ENEL 617 WINTER 2017 PROJECT REPORT

Millimeter-Wave Double Balanced Gilbert Mixer

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In this project, I present a double balanced mixer that would be used as part of a BPSK Modulator circuit to generate a spread spectrum radar waveform in the automotive frequency band (77-81 GHz). A similar modulator that uses a double-balanced mixer is described in [CITE]. The original design benchmarks for this mixer and the achieved final results are outlined in Table 1.

Parameter	**Original**	**Achieved**
Supply Voltage	1.8V	0.85V
Power Consumption	5mW	≈ **4.8mW**
Gain (dB)	5.4	≈ **-13 dB**
Input Match	50Ω	**45.5 + j0.1Ω**
Output Match	730Ω	**48.9 + j0.1Ω**
NF	10dB	≈ **16 dB**
P1dB	–	≈ 1.5dB
IP3	–	≈ 9.5dB

Table 1: Mixer Design Goals

The original values were generated based on a few simple simulations/calculations and a power budget provided by Dr. Belostotski. Once the Id-gm characteristics were understood from simulation, the gain estimate was calculated using the following equation.

$$G = \frac{2}{\pi}\frac{R_L}{R_s + \dfrac{1}{g_m}}; \tag{1}$$

The exact values including plots for the final results will be clearly outlined. Furthermore, deviations from original to achieved results will be described in detail. A different design topology was used in the final design than in the original biased circuit used to calculate the conversion gain. Some targets (such as output impedance) were changed intentionally (for practical purposes) while other values were adjusted based on non-ideal aspects of the circuit. A derivation of Equation 1 will be provided in the theory of operation section. A suitable value of R_L was chosen based on biasing and achieving high gain. This value, and others, deviate greatly from the final design. A thorough explanation of the reasons for deviating are provided. The interest in this particular-type of radar stems from spread-spectrum technology's built in interference rejection, which is an indispensable feature for automotive radar. This type of radar has recently been demonstrated in SiGe technology [CITE]. 65nm technology is chosen because the Figure of Merit, $f_T \approx 160GHz$, making it suitable for this millimeter-wave application.

2.1 Radar Theory of Operation

To demonstrate how this mixer could be used in a practical application, the theory of the type of radar is discussed. A simplified block diagram of an example spread spectrum ranging system is shown in Figure 1. The BPSK modulator is used to spread the carrier with a pseudorandom code. The parameters of the code, which govern the LO mixing frequency, are designed to provide an adequate range resolution within the context of automotive radar. The achievable range resolution of the radar system is related to the chip rate (mixer LO) of the code through Equation 2.

$$d_{min} \leq \frac{c}{2f_c} \tag{2}$$

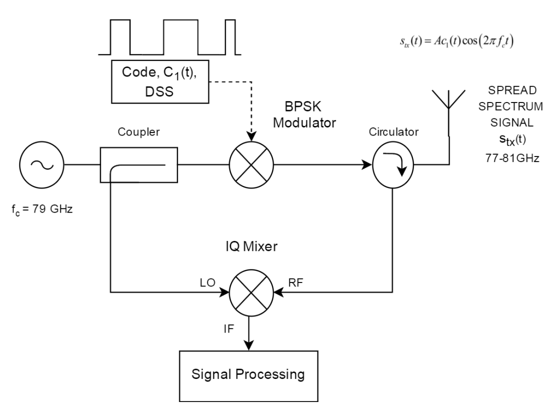

Figure 1: Radar Transceiver Block Diagram

Therefore to achieve a $10cm$ range resolution a chip rate of $1.5GHz$ is chosen. The rest of the code can be designed by choosing the appropriate length.

$$T_p = \frac{N}{f_c} \tag{3}$$

and then achievable unambiguous range of the radar becomes

$$d_{max} \leq \frac{c}{2T_p} \tag{4}$$

Since the code is pseudorandom, the LO frequency could be any integer division of $1.5GHz$ i.e $0.75GHz, 0.5GHz$ etc. For the purposes of design we will simulate with just a $1.5GHz$ signal to demonstrate the maximum bandwidth of operation.

3 Mixer Theory of Operation

3.1 Basic Principle

The Gilbert Cell is a linear time-varying circuit. The concept behind this circuit is intuitive. The RF transistors act as transconductance amplifiers which change the input voltage to a current. The differential ports act as switches that commutate the output. This creates the time-domain multiplication function. FIGURES X DEMOSTRATE THIS CONCEPT.

