COMPARISON OF 1/f PM NOISE IN COMMERCIAL AMPLIFIERS[1]

M.C. DELGADO ARAMBURO, E.S. FERRE-PIKAL, F.L. WALLS and H.D. ASCARRUNZ

National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80303, USA.

Abstract

In this paper we compare the 1/f phase modulation (PM) noise of two different families of commercial amplifiers under different operating conditions. The first family used GaAs heterojunction bipolar transistors (HBT) while the second used Si bipolar junction transistors (BJT) in a Darlington pair amplifier configuration. Three currents for the HBT family and four currents for the BJT family were chosen for study. The PM noise of the amplifiers was measured at carrier frequencies of 5, 10, and 100 MHz. In general, the HBT-based amplifiers had somewhat lower PM noise than the BJT based amplifiers. Amplifiers operating with higher current generally had lower PM noise than those operating with lower current. A commercial feed-forward amplifier had much lower 1/f PM noise than all the other commercial amplifiers tested.

Introduction

The purpose of this paper is to investigate some of the factors that contribute to the 1/f phase modulation (PM) noise in commercial amplifiers [1]. We made many measurements of PM noise in these amplifiers under different conditions. We used power supplies with different voltage noise, different carrier frequencies, and different input powers. We measured both the gain and the phase shift across the amplifiers. The amplifiers tested used either Si bipolar junction transistors (BJT) or GaAs heterojunction bipolar transistors (BJT) in a Darlington pair configuration, as shown in Fig. 1. One example of a feed-forward amplifier of the form shown in Fig. 2 was also tested. [2]

Table 1 shows the characteristics of the seven amplifiers from the two families and the special feed-forward amplifiers. The amplifiers vary considerably in gain, maximum output power, dc current, and bandwidth. In this paper we study in detail two amplifiers, one from each family. These are the E004, from the HBT family and the M011, from the BJT family since their gain and operating power are similar.

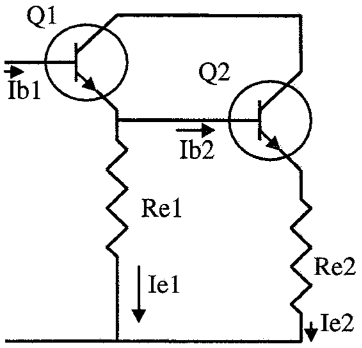

Figure 1. Block diagram of Darlington amplifier configuration

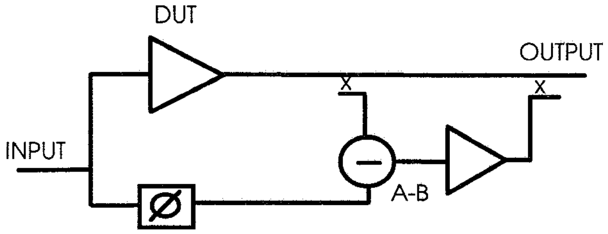

Figure 2. Simplified Block diagram of feed-forward amplifier configuration

Measurement system

To ensure that the measurement system did not contribute to the measured PM noise, the PM noise was measured using the two channel cross-correlation measurement system shown in Fig. 3. This system has two phase noise detectors that are fed into a two-channel cross correlation Fast Fourier Transform (FFT) spectrum analyzer. This system has a PM noise floor of approximately $\mathcal{L}(10\text{ Hz}) = -170$ dBc/Hz at a carrier frequency of 5 MHz [3]. This is typically 15 dB lower than the PM noise of the amplifiers measured.

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Table 1. Characteristics of the amplifiers studied. The amplifiers reported in detail are shown in bold. Power is given in dB relative to 1 mW (dBm)

AMPLIFIER NUMBER	GAIN, Typ, @ 100 MHz (dB)	MAXIMUM POWER		DC POWER		BANDWIDTH (GHz)
		Input (dBm)	1 dB compression (dBm)	Current (mA)	Voltage (v)	
E001 HBT	11.8	15	13	50	3.8	DC to 8
E002 HBT	22.1	13	11	35	3.8	DC to 8
E004 HBT	**13.8**	**13**	**19.1**	**80**	**5**	**DC to 8**
M001 BJT	18.5	20	1.5	17	5	DC to 1
M002 BJT	13	20	5	25	5	DC to 2.7
M006 BJT	20	20	2	16	3.5	DC to 0.8
M011 BJT	**12.7**	**20**	**17.5**	**60**	**5.5**	**DC to 1**
Feed-Forward	11.3	**15**	22	91	15	0.002-0.07

