Jens Daci (jd3693)
Rishabh Kumar (rk3149)
James Robinson (jtr2151)
Kaylx Yung Jang (kyj2110)
ELEN E6324
Principles of Microwave Measurement 12 / 06 / 2021

Lab 5 Report – Spectrum Analyzer – Measuring Power Amplifier Compression

I. Objective

The objective of this lab is to analyze and characterize a power amplifier using a spectrum analyzer. The characterization includes properly biasing the device and correctly measuring the P1dB compression of the amplifier. Analysis of results will be included in this report and compared with the amplifier's datasheet.

II. Theory

In this lab, the spectrum analyzer will be used to characterize an RF power amplifier designed by Minicircuits. The model of the wideband amplifier is ZX60-43-S+ and its operating frequency range covers from 0.05GHz to 4GHz. The figure down below shows the power amplifier being captured the day of the lab. As seen in the figure, the amplifier must be biased at around +5VDC in order for it to work properly. Moreover, it also has a limit for the input power specification which must not be greater than +13dBm. The precautions regarding the DC bias voltage will be the same as in the previous lab.

In order to measure the P1dB compression point of an RF device, the input power must be swept between very specific values. Some of these values must land in the linear region of the amplifier and some must be chosen after the compression has occurred.

Figure 1. Minicircuits Power Amplifier (ZX60-43-S+)

The figure down below, shows a general graph for finding the P1dB compression point of an RF device. As the input power level increases, there comes a point where the output power of the amplifier no longer increases by the gain value. At this moment, the amplifier output power starts to saturate. The 1 dB compression point (P1dB) is the output power level (or input power level, IP1dB) at which the gain decreases 1 dB from its constant value. Once an amplifier reaches its P1dB it goes into compression and becomes a non-linear device, producing distortion, harmonics, and intermodulation products. P1dB is one of the most important specifications for power amplifiers, as it is up to this point that we consider an amplifier to operate linearly. Amplifiers should always be operated below the compression point.

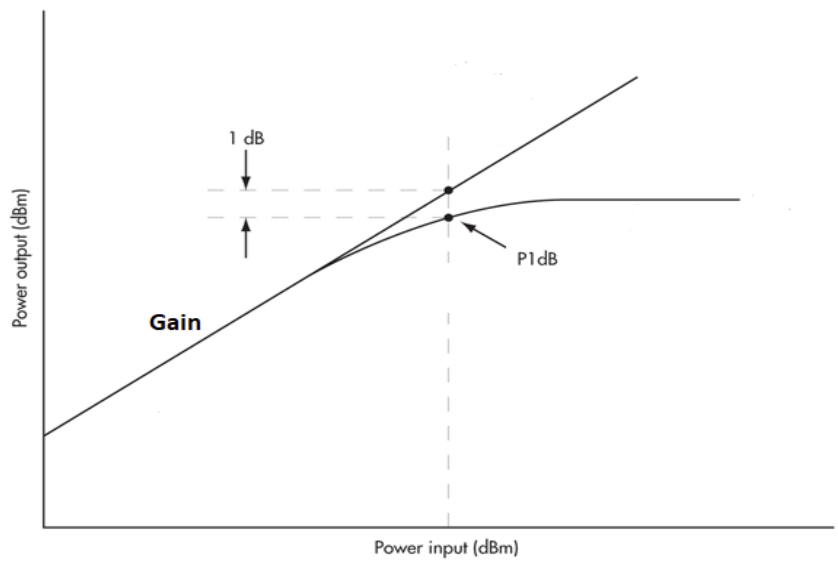


Figure 2. General Graph for Finding the P1dB Compression Point of an RF Device

An important part of this lab is to also automate the measurement of the output power of the amplifier. In order to make the measurements automatic, MATLAB will be used to communicate with the spectrum analyzer using SCPI commands. The connection between the MATLAB software and the analyzer is done through the use of a visa address provided by the Keysight Connection Expert tool.

SCPI is a programming language standard designed specifically for controlling instruments. It defines how you communicate with these instruments from an external computer. Keysight system instruments support SCPI commands using the IEEE 488 protocols, and each instrument manual gives detailed information on its particular SCPI programming language. One of these manuals is used in the lab for writing SCPI commands to the spectrum analyzer.

III. Initial Conditions and De-embedding

Before initiating the analysis of the characterization of the power amplifier, the initial conditions set for the spectrum analyzer must be discussed first. These initial conditions include the span, resolution bandwidth (RBW), video bandwidth (VBW) and many others. In contrast to the other labs, these values were set using the SCPI commands in the MATLAB code. To connect the spectrum analyzer to the lab computer, the Keysight Connection Expert tool was used. A visa address, obtained from the tool, was used as a connection port between the MATLAB script and the spectrum analyzer.

After the successful connection between the computer and the analyzer, the script for the de-embedding of the cable loss was written. De-embedding lets you remove fixturing and instrumentation effects from signal-integrity measurements. By removing the degrading effects of a signal path, you essentially make measurements at the desired point. After the de-embedding of the data, you've essentially moved the reference plane of a measurement closer to the device under test (DUT). In the case of this lab, the plot of the de-embedded matrix obtained from the test fixture can be seen in the figure below. The plot shows the cable loss as a function of the input frequency without an amplifier in the test setup. The trend shows that for each input power, as the frequency of the input signal increases, the loss in the cable becomes worse.

