Non-Linear Junction Detector

Prakirt Raj(140070027)
Debarnab Mitra(140070037)
Varunesh Goyal(140070006)

Special thanks to:

Salil Sir (Comm lab)
Mashewar Sir (Wel Lab)
Rinkee (Antenna Lab)
Sekhar Sir (Wel Lab)
Danish Sir (Comm Lab)
Priyanka Pola (TA)

supervised by
Prof. Shalabh Gupta

Abstract

A non-linear junction detector, or an NLJD is a counter-surveillance tool commonly used for detecting hidden transmitters or other electronic items. The device illuminates a small region of space with high-frequency RF energy. Any "non linear junction" in the vicinity—for example, and particularly, the p-n junction—will receive this energy, and because of the non-linear nature of the junction, it will re-emit harmonics of the illumination frequency. The detector detects these harmonic frequencies. Because the basis of almost all semiconductor electronics is the p-n junction, an NLJD is correspondingly capable of detecting almost any un-shielded electronic device containing semiconductors, whether the electronics are on or off.

Contents

1 Introduction

The project objective is to make a proof of concept (or prototype if possible) of a Non Linear Junction Detector with the bare minimum essentials.

NLJD got a reputation as perfect means of counter-espionage, as embassies and other diplomatic posts are known to be most popular targets for eavesdropping equipment. Some specific models of NLJD are used by the police in search for weapons during events involving great masses of people. These detectors are used for providing location secure from covert listening devices in different organizations.

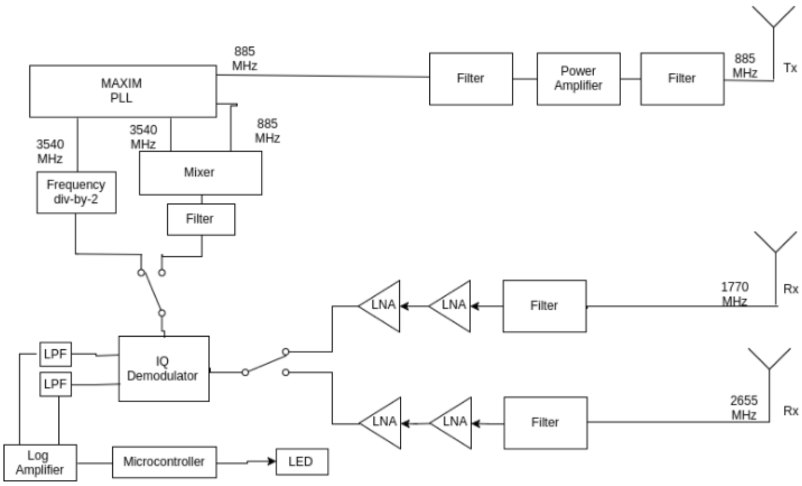


Figure 1: Block Diagram

Our motivation for the project however arose as it was floated as a project under NCETIS. In the naxalite affected regions of the country, the naxals regularly plant bombs under roads which are remote controlled. Detecting these is crucial for the CRPF jawaans. These bombs are a major cause of casualties to our security forces. NLJD is the most effective tool for them in order to counter this threat.

Currently the NLJDs used are imported from Germany and other places. They prove to be very expensive (around Rs. 12lakh per piece). Moreover the spare parts aren't easily available in the country and the foreign companies make a killing in supplying them. Thus there is a great need for indigenization of this device.

Indigenization would also allow to have the NLJDs customized to their requirements. In one meeting with some officers from the CRPF which Prof. Karandikar had arranged for us in our second year, we learned of many requirements from their side. The following were some of the practical specifications which they wanted the product to have -

- Atleast 2ft detection range in wet soil
- Battery life: 5-6hrs
- Battery should be easily available in market
- Lightweight overall equipment

2 Product Design

An NLJD works by detecting harmonics of emitted frequencies. Generally 888 MHz, 915 MHz or 2.4GHz is used as the transmit frequency and its 2nd and 3rd harmonics from the reflected signal are measured. Power levels ranging from 15 mW to 7.5W are used in commercially available devices.

So in a broad sense, the task at hand is to generate a tone at a desired transmission frequency and then develop a receiver to detect its harmonics.

The first design decision was to fix our frequency of operation. This depended on a lot of factors primarily being that the spectrum in which we intend to operate should be unlicensed (the transmitted frequency as well as its 2nd and 3rd harmonic). We are talking of detecting femtowatts level of power of the harmonics (-120 dBm) and thus it is crucial that no other equipment operates near the harmonic frequencies. Another factor was that components had to be available to work at the desired frequencies. This includes the ability to generate the transmit frequency using a PLL and availability of required filters in the market. All this led us to fix a transmission frequency of 885 MHz.

The second design decision was to fix the specifications which we wish to achieve. This mainly involved deciding on the transmit power and the receiver sensitivity.

The radiated power can range from tenths to tens of watts. However, it is important to realize that extremely high power radiations can destroy sensitive electronics and even cause harm to human health (like damage pacemakers). The following table summarizes this.

15 – 100 mW	Usually too weak
100 – 500 mW	Minimum use – weak
500mW – 2W	The most frequently used range- ideal for detection
2 – 5 W	Usually is not used
Nad 5 W	Too much power can destroy sensitive electronics
Nad 300 W	Bad for health but good for heating dinner

Figure 2: Transmission Power

Calculations for the desired receiver sensitivity involve considering the transmit power, antenna gain, path losses, and the actual amount of harmonic content generated by an electronic device under RF illumination. Considering the distance upto which we wish to detect to be 1m, transmit power to be 10 dBm and that ratio of harmonic content generated by a junction to the amount of power incident on it is -40dB, we get it to be around -120dBm[see ref]. What this amounts to in the design process is that since the signal is only around 54 dB above the thermal noise floor, we cannot use components having high noise figures.

The next crucial design step is to fix the transceiver architecture. The transmission side is pretty much same in all RF applications (apart from the modulation aspects which we are not concerned with as we only intend to send a pure tone). It involves using a PLL to generate the frequency of interest followed by a power amplifier and filtering of the output to remove the harmonics.

For the receiver part, our aim would be to detect the power levels of the reflected harmonics (1770 MHz and 2655 MHz). There are mainly two schemes which are used:

- The heterodyne receiver in which the signal is converted to an intermediate frequency (IF) and then passed on to a DSP.

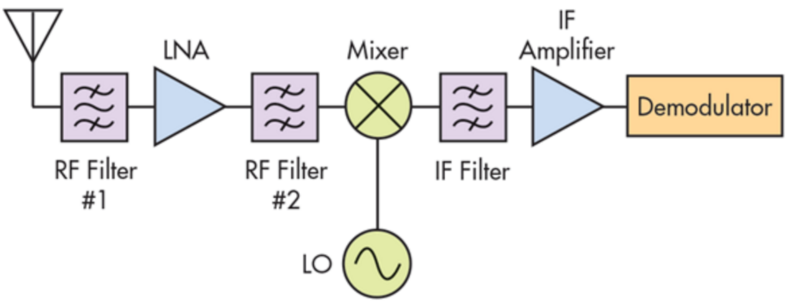


Figure 3: Heterodyne receiver

- The homodyne receiver (aka direct conversion receiver) in which the signal is directly brought to baseband.

The heterodyne receiver requires generating different frequencies for the downconversion. It also faces in general the issue of an image corrupting the signal. In our case, it could involve placing of extra filters to reject the image frequencies. Thus we decided to have a direct conversion receiver as generating the exact frequencies for downconversion is not difficult. We can get exact harmonic using the PLL generating the transmit frequency itself. Had the application involved having transmitter and receiver at different locations (as in communication areas), this would have been difficult.