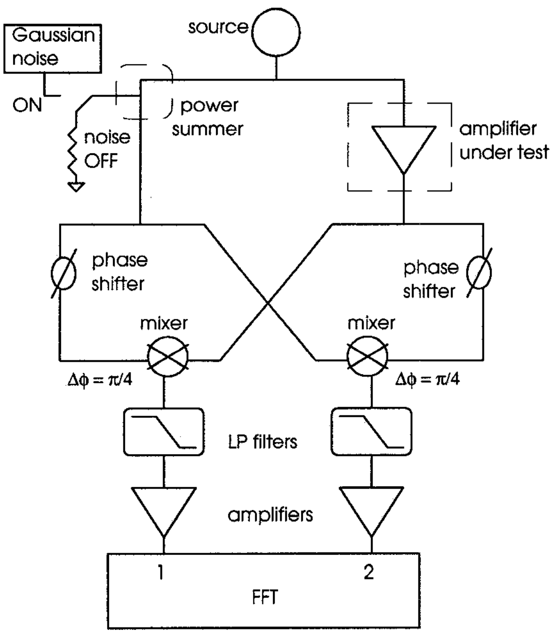
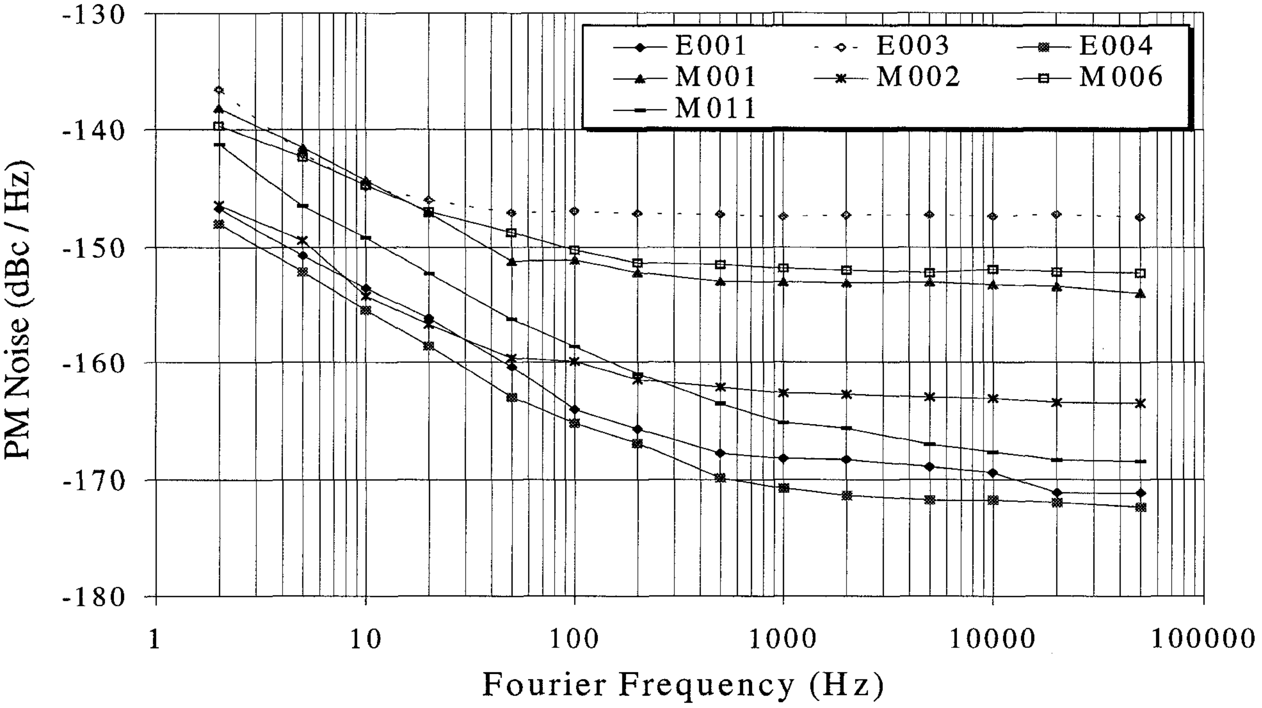