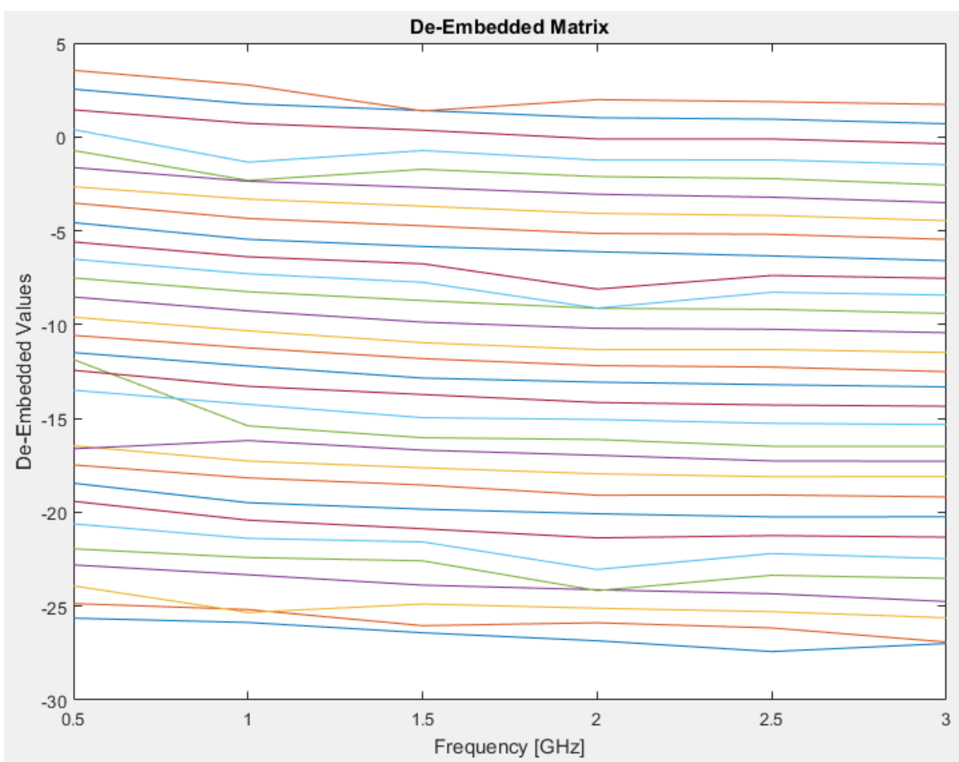


Figure 3. Plot of the De-embedded Matrix from the MATLAB Data

IV. Input Power Ranges

Based on the datasheet provided by Minicircuits, the power amplifier is rated for a 5V supply (nominal) with a minimum of 3.3V and a maximum of 7V. As a result of these specifications, it was decided that the amplifier would be biased at 5V. Moreover, the datasheet also provides the gain of the amplifier as well as the output P1dB compression point depending on the different input frequencies. The values presented in the datasheet can be seen in Table 1 down below.

Frequency (MHz)	Gain (dB)	Power Out @1dB Compression (dBm)
500	23.11	18.32
1000	21.69	18.37
1600	19.79	18.52
2000	18.66	18.59
2600	17.20	18.67
3000	16.29	18.98

Table 1. Compression Data Obtained from the Amplifier's Datasheet

Based on these values, one can calculate the power needed at the input of the amplifier so that the linear region can be plotted, as well as the compression and saturation of the gain would occur. In addition to plotting the compression correctly, we must also take into consideration the maximum input that the spectrum analyzer can handle which is 30dBm of input power. For safety precautions the output of the power amplifier was limited to 20dBm so that the analyzer's input is not damaged. The calculated values for the minimum and maximum input power needed to measure the P1dB compression point for each frequency can be seen in Table 2 on the next page.

To capture the P1dB compression point for all the frequencies in the table, it was decided that the input power should be swept from -25dBm to +4dBm. In this case, these values will not only show the compression and saturation of the device in the output power and gain plots, but they will also show the amplifier operating in the linear region. These values were entered as an input power array in the MATLAB code for use in the SCPI commands.

Frequency (MHz)	Minimum Input Power (dBm)	Maximum Input Power (dBm)
500	-23.79	-3.11
1000	-22.32	-1.69
1600	-20.27	+0.21
2000	-20.00	+1.34
2600	-18.00	+2.80
3000	-17.00	+3.71

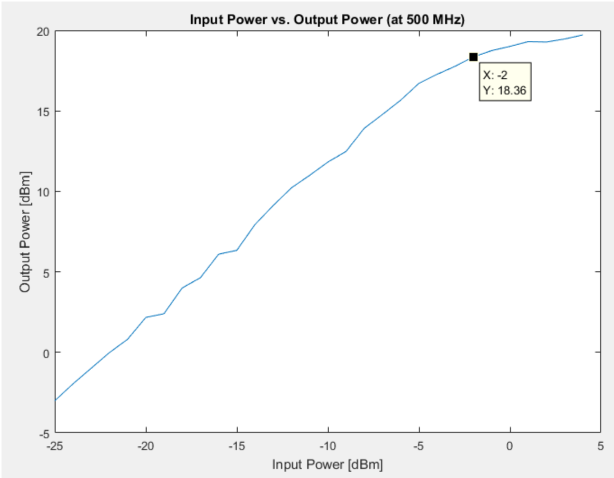
Table 2. Input Power Range Needed to Measure the P1dB Point for Each Frequency

