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MultiLevel RF Power Detector

Group Members:

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Abstract

- This project aims on desinging an RF power detector to detect the presence of the signal and display its power in three bands 433MHz and 915MHz as commonly available RF bands. This can be used in RF industry to detect the intensity of signals and also in telecommunication industry for similar purposes.

- The device has the following functionality.

    - Detect two RF bands individually.
    - Depict the relative power of the signal from an LED interface.
    - Functions from DC 9V supply.

- Currently the circuit has been implemented for 433MHz and 915MHz bands.

Abbreviations and Acronyms

RF Radio Frequency

SAW Surface Acoustic Wave

LNA Low-Noise amplifier

ADC Analog to Digital Converter

EMI Electro-magnetic Interference

ADS Advanced Design Software

**ISM** Industrial, Scientific and Medical

Contents

1 Introduction and Functionality

The primary idea behind this instrument is to identify relative power of signals transmitted in frequencies of 433MHz and 915MHz. The core principles used here are, filtering, amplification (low-noise), analog to digital conversion (ADC) and power regulation.

2 System Architecture

2.1 Initial architecture and block diagram
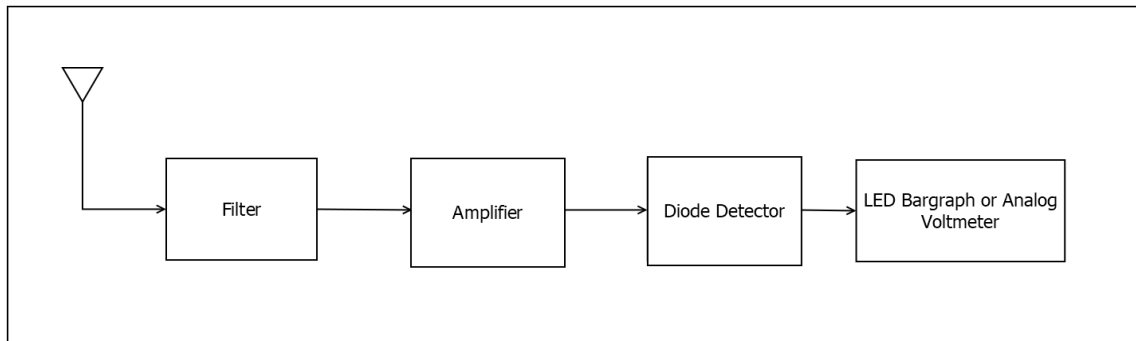
- The initial plan was to filter out the signals received from the antenna at first in the required frequency range. For 433MHz the target range was to be decided on the capability of the filter.

- Then the filtered response was planned to be amplified so as to acquire a considerable amplitude to the signal to be easily processed and detected.

- Afterwards the detection was planned to be done using a diode detector/envelope detector to convert the RF signal to a DC voltage so as to get represent its magnitude.

- Finally the DC voltage was planned to be displayed using an LED driver circuit.