Figure 3. PM noise measurement system for amplifiers

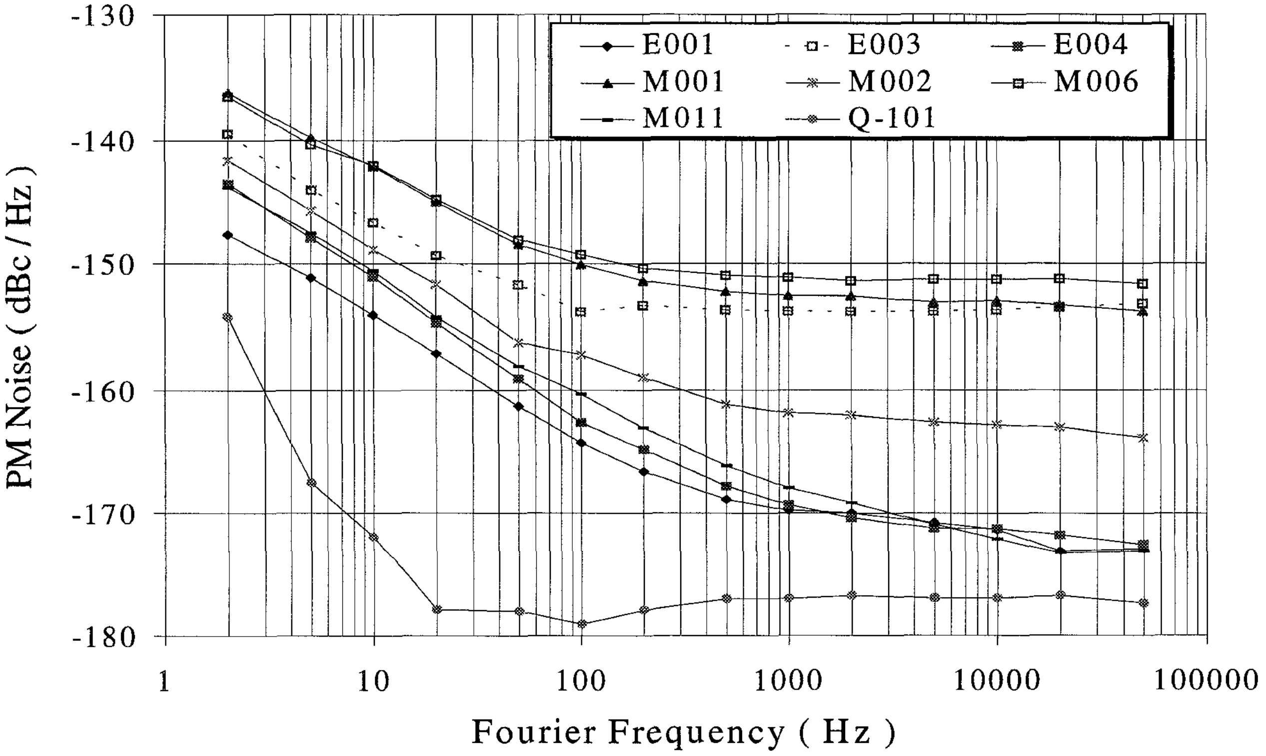
Experimental results

In the following we present the experimental PM noise results for the amplifiers operating in the linear region. Figure 4 shows the PM noise data of the amplifiers at carrier frequencies of 5, 10, and 100 MHz. The 1/f PM noise of the feed-forward amplifier in Fig. 4b is 15 dB lower than that of any other commercial amplifier we have tested and is certainly limited by the noise floor of our measurement system [1].

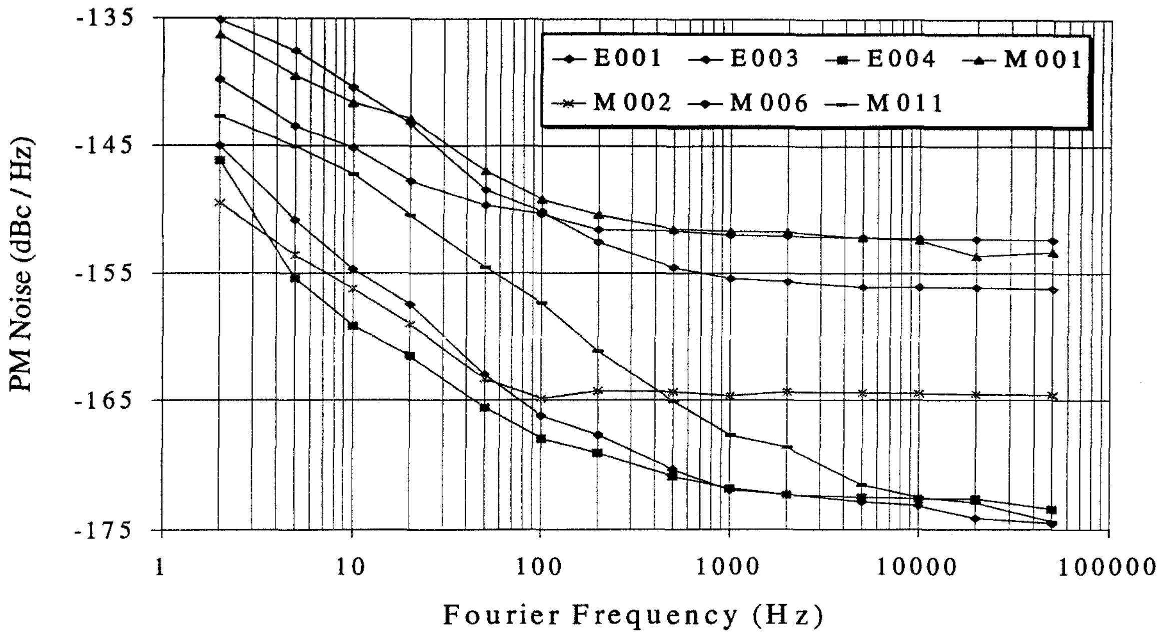
Figure 5a shows the PM noise data for amplifier E004 as a function of Fourier frequency at different carrier frequencies. The 1/f PM noise is lowest at a carrier frequency of 100 MHz and highest at 10 MHz. Similar data for amplifier M011 of the BJT family are shown in Fig. 5b. In this case the lowest 1/f PM noise is at a carrier frequency of 10 MHz and the highest 1/f PM noise is at a carrier frequency of 100 MHz.



