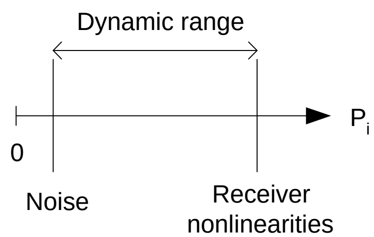
Lecture 33: Noise, SNR, MDS, Noise Power Density, and NEP

The performance of any receiver is limited by both the smallest and the largest signals it can receive.



On the low end, the receiver is limited by noise. On the high end, the receiver is limited by the strongest signal it can receive without producing spurious responses.

Both of these topics are discussed in Ch. 14 of the text. We'll begin with noise in this and the next lecture.

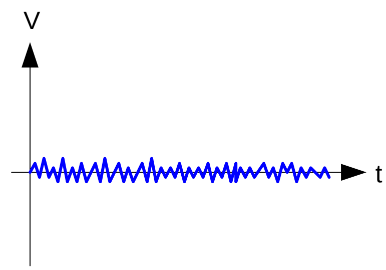
Noise

Noise has many origins in a circuit. For a receiver, noise is mostly thermally generated in resistors (including attenuators), semiconductors, amplifiers, mixers, and some filters.

Noise is generally not associated with inductors or capacitors.

Additionally, noise signals are also received through antennas. This noise is generated by thunderstorms, galactic and solar bodies, and manmade sources.

Noise measured on an oscilloscope gives the familiar "grass" signature:



While the time average of this noise voltage is zero, its RMS value is not zero:

$$V_{rms} = \sqrt{\frac{1}{\tau} \int_{t_0}^{t_0+\tau} V^2(t)\, dt} \tag{14.1}$$

where τ is an averaging time. This noise signal also has a time average noise power P_n associated with it

$$P_n = \frac{V_{rms}^2}{R} \quad \text{[W]} \tag{14.2}$$

where R is some resistance.

It really doesn't make sense to talk about "peak-to-peak noise voltage" since noise is not sinusoidal. Rather, it's some random waveform.

Signal to Noise Ratio

A receiver's audio output signal is characterized by its signal-to-noise ratio (SNR) defined as

$$\text{SNR} = \frac{P}{P_n} \tag{14.3}$$

where P is the audio RMS output power and P_n is the audio RMS output noise power.

Depending on your application, different receivers may require wildly different SNRs. Voice may require an SNR of 40:1, for example, while CW (Morse code) can be understood with an SNR approaching 1:1. Amazing!

Minimum Discernible Signal

A good all-around comparison of receiver performance is the minimum discernible signal (MDS).

MDS is defined as the *input* signal power required to produce a 1:1 SNR at the *output*. From (14.3), this implies

$$P = P_n \tag{1}$$

Dividing (1) by the overall receiver gain G we find

$$\text{MDS} = \frac{P_n}{G} \quad [\text{W}] \tag{14.4}$$

since P/G is the input signal power producing the 1:1 SNR.

To measure MDS in the lab, we generally do not directly apply the definition (14.4). Instead, MDS is computed from two receiver output (audio) measurements:

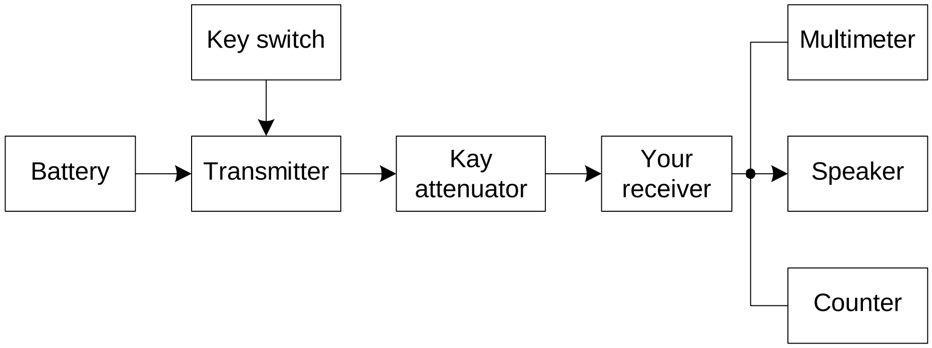
1. P_n of the receiver is measured (no input signal),
2. MDS *for receiver noise* is equal to the input signal power that doubles that output power (that is, to $2P_n$).

In the lab, you'll be measuring V_{rms}. Therefore, you need to measure the input signal power that increases the output voltage by $\sqrt{2}$ in order to compute MDS.