V. Input Power vs. Output Power

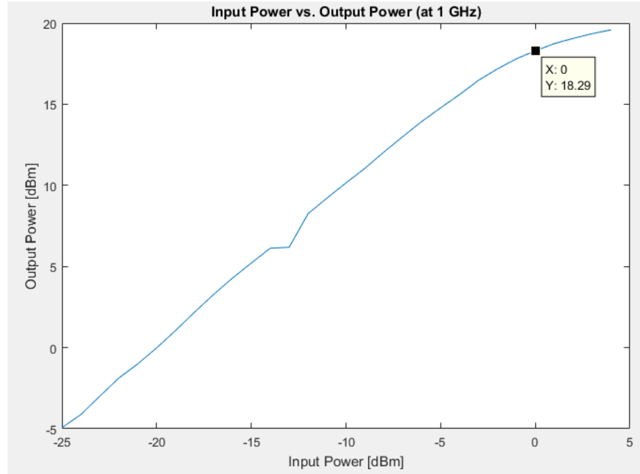
In order to characterize the gain saturation and compression of a power amplifier, the input and output power of the device must be plotted for each frequency. In the case of this lab, the compression of the amplifier must be analyzed at six different frequencies, which are 500MHz, 1GHz, 1.5GHz, 2GHz, 2.5GHz, and 3GHz. As explained in the previous section, based on theoretical calculations, the input power was swept from -25dBm to +4dBm to see the compression of the amplifier at all frequencies.

In the figure on the next page, the input and output power of the amplifier was plotted for all frequencies. The simulation using MATLAB and the SCPI commands was successful in telling the signal generator and the spectrum analyzer to capture the appropriate values. After the simulation, the data was analyzed in MATLAB and presented as a plot in this report. As seen in the graphs, in order to pass the compression point of the amplifier, more input power was needed as the frequency was increased. For the 500MHz, 1GHz, 1.5GHz, 2GHz, and 2.5GHz, the input power increased monotonically with an increase in frequency.

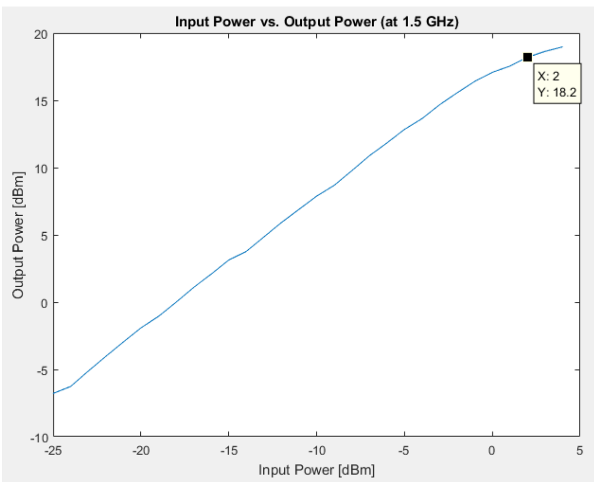
However, for the last frequency, at 3GHz, more input power was needed to view the compression of the amplifier. That is why the input power for the P1dB compression point is the same, since it reached its maximum in the MATLAB script. This happened because of a precaution taken not to damage the input of the spectrum analyzer. The output of the power amplifier was not allowed to go higher than the +30dBm maximum input for the analyzer (when using the low frequency gain in the calculations). Still, the measurements closely matched the values plotted in the datasheet (more explained in the next few sections).



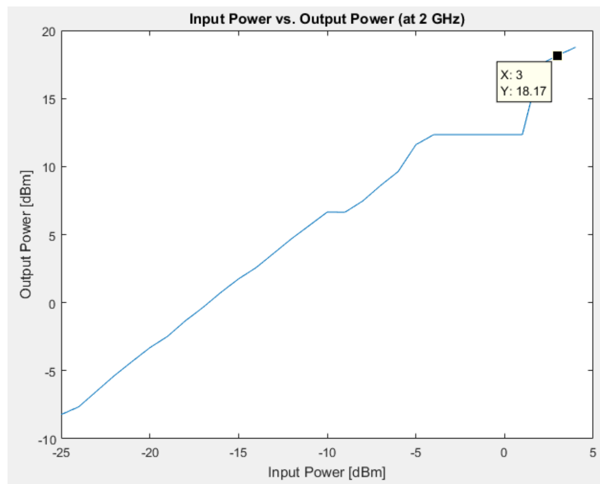
500 MHz, P1dB(-2 dBm, 18.38 dBm)



