Lab 7: Satellite Receiver System Measurements

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I. Introduction

Each of the individual components that have been designed throughout this course have a specific job as part of the weather satellite receiver chain. All of the circuit boards will be cascaded together using barrel SMA adapters in a chain. First the low-noise amplifier (LNA), then the bandpass filter (BPF), then the ERA amplifier, and lastly the mixer along with the voltage-controlled oscillator (VCO). The system will be characterized in terms of its S parameters using the vector network analyzer (VNA), it's noise figure using the same setup as previous labs, and its signal-to-noise-and-distortion (SINAD) ratio in dB. Finally, the weather satellite receiver system will be tested in the field to record the broadcast APT satellite signal.

II. Objectives

The first objective of this lab is to assemble the satellite receiver chain. The second objective of this lab is to characterize the receiver in terms of its gain, noise figure, and SINAD ratio. The last objective of this lab is to use the cascaded system to receive the Automatic Picture Transmission (APT) broadcast satellite signal and use a Software-Defined Radio (SDR#) to FM demodulate and record the audio output.

III. System Overview

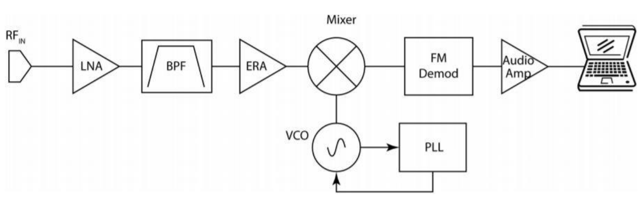

Fig. 1. Block diagram for the Weather Satellite Receiver system.

The weather satellite receiver system can be depicted in Figure 1. The quadrifilar antenna is a transducer that will convert the incoming electromagnetic waves to voltages with which the system can work, which will be called the RF input signal. After the antenna, the first stage of the receiver is the low noise amplifier (LNA) used to boost up the incoming RF signal by approximately 24 dB. The second stage is the bandpass filter (BPF) used to allow frequencies around 137.5 MHz into the receiver. The third stage of the system is the ERA "drop-in" amplifier used to boost up the filtered out signal by approximately 14 dB. Lastly, the 4th stage of the system is the mixer along with the local oscillator (VCO) used to mix down the RF input signal from around 137.5 MHz to 10.7 MHz, before entering the FM demodulator. For the FM demodulator, a Software-Defined Radio (SDR#) will be used to FM demodulate the 137.5 MHz carrier signal down to 2.4 kHz, where the message is found. Using the RTL-SDR dongle, the audio output resulting from FM demodulation will be recorded in order to be later analyzed or processed using a software such as WXtoImg in order to decode the APT message and convert it to a grayscale image.

IV. Experimental Results

Once the system is cascaded, all of the individual components can be powered using a single 10 V power supply to provide the bias voltage, since each component has a corresponding voltage regulator.

A. Cascaded System Gain

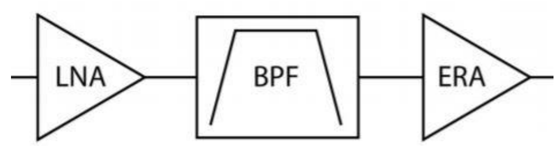

Fig. 2. System chain for S parameter measurement using the VNA.

The first cascaded system consists of the LNA, the BPF and the ERA connected together in order to confirm the gain of the amplifiers is correct, as well as confirming the bandpass filtering is working as expected. Figure 2 shows how this setup will be connected.