3.2 Detailed Analysis

4 Design Variations and Final Circuit Schematic

4.1 Circuit Schematic

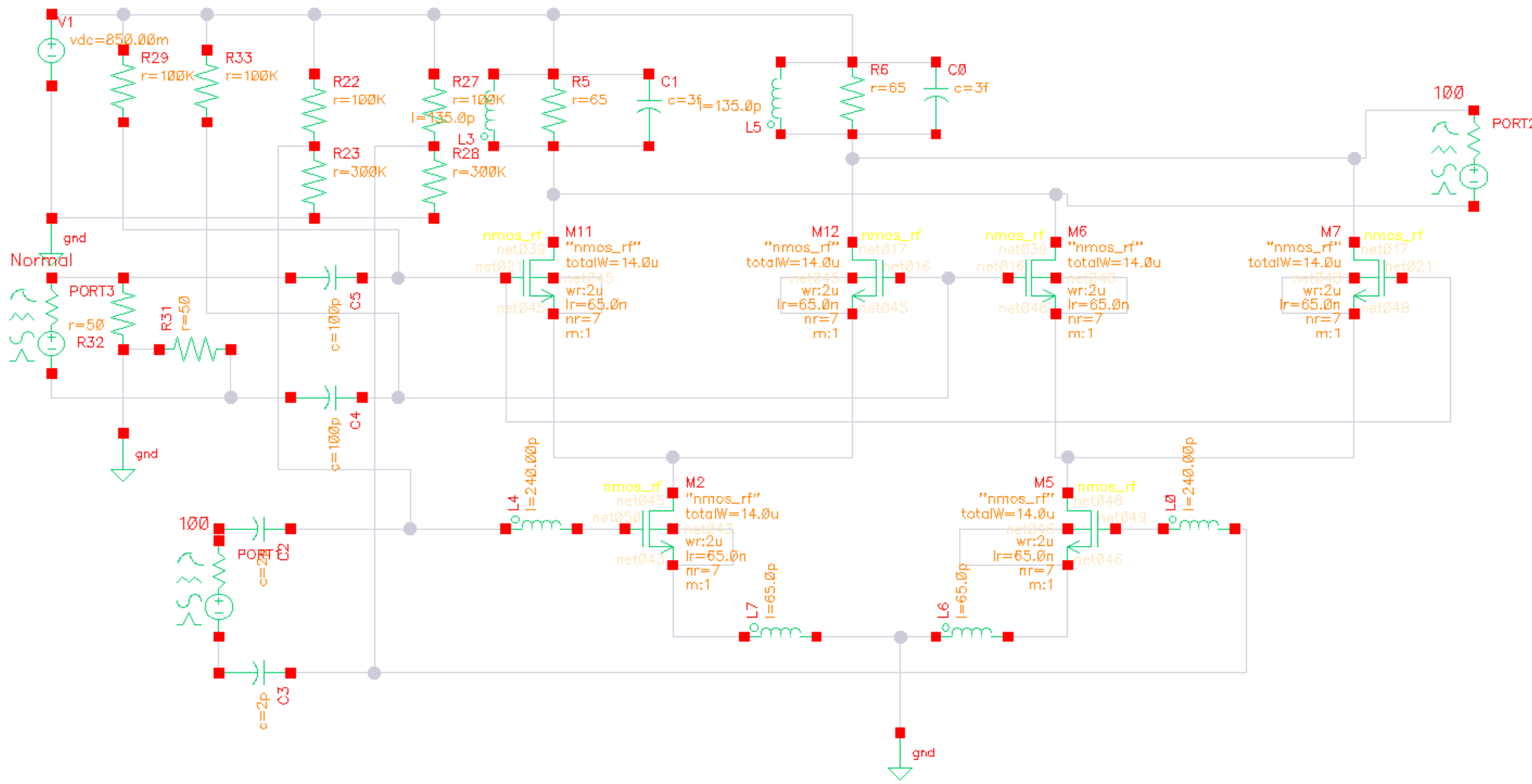

Figure 2: Final Design

At first the circuit was designed with a 1.8V power supply and a current mirror for biasing as seen in figure X. However, this topology was causing many problems. First of all, node X had to be maintained at ≈ 0.4V for the current mirror to function properly. This was causing a lot of problems because of voltage headroom and being able to design for a V_{od} of ≈ 0.1V while also staying under the power budget of 5mW. Therefore after (many weeks) of using that topology, I realized I could scrap the current mirror and lower the voltage. This then allowed me to increase the widths of the transistor, therefore increases the transconductance while still staying below the allotted power budget. The original transconductance was around 5mA/V while, as mentioned, the overdrive voltage was around 50mV (not good). After the supply voltage/topology change was implemented the transconductance achieved was WHAT NUMBA as shown in table BLAH At first, an output resistance of 730Ω was chosen to give approximately 5dB of gain based on fig REF. However, it was decided that it would be unusual to have such a high output impedance since in practice this device would need to interface with other components (PA). Therefore the target was reduced to 50Ω. The reduction in gain was somewhat compensated by the fact that I was now able to get a bigger gm with the reduced power supply.

5 Simulated Results

Table 2: Experiment Results-I

(a) RF Transistors

Parameter	**Value**
I_D	2.819mA
C_{gs}	9.468fF
C_{gd}	3.613fF
g_m	14.94mA/V
V_{ds}	331mV
V_{gs}	646mV
V_{th}	414mV

(b) LO Transistors

Parameter	**Value**
I_D	1.409mA
C_{gs}	8.754fF
C_{gd}	3.216fF
g_m	12.18mA/V
V_{ds}	510mV
V_{gs}	511mV
V_{th}	402mV

Overdrive voltage for LO transistors was lower than RF transistors. This is because it was important that the LO transistors would fall into Triode and Cutoff when Max/Min LO was used and the overdrive voltage for the RF transistors was designed high to get high transconductance while still remaining in saturation.