4a. 5 MHz

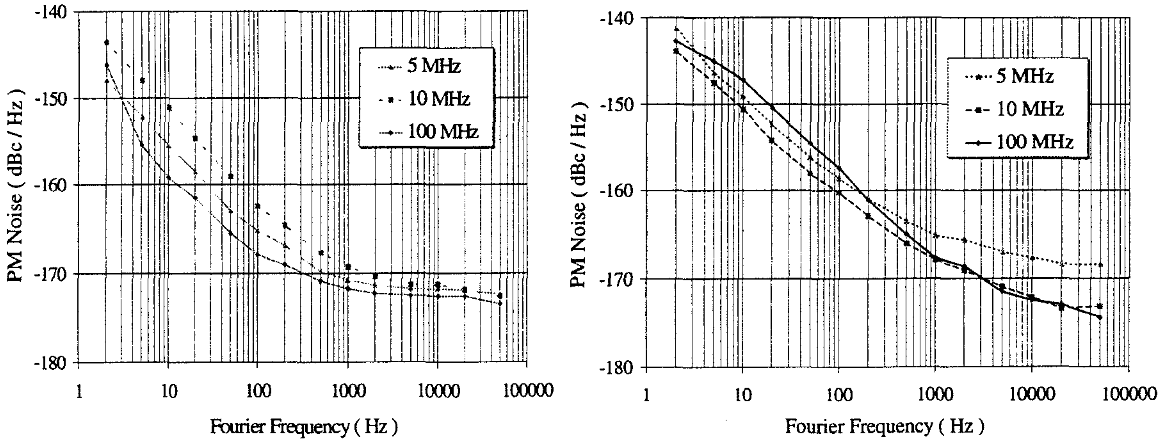


4b. 10 MHz



4c. 100 MHz

Figure 4. Comparison of the PM noise of the various amplifiers at different carrier frequencies. PM noise is given in terms of dB below the carrier in a 1 Hz bandwidth.

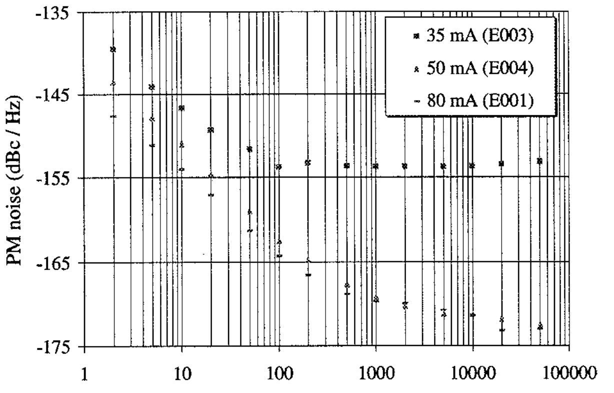


5a. E004 Amplifier

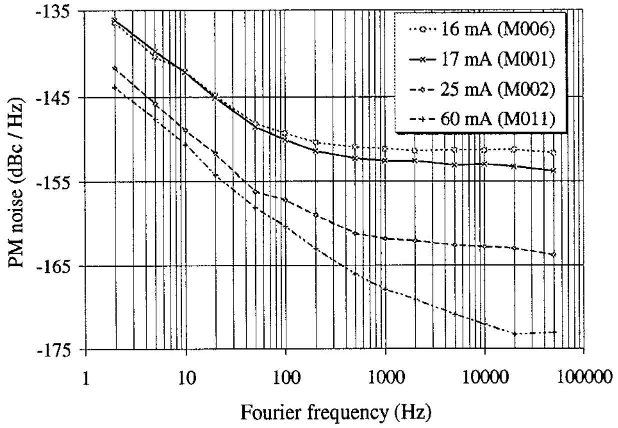
5b. M011 Amplifier

Figure 5. Dependence of PM noise in amplifiers E004 and M011 on both Fourier frequency offset and carrier frequency

Figure 6 compares the PM noise of amplifiers that operate at different dc currents. Figure 6a shows the data for the GaAs HBT family and Figure 6b shows the corresponding data for the Si BJT family. These measurements were made at carrier frequencies of 10 MHz. Both families show strong dependence of the 1/f PM noise on the dc current, with the lower current amplifiers having the highest PM noise, and the higher current amplifiers showing the lowest PM noise. Similar results were obtained at carrier frequencies of 5 and 100 MHz.