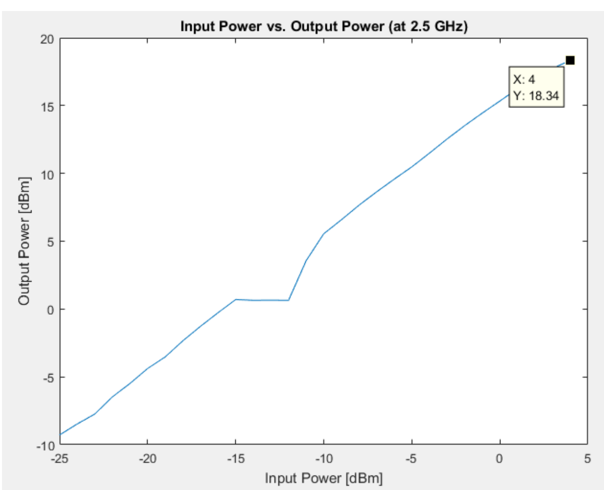
1 GHz, P1dB(0 dBm, 18.29 dBm)



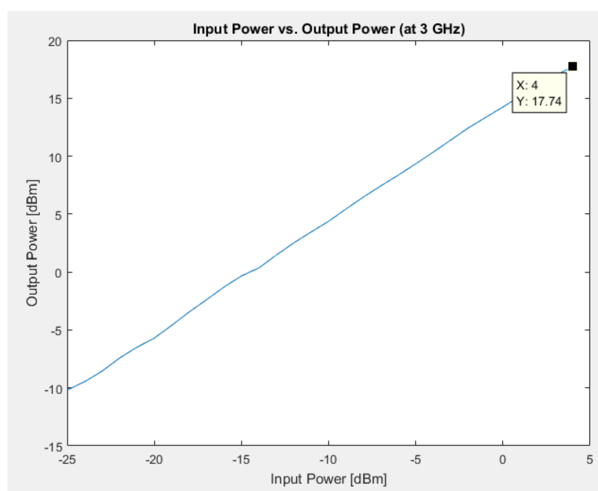
1.5 GHz, P1dB(2 dBm, 18.2 dBm)



2 GHz, P1dB(3 dBm, 18.17 dBm)



2.5 GHz, P1dB(4 dBm, 18.34 dBm)



3 GHz, P1dB(4 dBm, 17.74 dBm)

Figure 4. Input Power vs. Output Power for Different Input Signal Frequencies

VI. Input Power vs. Amplifier Gain

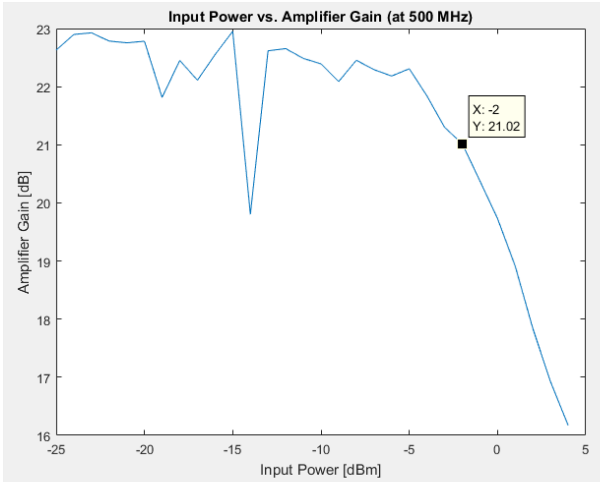
Besides the output power, the amplifier's gain was also plotted against the input power. Theoretically, as the input power is increased, there comes a point where the gain decreases and is not constant anymore. This is the same point as the one where the amplifier's output power saturates. For higher frequencies, when compared with lower frequencies, more input power is needed to reach this specific point.

Using the de-embedded matrix generated before the amplifier measurements, the input power vs. amplifier's gain plots are generated for each of the designated frequencies. The P1dB points are marked on each graph, along with the corresponding gain. For the most part, the graphs show a decrease in the gain as the input power is increased. Moreover, for higher frequencies, one can see that more input power is needed to reach the P1dB point. These results are expected, and they match the theoretical approach.

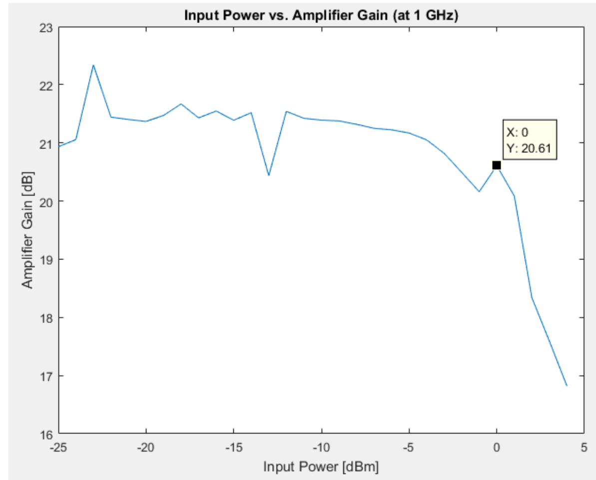
Some outlying points were ignored in this analysis when they appeared to represent non-physical variations, primarily dips from the apparent gain level in the primary region of operation. These are most notable in the 500MHz, 2.5GHz, and 3GHz cases, with the 1.5GHz case representing a more ideal output. It can be seen that the 1.5GHz plot shows a mostly constant amplifier gain for the low input powers and suddenly a decrease in the gain once the P1dB point is reached. It can also be concluded that these results are, once the 1dB offset of the gain relative to the P1dB point, very close to the gains listed in the datasheet.