5.1 Transistor Biasing and Power Consumption

5.2 Conversion Gain

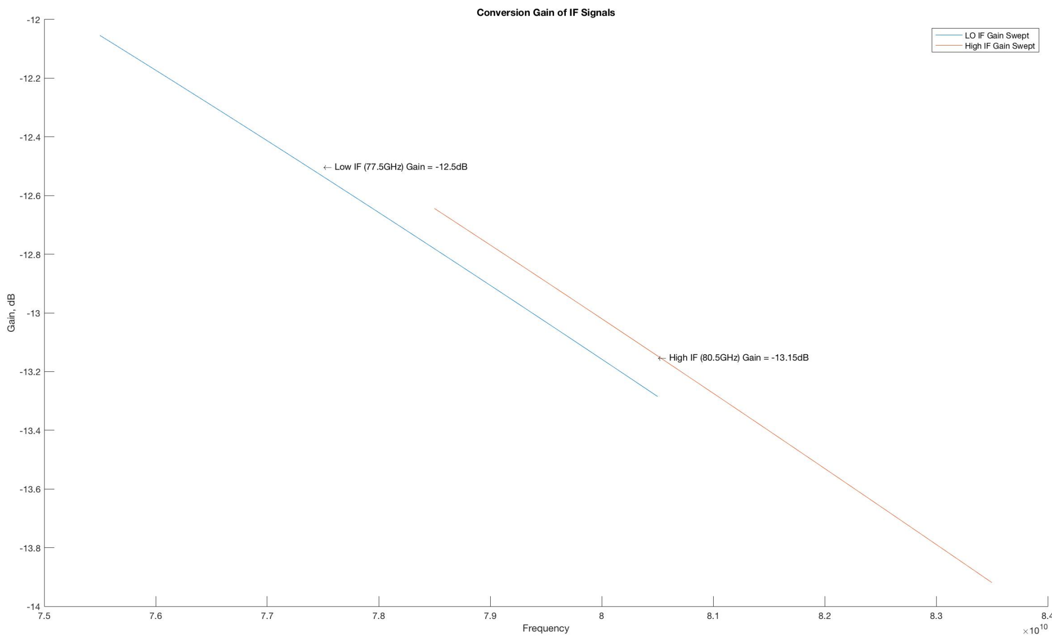

Figure 3: Swept Gain for Lo and Hi IF

5.3 Input and Output Matching

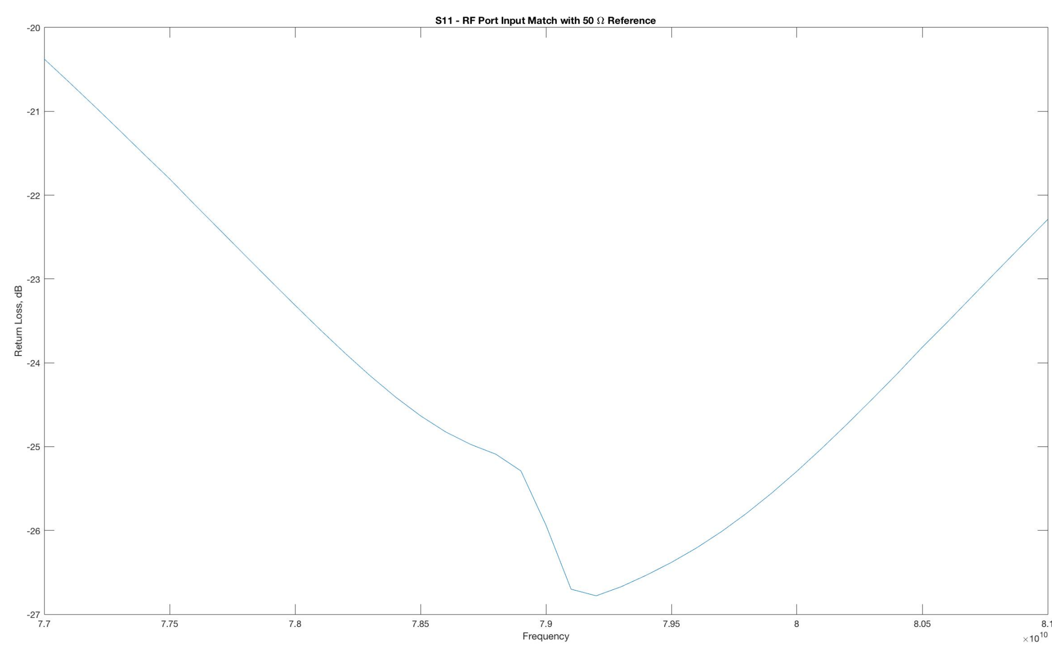

