MEASUREMENT OF THE CROSS CORRELATION BETWEEN BASEBAND AND TRANSPOSED FLICKER NOISES IN A GaAs MESFET.

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ABSTRACT

When an R.F. carrier is amplified by a GaAs MESFET, amplitude modulation (A.M.) and phase modulation (P.M.) noises are imposed on the carrier. This is generally believed to be caused by transposition to the carrier frequency of the low frequency flicker noise generated by the FET.

The cross correlation between the A.M. and P.M. noises and the low frequency (L.F.) noise observed on the drain of the FET is measured.

While the A.M. noise and the low frequency noise on the drain of the FET exhibit a high degree of correlation, the P.M. noise and the low frequency drain noise are not highly correlated. The latter result may explain the limited success of oscillator phase noise reduction methods which rely on the existence of a large cross correlation between the P.M. and low frequency noises.

INTRODUCTION

Most theories developed to explain the $1/\delta f^3$ ($\delta f = f - f_{CARRIER}$) characteristic of close to carrier noise in GaAs MESFET oscillators suggest it is due to low frequency $f^{-\varepsilon} \cong 1/f$ noise. This noise is said to be generated by generation-recombination centers in the active and depletion regions of the FET, and by quantum noise in the conducting channel (1), (2), (3), (4), (5). The low frequency noise is modulated onto the carrier (transposed) by non-linearities in the FET (6), giving mainly P.M. sidebands with a $1/\delta f$ spectrum. This spectrum is multiplied by the $1/\delta f^2$ oscillator loop frequency response, giving the observed $1/\delta f^3$ characteristic (7).

In order to test this theory, the cross correlation between the drain low frequency noise and the A.M. and P.M. noises is measured for a medium power GaAs MESFET amplifier. Measurements are made on an amplifier rather than an oscillator; this allows for accurate setting of the R.F. and bias levels, and eliminates the need to deconvolve the noise characteristic from the frequency response of the oscillator loop.

EXPERIMENTAL SYSTEM

The amplifier is an untuned, resistively loaded Avantek AT8140 GaAs MESFET, biassed at 8V, 300mA. It is operated at 4dB gain compression, which is typical for a FET used as the amplifying element of an oscillator.

A.M. and P.M. noise levels are measured separately using the phase bridge method (8). A 639 MHz signal from a high purity source is fed to the GaAs FET amplifier under test. The signal from the amplifier is mixed with a sample of the original 639MHz signal, demodulating the A.M. noise (both inputs to the mixer in phase) or P.M. noise (inputs to the mixer in quadrature).

The drain L.F. noise is measured directly from the drain of the FET, using a 50Ω resistor as the low frequency drain load (fig. 1).

After amplification and filtering, the drain L.F. noise and the demodulated A.M. or P.M. noise signals are sampled simultaneously, and the two 8192 sample windows are transferred to a computer.

Analogue and digital filtering are used to split the noise spectra into decade frequency bands; this reduces the effect of excessive weighting by the low frequencies on the cross correlation. D.C. offsets and mains hum lines are removed by digital filtering, and the cross correlation function is calculated (see appendix). The measured peak value of the