Frequency (MHz)	Input P1dB (dBm)	Amplifier Gain at P1dB (dB)
500	-2	21.02
1000	0	20.61
1500	2	17.84
2000	3	17.15
2500	4	16.46
3000	4	16.01

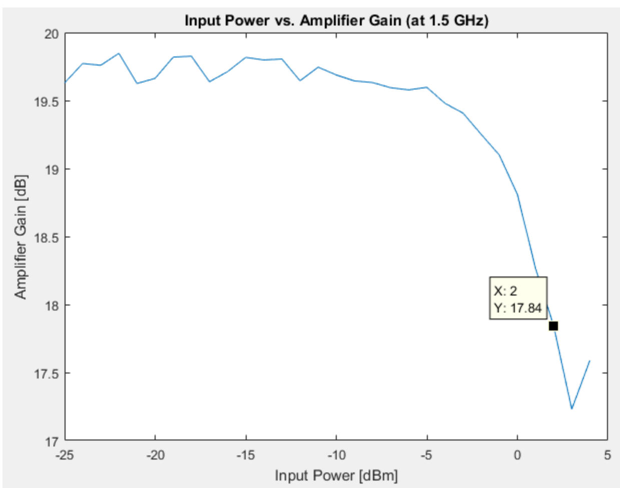
Table 3. Input Power Range Needed to Measure the P1dB (Tabulated)



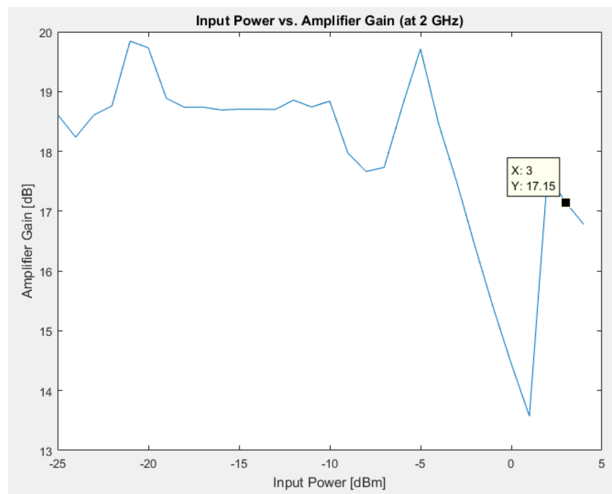
500 MHz, P1dB(-2 dBm, 21.02 dB)



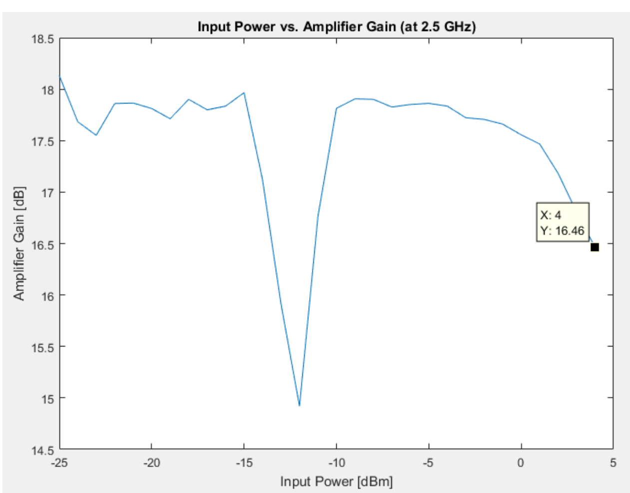
1 GHz, P1dB(0 dBm, 20.61 dB)



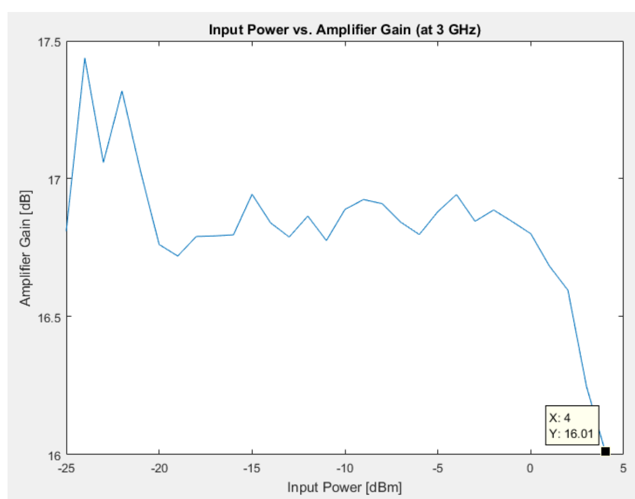
1.5 GHz, P1dB(2 dBm, 17.84 dB)



2 GHz, P1dB(3 dBm, 17.15 dB)



2.5 GHz, P1dB(4 dBm, 16.46 dB)



3 GHz, P1dB(4 dBm, 16.01 dB)

Figure 4. Input Power vs. Amplifier Gain for Different Input Signal Frequencies

VII. Amplifier Compression

Now that all of the plots for the input power, output power, and amplifier gain at the compression point have been presented, the power amplifier's compression will be characterized based on the input frequency. The following graphs in this section will show these amplifier compression parameters in terms of frequency.