Figure 4: Final Return Loss of RF Port

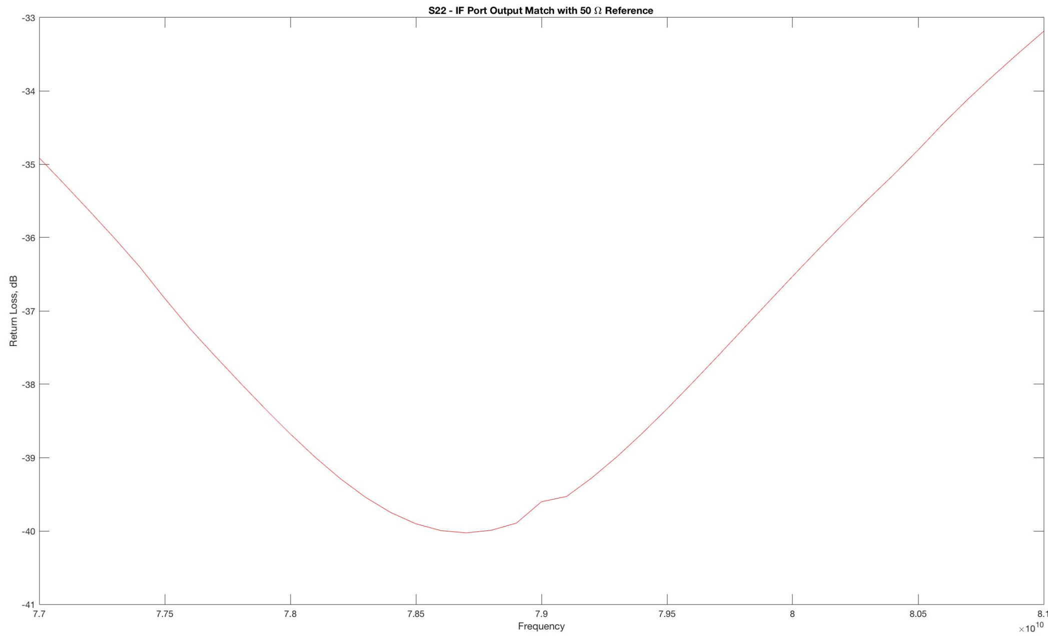

Figure 5: Final Return Loss of IF Port

5.4 Noise Figure

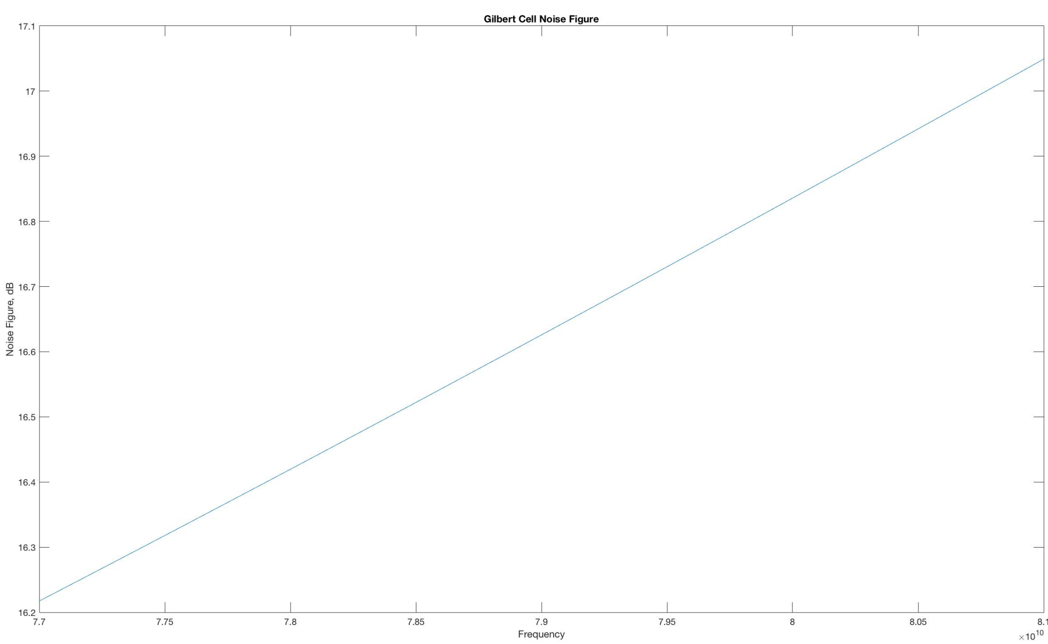

Figure 6: Final NF

5.5 P1dB & IP3

Write some stuff about this...

