Noise Figure vs. PM noise Measurements: A study at Microwave Frequencies

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- Noise Figure of an amplifier from PM noise measurement

- Thermal noise level in the presence of carrier (referenced to 0dBm)

  -177dBc/Hz

  or

  –174dBc/Hz

Noise Figure of an amplifier

- Noise figure:

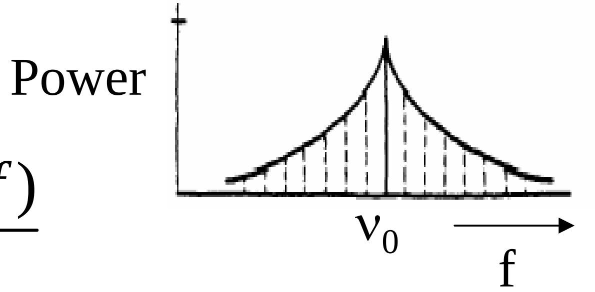
  It is a measure of degradation in the signal-to-noise ratio between input and output of an amplifier

$$\mathrm{NF} = \frac{\left(S_i / N_i\right)}{\left(S_o / N_o\right)}$$

- NF of a noiseless amplifier = 1 (0dB)
- NF of a noisy amplifier > 1 (0dB)
- Meaningful only at offset frequencies where phase noise is white

Derivation of noise figure from PM noise measurement in the presence of carrier

RF spectrum can be written as



$$S_{\mathrm{RF}}(f) = \frac{\mathrm{PSD}V_N(\nu_0 - f) + \mathrm{PSD}V_N(\nu_0 + f)}{V_0^2}$$

V_0 = rms voltage level of the carrier

$\mathrm{PSD}V_N(\nu_0 \pm f)$ = power spectral density of the voltage noise

ν_0 = carrier frequency

f = the offset or Fourier frequency

- **Random RF noise is divided equally between AM noise and PM noise**

$\Rightarrow$ PSD of PM noise, $S_{\phi}(f) = (1/2) S_{\mathrm{RF}}(f)$

- **Single sideband phase noise (by convention only)**

$\mathbf{\Lambda(\mathit{f}) = (1/2) \mathit{S}_{\phi}(\mathit{f}) = (1/4)\ \mathit{S}_{RF}(\mathit{f})}$

$$\Rightarrow L(f)_{rad} = \frac{\mathrm{PSD} V_N(\nu_0 - f) + \mathrm{PSD} V_N(\nu_0 + f)}{(4) V_0^2}$$

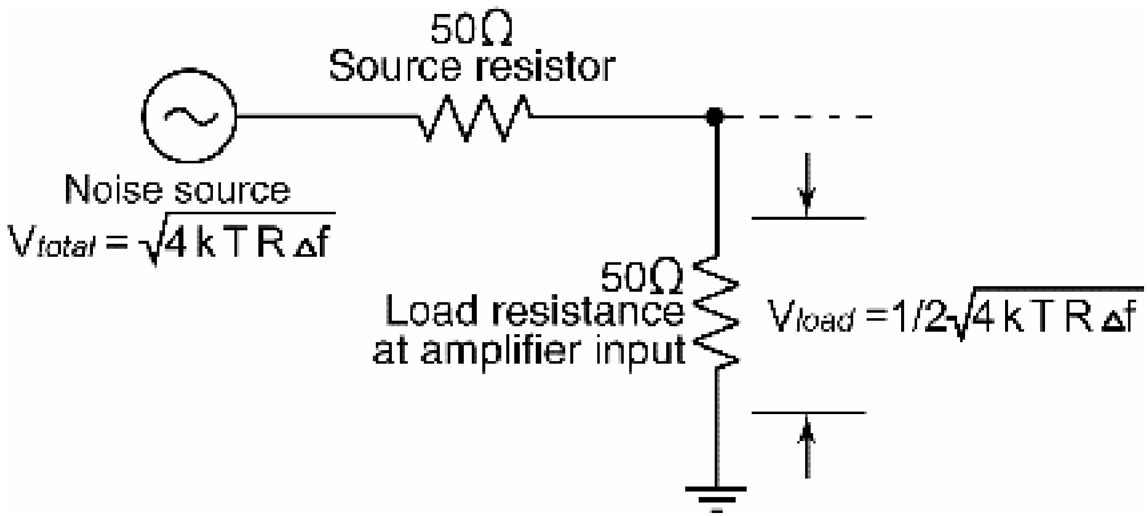


Fig: Equivalent input circuit showing the thermal noise generator with a source resistance and terminated into the amplifier input resistance

$$L(f)_{rad} = \frac{kTR}{2V_0^2} = \frac{kT}{2P_i} \qquad (\Delta f = 1)$$

T=290^0 K, k = 1.38 x 10^{-23} J/K

$\mathcal{L}(f)$ = =10log($\mathcal{L}(f)_{rad}$)=- 177dBc/Hz (Referenced to 0dBm)

