_{s2} have phase fluctuation of ψ.

Assuming that Y_{TA} ($= G_{TA}+jB_{TA}$) is perpendicular to $Y_{T\omega}$ ($= G_{T\omega}+jB_{T\omega}$), so that Y_{UB} ($= G_{UB}+jB_{UB}$) is to $Y_{U\omega}$ ($= G_{U\omega}+jB_{U\omega}$), on the admittance plane, $G_{T\omega}$, B_{TA}, $G_{U\omega}$ and B_{UB} can be made equal to zero, choosing proper reference planes at port 1 and 2. Here, suffixes, A, B and ω represent partial derivatives of Y_T and Y_U at the free-running operation point ($\omega=\omega_0$, $A=A_0$, $B=B_0$). On the basis of this assumption and the quasi-static approximation method,(6) Δf_{rms1} and Δf_{rms2}, FM noise of transmission-type injection and reflection-type injection locked oscillators (Fig. 6(b) and (c)), respectively, can be derived as

$$\Delta f_{rms1} = fm\sqrt{2\frac{\overline{|\psi|^2}\cos^2\phi_{01}+\left(\frac{f_0}{Q_{e1}\Delta f_{L1}}\right)^2 N_1(fm)/P_{01}}{\cos^2\phi_{01}+(fm/\Delta f_{L1})^2}} \quad (1)$$

$$\Delta f_{rms2} = fm\sqrt{2\frac{\overline{|\psi|^2}\cos^2\phi_{02}+\left(\frac{f_0}{Q_{e2}\Delta f_{L2}}\right)^2 N_2(fm)/P_{02}}{\cos^2\phi_{02}+(fm/\Delta f_{L2})^2}} \quad (2)$$

here,

f_0: free-running oscillation frequency

P_{01}, P_{02}: free-running output power at port 1 and 2, respectively

Q_{e1}, Q_{e2}: $Q_{e1}=\frac{\omega_0 B_{T\omega}}{2Y_S}=\sqrt{\frac{P_{02}}{P_{01}}}Q_{ext1}$, $Q_{e2}=\frac{\omega_0 B_{U\omega}}{2Y_L}=Q_{ext2}$

$2\Delta f_{L1}, 2\Delta f_{L2}$: locking range of the transmission and reflection type injection, respectively

ϕ_{01}, ϕ_{02}: phase difference between the injection signal and synchronized output

$N_1(fm), N_2(fm)$: power spectral density of $n_1(t)$ and $n_2(t)$, respectively

$\overline{|\psi|^2}$: power spectral density of injection signal phase fluctuation

Under the free-running operation ($\Delta f_L=0, \overline{|\psi|^2}=0$), FM noise, Δf_{rms1}, of the output signal at port 1 is identical to FM noise, Δf_{rms2}, at port 2;

$$\frac{N_1(fm)}{Q_{e1}^2 P_{01}} = \frac{N_2(fm)}{Q_{e2}^2 P_{02}} \quad (3)$$

From eq. (1), (2) and (3), it can be derived that Δf_{rms1} and Δf_{rms2} are equal when Δf_{L1} and Δf_{L2} are the same. In other words, lower FM noise will be obtained with transmission-type than with reflection-type even when the locking gain (P_{02}/P_i) is higher with transmission-type by a factor as much as $(Q_{ex2}/Q_{ext1})^2$ or $(Q_{e2}/Q_{e1})^2 P_{02}/P_{01}$.

FM noise of synchronized output in the case of (c) and (d) in Fig. 5, calculated from the FM noise at the free-running operation (Fig. 4), nearly coincides with the experimental data (Fig. 5).

Therefore, experimental results shown in Fig. 5 support the above discussion, taking measurement error into consideration.

Conclusion

FM noise for transmission-type injection was studied in comparison with reflection-type. Lower off-carrier FM noise was observed for transmission-types than for reflection-types when the injection power is the same for the both types or even 2-3 dB smaller for the transmission type. This superiority in suppression of FM noise could be attributed to the directivity between the two ports of the oscillator.

The overall features of transmission-type injection locking were found to be advantageous for FM signal amplification.

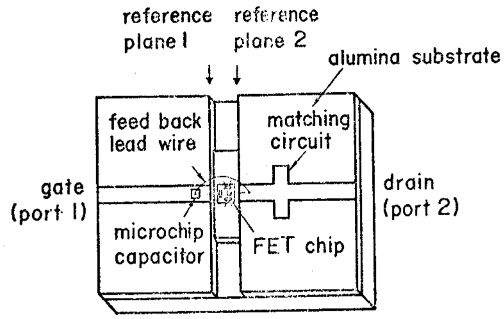

Fig.1 Two port oscillator using a common source GaAsFET

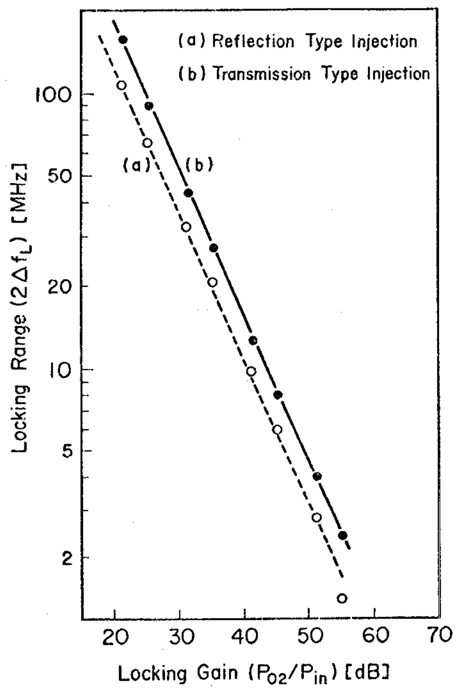

Fig.2 Locking characteristics of a two port oscillator. Signal is injected at (a) drain port and (b) gate port.