6 Discussion

6.1 Future Improvements

7 References

A Cadence Simulation Plots

A.1 Conversion Gain

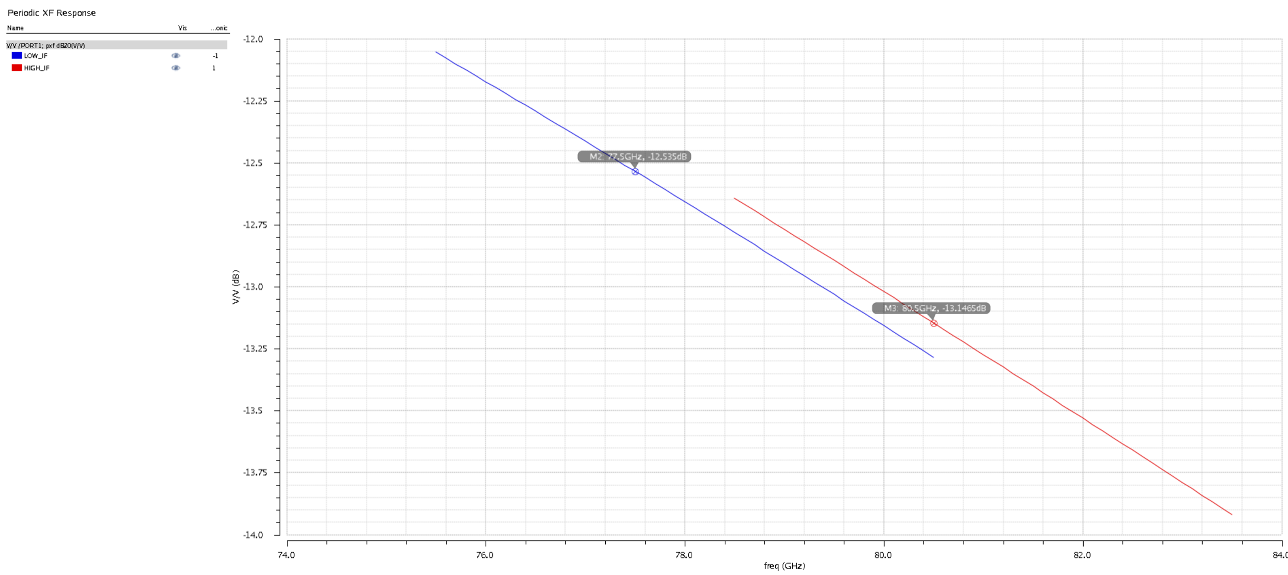

