Radio Frequency Receiver Circuit

Term Project Final Report

Brendan Farrell

BSEE Candidate

University of Massachusetts Lowell

Lowell, MA., United States of America

Brendan_Farrell@student.uml.edu

Kwun Yin Low

BSEE Candidate

University of Massachusetts Lowell

Lowell, MA., United States of America

KwunYin_Low@student.uml.edu

Abstract – The challenge of the project was to design a Radio Frequency receiver device with the highest possible cascade gain and Output Third-Order Intercept with given devices. The components that we were given to use were: two S-band amplifiers and one S-band attenuator. Through some research, hand done calculations, and simulations a circuit was designed to operate at the values that were expected. The final assessment of the circuit shows that the circuit is working within expected characteristics. Though the circuit is not the best in all areas it does work the best out of all the circuits worked with.

I. Introduction

The goal of this project was to create the best possible radio frequency receiver circuit with a given set of two amplifiers and one attenuator. All the components were classified as S-band devices meaning that they should be able to operate between two to four gigahertz. There were three values that we looked at to determine which circuit was the best. These were, which circuit had the highest maximum cascade gain, which one had the highest maximum cascade Output Third-Order Intercept (OTOI), and which circuit had the smallest noise figure. Since we had three possible circuits, we decided to narrow it down to one circuit. Initially, we looked over which circuit had the highest cascade gain and found that all of the gains were the same. Next, we looked over which circuit had the highest cascade OTOI and found that two of the circuits were extremely similar. Finally, to decide which circuit we would fully test.

II. Analysis Method

The methods that we used for testing were very similar for each value that we were measuring. These methods are doing calculation by hand and then by simulating the circuits using PathWave Advanced Design System (ADS). These steps were done for determining the cascading OTOI and cascading gain of the circuits. This matches what we expected based off the information given by the datasheets of the amplifiers and the attenuators. For determining the S-Parameters for the circuit we used ADS to simulate the circuit and gather the values. This method was also used to find the noise figure and the operating bandwidth of the circuits.

Originally the project was going to include us testing the physical circuit itself but thanks to the current pandemic we were unable to do this. We were able to test our components to make sure that the values they produced were the same as those on the datasheets. These tests did produce the same values as those on the datasheets.

III. Results

As stated previously stated, we started by doing hand calculations by using MATLAB as a method to quickly determine values. This was done for the cascading gain and the cascading OTOI of each circuit. The OTOI and cascade gain calculations of each circuit are in

Tables 1, 2, and 3. The cascading OTOI values were determined by using Eq.1 and Eq.2, to convert the dB and dBm values, respectively, to watts. Eq.3 was used to calculate the cascading OTOI value, and Eq.4 was used to convert the watts back to dBm. Most of the values for the components were determined from the datasheets of each component [1, 2].

Table 1. Attenuator Amplifier Amplifier Circuit

Device No.	1	2	3
Device Type	Attenuator	Amplifier	Amplifier
G (dB)	-3	13	13
OTOI (dBm)	60	38	38
G (power)	0.5012	19.9526	19.9526
OTOI (W)	1000	6.3096	6.3096
ΣOTOI (W)	1000	6.3076	6.0083
ΣOTOI (dBm)	60	37.9986	47.9315
ΣG (dB)	-3	10	23
ΣITOI (dBm)	63	27.9986	24.9315

Table 2. Amplifier Attenuator Amplifier Circuit

Device No.	1	2	3
Device Type	Amplifier	Attenuator	Amplifier
G (dB)	13	-3	13
OTOI (dBm)	38	60	38
G (power)	19.9526	0.5012	19.9526
OTOI (W)	6.3096	1000	6.3096
ΣOTOI (W)	6.3096	3.1523	5.7343
ΣOTOI (dBm)	38	34.9863	47.4647
ΣG (dB)	13	10	23
ΣITOI (dBm)	25	24.9863	24.4647

Table 3. Amplifier Amplifier Attenuator Circuit

Device No.	1	2	3
Device Type	Amplifier	Amplifier	Attenuator
G (dB)	13	13	-3
OTOI (dBm)	38	38	60
G (power)	19.9526	19.9526	0.5012
OTOI (W)	6.3096	6.3096	1000
ΣOTOI (W)	6.3096	6.0084	3.0023
ΣOTOI (dBm)	38	37.7876	40.9938
ΣG (dB)	13	26	23
ΣITOI (dBm)	25	11.7876	17.9938