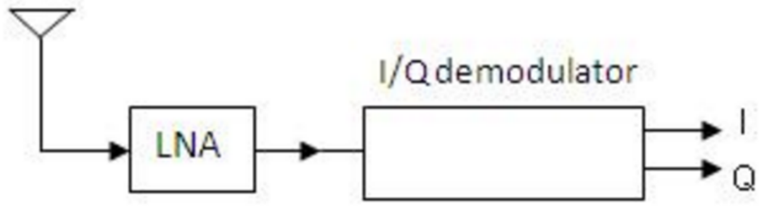


Figure 4: Homodyne receiver

We initially kept our options open with regard to how we exactly intend to generate the harmonics for LO to the downconversion mixer as we could always achieve it by using some frequency multipliers and filters. Later on as we got to know of MAX2870 (a PLL), we had our final block level design ready involving frequency divider, RF switches and an additional mixer.

2.1 Component Choice

At the component level too we had many choices to make:

- Antennas
  - Type of antenna: There are a ton of antenna types present - monopole, Yagi-Uda, spiral, parabolic reflector (dish), microstrip patch, horn etc. Making a patch antenna was the simplest as it didn't involve much hardware part and was comparatively easier to design and understand. Moreover it is smaller in size, could be directly connected to the rest of the circuit and once the design is finalized would take only 1 day to get it made from the PCB lab.
  - Single antenna vs different antennas for different frequencies We had the option of having one antenna catering to all the three frequencies concerned and adding a diplexer in our design to separate the transmitted and received signal. Achieving this would have taken a lot of time (given our zero background in antenna designing at that instant) and having the antennas ready was the first priority. So it was decided to have three separate antennas - one for each of the concerned frequency.
  - Antenna polarization: There is a choice here of having linearly polarized antenna or a circularly polarized one. A linearly polarized antenna would require sweeping over an area in both horizontal and vertical direction to fully ascertain the presence or absence of a

junction as the orientation of the junction affects how much of the incident power gets converted to harmonics.

A circularly polarized antenna doesn't face this issue. It however faces an additional 6dB loss (3dB less power converted by the junction to the harmonics, and 3dB again at the receiving antenna). Using circular polarization has another advantage. Say we are using right handed polarization. Then the harmonics which unwantedly get transmitted (aren't properly filtered) on reflection become left handed polarized. Whereas the harmonics which will be generated as result of a non-linear junction will have right handed polarization. This provides additional isolation.

We have however decided to have a linearly polarized antenna as it was comparatively simpler to design. Also an unnecessary loss of 6dB is avoided

- Frequency generation using PLL: The conventional method of frequency generation using general purpose programmable PLLs like LM565, LM565C, CD4046B, LTC6945 etc could have been used by programming them and giving them a clock signal from a local oscillator. However it was found that the IQ modulator board developed in WEL already had the required setup of programming a PLL using a microcontroller and an onboard Local oscillator at 10MHz.Keeping in mind the complexity of the project we decided to use evaluation boards was used instead of building the PLL circuit by own.

  There was also a similar board in Communications lab - MAX2870 which also had an onboard Local oscillator and programmable PLL.This board however had differential outputs of two different frequencies which proved to be favourable for generating carrier for transmission as well as for the downconversion process.

- Filters
  - At 885 Mhz : Power amplifier and the frequency generation devices are generally non-linear. We needed filters at 885 Mhz to filter out the harmonics produced by these devices. Also, we needed to suppress 2nd and 3rd harmonic so that the transmitted signal does not directly affect the received signal. We had 2 choices at 885 MHz, one is a low pass filter with cutoff frequency more that the 885 MHz but less than 2nd harmonic. Other choice was to use SAW filter with center frequency of 885 MHz.
  - At 1770 MHz : We needed sharp bandpass filters around 1770 MHz so that other devices operating at nearby frequencies does not interfere with the received signal. We had two choices at 1770 MHz, one

was to use the SAW filter and other was to design a LC resonator at that frequency. Distributed element filter was another kind of filter we came to know about, but their design was highly complicated.

  – At 2665 MHz : At 3rd harmonic, we had the option of using a SAW filter or a high pass filter.

  – Design: Low pass filter, High Pass filter and LC resonators for required frequencies can be easily designed using online simulators and softwares. ADS is one such software which we used for filter design. We knew the basics of filter design.

- Downconversion mixer: We have the choice of having a normal mixer or an IQ demodulator. Since the phase of the received harmonics would vary with the distance the device to be detected is placed, having IQ demodulator is prefered as by looking at bothe the I and Q channels, the received power of the harmonic can be accurately determined in DSP without worrying about the phase difference between the received signal and that which acts as the local oscillator to the mixer. The IQ demodulator which we finally decided to use was AD8347 as it also provided with upto 69.5dB gain. LTC5585 was another IQ demodulator considered but it doesn't provide any gain.

- Choice of controller and associated circuits: The demodulated harmonic would appear at baseband (i.e. around DC). Thus we don't require a controller which has an ADC providing a high sampling rate. An Arduino Uno (which can have a maximum sampling rate of 9.6kHz) is used. Coding an Arduino is also something which we already knew. However the quantization carried out is troublesome. Its ADC can only quantize in steps of around 5mV (5V/1024). Even after the gain provided by the entire receiver chain, we can expect at best to get around -30dBm power output. And in case some of the components give suboptimal performance, this is further reduced. Also dBm is a logarithmic scale. It is required to properly express the range of the received signal power. So a log amplifier is placed before the Arduino. Moreover, a low pass filter (10kHz) is placed before it to filter out components other than DC.

3 Project Implementation

The components made by us for the project along with their performances, and other relevant details are presented below.

3.1 Frequency Generator

3.1.1 IQ Modulator Board

The IQ modulator board developed by WEL lab was initially used as frequency generator. This board has a programmable PLL (phase locked loop) which generates the carrier signal from a fixed 10 MHz clock signal coming from an onboard crystal oscillator. The IQ modulator IC present on the board upconverts the analog baseband I and Q signals to the RF carrier frequency. However we only need the carrier output from the board. Hence no input is given to the I and Q channel and the output which we get from the board is the single ended unmodulated carrier. A microcontroller (PIC18F) present on the board programs the PLL when the board is turned on. The present code of the IQ modulator board developed by WEL was changed to get the desired carrier frequency of 885 MHz.

However this board generates strong 2nd and 3rd harmonic components as shown in figure, which interferes with the generated harmonic components from a non linear junction. The filtering of these harmonics is described in the later sections.

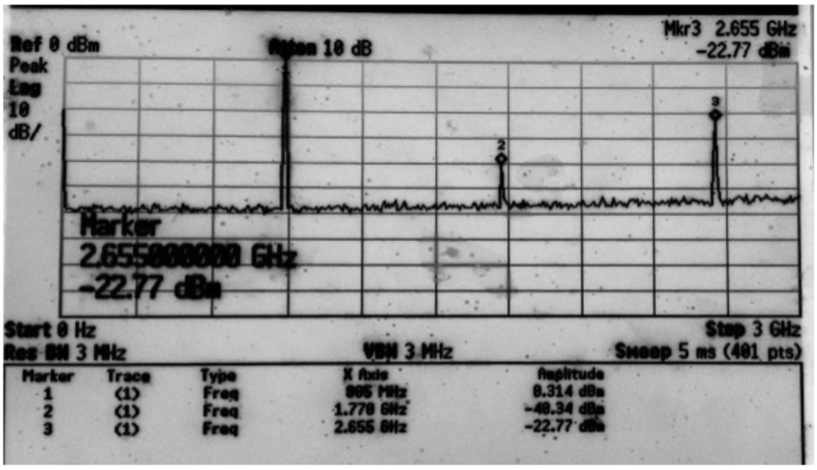


Figure 5: Output of IQ demodulator

3.1.2 MAX2870 Evaluation Board

This board also has a programmable PLL (MAX2870) which can be programmed to generate the desired RF frequency and also one of its harmonics (i.e we can program this board to get 2 carrier frequencies).The outputs from this board are differential. The differential carrier generated from this board (the second carrier) is used to generate LOs for the downconversion process as shown in the figure.