6 a. GaAs HBTs Amplifiers



6b. Si BJTs Amplifiers

Figure 6. Dependence of the 1/f PM noise on the dc current of a carrier frequency of 10 MHz and linear operation.

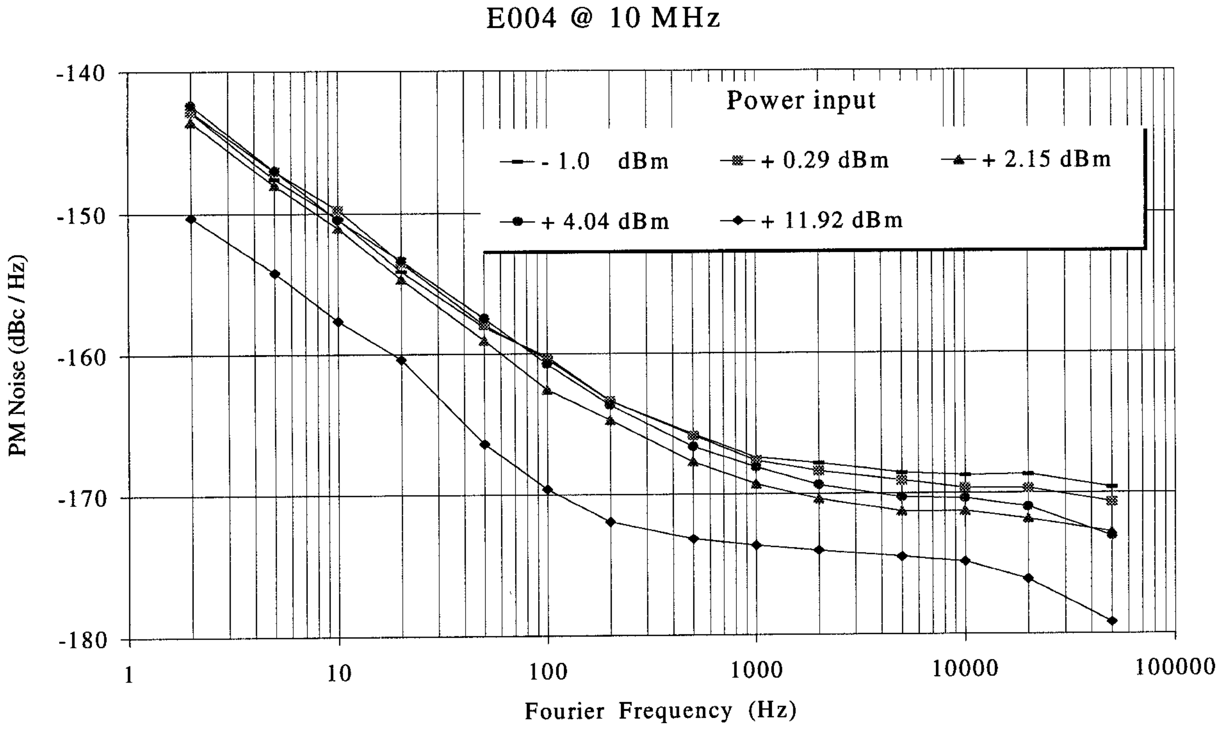
We also investigated the effect of the input power to the amplifiers on the PM noise. We expected to see a change in the level of thermal noise and possibly in the 1/f PM noise when the amplifiers were driven to saturation. Figure 7 shows the 1/f PM noise as factor of input powers for two amplifiers, the E004 (Fig. 7a) and M011 (Fig. 7b). The PM noise of E004 does not change much with input power when is operating in the linear region (power inputs: -1 dBm to + 4.04 dBm) but when driven to saturation (power input: + 11.92 dBm) we see a *decrease* of 5 to 7 dB in the PM noise, both 1/f and thermal. The 1 dB gain compression point for this amplifier occurs at an input power of approximately 5 dBm. The decrease in the 1/f PM noise was quite unexpected.

Figure 7b shows the data for the BJT amplifier M011. In this amplifier the 1/f PM noise degrades as the input power is increased. The highest PM noise was measured with the highest input power, when the amplifier was operating well into saturation.

