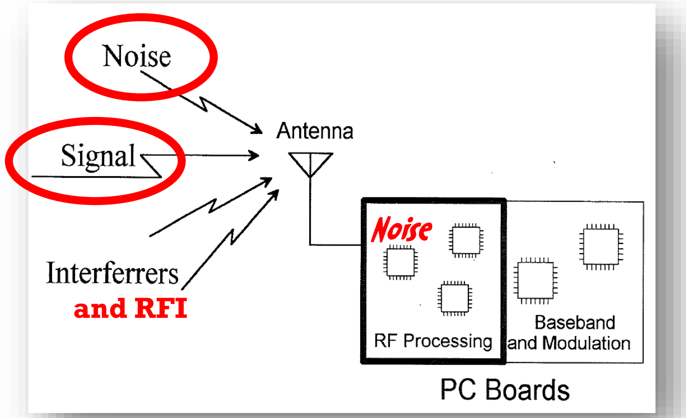
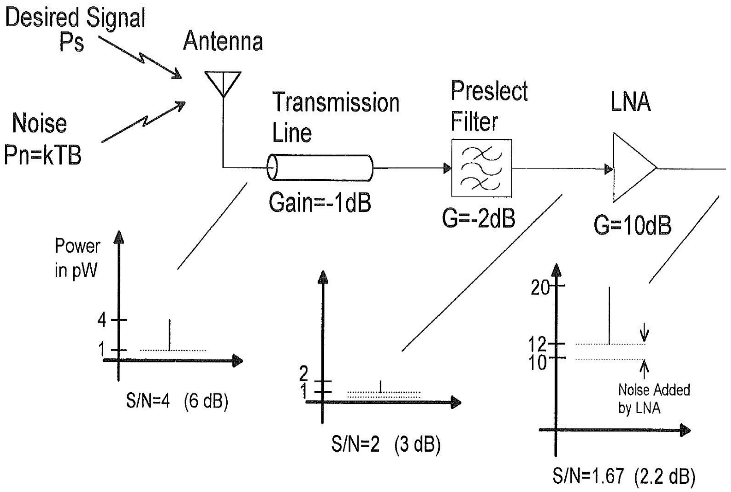
Radio Design 401, Episode 2 - SNR, Noise Figure, and Receiver Sensitivity

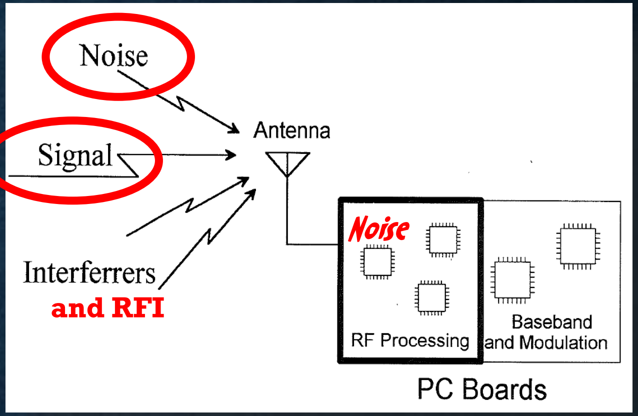
This is Episode 2 of our advanced series: Radio Design 401. In this episode we discuss signal-to-noise ratios, component and receiver noise figures, and how to estimate overall receiver sensitivity. The traditional definitions and formulas are covered, but within the context of real-world examples. The goal is to develop an intuitive understanding of the topics in addition to understanding the math involved in calculations. Radio Frequency Interference (RFI) is very briefly mentioned at the end, and will be elaborated in the next episode.