Before measuring this cascaded system, first the bandpass filter alone was connected to the VNA in order to measure its S21 parameter. Figure 3 below shows a graph of the S21 parameter of the bandpass filter, it can be seen that around 137.5 MHz the S21 parameter is -3.547 dB, which is really

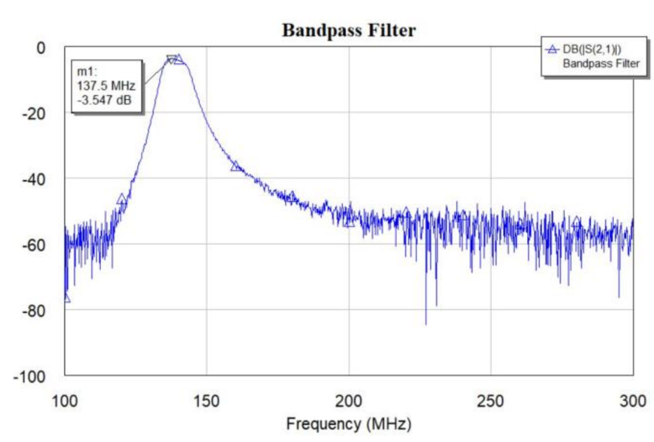

Fig. 3. Bandpass filter S21 parameter measured using the VNA.

close to zero, meaning most of the signal is propagated through this filter around this particular frequency. However, for frequencies that are not around 137.5 MHz, the S21 parameter was around -60 dB, which means those signals are rejected.

Once the performance of the bandpass filter was confirmed, the cascaded system was measured in terms of its S21 parameters using the VNA. A graph of this plot is shown in Figure 4. The LNA's gain was measured at approximately 25.5 dB, the ERA's gain was measured at about 14.5, and the BPF's loss was measured at about 3.5 dB. This means the cascaded system should have a theoretical gain of approximately 36.5 dB. The experimental gain of the cascaded system was found to be 36 dB, as seen in Figure 4, which coincides with the expected results.

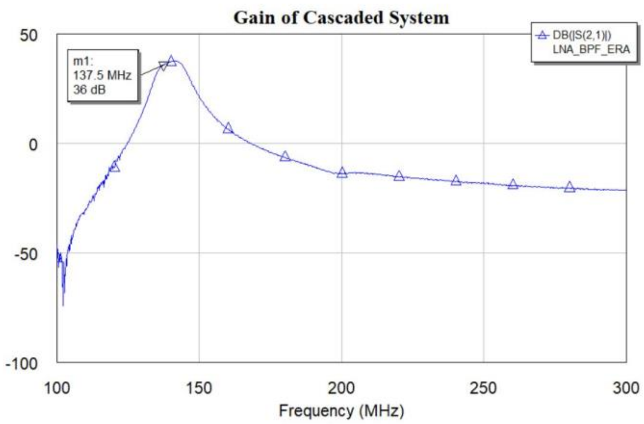

Fig. 4. Cascaded system S21 parameter measured using the VNA.

B. *Noise Figure*

To measure the noise performance of the receiver, the previous cascaded system was extended to include the mixer and a local oscillator input. The VCO was not able to be used as part of the receiver due to the PLL not working properly, so an oscillating signal was created using a signal generator. The setup for this measurement, and the next one, is shown in Figure 5.

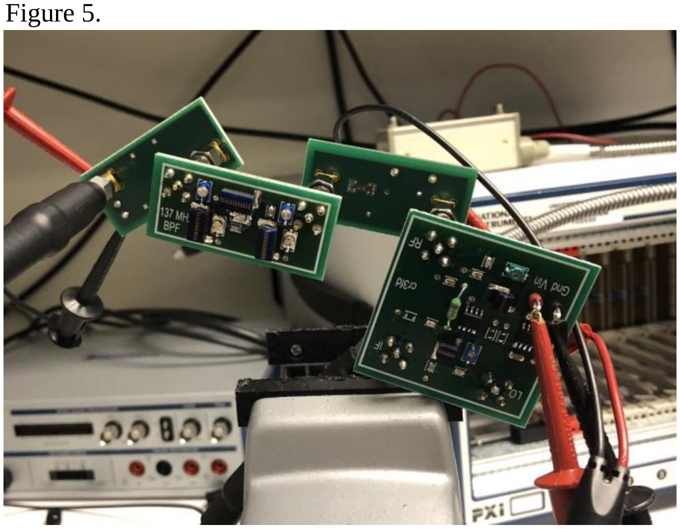

Fig. 5. Cascaded system (Receiver).