2.2 Revised architecture after feedback
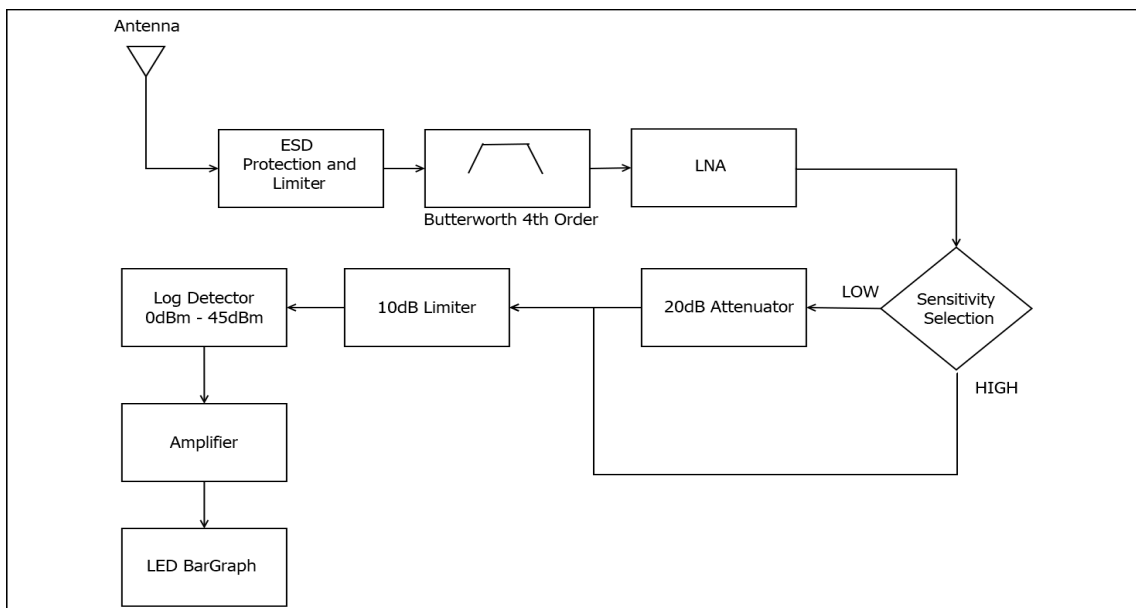
- After receiving feedback about impedance matching, low noise amplifiers (LNAs) and log detectors were proposed to be used in the place of traditional amplifiers and diode detectors to match with varying RF signal voltages and more accuracy.

- The attenuators and limiters were included so as to bring the signal within the input range of the log detector.

Calculation justification for introduction of attenuators and limiters

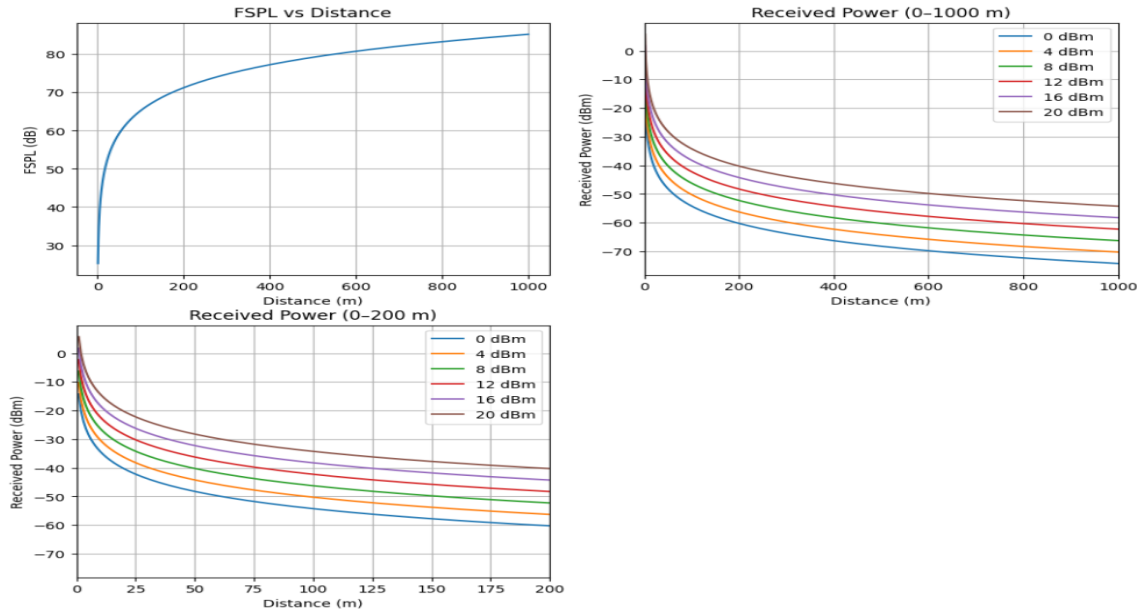At the antenna power $= 1 - 2\, dBi$ (typical power for an SMA antenna)
Insertion loss of limiter block $= 0.5 - 1\, dB$
LNA $= 13\, dB$ gain with a Noise Figure $= 1\, dB$
(To prevent saturation introducing an attenuator for short ranges $= 20\, dB$)
Hence estimated max loss before reaching log detector $= 1 - 1 + 17 + (-20) - 1 = -2\, dB$

Considering free-space loss and other losses expected received power is as follow

- Impedance matching was done through simulation from Advanced Design Software with corresponding s (scattering) parameter files obtained from manufacturers.