Wideband PM noise floor of an amplifier

- Output of amplifier

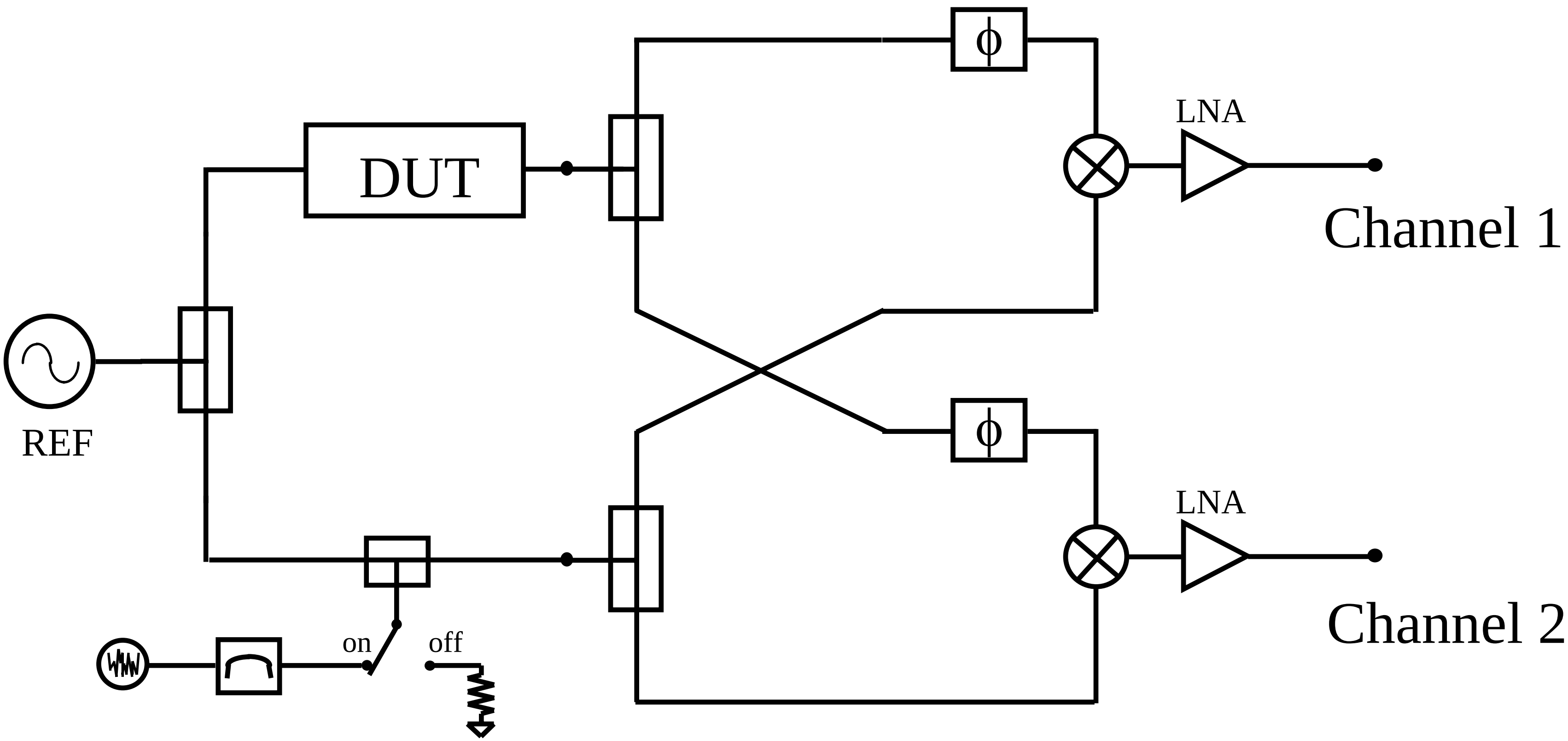
$$L(f)_{rad} = \frac{kTGNF}{2P_o} = \frac{kTNF}{2P_i}$$