Figure 7: Conversion Gain Cadence

A.2 RMS Spectrum

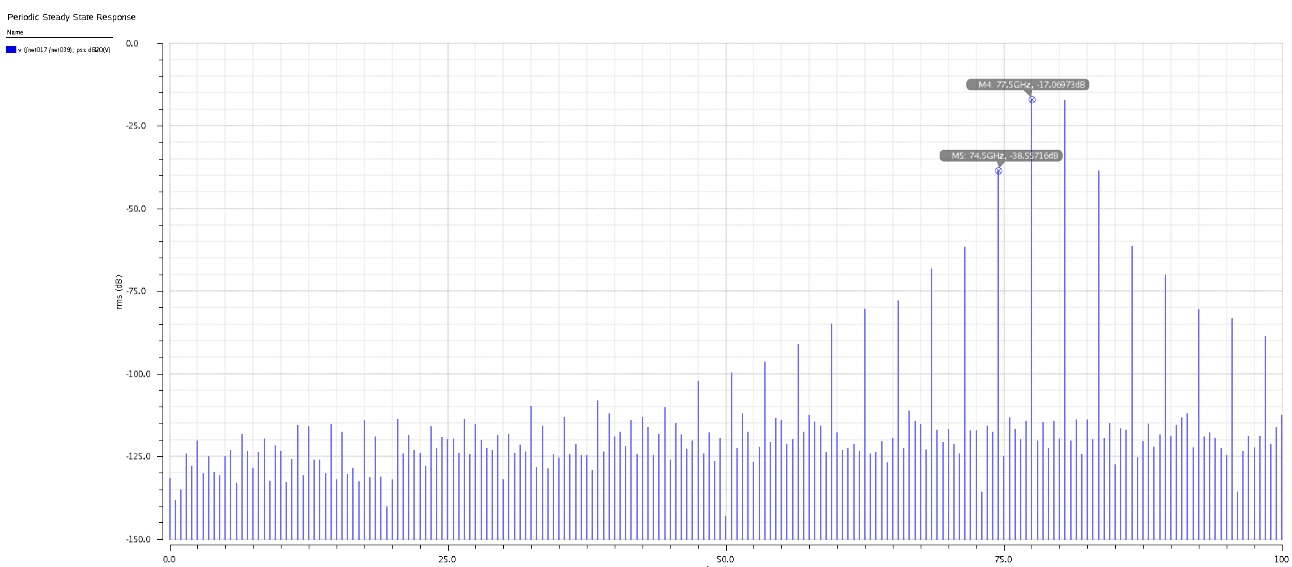

Figure 8: RMS Spectrum Cadence

A.3 Noise Figure

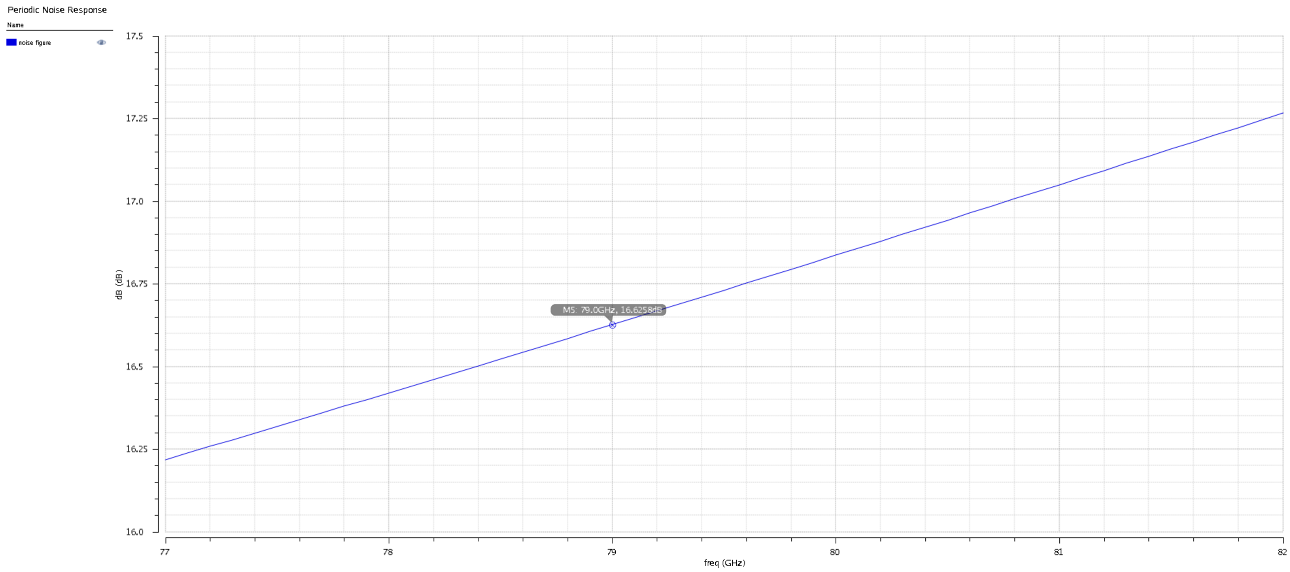