A calibrated noise source is used in order to apply two known noise powers at the RF input, then the IF output can be measured using a spectrum analyzer. The spectrum analyzer has a noise figure itself, so this must be taken into account in calculating the noise figure for the mixer. The experimental set up is shown in Figure 6.

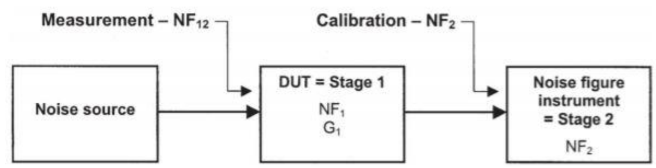

Fig. 6. Noise figure measurement setup.

In order to measure the noise figure at a particular frequency, first the noise figure of the spectrum analyzer itself is identified, then the noise figure of the entire cascaded system can measured. The noise figure of this system is determined by equation 1:

$$F_1 = F_{12} - \left(\frac{F_2 - 1}{G_1}\right) \tag{1}$$

Next, the measurewment system noise figure F_2, the gain of the cascaded system G_1, and the noise figure of the entire cascaded system F_{12} are calculated at each frequency using the following equations:

$$F_2 = \frac{ENR_1}{Y_2 - 1}, \qquad where\ Y_2 = \frac{N2_{on}}{N2_{off}}$$

$$G_1 = \frac{N12_{on} - N12_{off}}{N2_{on} - N2_{off}}$$

$$F_{12} = \frac{ENR_2}{Y_{12} - 1}, \qquad where\ Y_{12} = \frac{N12_{on}}{N12_{off}}$$

The ENR values in the equations above refer to the excess noise ratio (ENR) that is associated with the calibrated noise source for this measurement setup. For the particular noise source used in this experiment, the ENR_1 corresponds to the 10 MHz range and it is 16.18 dB, while the ENR_2 corresponds to the 100 MHz range and it is 16.23 dB. Using these equations, the noise figure for the cascaded system setup shown in Figure 5 is plotted in Figure 7 for frequencies ranging from 10 MHz to 15 MHz. At around 10.7 MHz, the noise figure was found to be approximately 2.4 dB. This experimental result will be compared to the analytical equivalent noise figure for a cascaded system.

The bandpass filter was not characterized by the students in the lab, so the noise figure of this stage is not known and will be excluded from the system's noise figure calculation. Therefore, assuming a 3 stage cascaded system consisting of the LNA, the ERA and the mixer, its noise figure can be found using equation 2 below:

$$F_{123} = F_1 + \left(\frac{F_2 - 1}{G_1}\right) + \left(\frac{F_3 - 1}{G_1 G_2}\right) \tag{2}$$

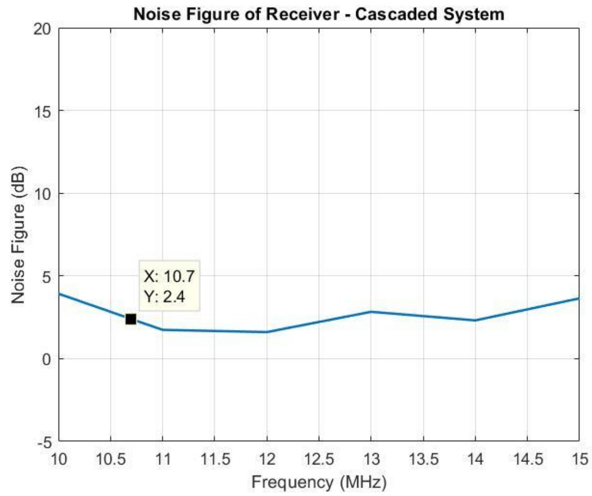

Fig. 7. Experimental noise figure of cascaded system (Receiver).

where G_1 is the gain and F_1 is the noise figure of the LNA, G_2 is the gain and F_2 is the noise figure of the ERA, and finally F_3 is the noise figure of the mixer. Using this information and equation 2, the analytical noise figure of the cascaded system excluding the BPF resulted in about 0.98 dB.