The results in Tables 1, 2, and 3 show that all of the circuits had the same cascade gain regardless of the order of components. Tables 1, 2, and 3 also shows that the attenuator amplifier amplifier circuit had the highest cascade OTOI, although the Amplifier Attenuator Amplifier had an extremely similar value. The two values respectively were 47.9315dBm and 47.4647dBm. This also resulted in the setups having very similar Input Third-Order Intercept (ITOI), 24.9315dBm and 24.4647dBm respectively. To determine which circuit would be determined as the better Radio Frequency receiver, my partner and I decided to simulate both circuits to see which one had a smaller noise figure. The reason for this is that the circuit with a lower noise figure would produce a cleaner signal.

The simulations that show us that the operating frequency is two to four gigahertz. Fig. 1 and 2 show the noise figures for both the amplifier attenuator amplifier circuit and the attenuator amplifier amplifier circuit, respectively. This told us that the amplifier attenuator amplifier circuit had the much smaller noise figure and was fully tested since it was determined to be the best circuit for its intended application. The simulations also gave us the results for the S-Parameters of the chosen circuit which is Fig. 3.

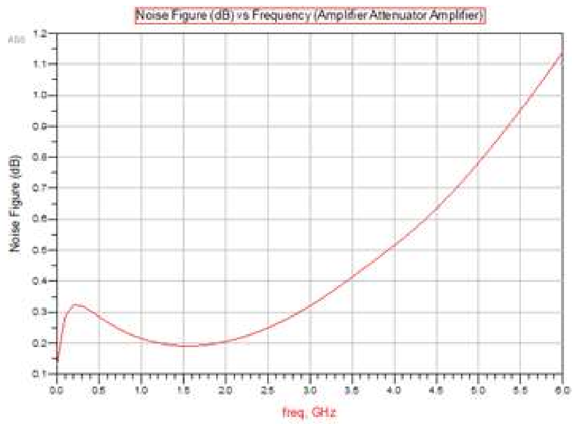

Fig. 1. The noise figure in dB over a range of frequencies for the amplifier attenuator amplifier circuit. For the operating range of the circuit, the noise figure ranged from about 0.2 to about 0.525.

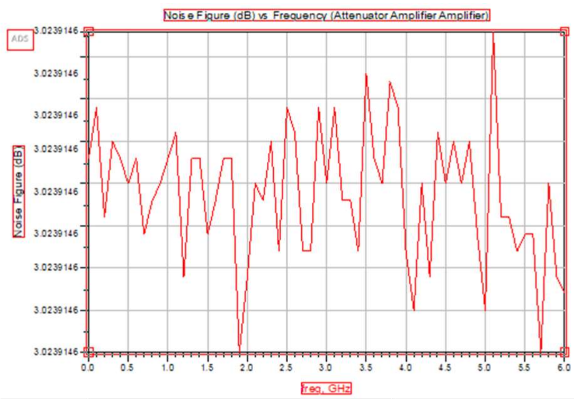

Fig. 2. The noise figure in dB over a range of frequencies for the attenuator amplifier amplifier circuit. For the operating range of the circuit, the noise figure essentially stayed the same at about 3.0239dB. The reason for how crazy the graph looks it's because of how small intervals are.

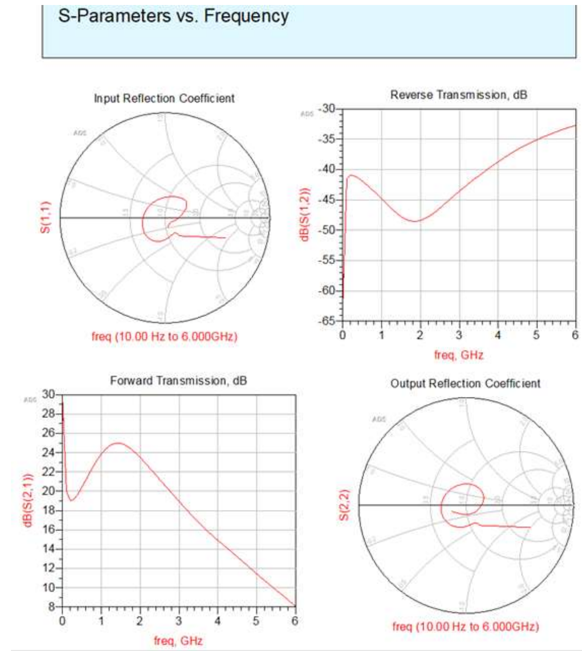

Fig. 3. The S-Parameters vs Frequency graphs for the amplifier attenuator amplifier circuit. The order of graphs is, from left to right and top to bottom, are S11, S12, S21, and S22.