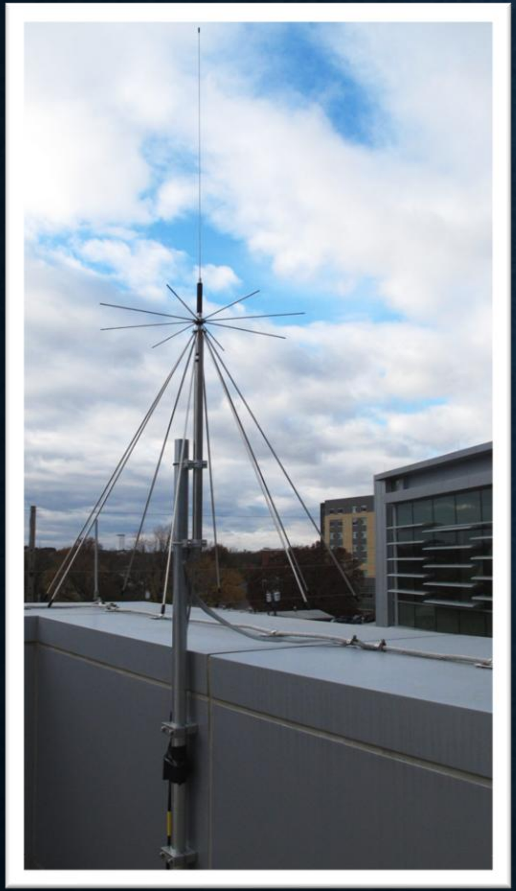
Radio Design 401

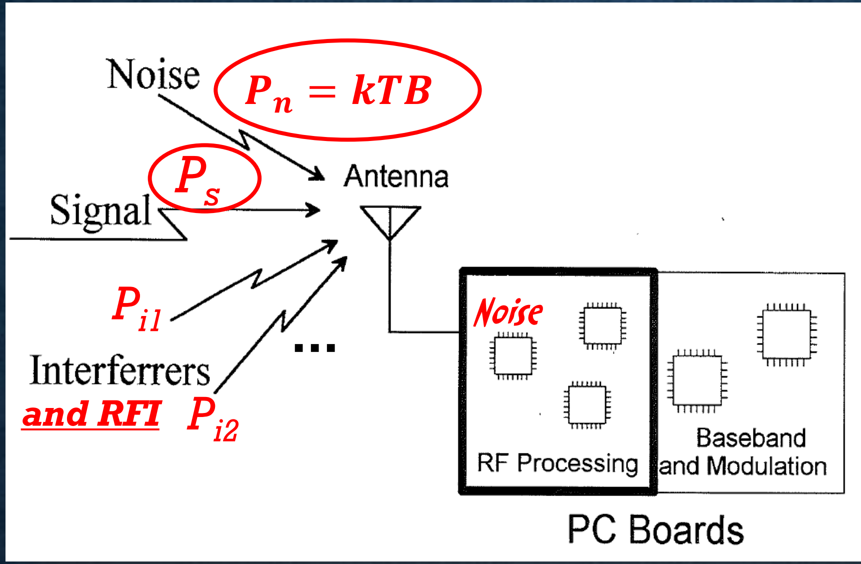
Episode 2

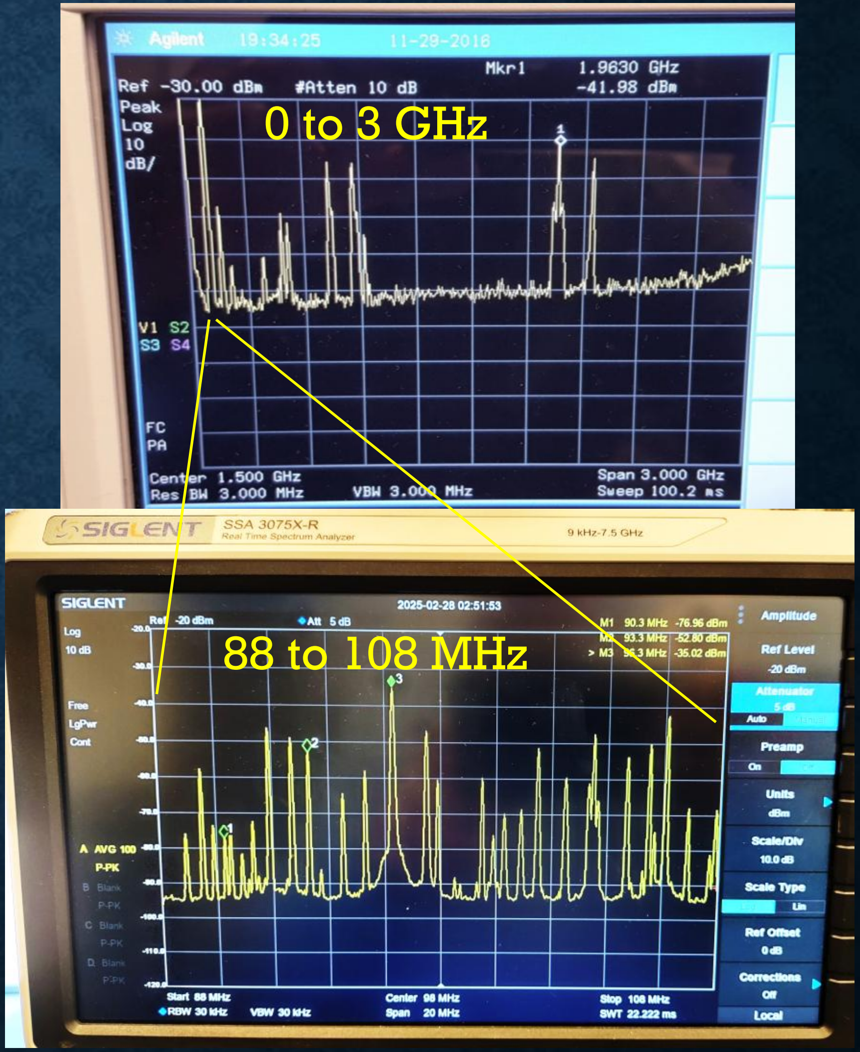


SNR, Noise Figure, and Receiver Sensitivity

Receiver Signal Environment







NOTE/CAUTION:

