Matthew Spencer – Fall 2023

Lab 6: Noise and Linearity in Amplifiers

In this lab you will use a spectrum analyzer to measure the propagation of noise and distortion products through several amplifiers in series.

After this lab, you will be able to:

1. Analytically predict distortion products produced by amplifiers and verity them with experiment.
2. Analytically predict the noise floor of a receiver chain and verify it with experiment.

Practical Questions

1. What is the maximum input power of the spectrum analyzer in our lab (an N9320b, linked below)? How many 30dBm amplifiers can you put in series with a -30dBm function generator before you are violating the maximum input power? https://www.keysight.com/en/pdx-x201742-pn-N9320B/rf-spectrum-analyzer-bsa-9-khz-to-3-ghz?cc=US&lc=eng
2. What is a typical range of received cell phone power levels?
3. What does VGA stand for and why are VGAs used in cell phone receiver chains?
4. What is a transmit/receive switch and why is it used in a cell phone?

Theory Questions

1. Use values on the datasheet to calculate the gain, noise figure, output power at P-1dB, and OIP3 of the ZX60-2531M-S+ amplifier at 600 MHz powered with a +5V supply.
2. Consider a two-tone intermodulation test using the frequencies ω1 and ω2. In the spectrum in Figure 1…
    a. Write a (1) over the fundamental tones
    b. Write a (2) over the second-order intermodulation products
    c. Write a (3) over a third-order intermodulation products
    d. Write an (H) over products that are harmonics of fundamental frequencies
3. Consider the log-log plot of output power against input power in Figure 2. Label…
    a. The line corresponding to the fundamental tones
    b. The line corresponding to the second-order products
    c. The line corresponding to the third-order products
    d. The 1-dB compression point
    e. The second-order intercept
    f. The third-order intercept
    g. The output-referred P-1dB power
    h. The output-referred IP2 power (OIP2)
    i. The output-referred IP3 power (OIP3)
    j. The input-referred IP2 power (IIP2)
    k. The input-referred IP3 power (IIP3)