- A 4th order band-pass filter was decided as best suiting to give the desired output in the required frequency range.

2.3   Current design after further discussion with mentors
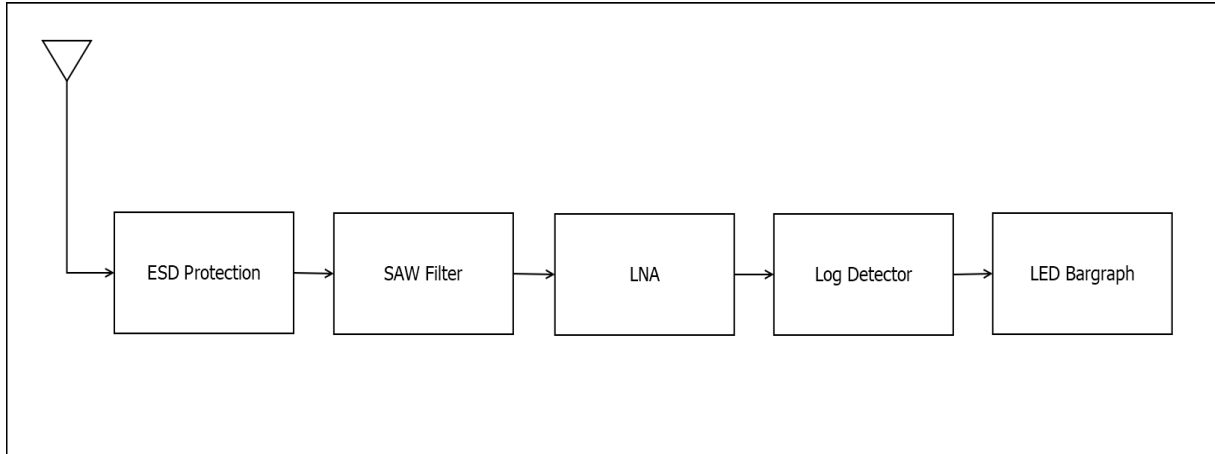
- After having a discussion with a senior from ENTC having expertise in RF engineering (Mr.Lasitha Jananjaya) the attenuators and limiters were removed from the second design since naturally due to the losses occurred, the signal came into the input range of the log detector.

- Then appropriate design choices were made for component selection as shown below.

3   Component selection

3.1   Antenna

- For both bands it was decided to use SMA-edge connected antennas since easy to connect to the PCB and guaranteed to provide a smooth RF interface with minimal losses under an affordable budget.

- Hence SMA type (rubber-ducky coiled) antennas were purchased from LCSC.

3.2   ESD protection

- Since components like the log detector and SAW filters are highly sensitive manufacturer's datasheet stresses the use of a specific ESD protection. In the case for SAW filters (since introduced at the antenna-filter interface) Qualcomm suggests to use BAV99W which contains two head-on diodes in series.

3.3   Filters

- For **433MHz** initially it was decided to use Qualcomm's B3710 SAW filter, but after iterative designs a 2nd order Butterworth bandpass filter was constructed with corresponding simulations with ADS.

- Due to high RF losses it was decided to use ABRACON's general purpose 915Mhz SAW filter considering noise figure and s parameters.

3.4   LNA

- Initially it was proposed to use an IC for the LNA as well, due to design complexity and signal losses, but after multiple iterative procedures with software simulations through ADS LNAs were constructed for bothe 433MHz and 915Mhz bands to achieve an acceptable amplification factor(20dB) with a minimal noise figure(3dB).