Figure 9: Noise Figure Cadence

A.4 P1dB

Figure 10: P1dB Cadence

A.5 IP3

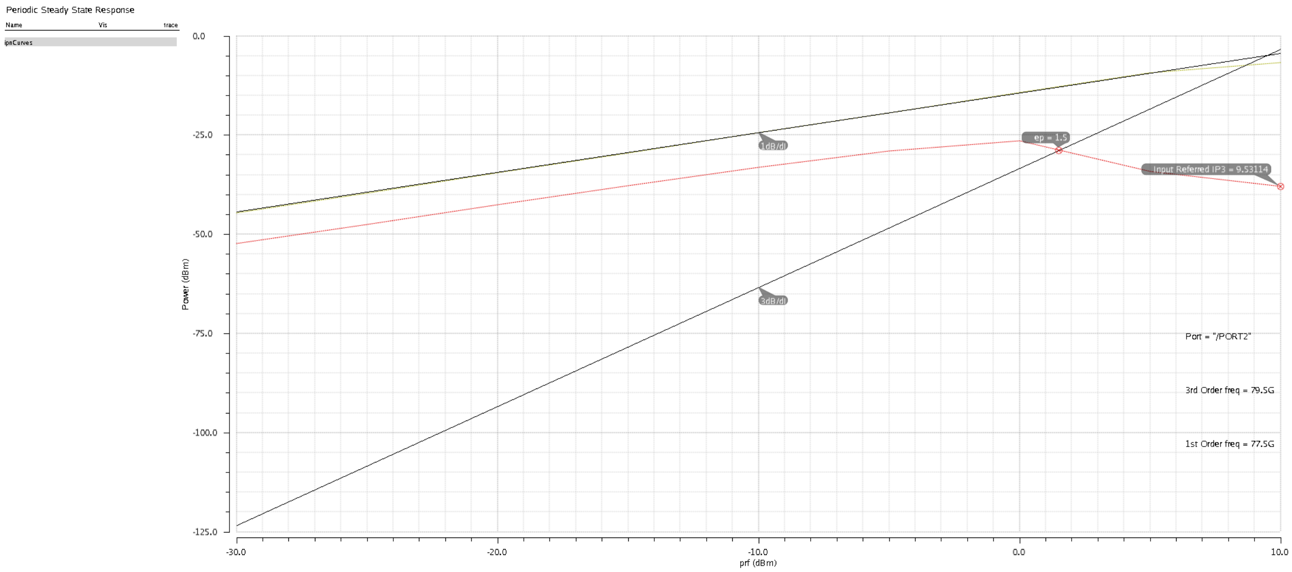

Figure 11: IP3 Cadence