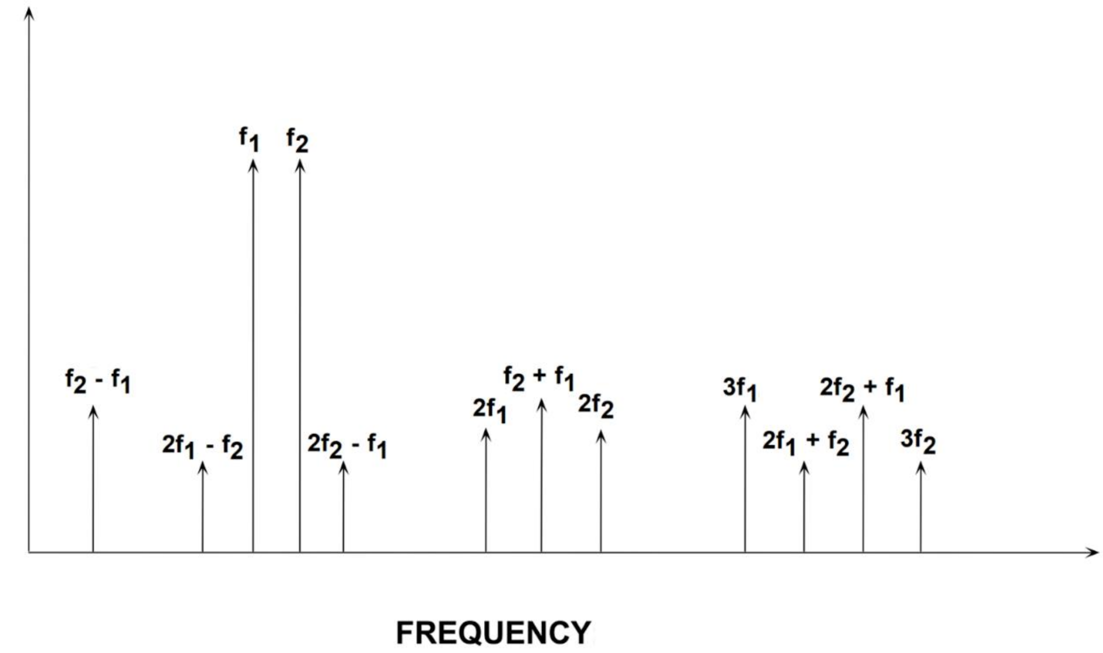

Figure 1

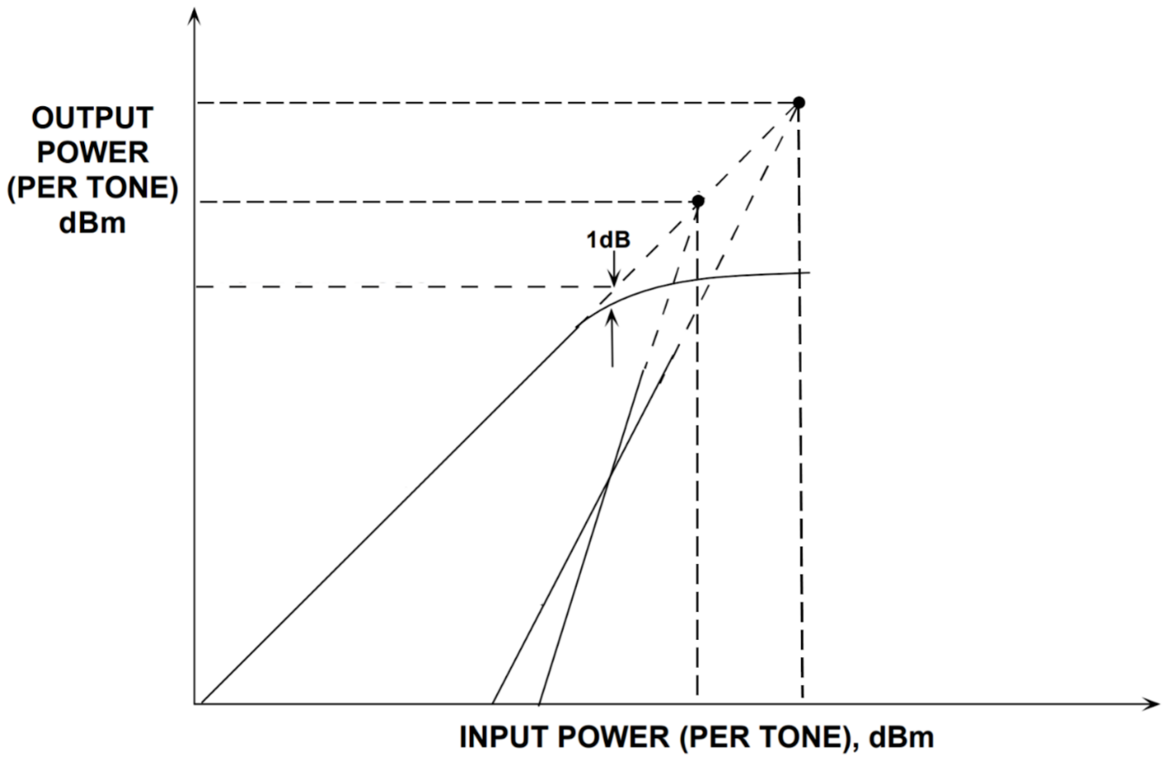

Figure 2

4. An amplifier with a gain of 12 dB, a bandwidth of 150 MHz, and a noise figure of 4 dB feeds a receiver with a noise temperature of 900 K. Find the noise temperature of the overall system.
5. An amplifier with a gain of 20 dB and an IIP2 of 5 dBm drives a filter with a gain of -10 dB and an IIP2 of 20 dBm. What is the IIP2 of the cascaded system?
6. (OPTIONAL, EXTRA CREDIT) We are going to do some joint computation / hand analysis to practice understanding noise density and noise power. The steps below instruct you to conduct various operations in Matlab (or Python). For each operation, you need to compare your computed results to "what you expect", which you should be able to determine using hand calculations. Include hand calculations and an FFT annotated with the important extracted values (usually signal and noise power levels) for each step. Instead of FFT coefficients, represent the power in each FFT bin (which may require you to find the magnitude of the bins to start), and do so in units of dBm. Also include your code.
    a. Create 20.0 cycles of a 20kHz sine wave representing a 0dBm sinusoid driven into a 50 Ohm load. This signal is intended to represent a continuous analog signal, though numerical software will always represent it as a vector of samples, so use a high sample rate: fs=2MHz. Add white noise to the sine wave with $\sigma_v = 10\text{mV}$.
        i. Where is the noise floor? (Note that the simulated value is easy enough to pluck off the graph, but finding the analytical value requires you to observe that 10mV is your total noise standard deviation, so you need to convert that back into a noise power in each bin. Here the observed noise in each bin represents some density captured across a bandwidth of the bin width.)
        ii. Where is the signal power level?
    b. Write a function that decimates and quantizes your signal like an 8-bit ADC sampling at 100kHz. Assuming the ADC full scale is equal to five times your wave amplitude.
        i. Is the noise floor where you expect? (Again, finding the simulated noise floor is easy by inspection, but we have to go back from total noise to a noise per bin, but we include quantization noise in our total noise this time. Note that quantization noise is white when viewed in the frequency domain, which is a byproduct of it being uncorrelated from one sample to the next.)
        ii. Does sampling produce tones where you expect?
        iii. Is your signal power level effected by decimation and quantization?
    c. Finally, multiply your signal by 5 before quantizing it with the same ADC, representing passing the signal through an impedance matched amplifier with a voltage gain of five.
        i. Is the noise floor where you expect?
        ii. Is the signal level where you expect?

