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Reduced Phase Noise of a Varactor Tunable Oscillator: Numerical Calculations and Experimental Results

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Abstract – Single sideband phase noise of a varactor tunable oscillator is much lower in case of using a resonator with coupled microstrip lines instead of a single microstrip line. Calculated and measured phase noise agree within the accuracy of measurements. The very low phase noise of –95 dBc/Hz at 100 kHz offset frequency has been achieved.

1. Introduction

Single sideband phase noise of planar GaAs–MESFET–oscillators with oscillation frequencies in the range of 10 GHz to 20 GHz amounts to –52 dBc/Hz to about –83 dBc/Hz at an offset frequency of 100 kHz [1]. We calculated and measured the single sideband phase noise of two types of planar integrated varactor tunable oscillators with different resonator circuits at the gate terminal. Very low phase noise of –95 dBc/Hz is obtained by an oscillator with coupled microstrip line resonator compared to a single microstrip line resonator. The phase noise calculation was done using a nonlinear method in the time domain [2].

2. Oscillator Design

The voltage controlled oscillators have been designed for maximum tuning bandwidth. In case of an oscillator circuit in common source configuration, it is obtained with the varactor at the gate circuit [3]. The frequency determining network at the gate of the GaAs–MESFET must form a series resonant circuit in order to obtain oscillation. The oscillator circuit with capacitive feedback at the source terminal together with two different tunable resonator circuits is shown in figure 1. One of the oscillators (called AM5) is designed with a coupled microstrip line together with the varactor as tunable resonator. In case of the other oscillator (called AM6), the varactor is coupled to the GaAs–MESFET using a single microstrip line. Coupled microstrip lines instead of a single microstrip line have the advantage of higher phase slope of the input impedance. It involves a planar thin film structure instead of a discrete Beam Lead capacitance for separation of varactor– and gate voltage of the GaAs–MESFET. In figure 2, the quality factor of both resonator circuits in dependence on the varactor voltage is depicted.

The quality factor of the resonator circuit with coupled microstrip lines is by a factor of 2 higher than the quality factor of the single microstrip line resonator.

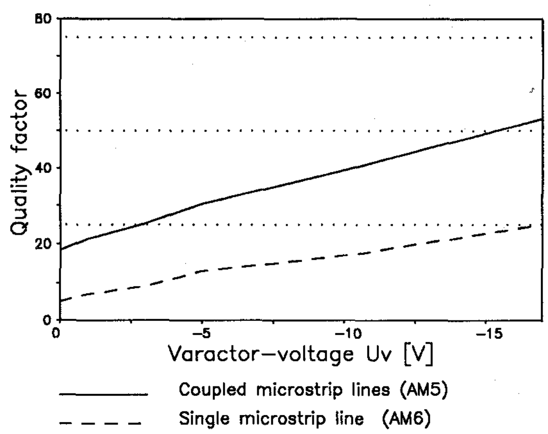
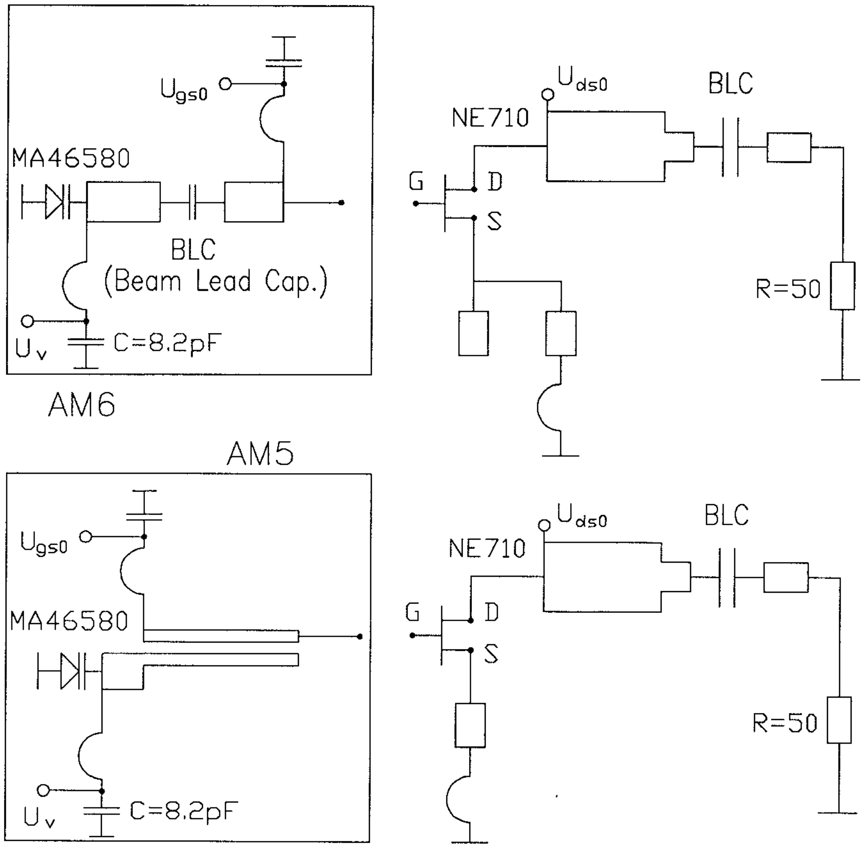