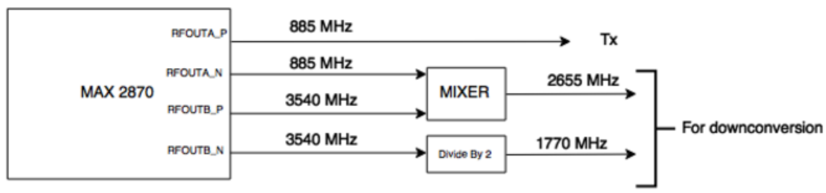


Figure 6: Downconversion Process

The advantage of using this PLL is that there will not be any frequency offset between the the LOs used for downconversion and the LO used for Transmission. This board also generates strong harmonic components which has to be effectively filtered out.

3.2 Power Amplifier

The 885 MHz signal generated by the IQ demodulator board or MAX2870 is very low in power. To increase the power of the transmitted signal, we are using a power amplifier.

3.2.1 MMG3003NT1

We used this power amplifier because it was already present in the antenna lab. The MMG3003NT1 is a General Purpose Amplifier that is internally input matched and internally output pre-matched. It is designed for a broad range of Class A, small - signal, high linearity, general purpose applications. Some of the features of this power amplifier :

- Frequency of operation is from 40 to 3600 MHz.
- Small signal gain is 20 dB at 900 Mhz
- Input supply voltage is maximum 7 volts
- Internally matched to 50 Ohm
- Low Cost SOT - 89 Surface Mount Package
- P1dB: 24 dBm at 900 MHz

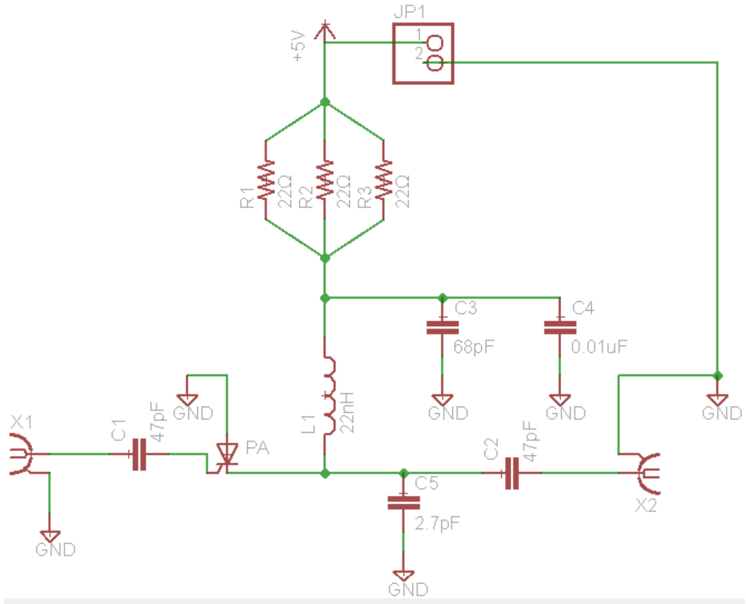


Figure 7: Schematic of Power Amplifier

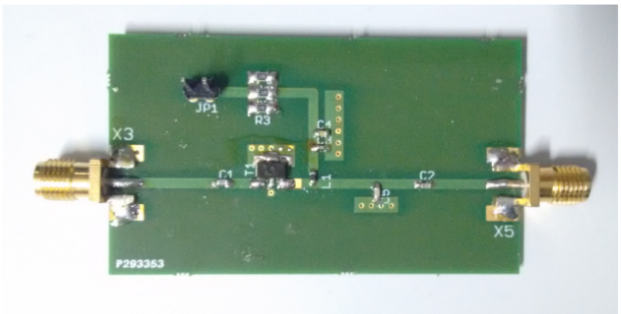


Figure 8: Power Amplifier Board

One problem with this power amplifier is that is Nonlinear in nature. It amplifies the power of the 2nd and 3rd harmonic also. To compensate for this, we had to use more filters the transmitter side to suppress the harmonics. The shielding is also required for this power amplifier.

3.3 Filters

The components at the transmitter are itself producing harmonics. Filters are used to reduce the power of the harmonics transmitted through the transmitter. Band pass filters are also used at the receiver side to keep the necessary frequency components and filter out the rest.

3.3.1 Lumped Circuit - Low Pass Filter

A low pass filter is made using lumped circuit elements. The LPF is needed only on the transmitter side to stop transmission of harmonics. The values of the LC elements in the low pass filter is derived using an online simulator *www-users.cs.york.ac.uk/ fisher/lcfilter/*. Another simulation was run in ADS software using these available values and fine tuning these values to meet the desired