*Signal, Noise, and Interferer levels may be in "**linear" units** (e.g. Watts, mW), or **log units** (dBW, dBm)*

Noise, SNR, and Noise Figure

Types of "Noise"

- Thermal: $P_n = k\,T\,B$ = 8E-16 Watts (-121dBm) w/ k=1.38E-23 $\frac{W}{K \cdot Hz}$, T=290K, B=200kHz
- RFI: Unintended emissions from lighting, switch-mode power supplies, etc.
- Circuit: Thermal, shot, 1/f, quantization … (e.g. for a resistor: $V_n = \sqrt{4kTRB}$)

Receiver needs $P_s > P_n$ to demodulate signal

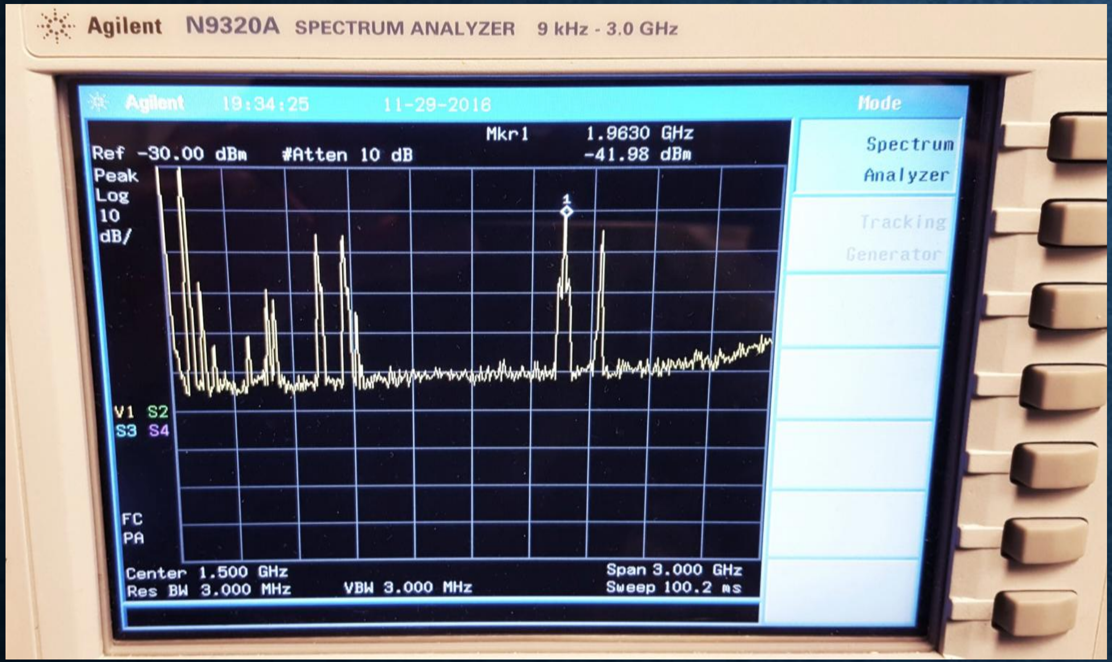
- S/N_{min} = 10 to 20+ dB for FM Broadcast
- S/N_{min} = 3 to 10 dB for deep-space probe using BPSK

Noise Figure

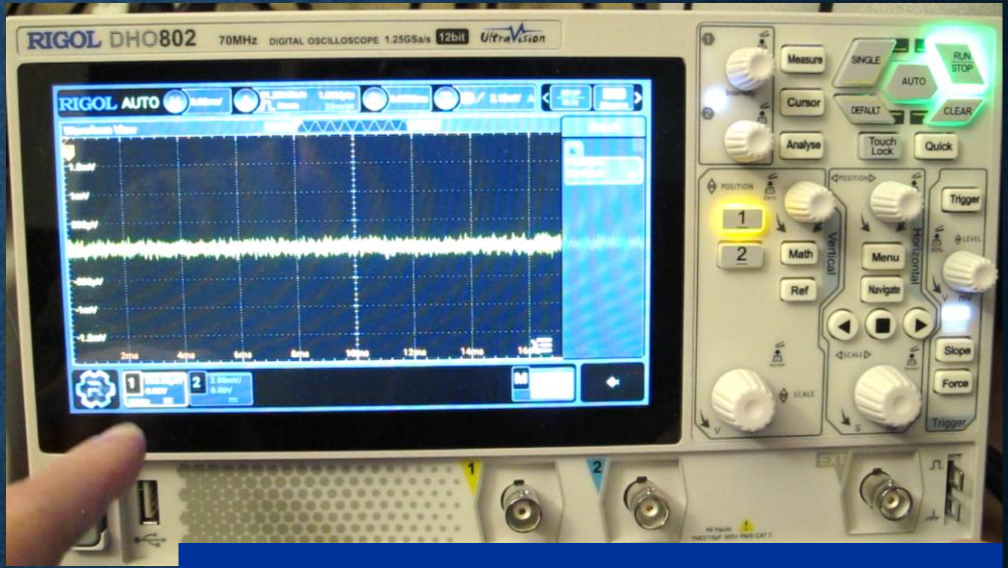
- (S_{in}/N_{in}) / (S_{out}/N_{out}) for front-end, or full receiver (front-end usually dominates)
- Difference (in dB) between theoretical and actual output noise levels