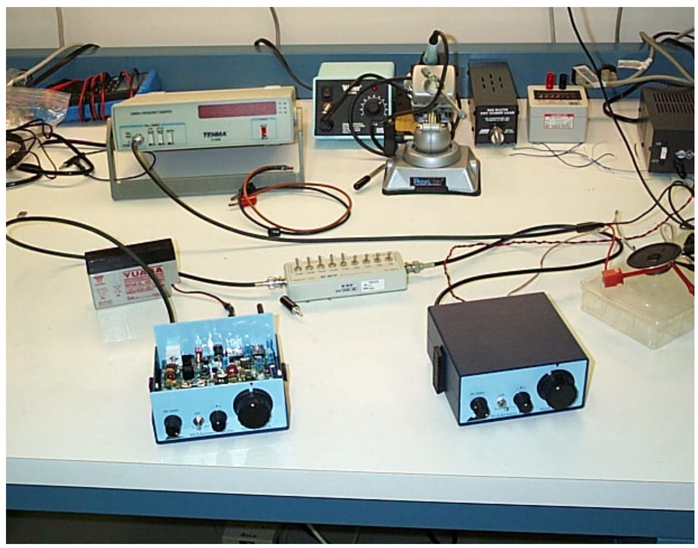
Laboratory Arrangement for MDS Measurement

In Prob. 34 "Receiver Response" you'll measure a number of receiver characteristics including MDS for receiver noise, and again later for antenna noise.

The experimental arrangement for this measurement is shown in Fig. 14.11:



Your equipment layout will look something similar to this:

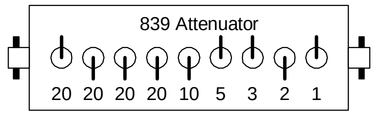


It's worthwhile to connect the counter to the speaker. Other important points related to this problem include:

1. You will need to work with pairs of receivers, so find a partnering team. One transceiver acts as the transmitter, while yours is the receiver. Then interchange the radios and repeat the measurements.
2. A battery powers the transmitter (or better, the receiver). We're dealing with very small signals in these measurements so we don't want signal coupling through the ac line.

3. You will use a Kay 839 attenuator. A toggle "up" adds that amount of attenuation to the line:

For example, 29 dB of attenuation is selected:



Decibels Above 1 mW (dBm)

Throughout these measurements, you'll be dealing with signals having average powers expressed in units of dBm. This is shorthand for "dB referenced to 1 mW." That is:

$$P(\text{dBm}) = 10\log_{10}\left(\frac{P}{10^{-3}}\right)$$

As an example, let's determine the absolute power given by -40 dBm:

$$-40 \text{ dBm} = 10\log_{10}\left(\frac{P}{10^{-3}}\right)$$

or
$$\log_{10}\left(\frac{P}{10^{-3}}\right) = -\frac{40}{10} = -4$$

Therefore
$$\frac{P}{10^{-3}} = 10^{-4}$$

or
$$P = 10^{-4} \cdot 10^{-3} = 0.1 \ \mu\text{W}$$

Noise Power Density and NEP

The noise power P_n does not appear at just one frequency. Instead, noise power is distributed over a range of frequencies.

In recognition of this, noise power density N is defined as the noise power per unit bandwidth (W/Hz) as:

$$\boxed{P_n = N \cdot B \quad [\text{W}]} \tag{14.5}$$

where B is a chosen bandwidth. We'll assume that N is constant here – which is certainly a reasonable approximation when B is small, say for a narrow band receiver such as the NorCal 40A.

This is important: We see from (14.5) that output (i.e., audio) noise power is proportional to bandwidth (BW). Some receivers actually have BW switches to choose a wider or narrower BW filter for different situations:

1. A wide BW for ease of locating stations,
2. A narrow BW for reducing noise.

We can now see that the MDS we defined earlier as

$$\text{MDS} = \frac{P_n}{G} \tag{14.4}$$

will depend on the bandwidth of the receiver since P_n is proportional to B in (14.5).

It is useful to have a measure of the receiver performance that is independent of BW. Why? Because BW is determined primarily by filters, but filters contribute little to receiver noise (mixers and amplifiers are the major contributors).

In this vein, noise equivalent (input) power density (NEP) is defined as

$$\boxed{\text{NEP} = \frac{N}{G} \quad [\text{W/Hz}]} \tag{14.6}$$

Comparing this definition with (14.4), we can see that NEP is similar to MDS in that NEP is related to N in the same manner as MDS is related to P_n.

Alternatively, we can derive an expression for NEP beginning with MDS defined in (14.4) as

$$\text{MDS} \equiv \frac{P_n}{G} \tag{14.4}$$

Then,

$$\underbrace{\frac{\text{MDS}}{B}}_{\equiv \text{NEP}} = \frac{P_n}{G} \cdot \frac{1}{B} = \underbrace{\frac{P_n}{B}}_{=N} \cdot \frac{1}{G}$$

Consequently,

$$\text{NEP} = \frac{N}{G}$$

which is (14.6).

NEP is simply all receiver output noise density referred to the receiver input, for a receiver with total gain G.

In Prob. 34F you will measure *N* and NEP for your receiver. Notice that for Probs. 34F through 34I you will *not* need the first NorCal 40A for input.

To determine NEP, it's useful to have a source that supplies noise of a given RMS level with a specified bandwidth.

Your Agilent 33120A provides such a signal. Select the "Noise" button and enter the power in dBm or the corresponding V_{rms}. Do NOT enter a p-t-p value since this doesn't make sense for noise signals.