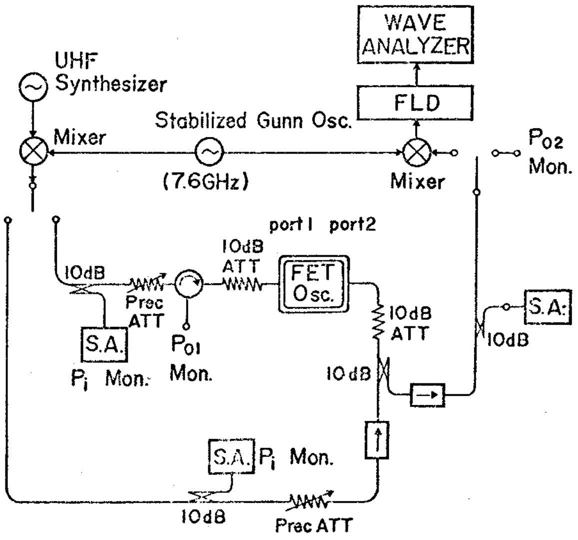

Fig.3 Block diagram of FM noise measurement circuit.

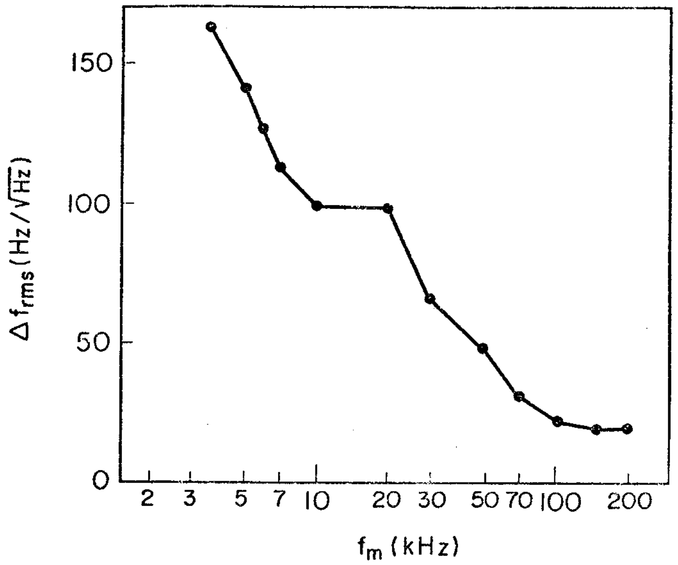

Fig.4 Off carrier FM noise spectrum at the free-running operation

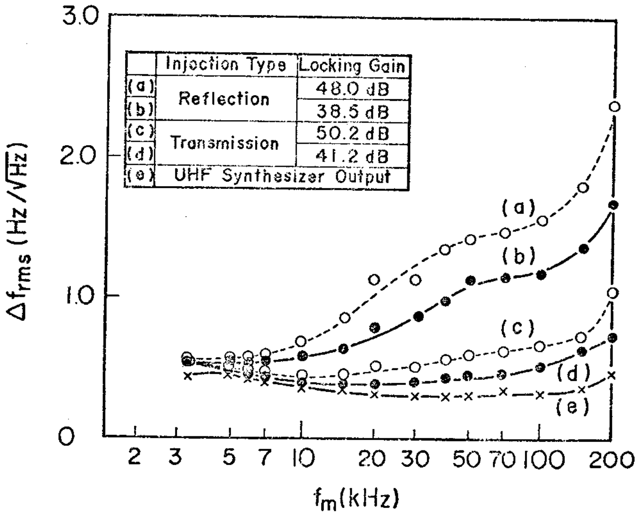

Fig.5 Comparison of FM noise suppression between transmission-type and reflection-type

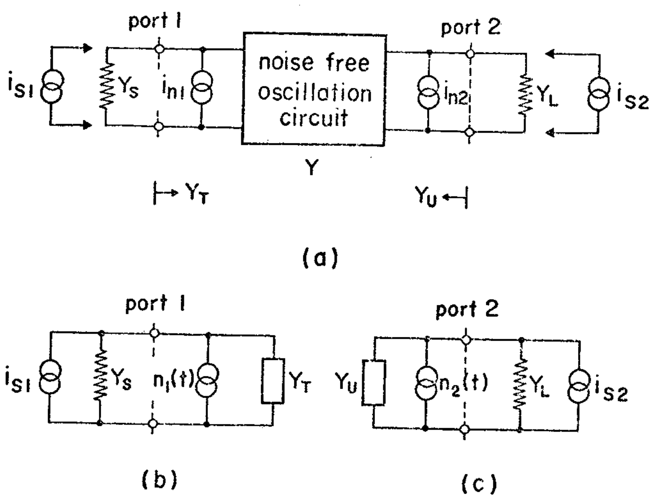

Fig.6 Circuit model for noise analysis of injection locked oscillators.

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