- In terms of dBc/Hz wideband noise floor of the amplifier

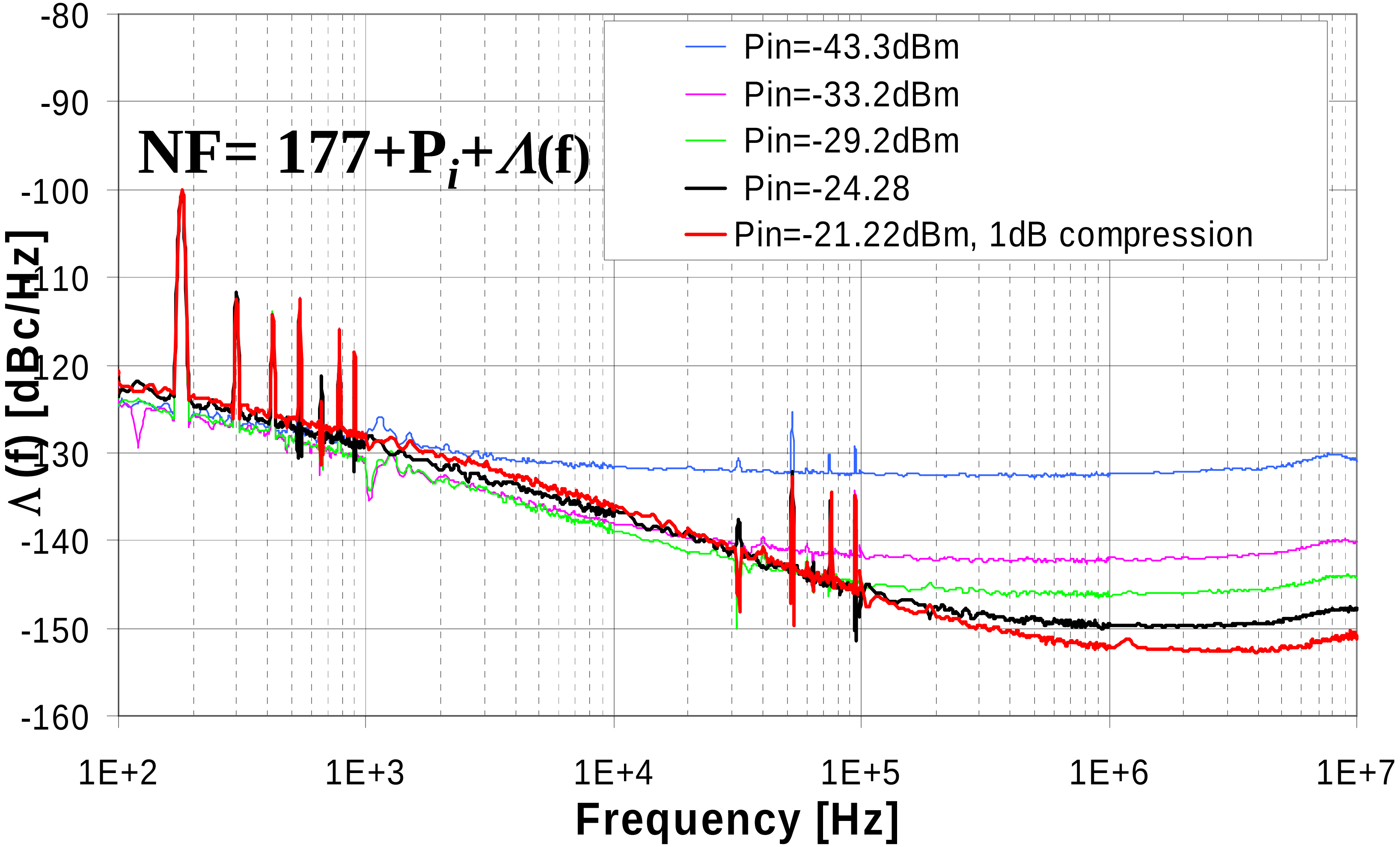
$$\mathcal{L}(f) = -177 - P_i + NF$$

$$NF = 177 + P_i + \mathcal{L}(f)$$

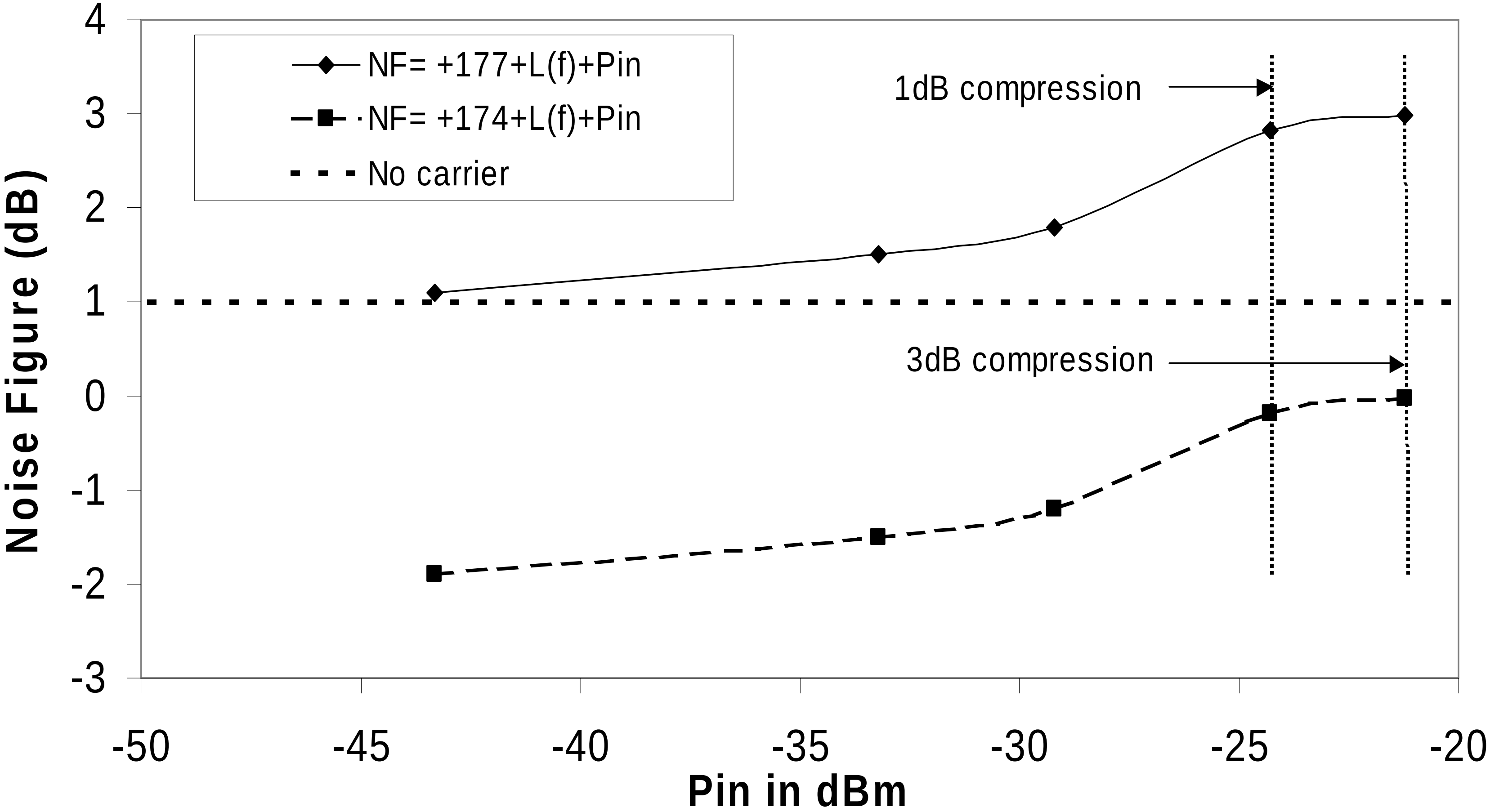
Two channel cross-correlation system for measuring PM noise of amplifier