On this lab, a trend that was noticed is that the gain deceases as frequency increases, as shown in section 6 of this report. So, more input power is needed to hit the 1dB compression point as shown in section 5. Therefore, we should expect that more input power needed to hit the 1 dB compression point (Pin1dB) as frequency increases. This trend is demonstrated in the figure below.

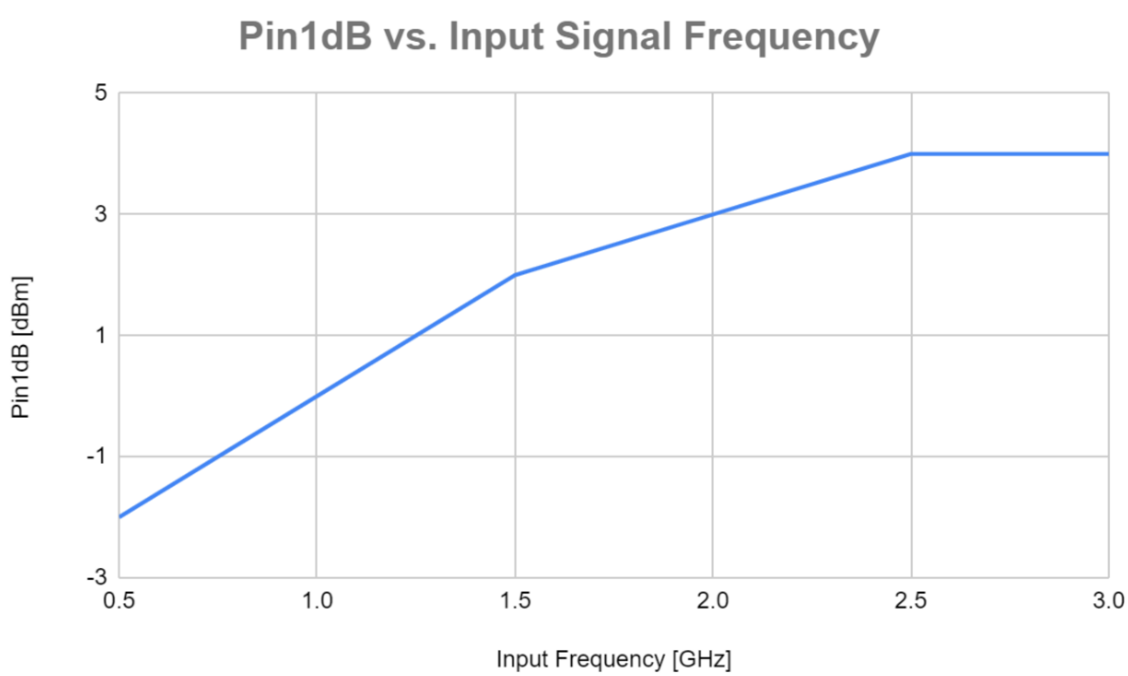


Figure 5. Input Signal Frequency vs. Input P1dB Compression

It is assumed that the amplifier was designed to maintain a flat Pout1dB from 0 to 4GHz. The plot from 500MHz to 3GHz of the measured device reveals that Pout1dB stays within 1dB of its specification sheet, but shows an earlier roll off starting at 2.5 GHz rather than at 3GHz. Moreover, at higher frequencies, the output power at 1dB compression should have increased to 19dBm. Because the input power was not high enough to put the amplifier to compression at high frequencies, the graph in Figure 6 shows a decrease in the Pout1dB at 3GHz.

The input power range was limited by the specifications of the spectrum analyzer. The output of the power amplifier was not allowed to go higher than the +30dBm maximum input for the analyzer (when using the low frequency gain). Nevertheless, the measurements graph shows a similar trend when compared to the one provided by the amplifier's datasheet. These discrepancies are within a reasonable tolerance for this type of demonstration.