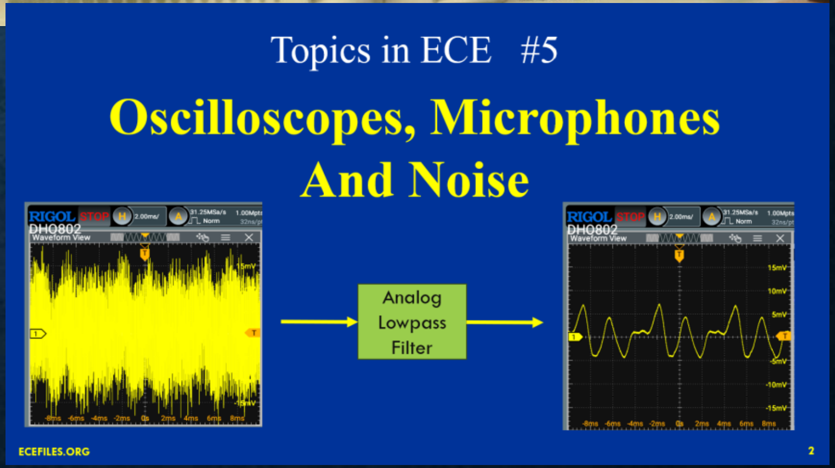
“Seeing” Noise ☺

Frequency Domain

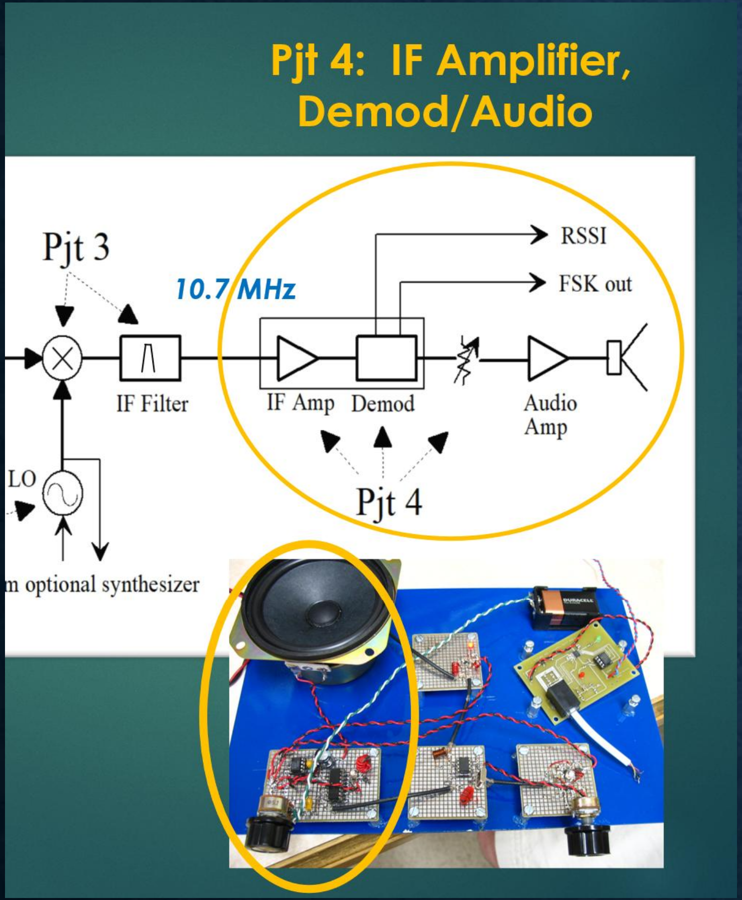


Time Domain