Phase Noise of GaAs HEMFET Amplifier
Gain=32.5dB, NF=1dB
Frequency = 10GHz

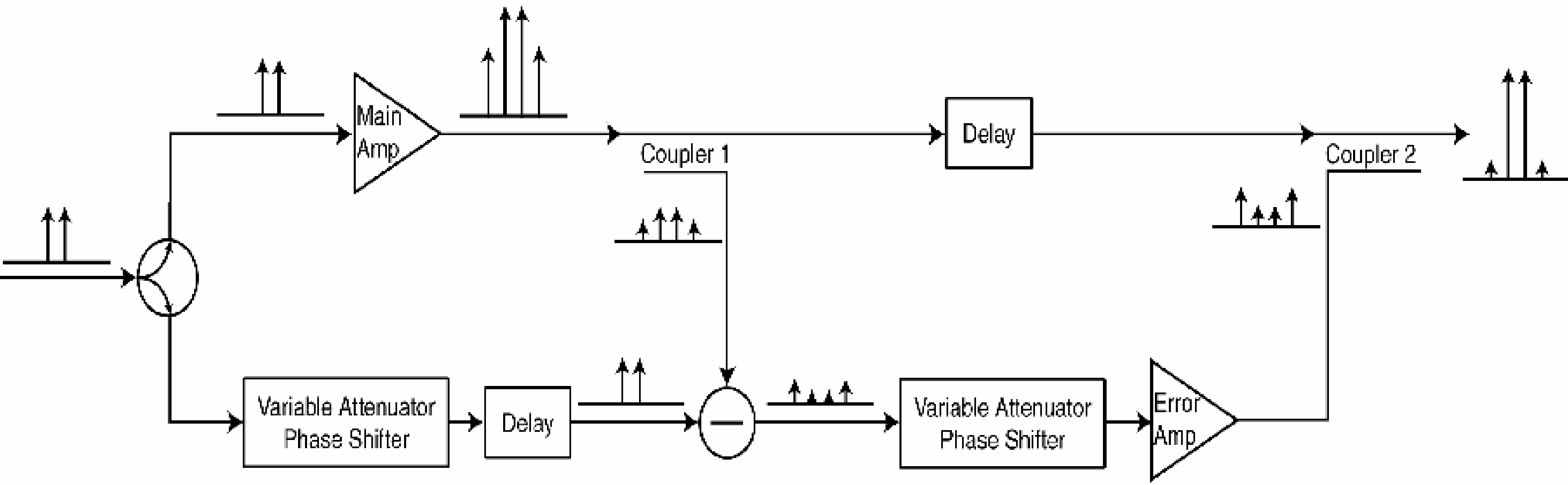


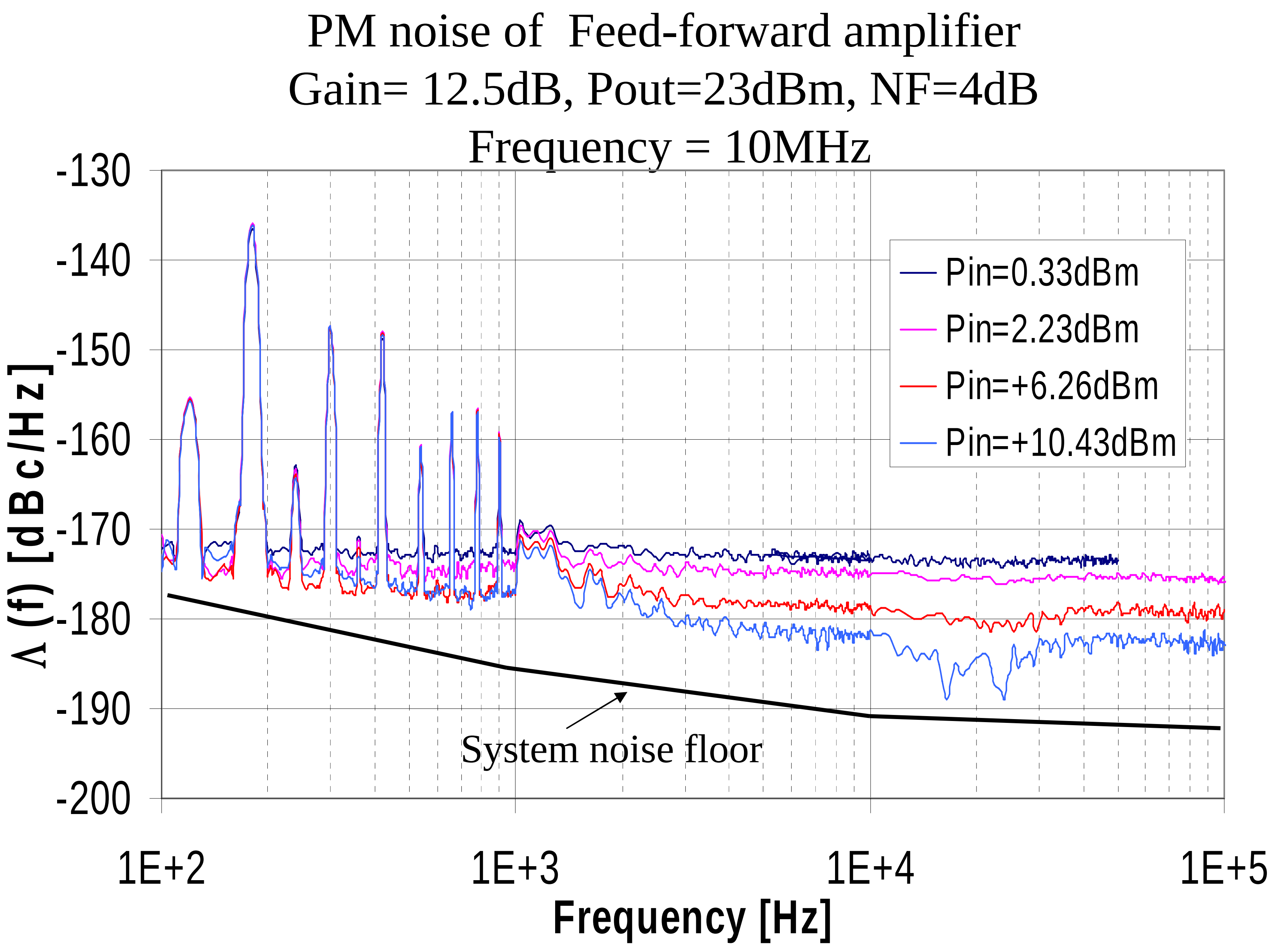
Input power vs NF



An example of an amplifier whose NF is not a function of carrier power

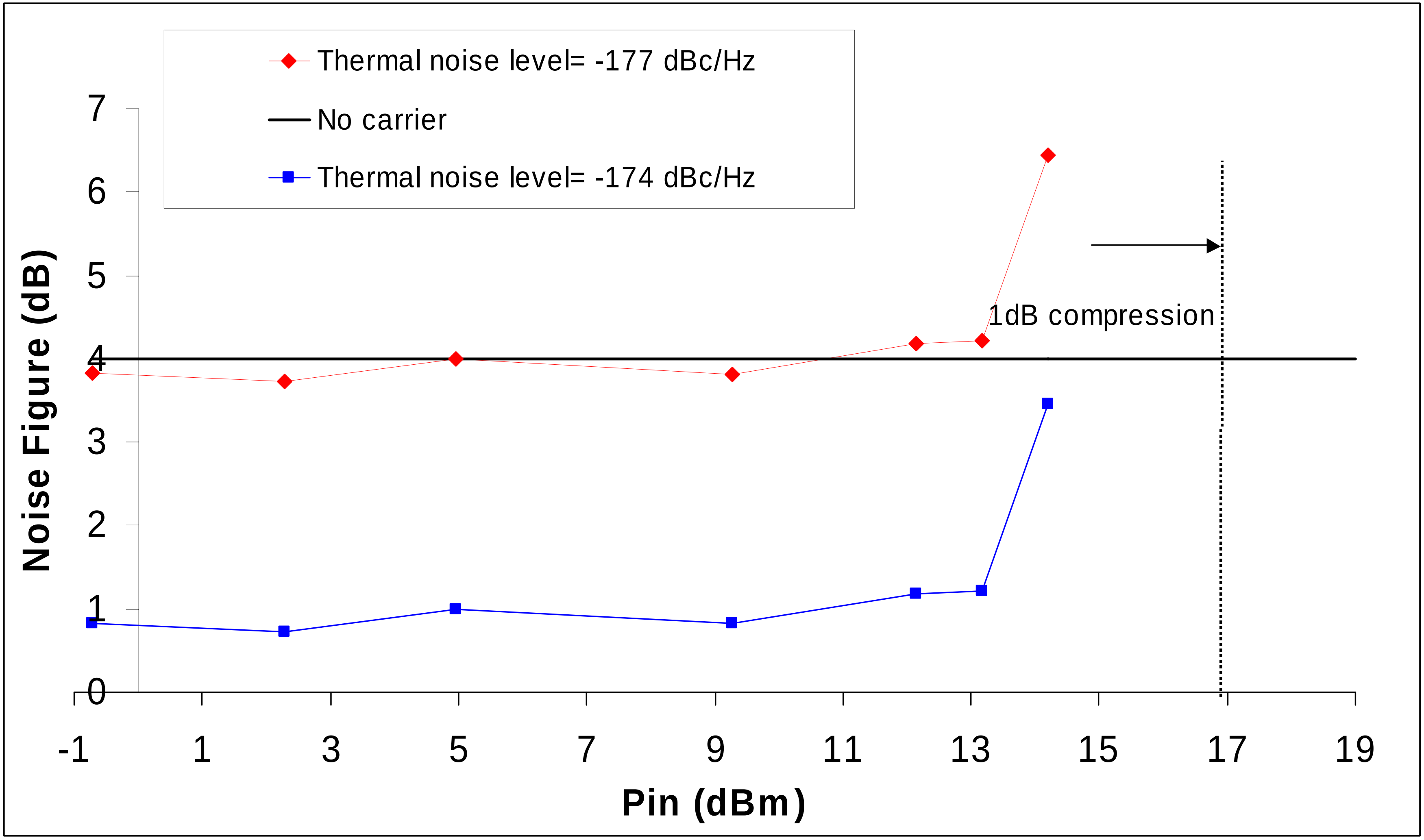