C. SINAD

The final measurement for the satellite receiver will be its 12 dB signal-to-noise-and-distortion (SINAD) ratio, which is the standard used for specifying the sensitivity for an FM receiver. In order to find the RF input power that results in a 12 dB SINAD, the signal generator will be used in order to generate a 2.4 kHz waveform and FM modulate it to a 137.5 MHz carrier frequency with 34 kHz bandwidth. A variable attenuator is then used between the signal generator and the receiver input in order to lower the RF input power. The variable attenuator is then connected to the input of the receiver, and the amplified/frequency-shifted IF output signal is then connected to the RTL-SDR dongle. The dongle is then connected to a computer running a software defined radio (SDR#) in order to FM demodulate this signal. This software can be used to record the audio output from FM demodulation, as shown in Figure 8.

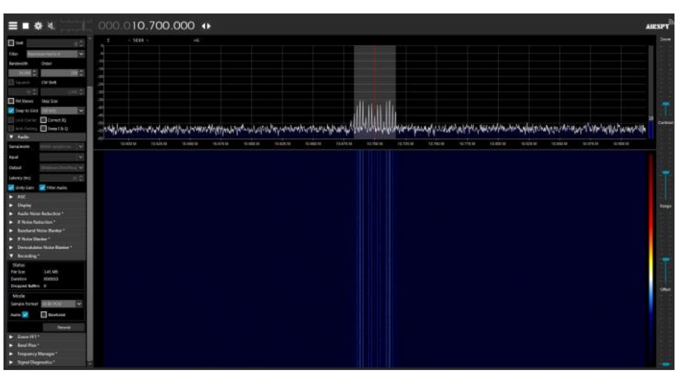

Fig. 8. FM demodulation and recording of IF signal at 10.7 MHz using SDR#

After having recorded the audio, the data can be extracted into MATLAB and analyzed using the **sinad(data,fs)** command, in order to generate a power spectrum plot of this data and calculate the SINAD ratio. A plot of this data can be seen in Figure 9, where a -122 dBm RF input signal yields a SINAD ratio of 11.17 dB, which is fairly close to the desired 12 dB.

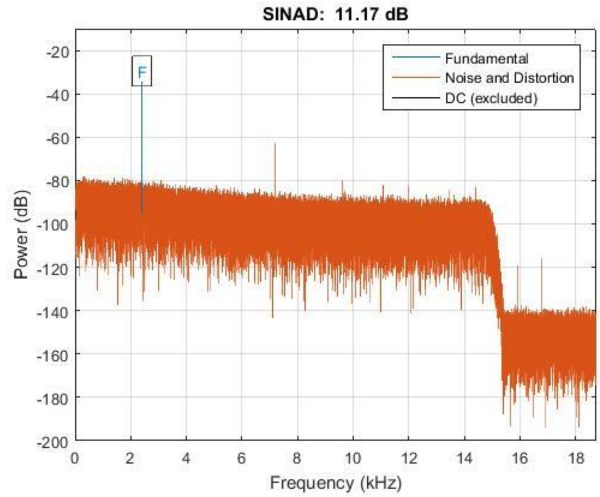

Fig. 9. Power Spectrum of audio file obtained using receiver and FM demodulator. The SINAD ratio for this signal was 11.17 dB with an RF input power of -122 dBm.