FM Demod SNR_{out} vs SNR_{in}



From Radio Design 101
Episode 6

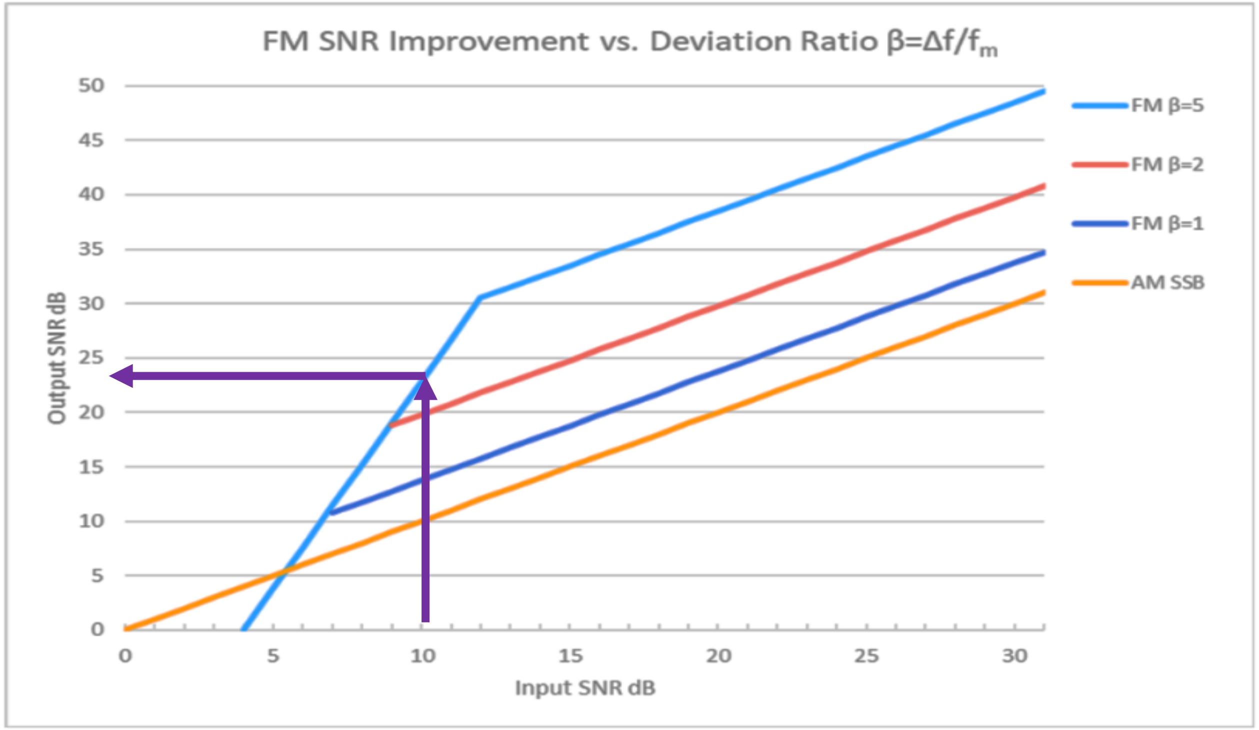
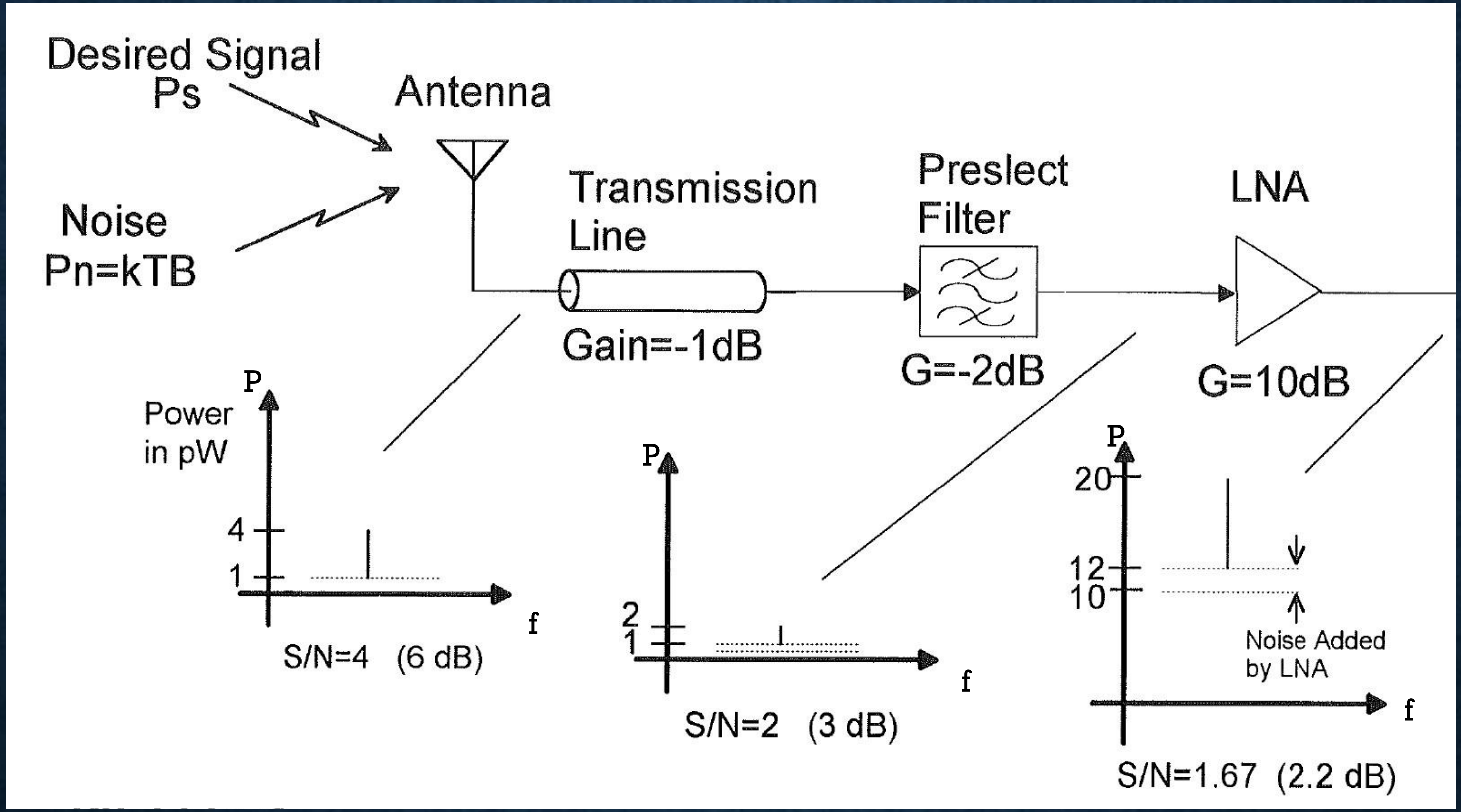