Simplified block diagram of feed-forward amplifier configuration





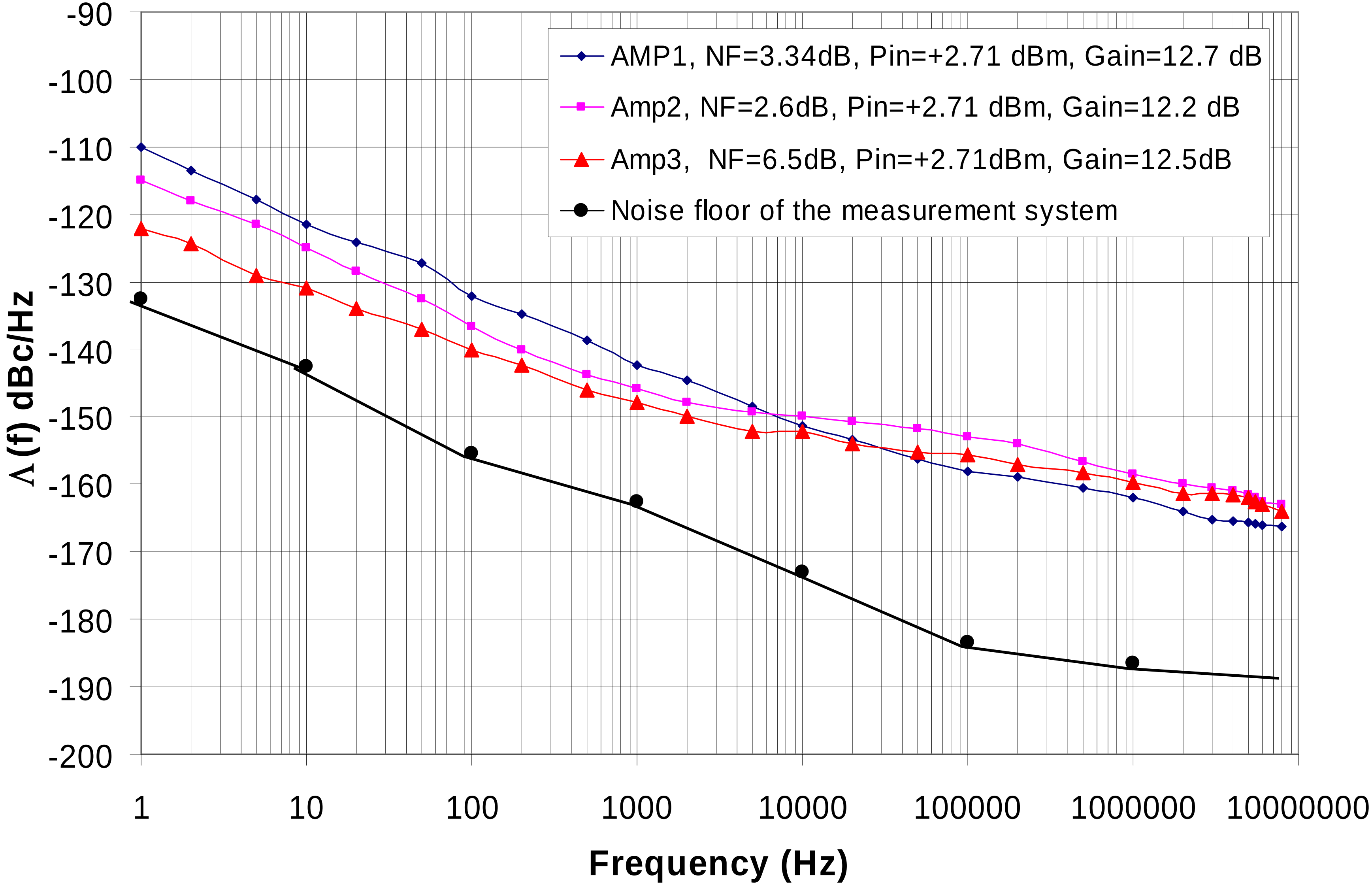
PM noise of Feed-forward amplifier
Gain= 12.5dB, Pout=23dBm, NF=4dB
Frequency = 10MHz
-130
-140
-150
-160
-170
-180
-190
-200
Λ (f) [dBc/Hz]
Pin=0.33dBm
Pin=2.23dBm
Pin=+6.26dBm
Pin=+10.43dBm
System noise floor
1E+2
1E+3
1E+4
1E+5
Frequency [Hz]