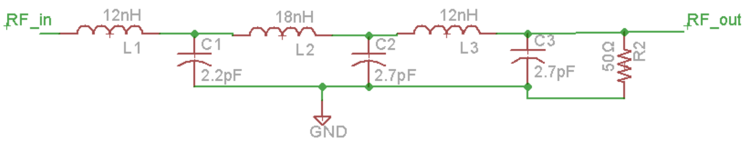


Figure 9: Schematic of LPF

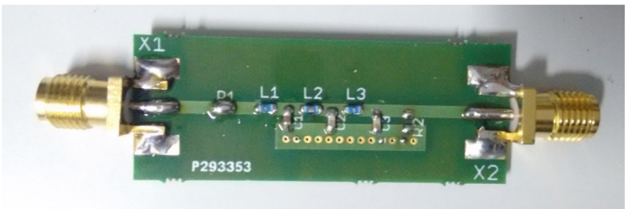


Figure 10: Board of LPF

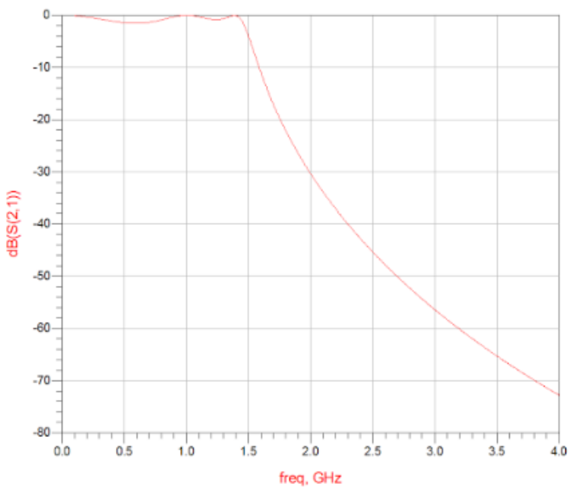


Figure 11: Simulated Response

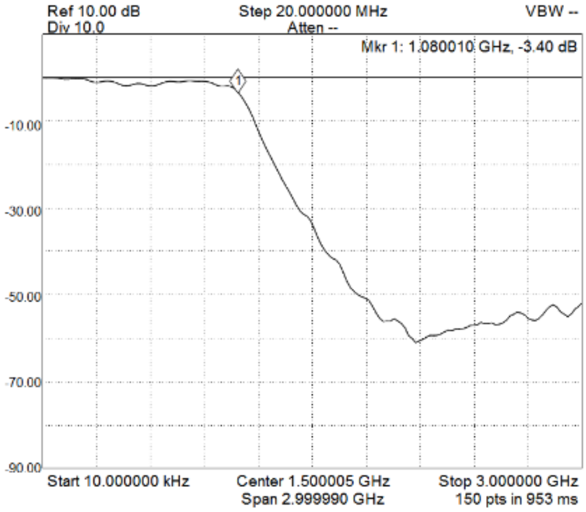


Figure 12: actual Response

The challenges faced during LPF design:-

- The 50 ohm resistors used for impedance matching were giving insertion loss. They were totally removed from the board, yet there was no problem with impedance matching.
- We initially used 0402 size inductors available in the communication lab. However the small size inductors were not able to handle the required power transmission. The 0402 inductor were replaced by 0603 size inductors present in the antenna lab.
- The cutoff frequency of the LPF board was shifted as compared to the simulated value. Initially we kept the cutoff frequency at 1 Ghz but the board was showing a cutoff at nearly 750 Mhz. The reason behind this might be the parasitic capacitance and inductance arising in the board. To tackle this problem, we simulated the LPF with a cutoff of 1400 Mhz and replaced the components accordingly, then the board was giving a cutoff at nearly 1 Ghz.

3.3.2 SAW Filter

A Surface Acoustic Wave (SAW) filter is a filter whereby the electrical input signal is converted to a acoustic wave by so-called interdigital transducers (IDTs) on a piezoelectric substrate such as quartz. The IDTs consist of interleaved metal electrodes (as shown in the figure) which are used to launch and receive the waves, so that an electrical signal is converted to an acoustic wave and then back to an electrical signal.

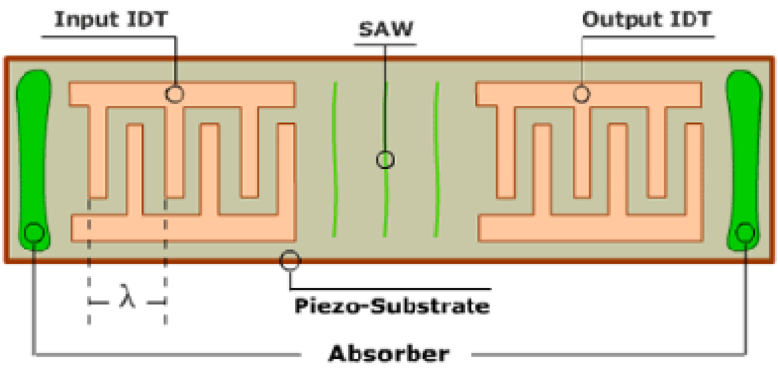


Figure 13: SAW Filter

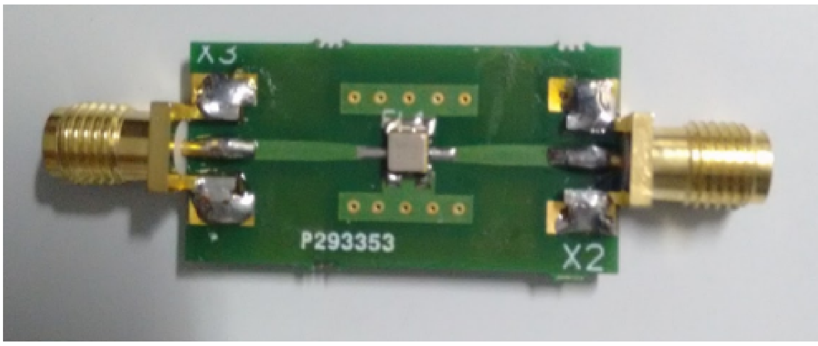


Figure 14: SAW Filter Board

There are many types with differing advantages, such as low shape factor, low insertion loss, small size, or high-frequency operation. The wide variety of types is possible because almost arbitrary shapes can be defined on the surface with very high precision. SAW filters are limited to frequencies from about 50 MHz up to 3GHz. Also, they are bidirectional.

The SAW filters we used are:

Part no.	Centre freq. (in MHz)	Bandwidth	Insertion loss
TA0798A	1795	15	3 dB
TA0835A	2665	70	3.6
TA0627A	895.5	39	2.7

Table 1: SAW Filters

The Response of TA0627A, TA0798A and TA0835A as measured by us:

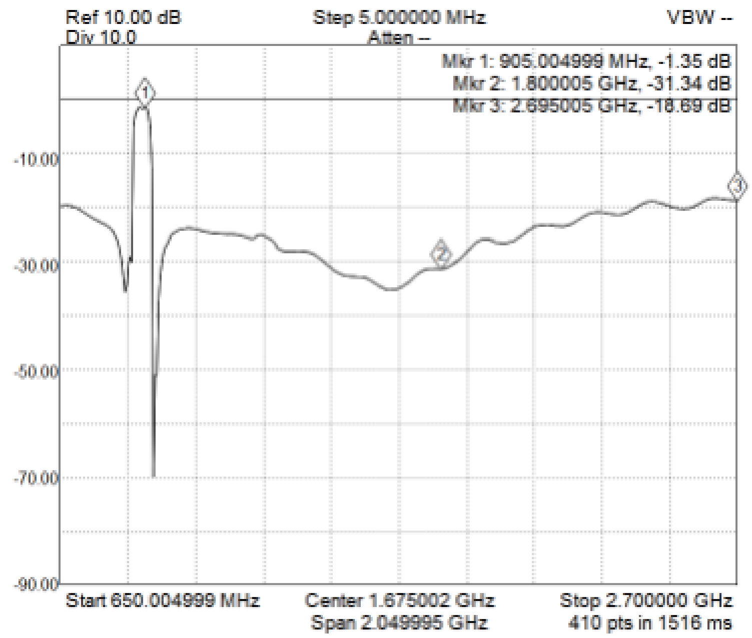


Figure 15: TA0627A

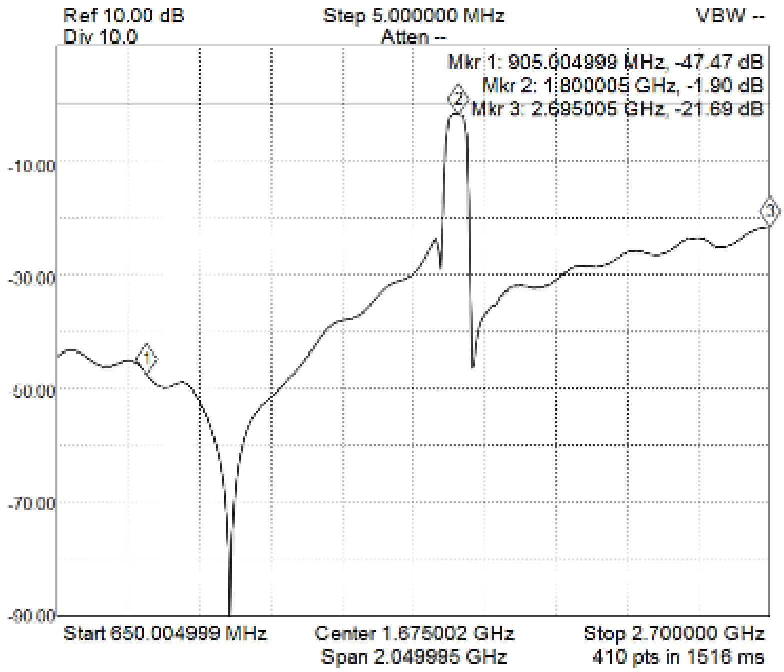


Figure 16: TA0798A

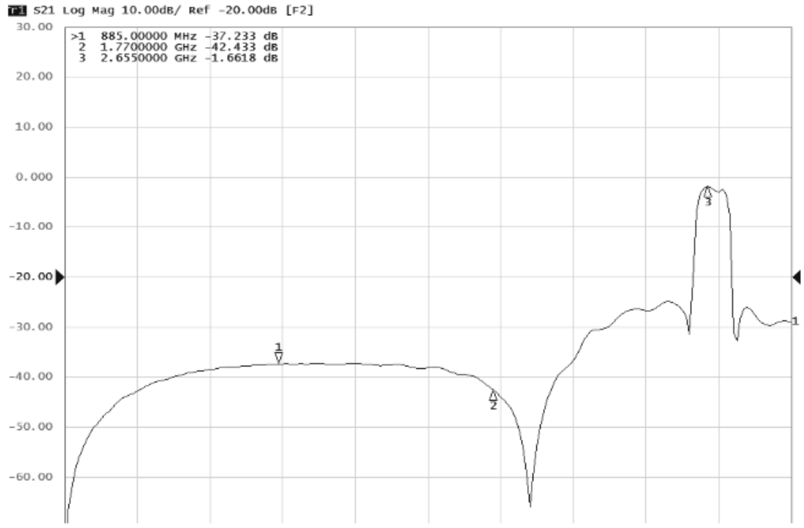


Figure 17: TA0835A

Challenges faced with the SAW filter are:

- The biggest challenge faced with SAW filter was of shielding. SAW filters were radiating harmonics directly which were interfering with the received signal.
- The isolation provided by the them between the transmitted signal and the harmonics at the transmitter side was not sufficient.

3.3.3 LC Resonator

LC Resonator works on the principle that when an inductor and a capacitor is connected in series or parallel, they have a resonance frequency. We simulated and designed a PCB layout for a LC Resonator at nearly 1800 MHz. But as the LPF was facing a significant shift in the cutoff frequency, we assumed that the LC resonator will also undergo a frequency shift. So, we did not implement the LC resonator on board and just used the SAW filter to fulfil our purpose.

3.4 Antenna

3.4.1 Air suspended antenna

We made a air suspended antenna using 3mm thick aluminium sheet. The dimensions and structure of the antenna required was figured out by simulating on CST. We cut the aluminium sheets according to that dimensions and measured the center frequency of the antenna which came out to be 850 Mhz. This was way off from the desired frequency of operation. Moreover, it was quite bulky.

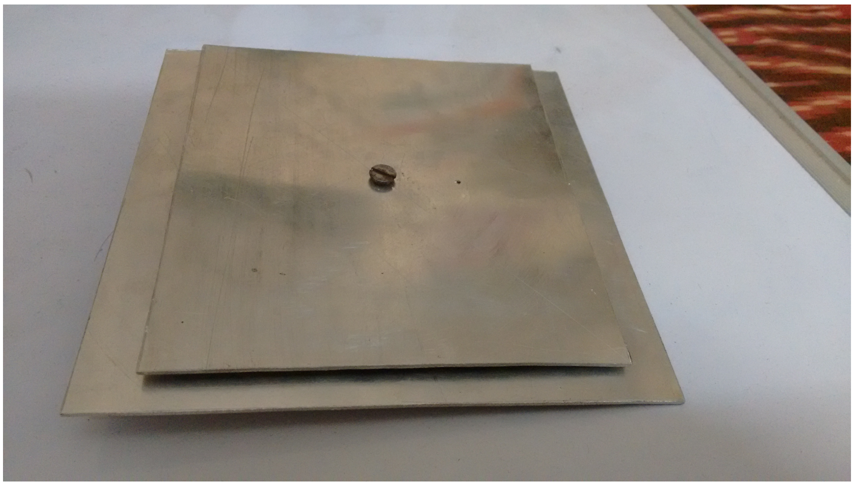


Figure 18: Air suspended antenna

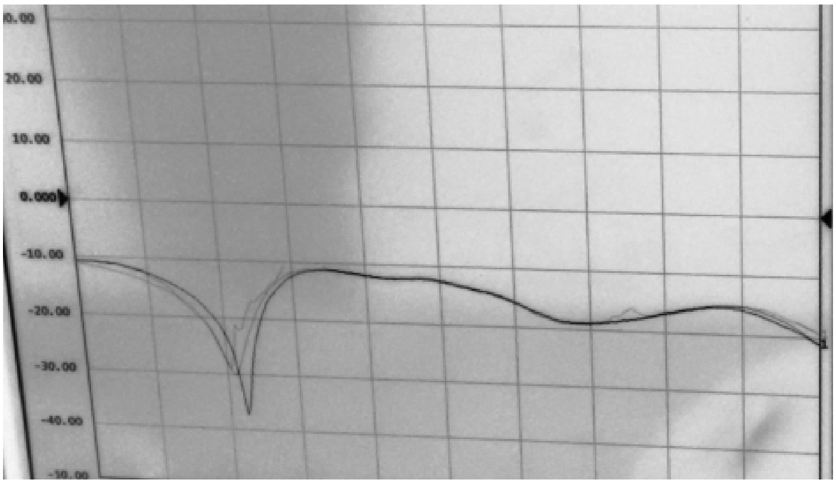


Figure 19: S11 parameter of the Air suspended antenna

3.4.2 Microstrip patch antenna

Linearly Polarised Microstrip Patch antennas were then designed to transmit and receive the signal and its harmonics respectively. A good estimate of the required dimensions can be found out using some equations[]. It basically depends on the dimensions of the copper patch, choice of PCB substrate and its thickness. The exact dimensions and placement of the feed to the antenna were then obtained by simulating with varying dimensions until the desired S11 parameters and impedance matching is obtained. CST was initially used for simulations. Later on we switched to using IE3D as it was much simpler to model antennas here and also obtain gerber files to get them printed.