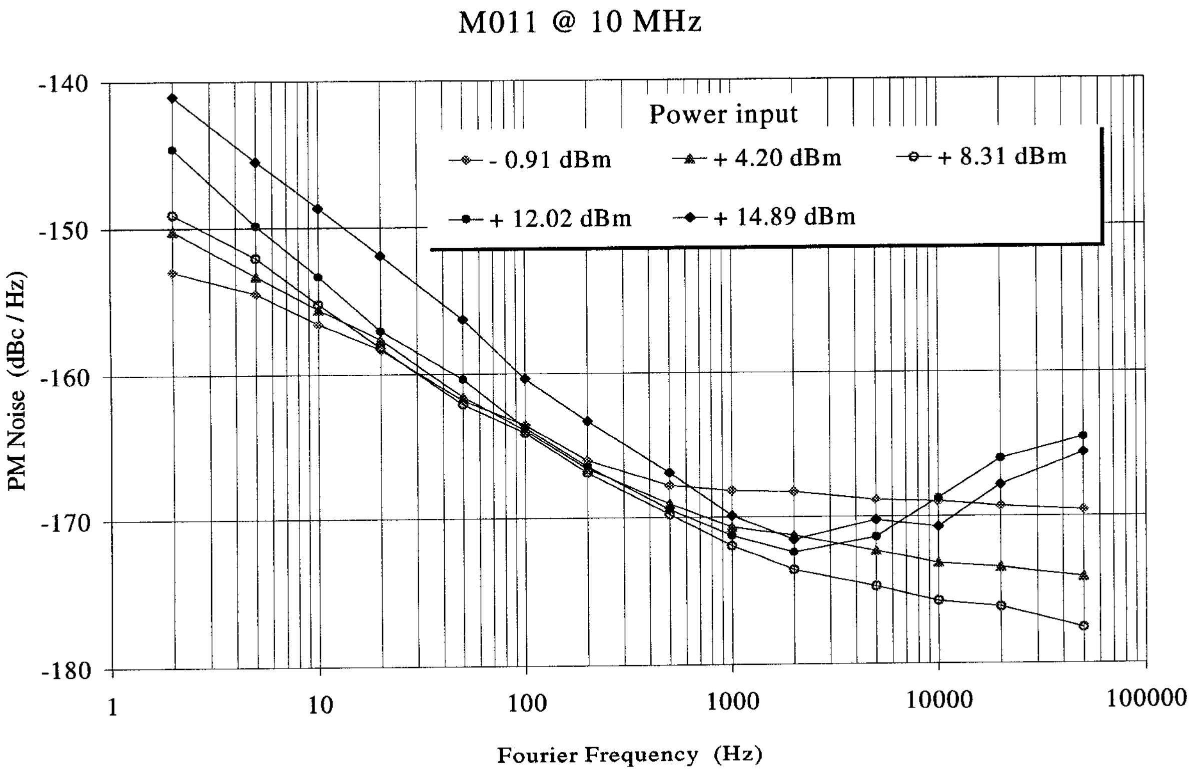
Figure 8 shows the PM noise measurement of a different BJT amplifier (M006) operating linearly and in saturation. Measurements were made at carrier frequencies of 5, 10 and 100 MHz. In this amplifier we can see the same response as in the E004 (HBT family). When the amplifier is driven to saturation the 1/f PM noise improves. This effect is more significant at carrier frequencies of 5 and 10 MHz than at 100 MHz. These results show that in some cases the 1/f PM noise degrades when driven in saturation and in some cases it improves, independent of the family (HBT or BJT).

We also measured the magnitude and phase angle of the gain of the amplifiers as a function of input power. The results shown in Fig. 9a correspond to amplifier E004, while those shown in Fig. 9b to amplifier M011. We did not see any significant change in the phase shift across either amplifier when the input power was increased and the amplifiers were driven into saturation. Therefore, the dependence of the 1/f PM noise on the input power is not due to a change in the phase shift. The smaller difference of the phase shift from -180° for amplifier E004 as compared to M011 is expected due to the larger bandwidth (smaller capacitance).

We measured the dependence of PM noise on the power supply voltage by injecting a large narrow band signal on the power supply and measuring the resulting phase modulation. Table 2 shows the measured sensitivity of the E004 amplifier and Table 3 shows the measured sensitivity of the M011 amplifier to power supply noise. The power supply sensitivity for the HBT (E004) amplifier is much smaller then for the BJT (M011) amplifier as expected since the phase shift, which is proportional to capacitance, is approximately 4 times smaller than for the BJT amplifier and the output capacitance of a HBT varies much more slowly with base collector voltage than a BJT. Tables 2 and 3 also show the expected PM noise due to power supply and the measured PM noise. The expected PM noise due to the power supply voltage noise is lower than the measured amplifier PM noise indicating that the power supply noise is not the limiting factor. See below for additional discussion.