Noise figure of Feed-forward amplifier
Frequency = 10MHz, Gain= 12.5dB, Pout=+27dBm, NF=4dB



1/f noise of different amplifiers having different NF

Frequency = 10GHz



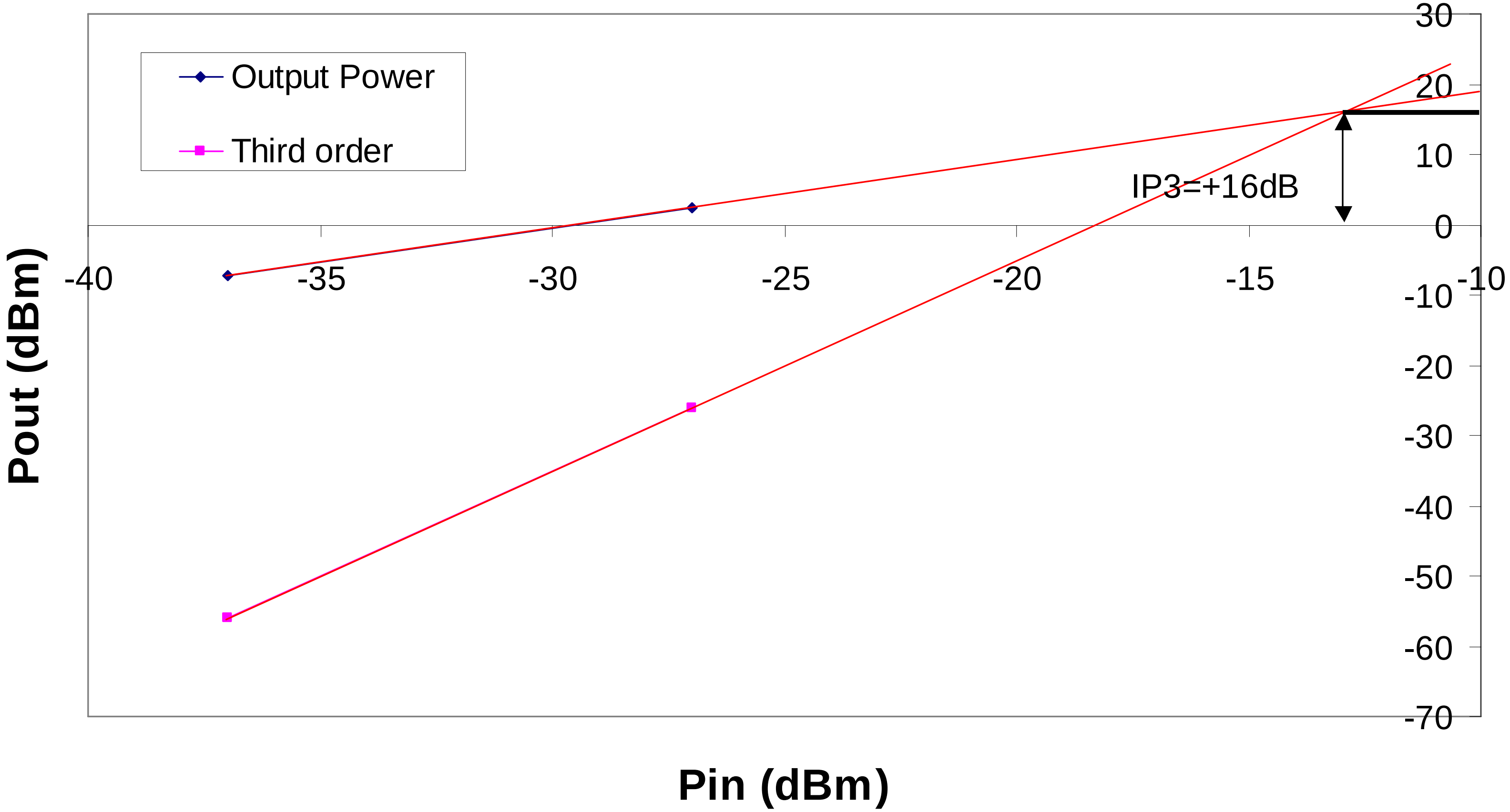
Conclusion

- Merit of an amplifier is better characterized by PM noise measurement than NF measurement with no carrier