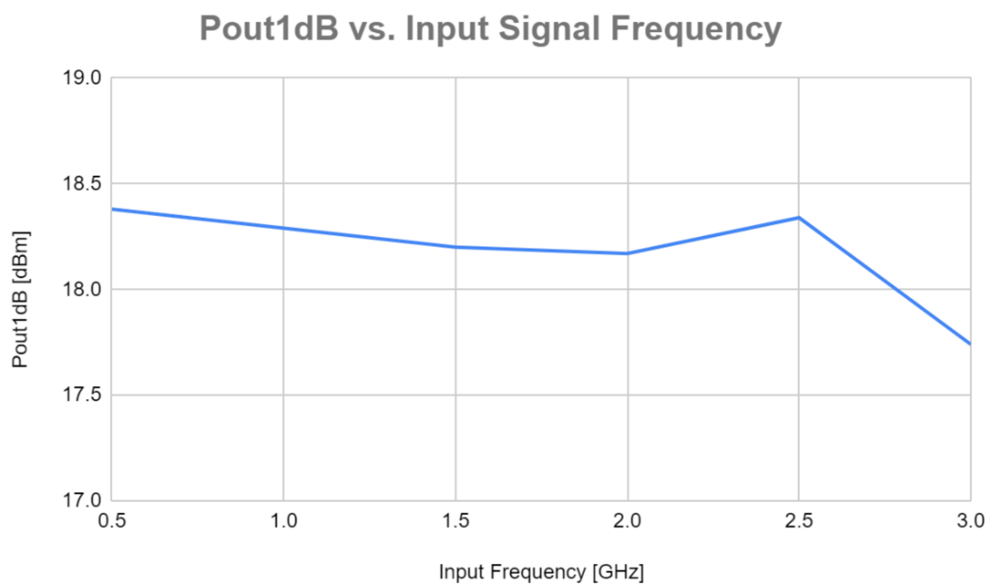


Figure 6. Input Signal Frequency vs. Output P1dB Compression

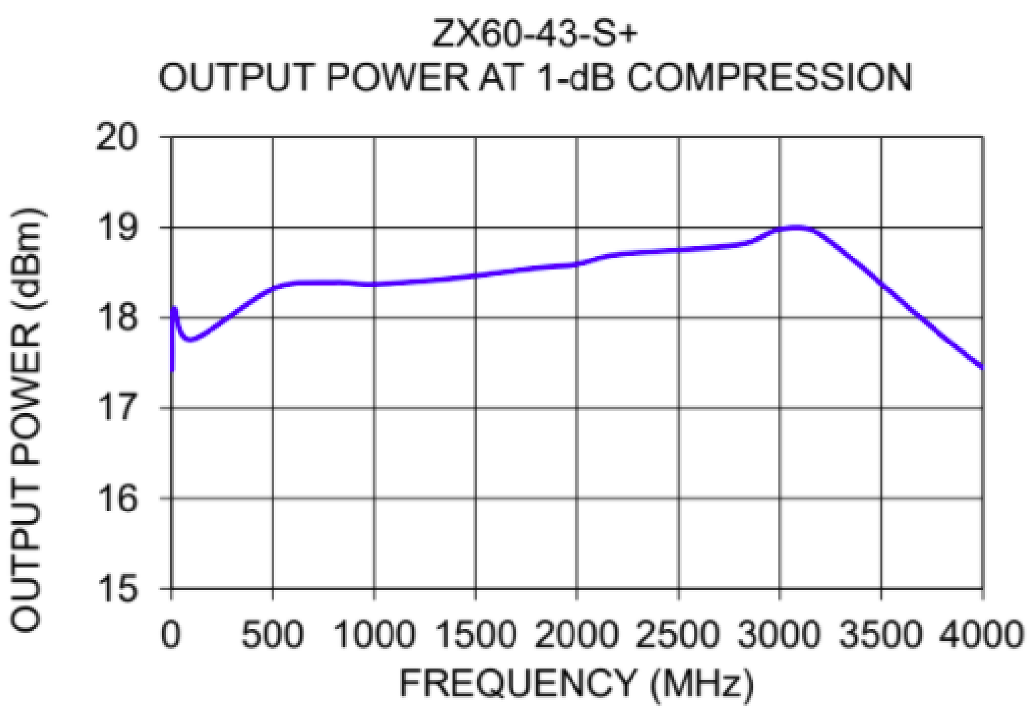


Figure 7. Input Signal Frequency vs. Output P1dB Compression (from datasheet)

In addition, another graph that could represent and characterize the power amplifier is the amplifier gain at the 1dB compression point in terms of the input signal frequency. As explained in section 6, gain of the amplifier at the 1dB compression point decreases with input frequency. As shown below, there is a sharper transition period where gain drops at a faster rate from 1GHz to 1.5 GHz and then drops at a slower rate from 1.5 GHz to 3 GHz.

