Lab 2. Passive Elements: Power Dividers and Impedance Matching

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INTRODUCTION

The goal of this lab was to design, provide fabrication outputs and characterize passive microwave circuits. We designed a Branch Line Coupler and a Wilkinson Power Divider using Microwave Office (MWO). In addition, we matched an RC load to a 50 Ω line at 4GHz. Power couplers and dividers have numerous applications in the microwave and RF regimes. Branch Line couplers.

BRANCH LINE COUPLER

A. Design

The Branch Line Coupler is a 4 port circuit that divides power equally between 2 output ports with phase offsets between the input and outputs ports. The final port (4) is the isolation port and receives no power from the input. The phase at port 2 (output 1) is 90°offset from the input and that of port 3 (output 2) is 180 °offset from the input. A schematic of a branch line coupler is shown below ADDFIGURE. The branch lines are spaced at a distance of $\lambda/2$ from the two main transmission line trunks.

The branch line coupler can be analyzed using Even and Odd Mode Analysis. The impedance of the branch is Z_0 while that of the main line is Z_1. For the even mode, we assume that +V volts are applied at both port 1 and port 4. In this case, there is no potential difference across the branches and therefore no current. We can thus split the circuit into 2 across the middle symmetry line by placing open circuit terminations at the ends of the half branches. In addition, we terminate the output ports by resistors equal to the characteristic impedance Z_0. In the resulting half circuit, there are reflections at the 2 contacts between the Z_0 and Z_1 transmission lines.

For impedance of the branch lines equal to 50 Ω that of the main transmission line will be $\sqrt{50 \times 100} = 35.56$ Ω.

For this lab, all the transmission lines were microstrip made out of 35 μm thick copper deposited on 50 mils of Rodgers RO3210 which has a dielectric constant of 10.2 and loss tangent 0.0027. The widths of the microstrip lines for the desired characteristic impedances were calculated using the TXLine program in Microwave Office. The lengths of the quarter wavelength sections were also computed in the same way. The table **??** summarizes the dimensions of the Branch Line Coupler after the circuit was optimized for power transmission at 5.9 GHz. After tuning, the designed circuit coupled -3.145 dB of power to port 2 and -3.137 dB to port 3 with -20 dB isolation on port 4 as shown in figure **??**.

Z [Ω]	W [mils]	$\lambda/4$ [mils]
50	44.5	175.0
35.36	73.5	167.5

Using the circuit design, we made a layout and routed the input and output lines to fit the 1x1 inch circuit size. The spacing between the input and output traces was set to about 500 mils for ease of mounting the SMA connectors.

B. Lab Testing and Analysis

In lab, we soldered the SMA connectors to the input and output traces of the circuit after deburring the edges of the fabricated circuit for a snug fit. We then calibrated the FieldFox Network Analyzer with the input power set to -10.0 dBm. Once calibration was done, we measured 3 2-port responses of the branch line coupler; S_{21}, S_{31} and S_{41}. The results in comparison to the simulated circuit response are shown in figure **??** and **??**.

From the figure, we can see clear deviations in the measured vs. simulated response of the circuit. There are a number of possible explanations for these effects. For starters, the solder joints between the SMA launches and the circuit could introduce unwanted impedances into the circuit. Capacitive and Inductive connections would modify the circuit response. ADDSECTION.

Some of the deviations could also be explained by the tolerances in the fabrication of the circuit. The substrate material datasheet lists 2 different values for the dielectric constant as measured by different techniques. Setting the dielectric constant in the range 10.2 - 10.8 gives trace widths in the range ADDVALUE and quarter wavelength ranges ADDVALUE for the 50 Ω sections. This could change the response of the circuit as shown below.

We tested these hypotheses by varying the coupler line widths to make simulations that matched the measured results. The results are shown in figure ADDFIGURE.

WILKINSON POWER DIVIDER

The figure shows the experimental setup used to measure the amplifier S parameters on the NA. The amplifier was biased at 5.00 V and 70 mA for all the measurements. In addition, we set the over voltage protection (OVP) to 5.5 V and the over current protection (OCP) to 100 mA. These two limits prevent the amplifier from exceeding its design current and voltage limits. The VNA was allowed to sweep multiple times and the 4 2 port S parameters were measured. The amplifier measurements showed good match with the response specified in the amplifier datasheet. The comparison plots are shown in figure. The key differences are the presence of noise fluctuations in the VNA measurements as well as intermittent dips in the response especially in the S_{22} parameter. These dips are likely a result of stray frequency dependent impedances that introduce additional reflections that suppress the response at particular frequencies. These stray impedances are likely due to the connectors used to attach the components.

We also performed S parameter measurements of the filter using the circuit shown in figure and with the response shown in figure . Note that the filter is a passive device and its scattering matrix is reciprocal i.e. $S_{21} = S_{12}$ unlike the amplifier. The bandpass filter has a flat forward response in band (about 4.9 - 6 GHz).

With the filter circuit added to the output of the amplifier, the response of the amplifier is shaped by the transfer function of the filter. The experimental setup is shown in figure and the combined amplifier and filter response as measured vs. the simulated response is shown in figure . The filter acts as a bandpass suppressing amplifier transmission below about 4.9 GHz and above about 6 GHz. The out of band sidelobes in the frequency response are also clearly visible.

IMPEDANCE MATCHING

In order to correctly measure the input power vs. output power response of the MC amplifier, we needed to first quantify the losses in the circuit due to the cabling and connectors. To do so, we connected a signal generator through the SMA cables to the SA and measured the power in the SA as a function of the power from the signal generator. We swept Pin from -20.0 dBm to 0.0 dBm in 1 dB steps. The results are shown in figure . This shows that we have about 2dB loss due to the cables.

Once the amplifier is connected in the circuit as shown in figure, we measured the output power of the amplifier as a function of the input power from the signal generator, adjusted for losses in the cables. In addition, a 10dB attenuator was added to the output of the amplifier to protect the SA from damage. This value was added back to the power measured by the SA. The signal generator provided a single tone at 5.9 GHz. At low input powers, the response of the amplifier is mostly linear as is shown in figure fig:ampcompress. At higher input power, the amplifier saturates and delivers less power at 5.9 GHz than the expected linear response. This deviation is due to non-linearities becoming more and more important in the amplifier. From this, we measured the 1dB compression point of the amplifier as at an output power of 10.9 dBm at 5.9 GHz. The datasheet reports a 1dB compression point of 12.1 dBm at 6.00 GHz in contrast.

As described in the introduction section, the drop in response is due to the excitation of higher order harmonics that move power away from the fundamental. This can be clearly seen in the spectral traces of the amplifier at input power of -20.0 dBm vs. 0.0 dBm as shown in figure. At low input power, only the fundamental tone is visible above the noise floor and at high SNR. At higher input power levels the second harmonic at 11.8 GHz is also clearly visible above the noise floor of the instrument.

CONCLUSIONS

At the end of this document, I have also attached the code used to generate the plots for the SA measurements. The biggest takeaways from this lab were the fundamentals of using a Network Analyzer to perform measurements of the S parameters. I learned how to interpret the NA results and compare them with datasheet specifications using Microwave Office. I also learned how to chain different S parameter files to simulate the combined response of the total network. The use of Spectral Analyzers to investigate the non-linearities of amplifiers was also a key aspect of this lab. My suggestion for improvement would be better guidance on exactly what is expected in the lab reports. I spent a lot of time writing this one up.