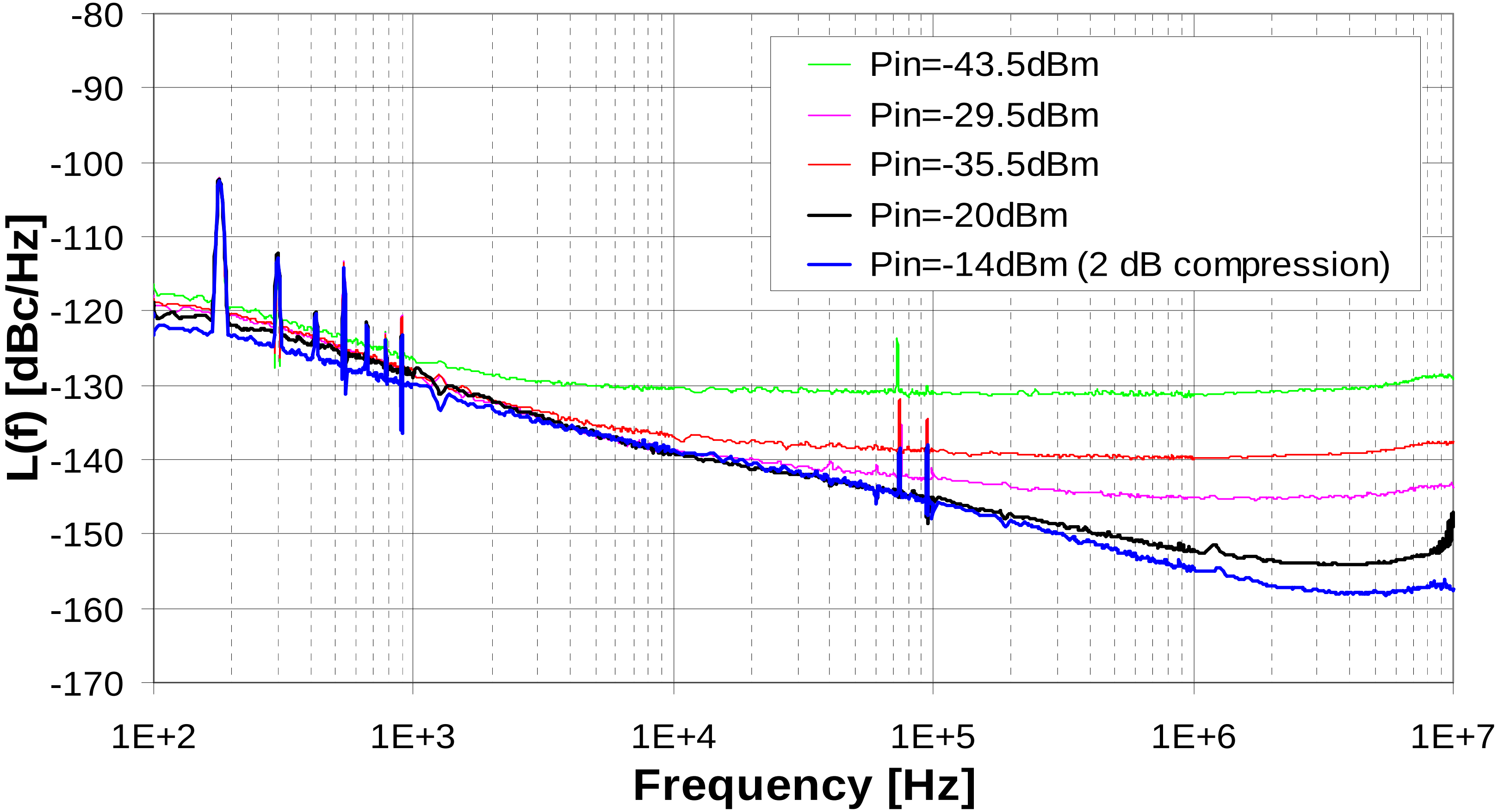
- NF of a non-linear amplifier is a function of carrier power due to non-linear inter modulation process whereas for linear amplifier NF is independent of carrier power

- In the presence of carrier, thermal noise level is –177dBc/Hz referenced to 0dBm

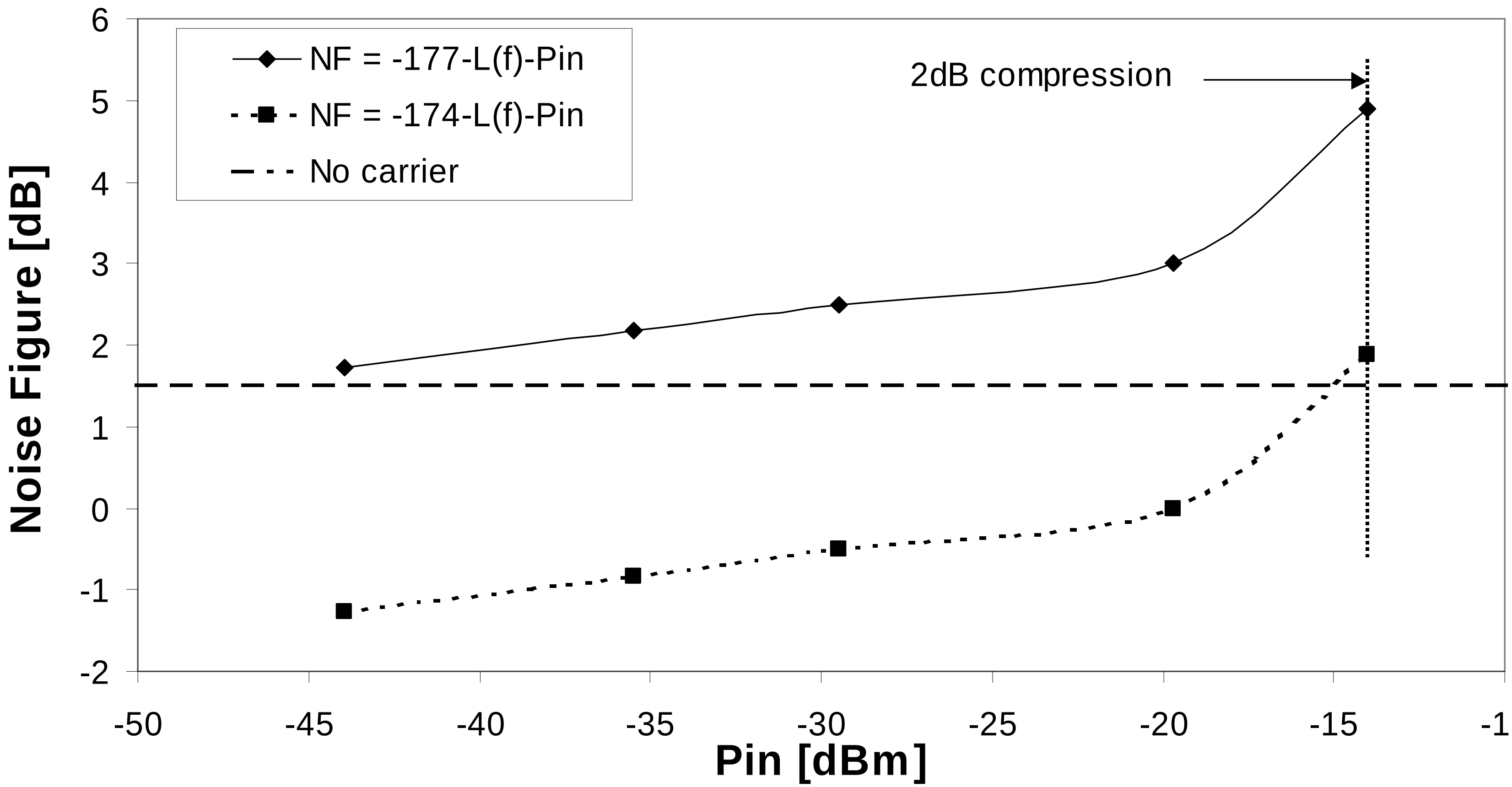
Third order inter-modulation product IP3