Lab Instructions

This lab doesn't require any circuit simulations. Instead of comparing measurement, simulation and analysis for each problem, just compare measurement and analysis. We will use the Keysight N9320B Spectrum Analyzer, the Keysight E4438C signal generator, the HP 8665B signal generator, the ZN2PD2-63-S+ power splitter and the ZX60-2531M-S+ amplifier (possibly among others), plus assorted attenuators. Datasheets below:

- https://www.keysight.com/us/en/product/N9320B/rf-spectrum-analyzer-bsa-9-khz-3-ghz.html
- https://www.keysight.com/us/en/assets/7018-01039/data-sheets-archived/5988-4039.pdf
- https://www.keysight.com/us/en/product/8665B/highperformance-signal-generator-6-ghz.html
- https://www.minicircuits.com/pdfs/ZN2PD2-63-S+.pdf
- https://www.minicircuits.com/pdfs/ZX60-2531M-S+.pdf

1. Noise performance of the spectrum analyzer
    a. Attach the output of the vector signal generator to the input of the spectrum analyzer. Set the center frequency to 2.4GHz and the span to 400MHz on the spectrum analyzer. Set the signal generator to produce a -40dBm signal. Observe the signal and make note of the resolution and video bandwidth of the spectrum analyzer. Repeat for a span of 40MHz and a span of 4MHz. Using these measurements, determine the noise temperature of the spectrum analyzer. (Assume the input signal has no noise.)
    b. Keep the span constant and adjust the resolution and video bandwidth. Find a relationship between these bandwidths and the sweep time. Adjust the ratio of video bandwidth to resolution bandwidth and comment on the effects on the trace.
    c. Adjust the span and the resolution bandwidth such that the resolution bandwidth is 10Hz and the sweep time is reasonable. What is the measured signal power and why?
2. Noise in cascaded elements
    a. Set the resolution bandwidth of the spectrum analyzer to 10kHz. Add 30dB of attenuation in series between the function generator and the spectrum analyzer. Can you observe the attenuation’s contribution to the noise floor? What is the noise temperature of the attenuator and how does it compare to the noise temperature of the spectrum analyzer?
    b. Add a 60dB of amplification after the 30 dB of attenuation. Can you observe the attenuator’s contribution to the noise floor? Justify with calculations and measurements. Use interstage attenuators (of ~1dB) to keep your amplifiers stable.
    c. Replace the attenuator between your first two amplifiers with a band pass filter and discuss the measured spectrum.
3. Linearity of amplifiers
    a. Perform one tone nonlinearity tests on the ZX60-2531M-S+ amplifier at a frequency of 600MHz and use these tests to determine the amplifier’s P_{-1dB}. Compare your measured value to the datasheet.
    b. Power splitters can be used backwards as power combiners. Use a power splitter to perform two tone non-linearity tests on ZX60-2531M-S+ amplifier using two tones of P_{-1dB}-10dB at 600MHz and 601MHz. Vary the input power and plot the power of the intermodulation tones. Use this plot to calculate the IIP2 and IIP3. Compare these values to the datasheet and determine if IIP3 has the expected relationship to P_{-1dB}.
    c. Reduce the power of one tone by 3dB and record the resulting spectrum. Compare it to theory. Also, add a second amplifier in cascade with the first with a 1dB attenuator between them. Measure the cascaded IIP3 and compare to calculations.

Required data:

- Spectra gathered to calculate Spec An noise temperature
- Math to calculate effect of RBW and VBW, possibly captured in a plot of sweep time vs. some x
- Math for signal power at 10Hz RBW
- Spectra of noise temperature for: attenuator, atten + 60dB gain, atten + 60dB gain + filter
- One tone non-linearity spectrum and math compared to data sheet
- Two tone non-linearity spectrum and math compared to data sheet
- Spectrum with one tone reduced by 3dB and math to justify result.