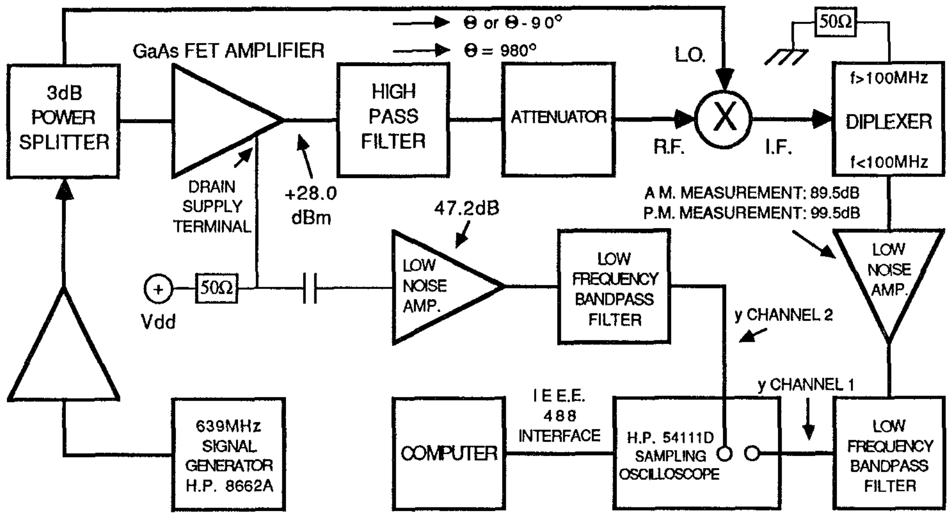

FIG: 1: Measuring system.

function, r_{MEAS}, occurs at ≅ 0 delay.

Noise from the measuring system reduces the measured correlation; r_{MEAS} is multiplied by a correction factor to compensate for this, giving r_{COMP}. This compensated value is effectively the percentage of the total A.M. or P.M. noise, in R.M.S. voltage terms, which is correlated with the drain L.F. noise.

Experimental results.

The spectra of the measured single sideband A.M. and P.M. noise powers, normalised to the carrier power, are shown in figs. 2 and 3 respectively. Figure 4 shows the L.F. drain noise spectrum.

All components of the measuring system (amplifiers, signal source etc.) generate noise. This appears at the outputs of the system, either directly or by conversion between A.M, P.M. and baseband noise by the GaAs FET amplifier and the mixer. The measuring system noise levels shown in figs. 2, 3 and 4 are determined by summing all noise power contributions, whether direct or through conversion, of each measuring system component.

The correlation values r_{MEAS} and r_{COMP} are given in table 1. The listed deviations of r_{COMP} from the calculated values given are for a possible error of up to ±2dB in the noise level measurements.

The A.M. noise correlates well with the L.F. drain noise; this can also be seen qualitatively from the time domain signals (fig. 5).

DISCUSSION

The A.M. noise on the carrier is closely related to the low frequency noise on the drain of the FET. This is likely to be because the A.M. noise is drain L.F. noise modulated onto the carrier, as predicted by the transposition theory (6).

The P.M. noise on the carrier is not highly correlated with the drain low frequency noise. According to Siweris and Schiek (6), the P.M. noise is generated primarily by fluctuations in the non-linear gate to source capacitance C_{GS} with noise in the gate depletion region. This indicates that the drain L.F. noise is not caused solely by charge fluctuations in the gate depletion region, which is in agreement with the observations of Hasiguchi et al. (2); they model the drain L.F. noise by the gate noise referred to the drain, and a separate drain current noise source i_D, which is not correlated with the gate noise sources. In their devices, i_D was the dominant source of low frequency drain noise.

Methods for reducing oscillator phase noise by low frequency noise cancellation, such as low frequency feedback (9) and push-pull techniques (10), (11), rely on the connection between drain L.F. noise and phase noise. Experiments have shown that these methods are not particularly effective, as suggested by the low correlation.

TABLE 1				
FREQUENCY RANGE	L.F. DRAIN NOISE - CARRIER A.M.		L.F. DRAIN NOISE - CARRIER P.M.	
	r_{MEAS}	r_{COMP}	r_{MEAS}	r_{COMP}
40Hz - 400Hz	91.1%	93.3 +1.4/-0.8%	23.0%	25.6 +2.1/-1.0%
200Hz - 2KHz	92.9%	97.2 +2.7/-1.7%	35.5%	39.3 +2.8/-1.6%
1KHz-10KHz	89.9%	95.9 +4.1/-2.3%	37.0%	41.6 +3.7/-1.9%
4KHz-40KHz	81.0%	101.5 (+22.9)/-9.2%	40.1%	46.5 +5.6/-2.7%

A possible exception is the work by Prigent and Obregon (9), who observed a significant difference in oscillator P.M. noise (4.5dB, δf = 10KHz at 10.3GHz) between high impedance and short-circuit low frequency drain loads. This may be due to A.M. to P.M. conversion in their oscillator (12), as a reduction of the A.M. noise would give a reduction in oscillator phase noise.