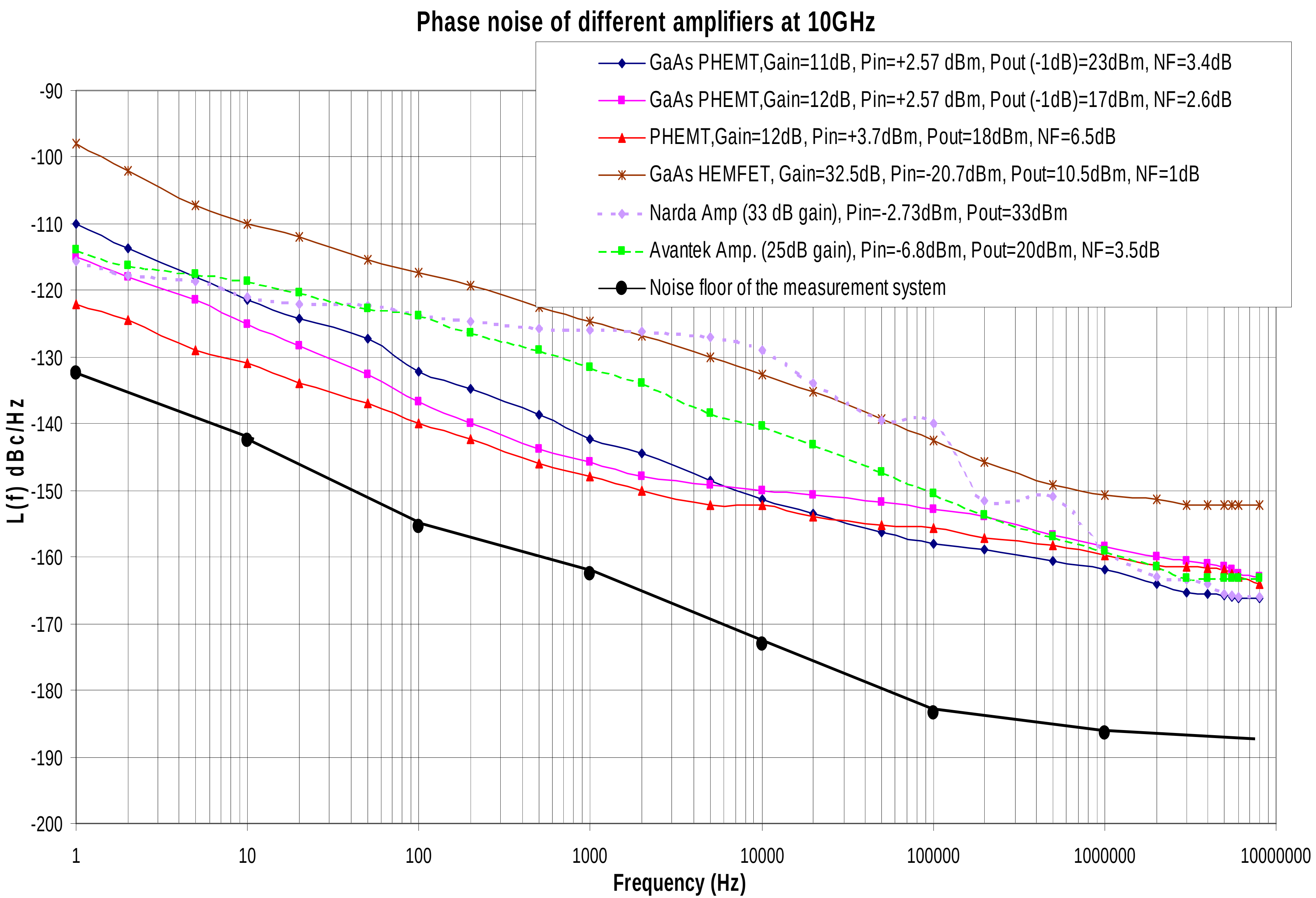


Phase Noise of GaAs FET amplifier, NF= 1.5, Gain=35dB
Frequency=10GHz



Input power vs NF




Phase noise of different amplifiers at 10GHz
GaAs PHEMT,Gain=11dB, Pin=+2.57 dBm, Pout (-1dB)=23dBm, NF=3.4dB
GaAs PHEMT,Gain=12dB, Pin=+2.57 dBm, Pout (-1dB)=17dBm, NF=2.6dB
PHEMT,Gain=12dB, Pin=+3.7dBm, Pout=18dBm, NF=6.5dB
GaAs HEMFET, Gain=32.5dB, Pin=-20.7dBm, Pout=10.5dBm, NF=1dB
Narda Amp (33 dB gain), Pin=-2.73dBm, Pout=33dBm
Avantek Amp. (25dB gain), Pin=-6.8dBm, Pout=20dBm, NF=3.5dB
Noise floor of the measurement system
L(f) dBc/Hz
-90
-100
-110
-120
-130
-140
-150
-160
-170
-180
-190
-200
1
10
100
1000
10000
100000
1000000
10000000
Frequency (Hz)

Confidence Interval

$$S_{\phi}^{m}(f) = S_{\phi}^{s}(f)\left[1 \pm \frac{k}{\sqrt{N}}\right]$$

$$= S_{\phi}^{s}(f)\left[1 \pm 0.00038\right]$$

m= cross-correlated noise

s= single channel noise

N= number of samples =5000

K = confidence interval index=1.9