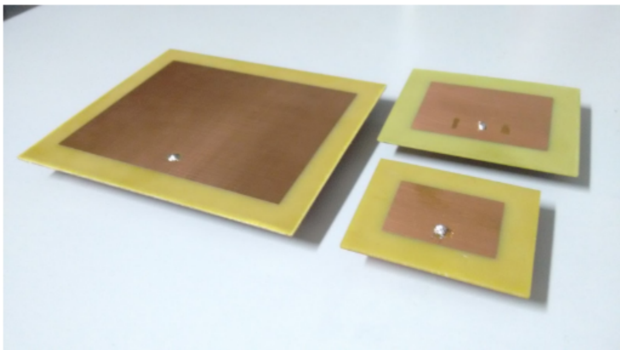


Figure 20: Microstrip patch antenna

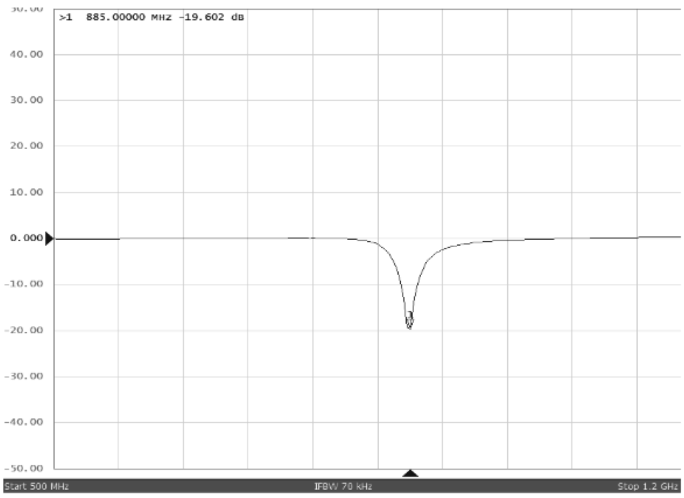


Figure 21: S11 parameters of the antennas built at 885 KHz

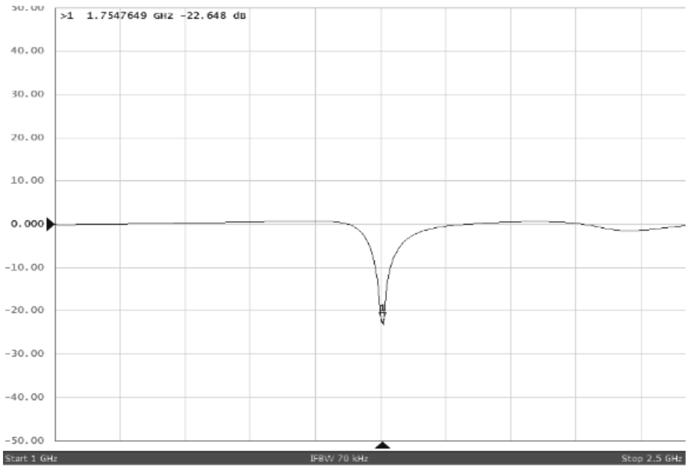


Figure 22: S11 parameters of the antennas built at 1770 KHz

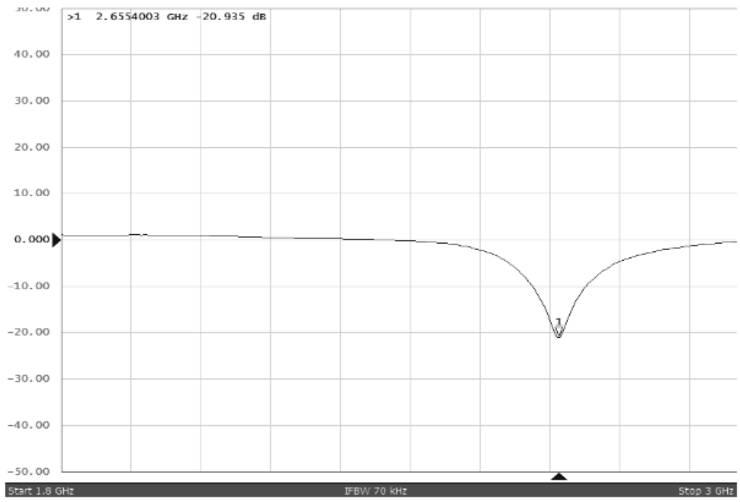


Figure 23: S11 parameters of the antennas built at 2655 KHz

Some of the challenges faced in antenna design are:

- Simulations were time consuming as you need to try with many different patch lengths until you get the antenna operating at the desired frequency, then try different feed positions in order to have a 50 ohm impedance match, and every simulation took around 2 to 3 minutes to run.
- Since patch antennas have a very high quality factor, minute changes which shift the center frequency of operation of the antenna by even 1-2 MHz affect us drastically. We regularly had the printed antenna having their center frequency a few MHz less than that predicted by in simulation. Reasons behind this were inaccurate information about the permittivity of the substrate used and improperly soldered feed.

3.5 Frequency divider

Frequency divider is used to produce the 1770 and 885 MHz signal from 3540 Mhz signal. We used the following frequency divider for this purpose.

3.5.1 HMC432E Divide by 2

The HMC432(E) is a low noise Divide-by-2 Static Divider in ultra small surface mount SOT 26 plastic packages. This device operates from DC (with a square wave input) to 8 GHz input frequency with a single +3V DC supply. Single-ended inputs and outputs reduce component count and cost.

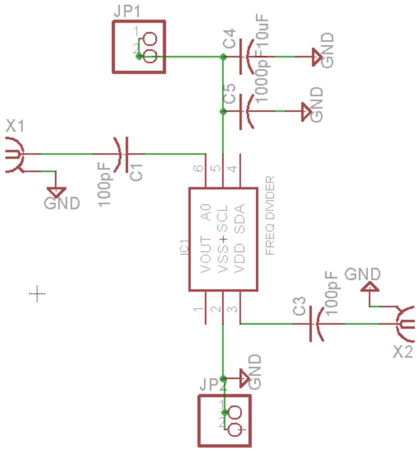


Figure 24: Schematic of Frequency Divider

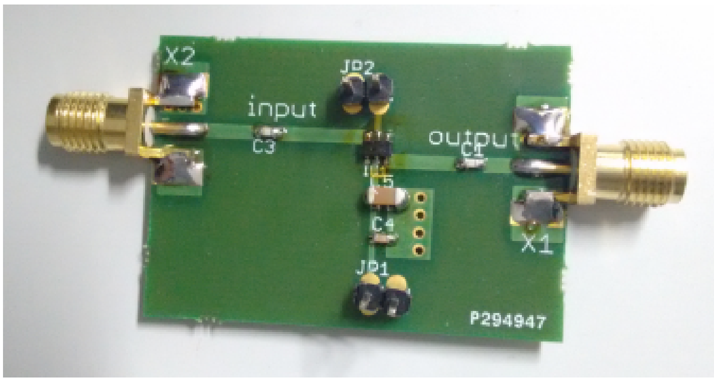


Figure 25: HMC432E Board

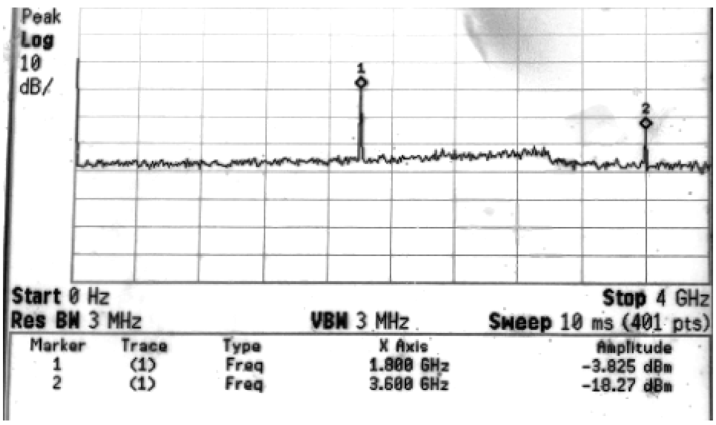


Figure 26: Response of HMC432E Board

3.6 Mixer

To downconvert the second harmonic to baseband, we need 1770 MHz signal. To generate this frequency, we are using a mixer that takes 885 MHz and 3540 Mhz signal and gives 2655 MHz as output.

3.6.1 LTC5510

The LTC5510 is a highly linearity mixer optimized for applications requiring very wide input bandwidth, low distortion, and low LO leakage. The chip includes a double-balanced active mixer with an input buffer and a high speed LO amplifier. Some of the features of this mixer is:

- Can be used for both up-and down-conversion and can be used in wide-band systems.
- The input is optimized for use with 1:1 transmission line baluns, allowing very wideband impedance matching.
- The LO can be driven differentially or single-ended and requires only 0 dBm of LO power to achieve excellent distortion and noise performance, while also reducing external drive circuit requirements.
- Offers low LO leakage, greatly reducing the need for output filtering to meet LO suppression requirements.
- Optimized for 5V but can also be used with a 3.3V supply with slightly reduced performance.

