REDUCING THE 1/f AM AND PM NOISE IN ELECTRONICS FOR PRECISION FREQUENCY METROLOGY*

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Abstract - 1/f phase modulation (PM) commonly limits the short-term frequency stability of many areas of frequency metrology. We report on a fundamental breakthrough in understanding how 1/f PM and amplitude modulation (AM) noise are generated. We show how to analyze the transfer function of a two-port device to calculate the dependence of added AM and PM noise on circuit and the active element parameters. Using this new approach we have developed sample silicon bipolar junction transistor amplifiers with exceptionally low 1/f AM and PM noise. For example, the 1/f PM noise of our 5 and 100 MHz common emitter amplifiers is below our measurement floor of $\mathcal{L}(10\ \text{Hz}) = -162$ dBc/Hz. We expect to be able to extend this approach to the microwave region.

Theory of AM and PM Noise in Amplifiers

The basic problem is that low frequency current and voltage noise are upconverted to AM and PM noise around a high frequency carrier signal, ω, by nonlinear processes primarily associated with the active element. Our theory shows how the added AM and PM noise can be calculated from the transfer function of a linear amplifier. See [1,2] for details on the derivation. The gain of an amplifier is

$$G(\omega) = G_v(\omega)e^{j\vartheta(\omega)} \tag{1}$$

where G_V is the magnitude of the gain and ϑ is the phase shift. The power spectral density of the 1/f noise added by the amplifier can be expressed as

$$S_V(f) = AM + PM = \left(\frac{\Delta G_V(\omega)|_f}{G_V(\omega)}\right)^2 \frac{1}{BW} + (\Delta\vartheta(\omega)|_f)^2 \frac{1}{BW} \tag{2}$$

where BW is the bandwidth of the measurement, and ΔG_V and $\Delta\vartheta$ are fluctuations evaluated at the frequency offset f from the carrier ω, and explicitly contain the dependence of the gain on current, voltage, carrier frequency and Fourier frequency. Equation (2) can be applied to any amplifier configuration, and the functional dependence of 1/f AM and PM noise on transistor parameters, circuit parameters, and signal frequency can be obtained. The complete details of the derivation for a common emitter (CE) amplifier can be found in [1]. Numerous tests confirm the functional dependencies and typically agree to within a few dB with experimental measurements [1]. Once the functional dependence for the added 1/f AM and PM noise is known it is straightforward to minimize their effect. The guidelines for designing low 1/f noise CE amplifiers are the following [2]: (1) large dc current, (2) servo to reduce current noise, (3) transistors with

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 This paper is abstracted from references 1 and 2.

low input and output capacitances, (4) large collector-base voltage, (5) filters to reduce voltage noise at transistor terminals, (6) small dc gain, and (7) small source impedance.

Figure 1 shows AM and PM noise for two different CE amplifiers based on bipolar junction transistors. CE amplifier 1 is a traditional CE amplifier while CE amplifier 2 was designed using the guidelines mentioned earlier. For circuit details see [2]. Both the 1/f AM and PM noise were reduced by more than 15 dB when using our design guidelines.

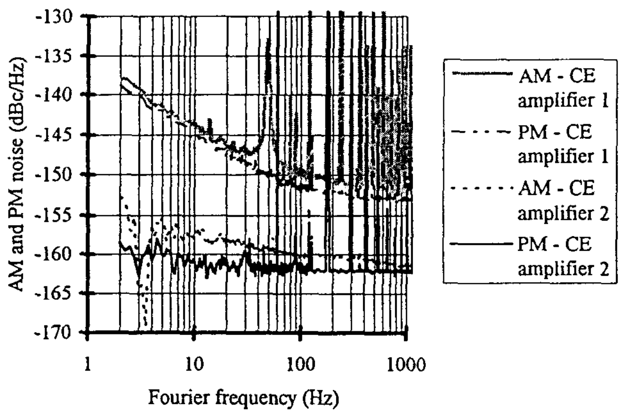

Figure 1. AM and PM noise for CE amplifiers 1 and 2 at 5 MHz.

Conclusion

We have presented a theory that explains the upconversion of baseband noise into AM and PM noise about a carrier in amplifiers. From the theory, AM and PM noise equations can be derived for any linear amplifier configuration. The noise equations provide the functional dependence of AM and PM noise on transistor parameters, circuit parameters and carrier frequency. The developed theory lays the groundwork for a comprehensive theory of AM and PM noise in amplifiers, and provides a basis for the design of low noise amplifiers. We were able to design a 5 MHz CE with 25 dB of gain with 1/f AM and PM noise less than -160 dBc/Hz at 10 Hz from the carrier by following the low noise design guidelines derived from the theory.

References

[1] F.L. Walls, E.S. Ferre-Pikal, and S.R. Jefferts, "The origin of 1/f PM and AM noise in bipolar junction transistor amplifiers," to be published in Proc. 1995 IEEE Freq. Cont. Symp.
[2] E.S. Ferre-Pikal, F.L. Walls, and C.W. Nelson, "Design criteria for BJT amplifiers with low 1/f AM and PM noise," to be published in Proc. 1995 IEEE Freq. Cont. Symp.