Figure 1: Input vs. output SNR for FM reception/demodulation for β = 1, 2, and 5 showing FM threshold and improvement.

From Mini-Circuits blog:
https://blog.minicircuits.com/frequency-modulation-fundamentals/

Front-End Noise Figure



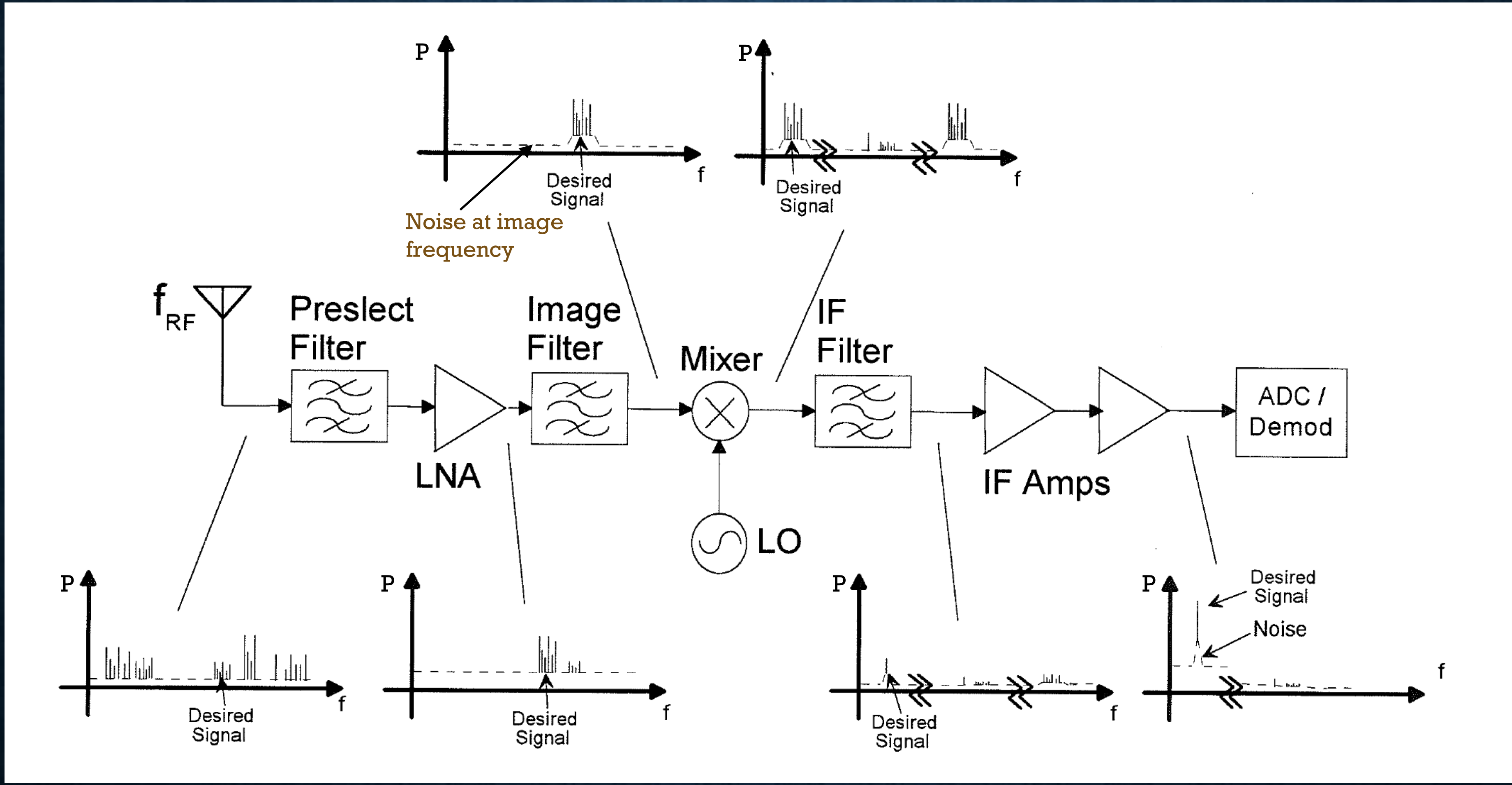
*Signal, Noise, and Interferer levels shown in **linear** power units here !*