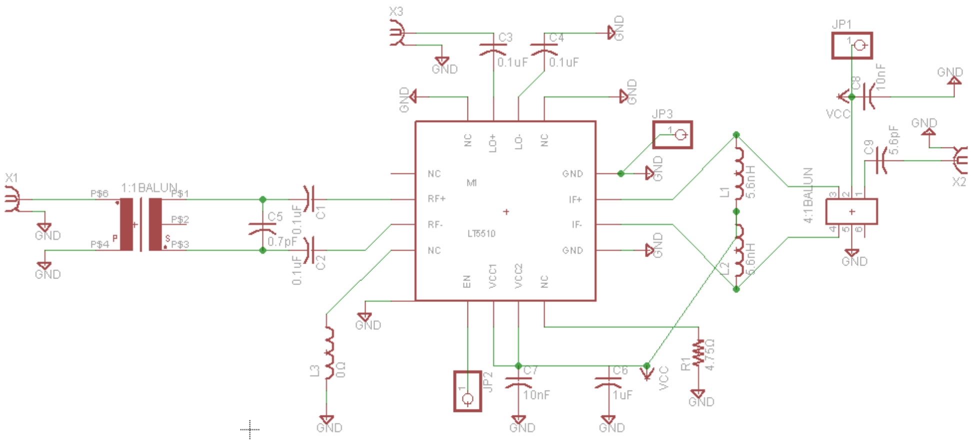


Figure 27: Schematic of LTC5510

The problems associated with this mixer are:

- The PCB layout of this Mixer as given in the datasheet is four layered. The reason behind it being 4 layered is that, one of the layer was bias voltage. This four layered PCB was increasing the cost of the PCB printing to a large extend. To tackle this problem, we made two solder patch and connected them with wire afterwards. This reduced the numbers of layers required to 2. The wire was part of power supply of this mixer, so it had to kept perpendicularly with the RF line.

- Another problem was that, this mixer required the use of two baluns. We had to order these baluns as it was not available in the lab.

3.6.2 Baluns

A balun is an electrical device that converts between a balanced signal (two signals working against each other where ground is irrelevant) and an unbalanced signal (a single signal working against ground or pseudo-ground). Transformer baluns can also be used to connect lines of differing impedance. We used the following two baluns to complete the mixer circuit:

- ETC1-1-13 : The ETC1-1-13 is a 1:1 transmission line transformer in a low cost surface mount package.

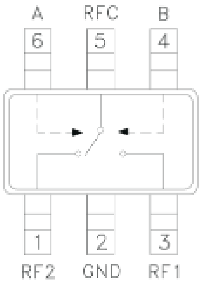
- BD1222J50200AHF : The BD1222J50200AHF is a low profile sub-miniature balanced to unbalanced transformer designed for differential inputs and in an easy to use surface mount package. It has an unbalanced port impedance of 50 and a 200 balanced port impedance. This transformation enables single ended signals to be applied to differential ports on modern semiconductors.

3.7 RF Switch

RF switch is used to toggle between the 2nd and 3rd harmonic at the receiver side.

3.7.1 HMC595AE

The HMC595AE are low-cost SPDT (Single Pole Double Throw) switches in 6-lead SOT 26 packages for use in transmit/ receive applications which require very low distortion at high incident power levels. The device can control signals from DC to 3 GHz with only 0.3 dB typical insertion loss.



Truth Table

Control Input (Vctl)		Signal Path State	
A	B	RFC to RF1	RFC to RF2
High	Low	Off	On
Low	High	On	Off