3.5 Log detector

- The log detector was initially designed and implemented with LTSpice with successive op-amps , but for realization high frequency op-amps need to be used which themselves are not recommended to be used in constructing new designs.Hence it was decided to use LT5534 log detector from Analog devices as the log detector.

3.6 ADC

- The ADC was implemented with an array of op-amps arranged as sinks.

- The op-amp TL072 was selected based on availability and adequate switching speed.

3.7 Power Supply

- Since the designed LNA required a constant and stable 6V power supply, 7806 6V regulator was used to supply power from 9V battery.

- To supply 5V to other components, a series regulator with feedback that uses a TL431 as reference was chosen due to its less heat generation and high stability over variation in load resistance.

4 PCB Design

- Based on the current design the schematic was designed and a 4-layer PCB was designed in accordance with RF design principles for the RF part.
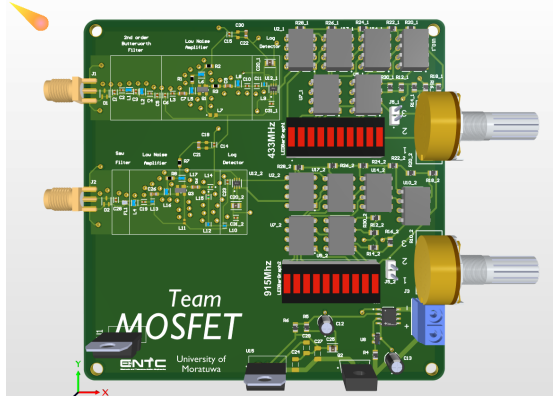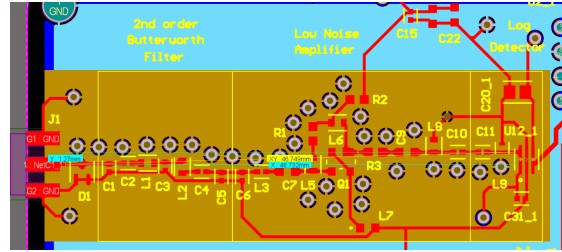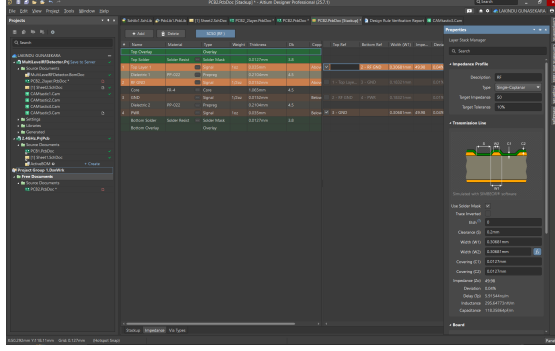

Figure 1: 3D model of PCB

Figure 2: RF trace

- RF practices followed to ensure signal integrity and minimal EMI.
    - RF traces were isolated as much as possible from power traces.
    - A solid ground plane was included in the 2nd layer to make sure the RF trace has a return path.
    - Based on the JLC controlled impedance stack JLC0416H - 7628 for 50 with $h = 1.065mm$ the trace width is $0.3493\,mm$ as per JLC impedance calculator. (The altium impedance calculator provided slightly different value, but selected manufacturer's value)
    - Components related to RF part were placed close enough so that the total RF trace is about 28.626 mm.
      Consider the wavelength calculation for 433MHz for FR-4 di-electric material with 1.6mm thickness.

Figure 3: Altium impedance control

Figure 4: JLC impedance control

$\lambda = \frac{c}{\nu} = \frac{3 \times 10^8}{433 \times 10^6} = 0.6928\,m = 69.28\,cm$

Effective wavelength for FR-4 ($\epsilon_r = 4.4$)

$$\varepsilon_{\text{eff}} \approx \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{w}\right)^{-\frac{1}{2}}$$

$$\lambda_{eff} = \frac{\lambda_0}{\sqrt{\epsilon_{eff}}} = \frac{0.6928}{\sqrt{2.997}} = 0.4002$$

Hence because the actual RF trace length close to 46mm being slightly larger than $\lambda/10$, transmission line effects can be neglected.