We did have some complications with determining results with the by hand calculations. One of the issues was we could not find the OTOI value of the attenuator in its datasheet. The way that we got around this is by taking all of the information that we had on the device from its datasheet [2] and simulating the component in ADS. The value that we got for the OTOI was 60 dBm.

IV. Conclusion

Based on the measurements that we have obtained during the project we have determined that the amplifier attenuator amplifier circuit is the best circuit based on the attributes that we were looking for. These attributes are the highest possible cascading gain, highest possible cascading OTOI, which was a very close second to attenuator amplifier amplifier circuit, and the lowest possible noise figure with the components that we had. The operating bandwidth of the circuit falls with the S-band frequency range of two to four gigahertz. The cascading gain of the circuit was 23dB and the cascading OTOI of the circuit was 47.4647dBm. The noise figure of the circuit ranged from between about 0.2dB to about 0.525dB. Fig. 4 is the amplifier attenuator amplifier circuit that was chosen as the best for its intended application of being a Radio Frequency receiver circuit.

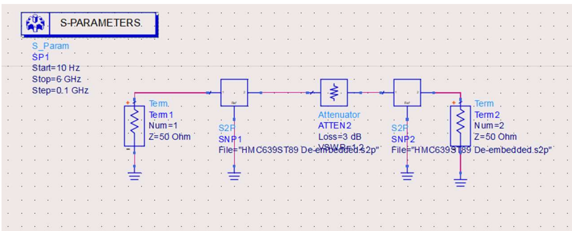

Fig. 4. The circuit diagram for the amplifier attenuator amplifier circuit that was tested and determined to be the best Radio Frequency Receiver circuit that we could make with the parts we had.

APPENDIX

EQUATIONS

Eq. 1: $\boldsymbol{P(watt) = 10^{\frac{P(dB)}{10}}}$

Variables: P(watt) is the power measured in watts, P(dB) is the power measured in dB.

Eq. 2: $\boldsymbol{P(watt) = \frac{10^{\frac{P(dBm)}{10}}}{1000}}$

Variables: P(watt) is the power measured in watts, P(dBm) is the power measured in dBm.

Eq.3: $OTOI_2' = \left(\frac{1}{G_2 OTOI_1} - \frac{1}{OTOI_2}\right)^{-1}$

Variables: $OTOI_2'$ is the cascading value of the Output Third-Order Intercept measured in watts, G_2 is the gain of the next device in the cascade and is measured in watts, $OTOI_1$ is the Output Third-Order Intercept of the total circuit up to the point being calculated and is measured in watts, $OTOI_2$ is the Output Third-Order Intercept of the next device in the chain and is measured in watts.

Eq.4: $P(dBm) = 10Log\big(P(watts)\big) + 30$

Variables: P(dBm) is the power measured in dBm, P(watts) is the power measured in watts.

REFERENCES

[1] Analog Devices, “Amplifiers-Linear & Power-SMT,” HMC639ST89/639ST89E datasheet, NA. [Online]. Available: https://ieee-dataport.org/sites/default/files/analysis/27/IEEE%20Citation%20Guidelines.pdf [Accessed March 1, 2020].

[2] XMA Corporation, “SMA Fixed Coaxial Attenuators,” 2082 Series DC-18 GHz-Round Body datasheet, NA. [Online]. Available: https://www.datasheet.directory/index.php?title=Special:PdfViewer&url=https://datasheet.iiic.cc/datasheets-1/xma/2082-6145-03.pdf&fbclid=IwAR2pIuLJE3rATHH6nlLYO3QzCqLAVH9hQZcY-_6lOGKr1yvyvZmjWVtDb2Y [Accessed March 1, 2020]