In contrast, methods which do not depend on the relation between the L.F. drain noise and the oscillator phase noise are more successful. Riddle and Trew (13) found that a significant reduction in phase noise could be had (15dB, δf = 100KHz at 7.4GHz) by setting the L.F. gate resistance for the best compromise between gate L.F. noise voltage e_G and gate L.F. noise current i_G. Galani et al. (14) used a discriminator to demodulate the frequency modulation noise, and fed the demodulated noise back to the gate. This gave a 20dB noise reduction from 5KHz to 100KHz from carrier on a 10GHz oscillator.

CONCLUSION

The cross correlation between the low frequency noise on the drain of a GaAs MESFET and the A.M. and P.M. noises imposed on an R.F. carrier by the FET have been measured.

The L.F. drain noise and the A.M. noise are highly correlated, suggesting that the A.M. noise is the low frequency drain noise transposed by non-linearities in the FET.

P.M. noise on the carrier does not appear to be highly correlated with the L.F. drain noise. In the device tested the gate noise, which is believed to be the main cause of P.M. noise, is therefore not the prime contributor to L.F. drain noise. This may explain why some low frequency noise cancellation methods only give a limited reduction in oscillator phase noise.

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APPENDIX

The observed L.F. drain noise voltage B(t) is split into two components: D(t), the true L.F. drain noise, and BN(t), the measuring system noise. Similarly, the demodulated A.M. or P.M. noise voltage T(t) is separated into three components: U(t), the noise component uncorrelated with D(t), C(t), the noise component correlated with D(t), and TN(t), noise from the measuring system. For BRMS, TRMS (etc.) the R.M.S. voltage values of B(t) and T(t) respectively, $BRMS^2=DRMS^2+BNRMS$ and $TRMS^2=URMS^2+CRMS^2+TNRMS^2$.

The cross correlation $r(\tau)$ for window of time width W is

$$r(\tau) = 100\% \cdot 1/W \cdot \int_0^W \{[U(t)+C(t)+TN(t)]/TRMS \cdot$$
$$\cdot [D(t+\tau)+BN(t+\tau)]/BRMS\}\, dt$$

C(t) and D(t) are the only two correlated random components, so for large W only these terms remain. If C(t) is fully correlated with $D(t+\tau)$ at $\tau=\tau c$, which is the point where $r(\tau)$ is maximum ($=r_{MEAS}$), then $K \cdot C(t) = D(t+\tau c)$, with K a constant, giving

$$r(\tau c) = 100\% \cdot 1/(TRMS \cdot BRMS) \cdot 1/W \cdot \int_0^W K \cdot [C(t)]^2\, dt$$

The integral is equal to $W \cdot K \cdot CRMS^2$. After some manipulations, we get

$$r(\tau c) = r_{MEAS} = [100\% \cdot CRMS/(URMS^2+CRMS^2)^{1/2}] \cdot$$
$$\cdot [1+1/(TRMS/TNRMS)^2-1]^{-1/2} \cdot$$
$$\cdot [1+1/(BRMS/BNRMS)^2-1]^{-1/2}$$

The first term in square brackets is the true cross correlation, r_{COMP}, which is calculated using this equation with TRMS, TNRMS from figs. 2 (A.M.) and 3 (P.M.) and BRMS, BNRMS from fig. 4