7a. E004 amplifier



7b. M011 amplifier

Figure 7. Dependence of PM noise on input power.

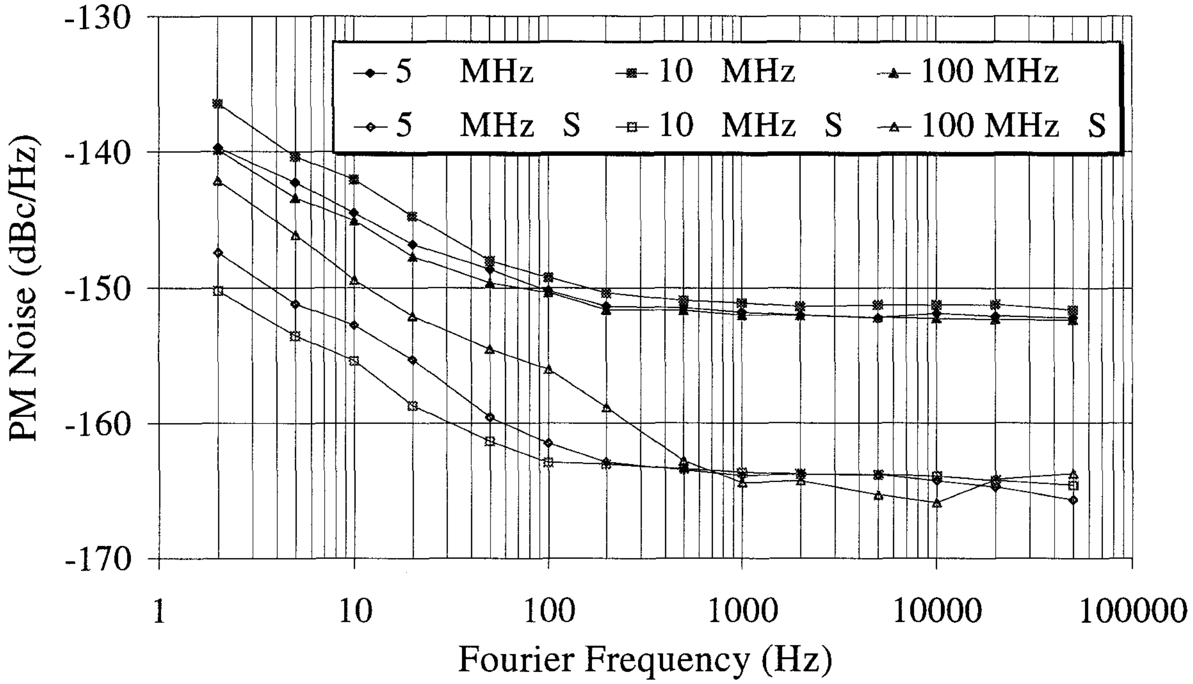
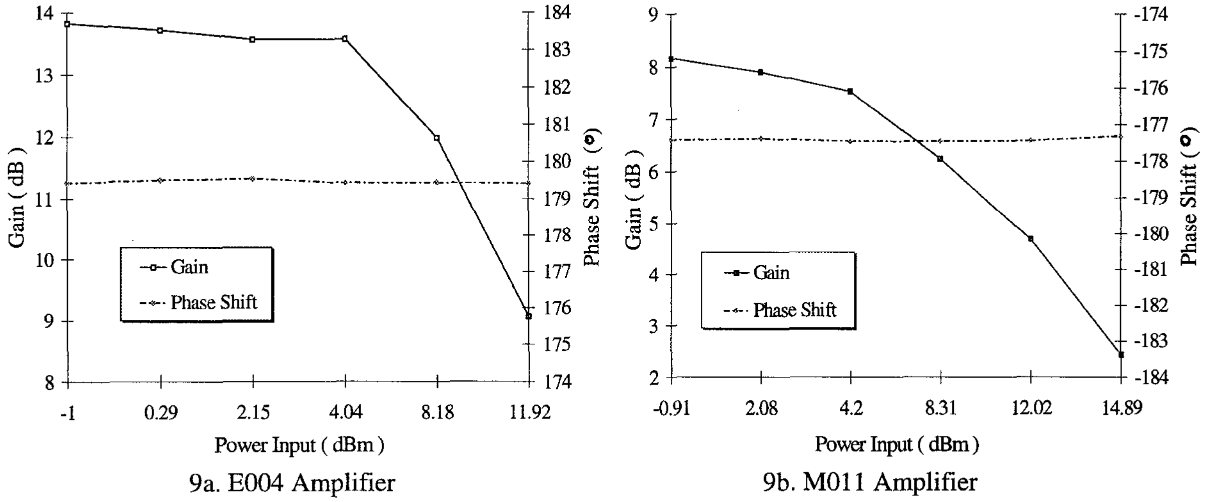


Figure 8. PM noise of amplifier M006 operating linearly and in saturation at 5, 10, and 100 MHz.