– Adequate space was left between the two RF traces of 433MHz and 915Mhz to avoid any EMI.

– Closely located inductors were place in orthogonal orientation to avoid a transformer effect.

• The components were powered from a 7805 linear regulator from direct power supply from 9V battery. The input and output ports of the regulator were connected to capacitors for filtering of low frequency and high frequency noise.
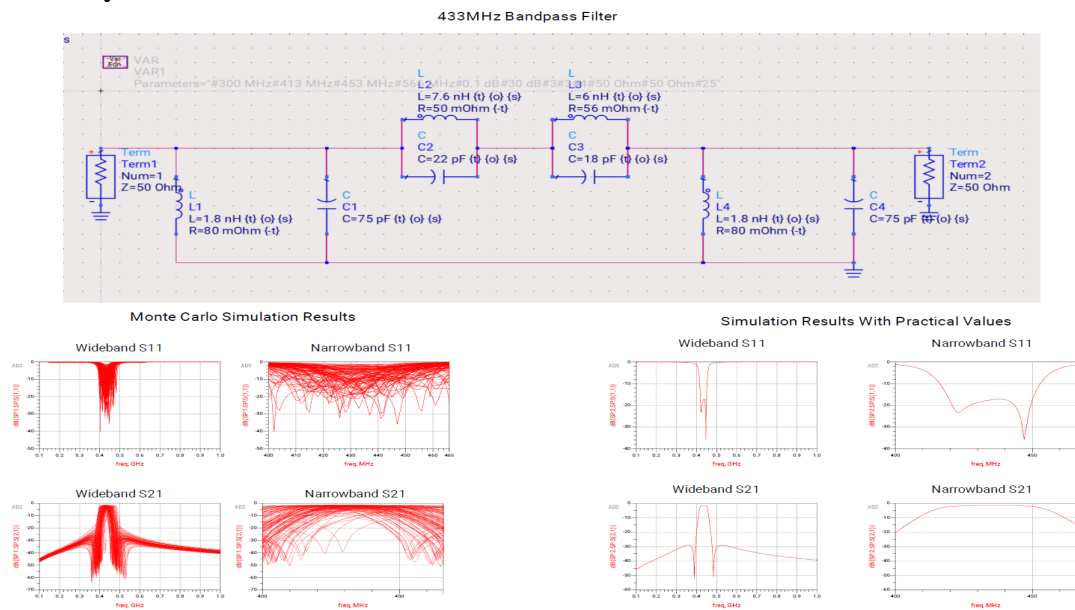
5   Enclosure Design
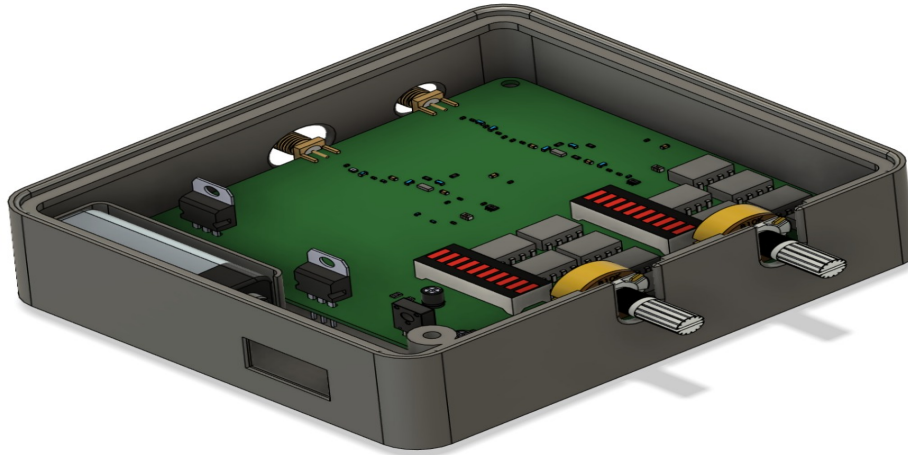
6   Software Simulation and Hardware Testing

6.1   Filters

Comparison of LC filter constructed for Butterworth 2nd order bandpass filter with response of Qualcomm's B3710 SAW filter for 433 MHz.