Fig. 2: The quality factors of the series resonance circuits at the gate terminal of both oscillators

Both oscillators were fabricated in hybrid thin film technology on semi–insulating GaAs–substrate, whereby the microstrip lines are connected directly to the transistor pads without using bondwires [4].

3. Signal calculation

Tuning characteristics and output power were computed with the FATE–method [5]. The varactor–diode was modeled according to [6], for the GaAs–MESFET a modified SPICE–model was used [7,8]. Fig. 3 shows the tuning characteristic and fig. 4 the output power of both oscillators. With the oscillator with coupled microstrip line resonator, a tuning bandwidth of nearly 3 GHz is achieved, while the tuning bandwidth with the single microstrip line resonator amounts to 4.6 GHz. The output power of the oscillators, measured with a HP71000 spectrum analyser, is between 5 dBm and 14 dBm. Up to 5 dB higher output power is achieved by the oscillator with coupled microstrip lines.



Gate circuit

Fig. 1: The oscillator circuit with two different tunable resonator circuits at the gate terminal of the GaAs–MESFET

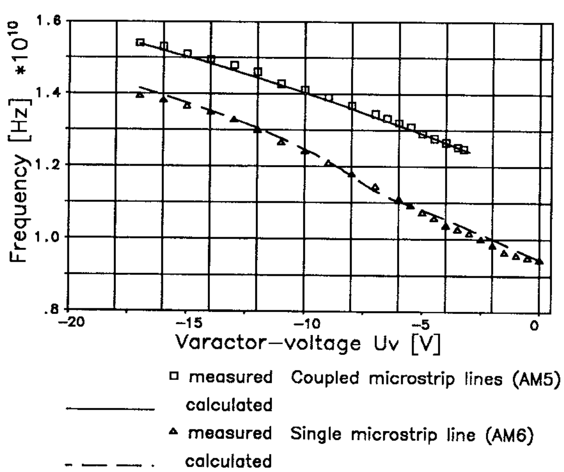


Fig. 3: The tuning characteristic of both oscillators

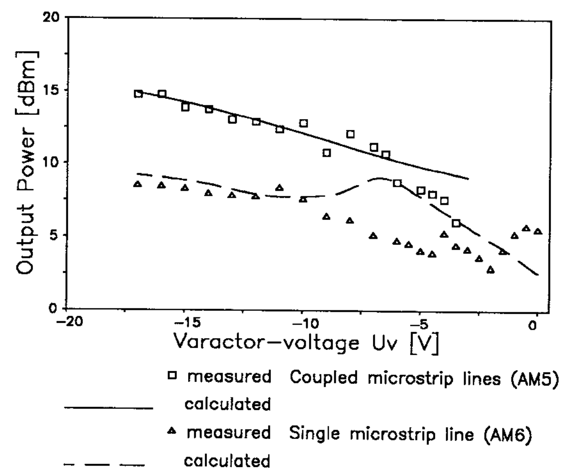


Fig. 4: Calculated and measured output power of both oscillators

4. Phase noise calculation

The determination of the single sideband phase noise of the oscillators was done, using the method of F. X. Kärtner [2]. The oscillator circuit is described by a lumped element model together with white– and $1/f^{\alpha}$ – noise sources. The normal form equations of the circuit are given by

$$\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}) + \mathbf{G}(\mathbf{x})\xi + \sum_{m} \mathbf{g}^{m}(\mathbf{x}) y_m \qquad (1)$$