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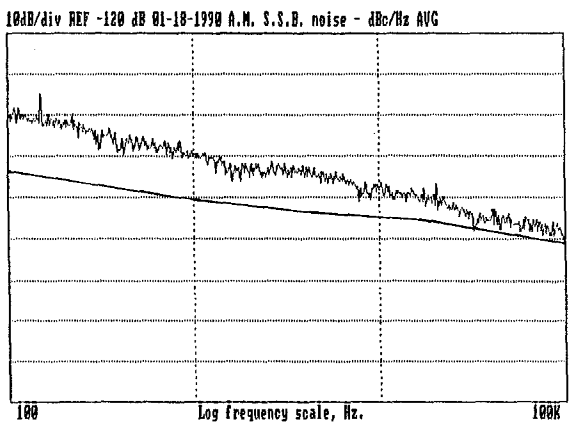

FIG. 2: Measured A.M. single sideband noise power spectrum, relative to carrier power, and equivalent measuring system noise power spectrum (bold line), relative to carrier power. Top of graph = -120dBc/Hz, 10dB/div.

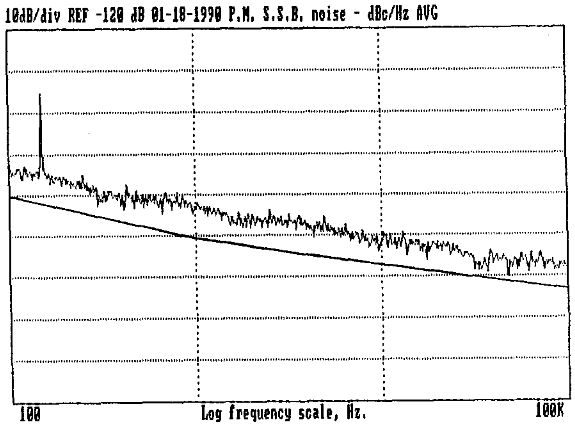

FIG. 3: Measured P.M. single sideband noise power spectrum, relative to carrier power, and equivalent measuring system noise power spectrum (bold line), relative to carrier power. Top of graph = -120dBc/Hz, 10dB/div.

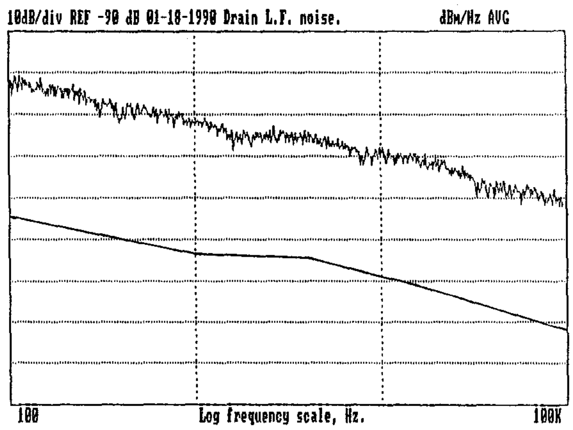

FIG. 4: Measured L.F. drain noise power spectrum, and equivalent measuring system noise power spectrum (bold line). Top of graph = -90dBm/Hz, 10dB/div.

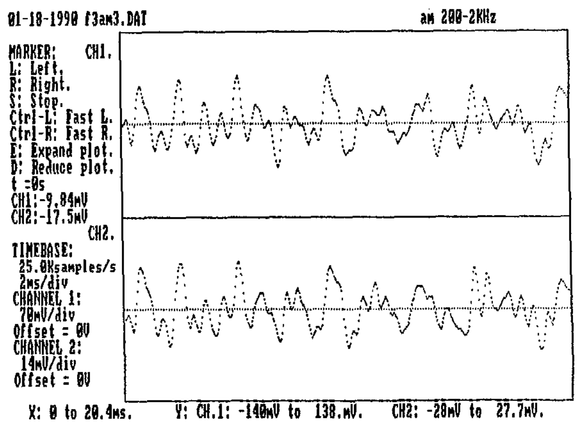

FIG. 5: Time domain samples of demodulated A.M. noise (upper section) and baseband L.F. drain noise (lower section), in the range 200Hz-2KHz.