The image on the right shows the S parameter simulations for the realizable LC circuit constructed from ADS, which shows promising frequency responses. But the image on the left which is a **Monte Carlo** simulation for practical tolerances says otherwise.
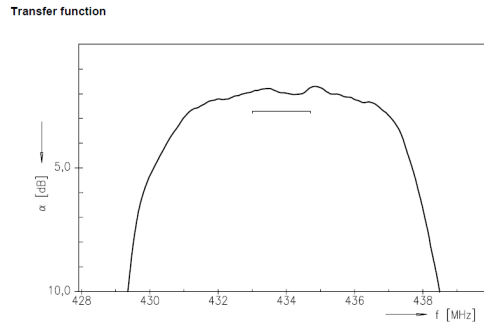
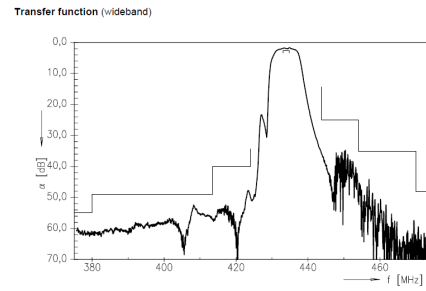Figure 5: "Narrowband response"

Figure 6: Wideband reponse

- But it was decided to implement the 433Mhz filter with the constructed Chebyshev filter and a SAW filter to 915MHz.

6.2   LNA

LNAs were constructed for both bands under iterative procedures with ADS to give acceptable amplification and Noise Figures.
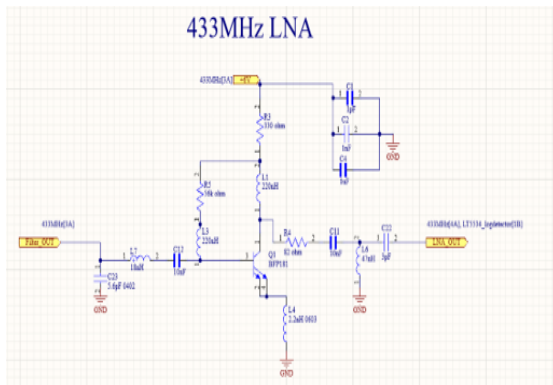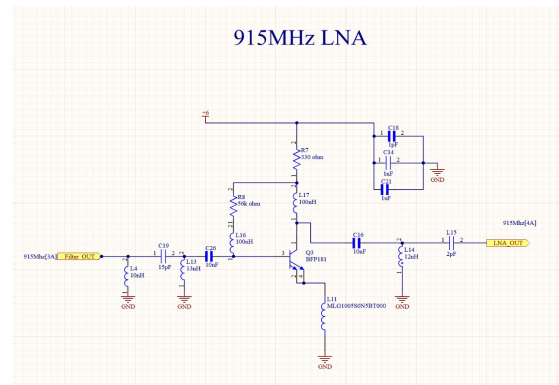