Noise Figure $(S_{in}/N_{in}) / (S_{out}/N_{out}) = 4 / 1.67 = 2.4$ here,

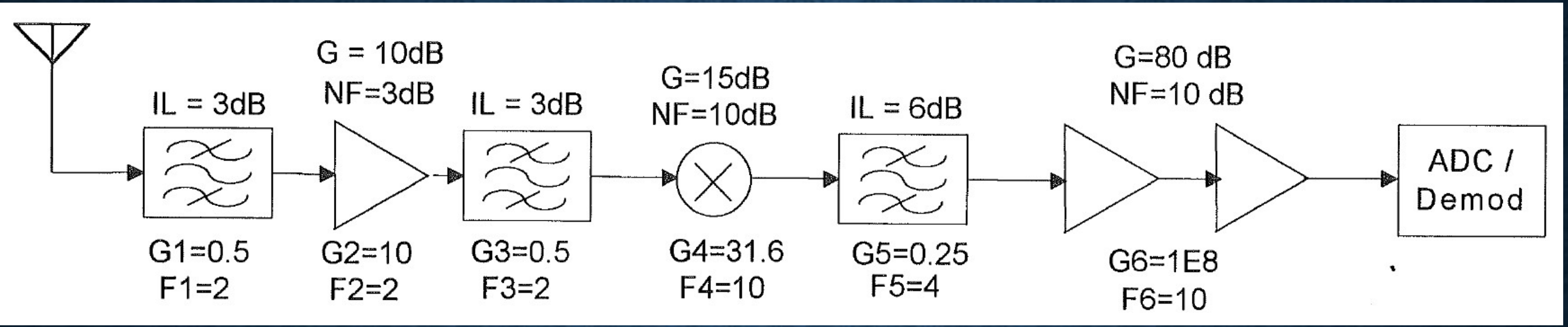
or, in dB: $(S_{in}/N_{in})_{dB} - (S_{out}/N_{out})_{dB} = 6\text{dB} – 2.2\text{dB} = 3.8\text{ dB}$

What is the LNA's NF in this example?

Typical Radio Receiver



Overall Receiver Noise Figure



Friis Noise Figure calculation (Note: F is NF in linear power units)

$$F_{rcvr} = F_1 + \frac{F_2-1}{G_1} + \frac{F_3-1}{G_1G_2} + \frac{F_4-1}{G_1G_2G_3} + \frac{F_5-1}{G_1 \ldots G_4} + \frac{F_6-1}{G_1 \ldots G_5}$$