A.6 S11

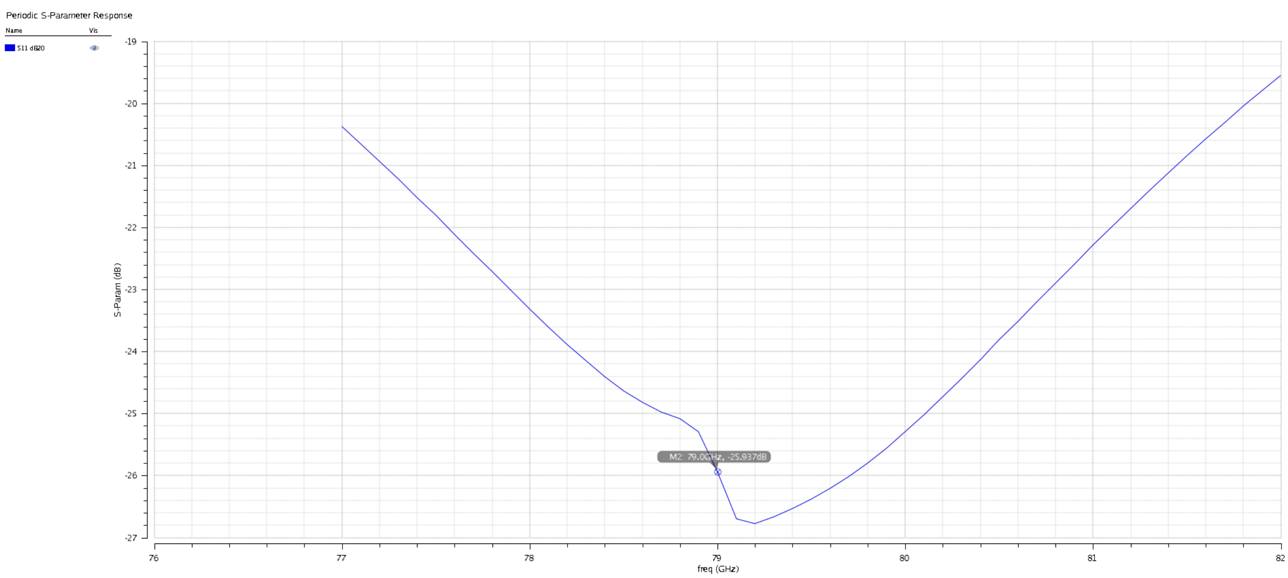

Figure 12: RF Port Match

A.7 S22

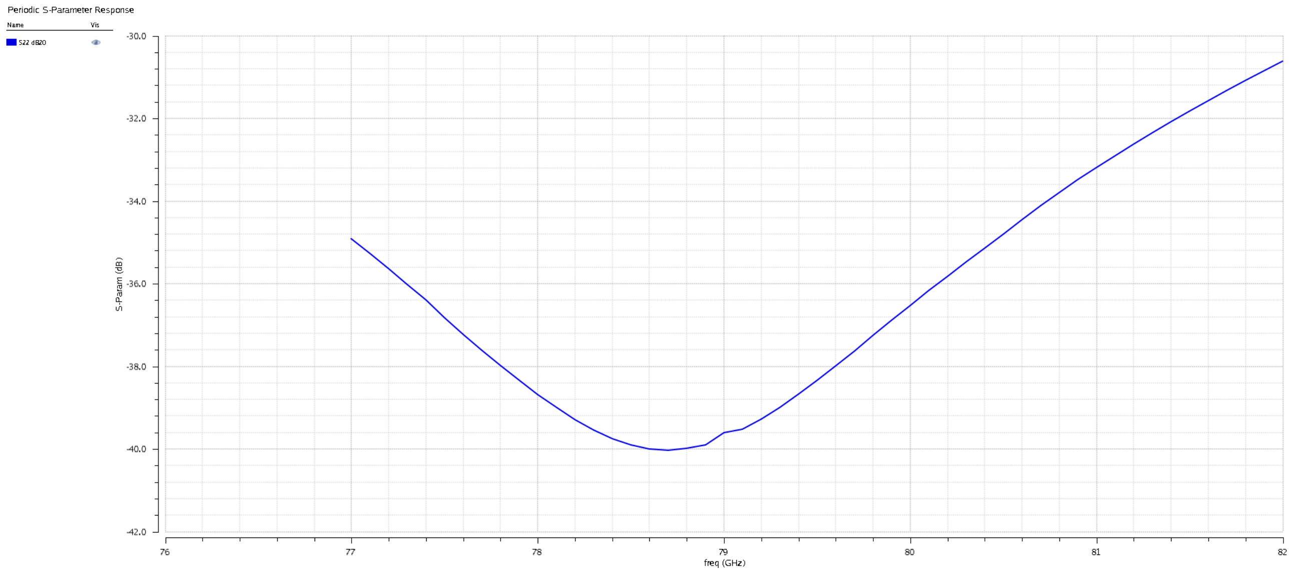

Figure 13: IF Port Match