Figure 7: 433MHz LNA

Figure 8: 915MHz LNA

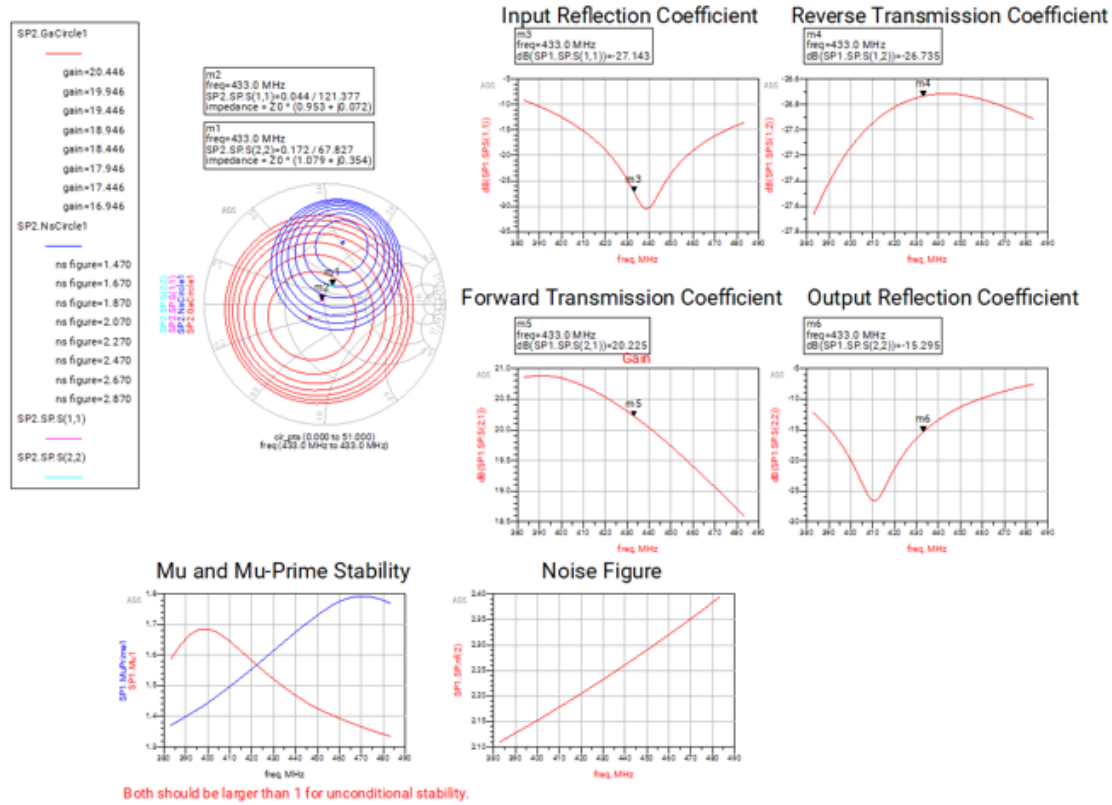The results of the final simulation done with ADS were as follows.