$$= 2 + 2 + 0.2 + 3.6 + 0.04 + 0.46$$

$$= 8.3 \quad => \quad NF = 9.2\ dB$$

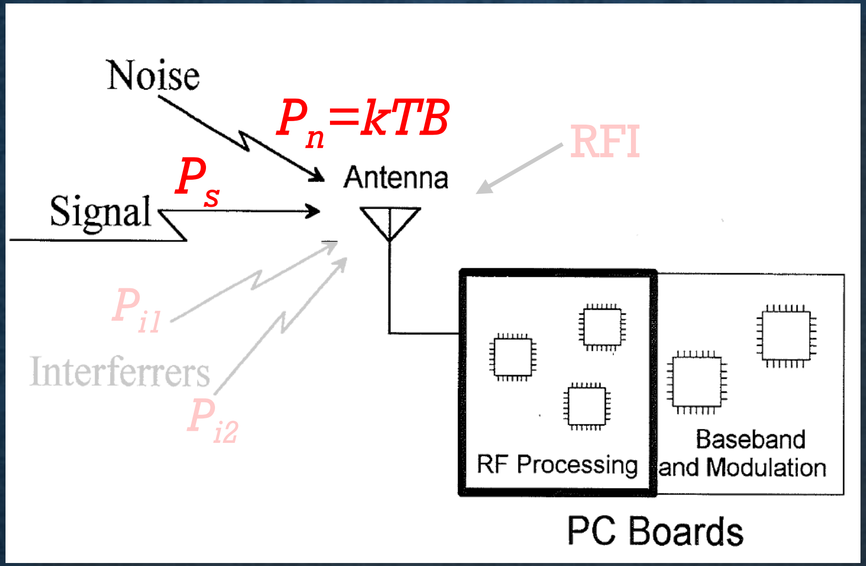
Observations:

Losses ahead of LNA degrade NF significantly here

Front-end usually sets/controls overall receiver NF

Need to increase LNA gain, and/or lower mixer NF !

Overall Receiver Sensitivity



$$P_{s\_min} = -174 \text{ dBm} + 10\log(B) + S/N_{min} + NF_{rcvr}$$

Caveats: Assumes $T \approx 290K$, no RFI, and High Dynamic Range receiver (no receiver intermod issues)

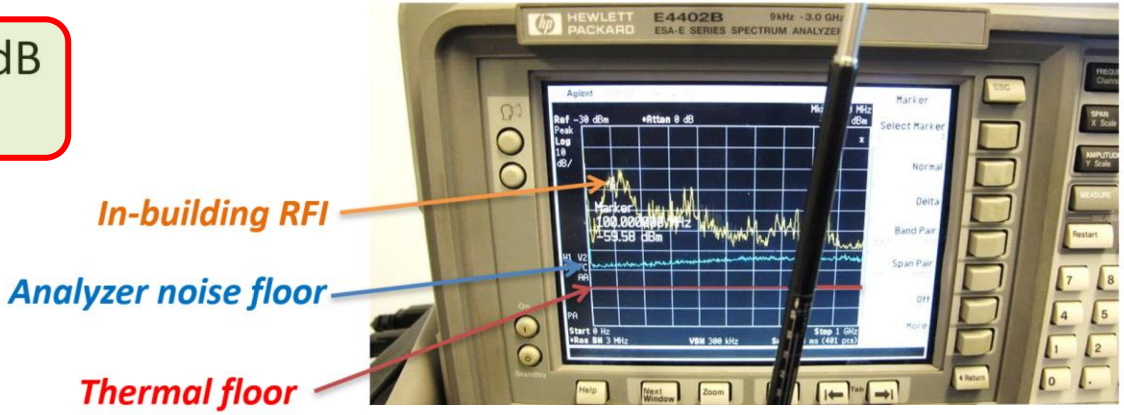
Example: FM Broadcast (mono) with B=200 kHz, S/Nmin=10 dB and NF = 3 dB

$$P_{s\_min} = -174 \text{ dBm} + 10\log(200k) \text{ dB} + 10 \text{ dB} + 3 \text{ dB} \approx \underline{-108 \text{ dBm}}$$

RFI Limitations

See: "Wireless communication problems in energy-efficient building construction," IEEE International Symposium on Electromagnetic Compatibility (EMC), 2016

- The problem is two-fold:
  - *Energy efficient exterior glass attenuates signals entering (or leaving) the building*
  - *Interior lights produce high levels of RFI*
- Glass attenuation measured up to 30 dB
- RFI from interior lighting is up to 60 dB or more above thermal noise floor
- **Wireless communication links (especially at VHF) can be strongly impacted**



Possible Future Videos

- ***Receiver Performance*** **(Including the math)**
  - *Noise analysis and simulation in circuits*
  - *Compression, Intermodulation, 3rd Order Intercept Point, and SFDR*
  - *Noise Figure Tradeoffs with Intermod Performance (including CTB ?)*

- ***Design of Q-enhanced Front-ends*** **(Follow-up to Episode 1)**
  - *Effects of positive feedback on gain, selectivity, input Z, ...*
  - *Core CB amplifier design (Q_o of inductors, feedback topology, biasing for desired gain…)*
  - *Self-tuning hardware and software ?*

- ***Effects of Flourescent/LED lighting, switch-mode power-supplies, and other RFI sources on radio system noise floor***

Thanks For Watching !