9a. E004 Amplifier

9b. M011 Amplifier

Figure 9. Phase shift across the amplifier and gain as a function of input power at a carrier frequency of 10 MHz.

To further investigate the influence of power supply noise on the 1/f PM noise, we measured the PM noise in some of the BJT and HBT amplifiers with two power supplies with different voltage noise. Figure 10 shows the PM noise of the M011 amplifier when using a standard power supply and a power supply with 20 dB lower noise. There is a small improvement in the 1/f PM noise when the low noise power supply was used. Similar results were obtained for other BJT amplifiers. In the case of the HBT family we could not see any improvements; this result agrees with the data of Table 2. The linear analysis shown in Table 3 indicates a maximum improvement in the PM noise of amplifier M011 of approximately 1 dB for a 20 dB reduction in voltage noise. The measured improvement of 2-3 dB for Fourier frequencies from 2-100 Hz indicates a small amount of low frequency nonlinear mixing in the dc bias circuits. No such effect is evident in the HBT amplifiers.

Table 2. Sensitivity of E004 amplifier to the power supply noise at a carrier frequency of 10 MHz.

Fourier frequency (Hz)	Sensitivity $d\phi / dv$	Voltage noise (dBVrms/ Hz)	Expected PM noise (dBc/Hz)	Measured PM noise (dBc/Hz)
2	-51.7	-113.3	-165	-143.56
20	-50.66	-120.4	-171.06	-154.66
200	-49.37	-132.9	-182.27	-164.76
2000	-48.1	-134.3	-182.4	-170.36
20000	-51.7	-134.4	-184.1	-171.82
50000	-51.99	-133.7	-185.69	-172.78

Table 3. Sensitivity of M011 amplifier to the power supply noise at a carrier frequency of 10 MHz.

Fourier frequency (Hz)	Sensitivity $d\phi / dv$	Voltage noise (dBVrms /Hz)	Expected PM noise (dBc/Hz)	Measured PM noise (dBc/Hz)
2	-48.8	-106	-154.8	-149.98
20	-42.8	-120.4	-163.2	-158.34
200	-37.94	-133.3	-171.24	-166.07
2000	-39.24	-134.5	-173.74	-168.29
20000	-40.8	-134.4	-175.2	-169.32
50000	-41.7	-134.1	-175.8	-169.6

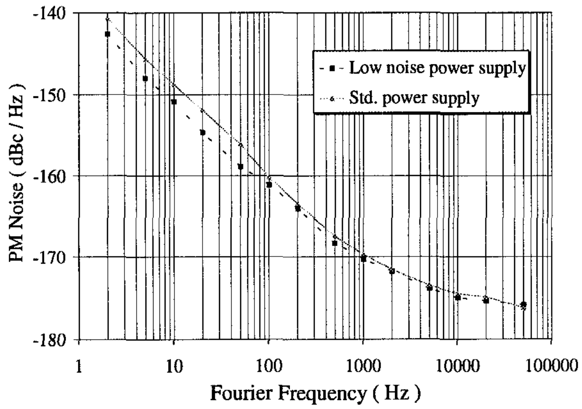


Figure 10. Influence of the power supply noise on the 1/f PM noise at a carrier frequency of 10 MHz.

Conclusions

We have studied the 1/f and thermal PM noise of two families of commercial amplifiers, one based on Si BJTs and one based on GaAs HBTs. In both cases, we find a significant dependence of the 1/f and thermal PM noise on the dc current, carrier frequency and the degree of gain saturation. In general amplifiers with larger dc standing current have lower 1/f and thermal PM noise. The HBT family generally had somewhat lower 1/f PM noise than a BJT based amplifier with the same dc current. The PM noise of some amplifiers increased and (surprisingly) some decreased when operated at input powers 5-7 dB above the 1 dB compression point. The PM noise of all the amplifiers changed with carrier frequency, however, no general trend with carrier frequency emerged. The HBT amplifier tested exhibited a sensitivity to power supply voltage noise of approximately -50 dBc/Hz for a power supply noise of 1 V^2/Hz (0 dBV/Hz). This is approximately 10 dB better than the BJT based amplifiers. The 1/f PM noise of the commercial feed-forward amplifier was more than 15 dB lower than any of the other commercial amplifiers tested. This result is due to the feed forward architecture which greatly improves the linearity as compared to conventional amplifiers. The theory of [4] shows that the PM (and AM) noise added by an amplifier, due to the baseband flicker of the gain and phase, is reduced when the amplifier is linearized.

References

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