433MHz LNA
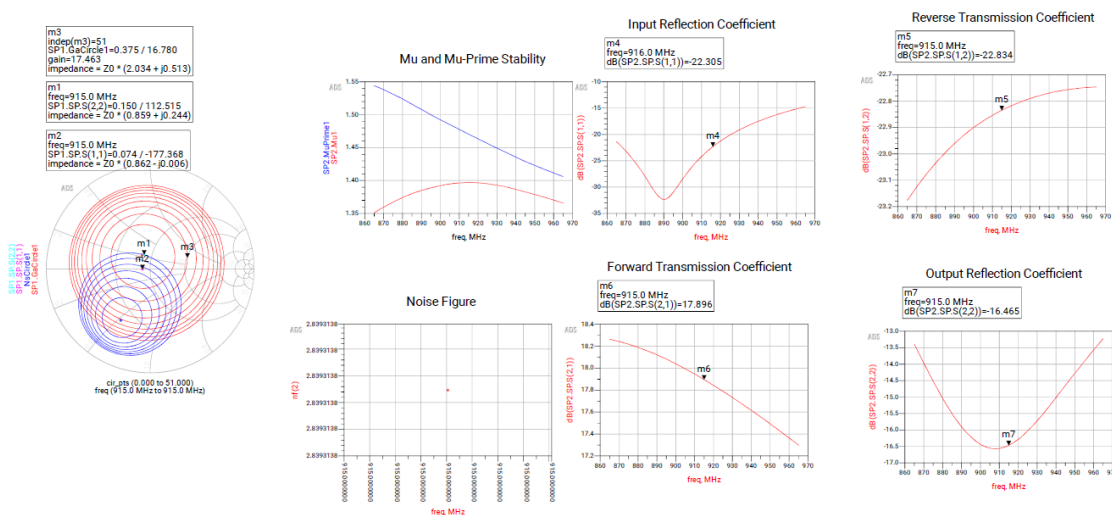

Figure 9: 433MHz LNA

915MHz LNA

Figure 10: 915MHz LNA

6.3   Log Detector

Initially the Log detector constructed virtually with successive universal op amps were simulated with LTspice. The response is satisfactory as shown below. But due to unavilability of practical op-amps the design was not implemented. Instead Analog devices's LT5534 was used.
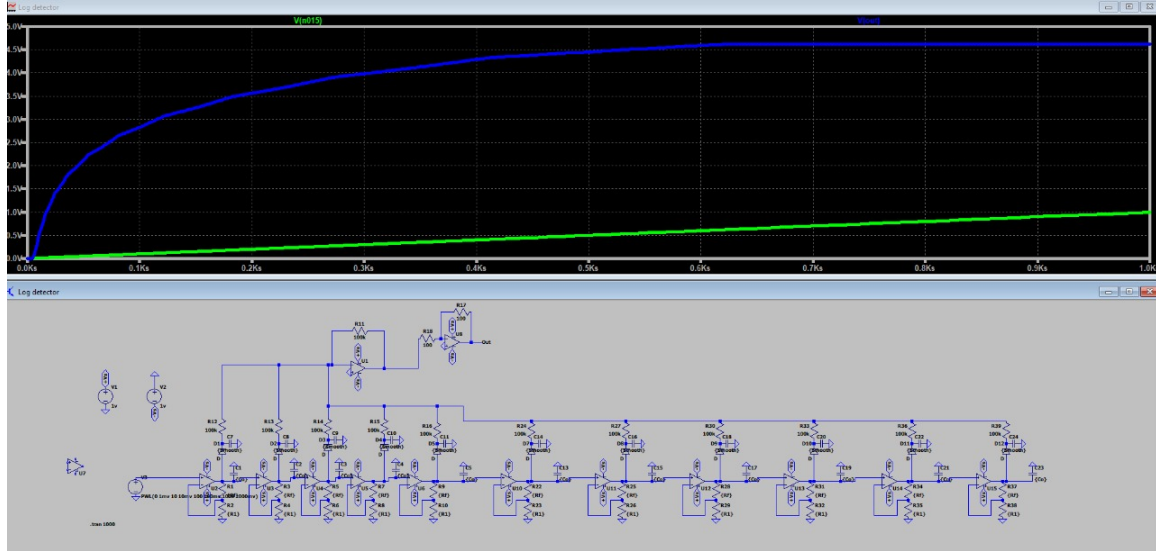

Figure 11: Logdetector LTSpice siumlation

7   Conclusion & Future Works

The initial plan for this implementation was for 3 ISM bands: 433MHz, 915MHz and 2.4GHz. But due to time constraints and design complexity 2.4GHz was omitted. The project holds a future progression with the inclusion of 2.4GHz band as well.

8   Contribution of Group Members

Gunasekara L.U.A.	PCB Design and documentation
Elapatha C.D.	Simulations and design choices
Peiris T.S.R	Simulations and design choices
Kariyawasam J.H.D	PCB Design and enclosure design

Acknowledgment

References

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[2] Qualcomm, *B3710 433MHz SAW Filter*, Datasheet.

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[6] Texas Instruments, *LM7805 Voltage Regulator*, Datasheet.

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[8] C. H. W. Wijegunawardana, B. W. J. C. Kumara, C. J. Kurukulasuriya, and C. S. Liyanage, "Doppler radar-based drone detection in dense urban environments,"

[9] Qualcomm, *Application Note: SAW Components ESD Protection for SAW Filters*, Technical Note.