The components of the vector $\mathbf{x}$ are the state variables of the system. The vector ξ describes white noise sources and y_m represent $1/f^{\alpha}$ – noise sources. The matrix $\mathbf{G}(\mathbf{x})$ is given by

$$G_{ij} = \left. \frac{\partial f_{ik}(\mathbf{x},\xi,y_1,..,y_m)}{\partial \xi_j} \right|_{\substack{\xi = 0 \\ y_1 = . = y_m = 0}} \qquad (2)$$

and the vector $\mathbf{g}^{m}(\mathbf{x})$ by

$$g_i^{m} = \left. \frac{\partial f_i(\mathbf{x},\xi,y_1,..,y_m)}{\partial y_m} \right|_{\substack{\xi = 0 \\ y_1 = .. = y_m = 0}} \qquad (3)$$

The noise sources are assumed to be Gaussian and the statistics of the white noise sources ξ is completely descibed by the correlation functions

$$<\xi_i(t)\xi_j(t')> = \Gamma_{ij}\delta(t-t') \qquad (4)$$

with mean values

$$<\xi_i(t)> = 0 \qquad (5)$$

where $\Gamma \in \mathbb{R}^{KxK}$ is the correlation matrix of a K–dimensional stationary white noise process.

The $1/f^{\alpha}$ – noise sources are characterized by the autocorrelation spektrum

$$C_{yy}^{m} = \frac{c_m(U_{gs0},U_{ds0})}{|2\pi f_m/10\,kHz|^{\alpha_m}} \qquad (6)$$

whereby $c_m(U_{gs0},U_{ds0})$ is a function of the spectral density of the low frequency noise of the transistor at 10 kHz. The low frequency noise of the GaAs–MESFET was measured at several voltages using a signal analysator HP3561A up to a frequency of 100 kHz and a spectrum analyzer HP71000 up to a frequency of 10 MHz. Its voltage dependent behaviour is modeled by a noise voltage source at the gate terminal of the transistor.

The single sideband phase noise $L(f_m)$ [dBc/Hz] is given by

$$L(f_m) = \frac{\Delta f_{3dB}}{\pi f_m^{\,2}} + \frac{c \cdot \omega_0^{2} \cdot |g_{10}|^{2}}{(2\pi f_m)^{2+\alpha_m}} \qquad (7)$$

Δf_{3dB} denotes the 3 dB bandwidth of a Lorentzian line, produced by the Brownian motion of the phase. The mixing and upconversion of noise due to the non–linearities of the oscillator circuit, which enter into the formula for the phase noise (7) via the coefficient $|g_{10}|^{2}$, is taken into account. The feedback of the oscillation onto the noise sources, which results in multiplicative noise described by $\mathbf{G}(\mathbf{x})$ and $\mathbf{g}(\mathbf{x})$ in equation (1), is considered.

5. Results

The single sideband phase noise of the oscillators is shown in Fig. 5 and 6, measured on a HP3048 system using the frequency discriminator method.

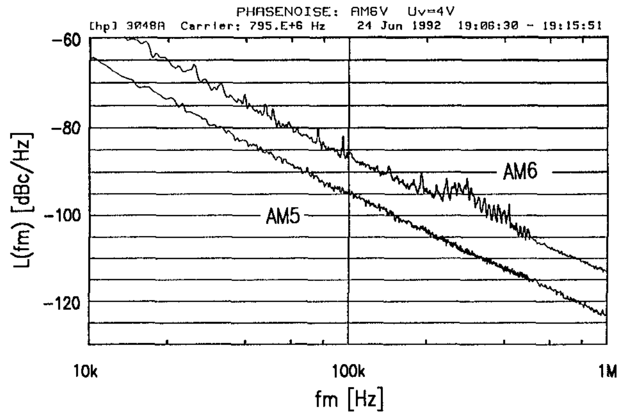


Fig. 5: Single sideband phase noise of both oscillators at a varactor voltage of –4 V