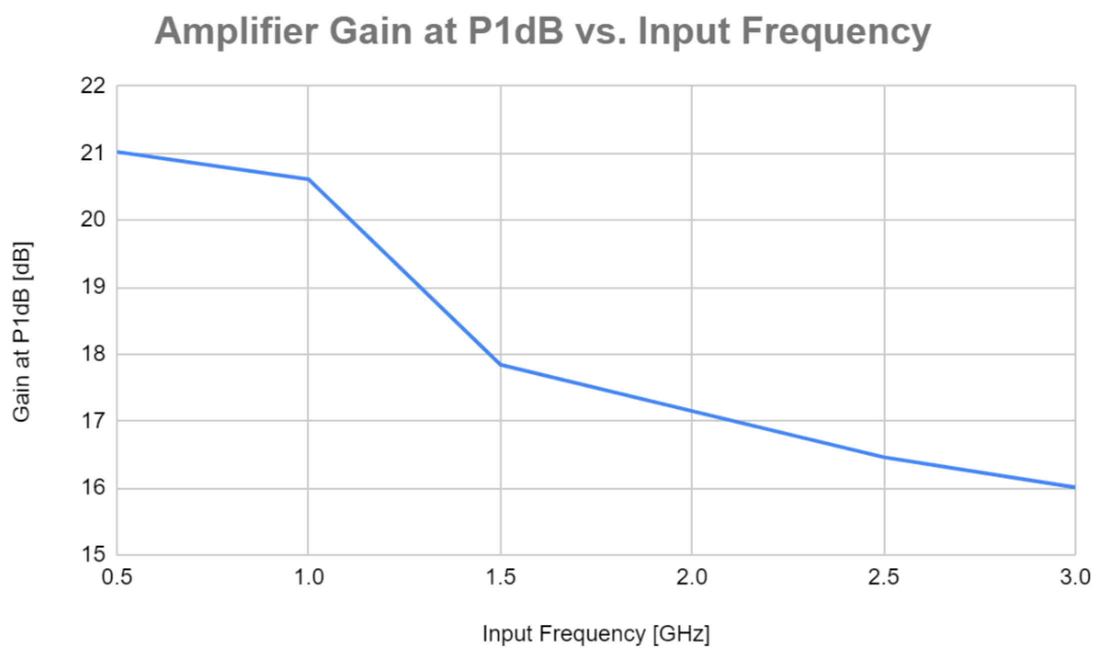


Figure 7. Input Signal Frequency vs. Amplifier Gain at 1dB Compression Point

VIII. Conclusion

In conclusion, the objective of this lab was to analyze and characterize a power amplifier using a spectrum analyzer. The characterization included properly biasing the device and correctly measuring the P1dB compression of the amplifier. The amplifier's compression was characterized using input and output power at P1dB compression as well as the amplifier gain at that specific point. The device's datasheet included a graphing that plotted the input frequency against the output power at the P1dB point. The values obtained during the lab closely matched the ones presented on the power amplifier's datasheet. At high frequencies, the amplifier barely reached its gain saturation and compression. However, these discrepancies are within a reasonable tolerance for this type of demonstration.

Appendix A – Commented MATLAB Code

(Also included as a file attachment in the submission)

```
%SA = visa('AGILENT', 'USB0::0x2A8D::0x0E0B::MY55360022::0::INSTR');
%SA.Timeout = 10.0;
%fopen(SA);
%fprintf(SA, '*IDN?');
%idn = fscanf(SA);

% Find a VISA-USB object.
SA = instrfind('Type', 'visa-usb', 'RsrcName',
'USB0::0x2A8D::0x0E0B::MY55360022::0::INSTR', 'Tag', '');

% Create the VISA-USB object if it does not exist
% otherwise use the object that was found.
if isempty(SA)
   SA = visa('AGILENT', 'USB0::0x2A8D::0x0E0B::MY55360022::0::INSTR');
else
   fclose(SA);
   SA = SA(1);
end
fopen(SA);
% Find a VISA-USB object.
%%
SG = instrfind('Type', 'visa-usb', 'RsrcName',
'USB0::0x0957::0x2018::0116A928::0::INSTR', 'Tag', '');
% Create the VISA-USB object if it does not exist
% otherwise use the object that was found.
if isempty(SG)
    SG = visa('AGILENT', 'USB0::0x0957::0x2018::0116A928::0::INSTR');
else
    fclose(SG);
    SG = SG(1);
end
SG.Timeout = 10.0;
% Connect to instrument object, obj1.
fopen(SG);

%%WORK SPACE

freq_arr = [0.5,1,1.5,2,2.5,3]; %Frequency values in GHz
%freq_arr = [1,3]; %Frequency values in GHz
pow_in_arr  = -25:1:4; % Input power in dB
pow_out_mat = zeros(length(freq_arr),length(pow_in_arr)); %Pout matrix
pow_out_mat_de = zeros(length(freq_arr),length(pow_in_arr)); %Gain matrix
%deembed = zeros(length(freq_arr),length(pow_in_arr)); % De-embed matrix


x = 1; % Loop counters
y = 1;

fprintf(SA, 'CALC:MARK1:STAT ON') %Setting state for marker display
fprintf(SG, 'OUTP ON') %Turning on the signal generator RF Power
```

```matlab
% Looping through all the frequencies
for f=freq_arr

    sg_freq_set = sprintf('FREQ:CW %d GHz',f); %Setting SG freq
    sa_freq_set = sprintf('FREQ:CENT %d GHz',f); %Setting SA center freq
    fprintf(SG, sg_freq_set)
    fprintf(SA, sa_freq_set)
    pause(0.5)
    y=1;

    % Looping through the input power -25 to 4
    for pow_in=pow_in_arr

        sg_pow_set = sprintf('AMPL:CW %d dBm', pow_in); %Setting input power
        sa_mark_max = sprintf('CALC:MARK1:MAX'); %Marker search type to max
        sa_query_data = sprintf('CALC:MARK1:Y?'); %Getting y-axis value


        fprintf(SG, sg_pow_set) %Input power to signal generator
        pause(0.1);
        fprintf(SA, sa_mark_max) %Saving max pout
        fprintf(SA, sa_query_data)
        pause(0.1);

        pow_out_mat(x,y) = str2num(fscanf(SA)); %Saving pout as number

        y = y+1; %Loop counters
    end
    x = x+1; %Loop counters
end

pow_out_mat_de = pow_out_mat - deembed; %Saving gain by de-embedding

%deembed = pow_out_mat;

%%END WORK SPACE

fclose(SA);
fclose(SG);
```