In order to find the RF input power that resulted in a SINAD ratio of approximately 12 dB, the variable attenuator was gradually changed in order to find the minimum detectable signal for this receiver. Table I shows the different SINAD ratios obtained from varying the RF input power. For RF input powers higher than -120 dBm, it can be seen that the SINAD ratio was higher than 16.84 dB, but when the power dropped to -130 dBm the SINAD ratio went all the way down to -4.92 dB. However, for an RF input power of -122 dBm, the SINAD ratio falls to approximately 11.17 dB.

TABLE I
RECEIVER SINAD MEASUREMENTS

Signal Generator RF Power (dBm)	Attenuation (dB)	Receiver input RF Power (dBm)	SINAD (dB)
-60	30	-90	32.52
-60	40	-100	32.12
-60	60	-120	16.84
-60	70	-130	-4.92
-62	60	-122	11.17

V. SATELLITE RECEPTION

After the receiver chain's performance was experimentally characterized, a field experiment was performed by taking the receiver, antenna, and other equipment to Darden courtyard and attempt to receive a signal from one of the weather satellites orbiting Earth. The satellite chosen was NOAA-19, which operates at a carrier frequency of 137.1 MHz. Since the PLL was not working, and a portable signal generator was not available, the mixer was excluded from the receiver chain for this experiment. Using the same setup as the SINAD measurement performed in the lab, a signal was attempted to be recorded as shown in Figure 10, but it failed.

Fig. 10. Field experiment setup in order to attempt to get a satellite signal.

Although the field experiment did not find a proper signal and the audio output was essentially all noise, the audio file provided in Collab was used to visualize what the data would have looked. Using audacity, this audio was low-pass filter with a cutoff frequency of 5 kHz and then down-sampled. The filtered audio was then converted to a gray scale image using WXtoImg software to decode the audio message and overlay a picture of the Earth. Figure 11 shows an image from the satellite, and what the data would have looked if the signal was found.

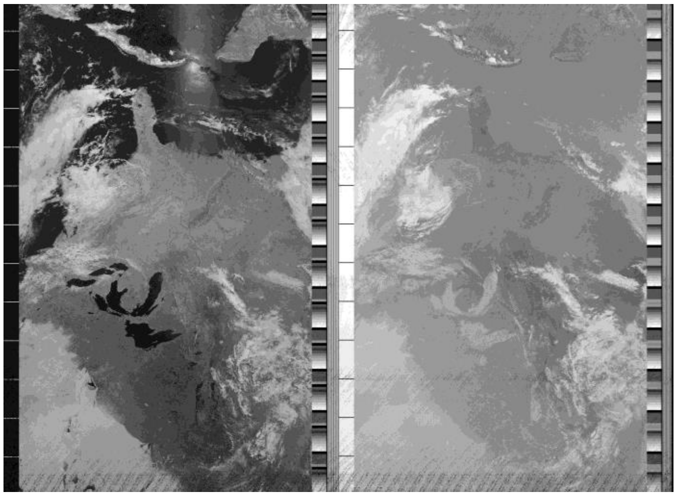

Fig. 11. Decoded Satellite Image from audio file provided in Collab.

VI. Discussion and Conclusion

The main objective of this lab was to experimentally characterize the receiver chain in the lab and then perform a field experiment in Darden courtyard. The gain of the receiver chain resulted in 36 dB around 137.5 MHz, which was very close to the expected value of 36.5 dB (accounting for the BPF's loss). The noise figure was analytically calculated to be approximately 1 dB, but the experimental results gave the system a noise figure of 2.4 dB. The reason for this discrepancy is probably due to the fact that the BPF was excluded from the analytical noise figure calculation. Lastly, the RF input power at 12-dB SINAD ratio for the receiver was found to be approximately -122 dBm. The field experiments were inconclusive, as a signal was not received during the available time. I found an online NOAA satellite tracker and the posted times did not seem to coincide with the real-time tracker, so the satellite was potentially not there when we tried to get a signal.