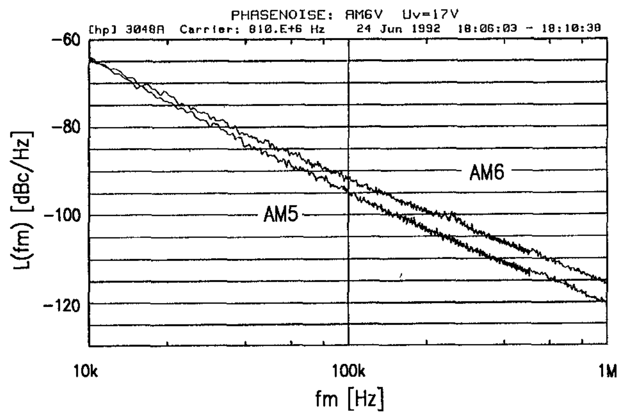


Fig. 6: Single sideband phase noise of both oscillators at a varactor voltage of –17 V

At a varactor voltage of –4 V the single sideband phase noise of the coupled microstrip line oscillator AM5 is about 8 dB lower than the phase noise of the oscillator with single microstrip line. The difference appears over the whole frequency range, where low frequency noise and white noise determine the phase noise. At a varactor voltage of –17 V different phase noise occurs mainly in the range, where white noise sources predominate. The single sideband phase noise of the oscillator AM5 is about –95 dBc/Hz at a varactor voltage of –4 V likewise –17 V. In contrast to this, single sideband phase noise of the oscillator AM6 changes by variation of the tuning voltage.

In the figures 7 and 8 calculated and measured phase noise of the oscillator with single microstrip line (AM6) is depicted exemplarily.

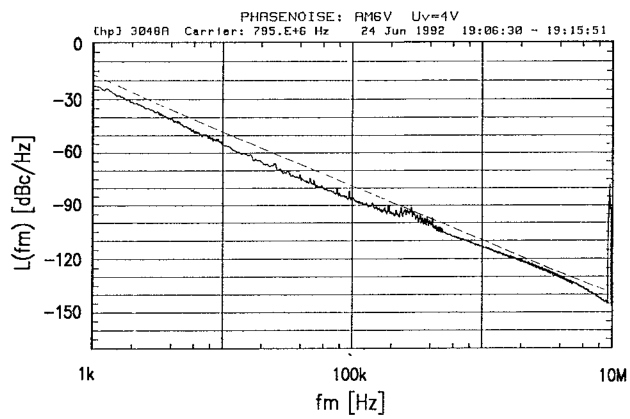


Fig. 7: Calculated (– – –) and measured single sideband phase noise of the single microstrip line oscillator AM6 at a varactor voltage of –4 V

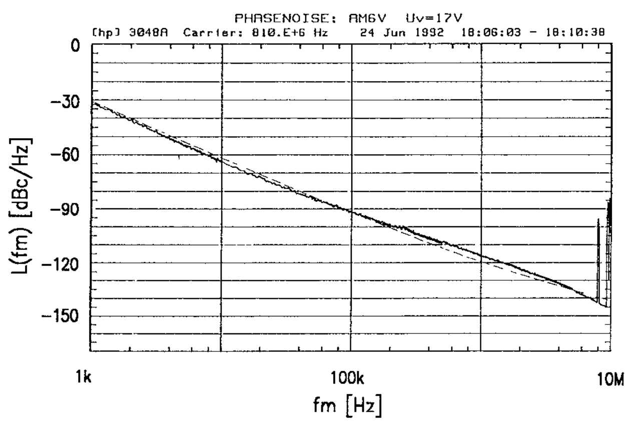


Fig. 8: Calculated (– – –) and measured single sideband phase noise of the single microstrip line oscillator AM6 at a varactor voltage of –17 V

Phase noise data agree within the accuracy of measurements. Deviation at offset frequencies above 3 MHz is due to the length of the delay line and the related measurement sensitivity. Calculated and measured phase noise of the oscillator with coupled microstrip lines agree within the same range.

6. Conclusion

Signal and phase noise properties of two planar integrated tunable GaAs–MESFET–oscillators with different resonator circuits at the gate terminal of the transistor are investigated, using nonlinear calculation methods. The phase noise is calculated in the time domain by pertubation methods [2]. The single sideband phase noise of a varactor tunable microwave oscillator is reduced significantly to a value of –95 dBc/Hz, using a coupled microstrip line at the gate terminal of the transistor for determining the oscillation frequency. Measured output power of the oscillator is about 12 dBm. In spite of the higher quality factor of this resonator circuit compared to a single microstrip line, a tuning bandwidth of more than 20% is achieved.

7. References:

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