Figure 28: Truth Table of Switch

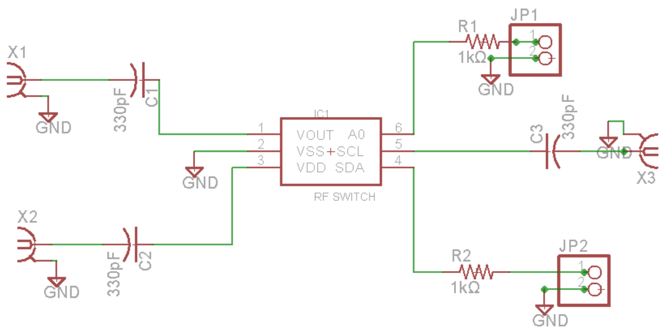


Figure 29: Schematic of RF switch

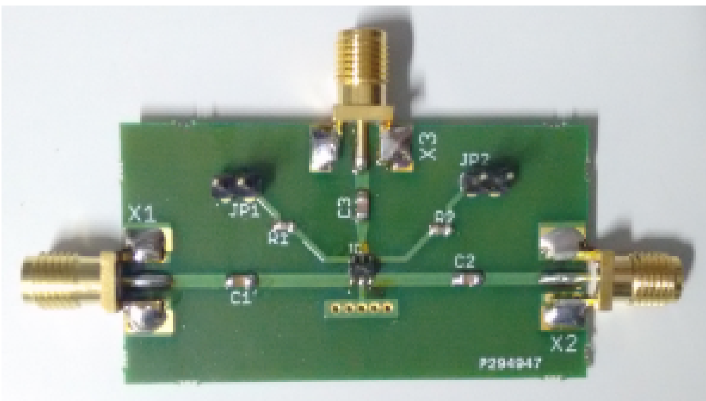


Figure 30: Board of RF switch

The response of the RF switch as seen on the spectrum analyzer

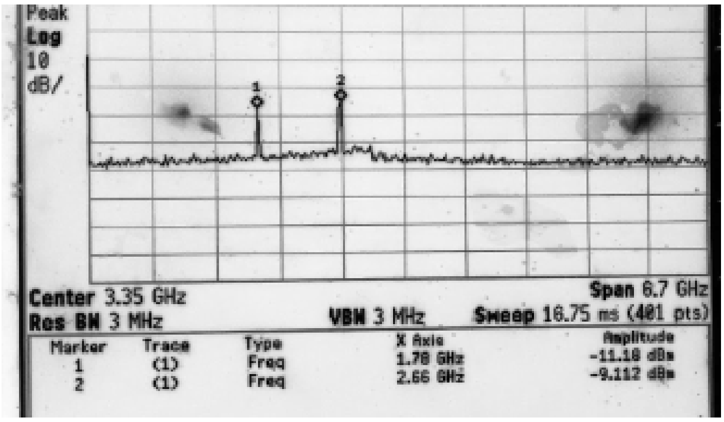


Figure 31: When both are off

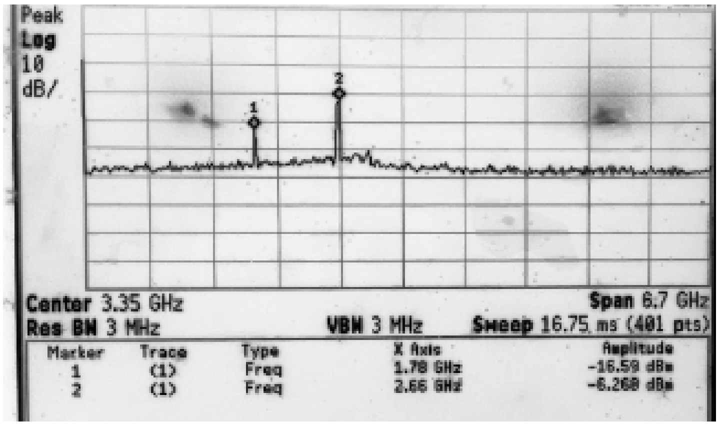


Figure 32: When One is on

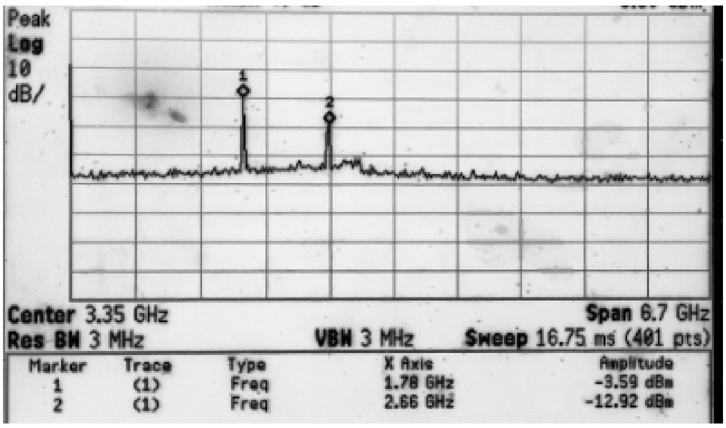


Figure 33: When other is on

3.8 Low Noise Amplifier

A low noise amplifier is used to amplify weak signals such as those received by an antenna. It amplifies a very low-power signal without significantly degrading its signal-to-noise ratio. We are using the LNA to increase the power of the received signal.

3.8.1 SGL0622Z

The SGL0622Z is a low noise, high gain LNA. Some features of this LNA are:

- Low power single-supply operation from +2.7 V to +3.6 V
- Internally matched from 5 MHz to 4000 MHz
- Low Noise Figure, 1.4 dB at 1575 MHz
- High Gain of 28.6 dB at 1575 MHz

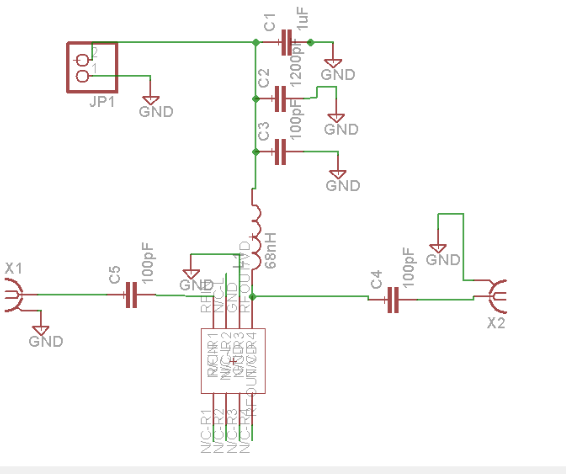


Figure 34: Schematic of LNA

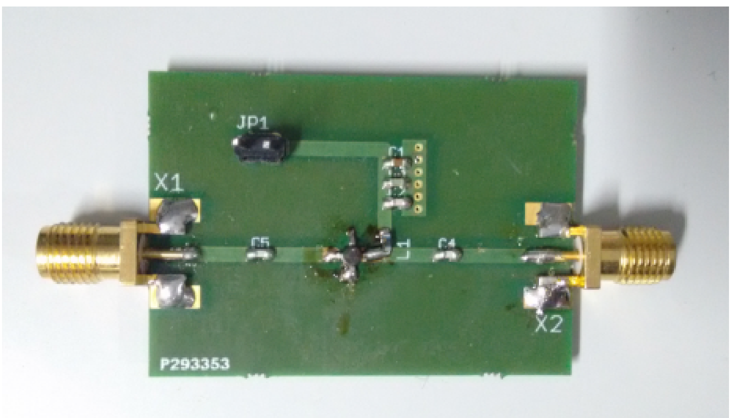


Figure 35: Board of LNA

The problem with this LNA it is not working as expected. It is producing high power signal at 470 MHz for some unknown reasons. Also, It is not providing the expected gain. We had to use a separate LNA altogether.

3.8.2 Crystek LNA

Figure 36: Crystek LNA

Crystek's model CRBAMP-100-6000 is a low-noise amplifier covering a frequency range of 100MHz to 6GHz. The unit operates from a single +5V supply consuming only 60mA. This broadband, low-noise amplifier has a small signal gain of 18dB. We used this LNA because our earlier LNA was not working and this LNA was already available in communication lab.

3.9 IQ Demodulator

3.9.1 ADC8347 Evaluation Board

The AD8347 is a broadband direct quadrature demodulator with RF and baseband automatic gain control (AGC) amplifiers. This board performs quadrature demodulation directly to baseband frequencies with an overall gain of 69.5 dB. The AD8347 has an on-board sum of squares detector to allow the AD8347 to operate in an automatic leveling mode. This mode is on by default in the evaluation board. We however want the gain to be constant hence we operate in non AGC mode by removing the connection between the VAGC and VAGIN. The gain of the RF amplifiers is controlled by Voltage on the VGIN pin. The gain control voltage range is from 0.2 V to 1.2 V and corresponds to a gain range from +39.5 dB to 30 dB. We operate this board with a VGIN of 0.4 V which provides an overall gain of 50 dB. Operating at lower VGIN (more gain) amplifies the noise and deteriorates the SNR.

3.10 Log Amplifier

A log amplifier is an amplifier for which the output voltage Vout is K times the natural log of the input voltage Vin. This can be expressed as, resistor on capacitor

$$V_{\text{out}} = -V_{\text{T}} \ln\left(\frac{V_{\text{in}}}{I_{\text{S}}\, R}\right)$$

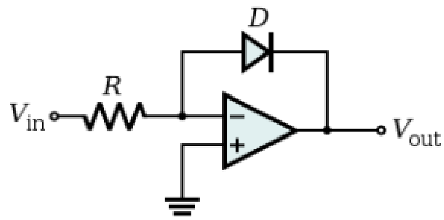


Figure 37: Log Amplifier

where I_s and V_T are the saturation current and the thermal voltage of the diode respectively. The value of R as we used is 220 Ohm and D is 1N4007 Zener diode. The input to the log-amplifier is a differential input. A simple RC low pass filter is also put in cascade with the log amplifier to filter out the signal above 15 KHz. The output of this log amplifier is to be directly given to arduino to give final measurements. To power this board we are using the +12V and -12V boards using 7812 and 7912 IC designed in the EDL during Eagle design assignment.

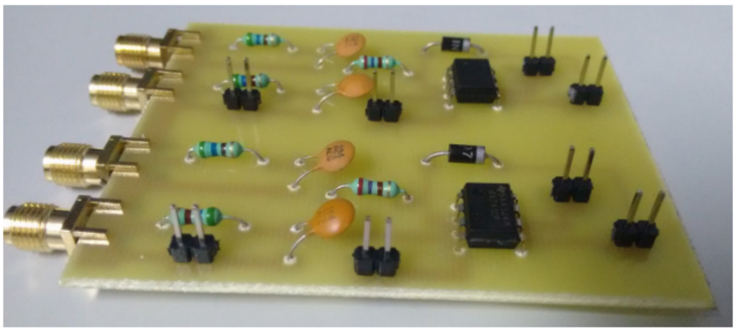


Figure 38: Board of Log Amplifier

3.11 Power Supply

We made the board that uses a 12 volt power supply and converts it to different required levels.

3.11.1 LM317

We used multiple LM317 to provide the power supply to various components with different required power supply. The LM317 is an adjustable threeterminal positive-voltage regulator capable of supplying more than 1.5 A over an output-voltage range of 1.25 V to 37V. It requires only two external resistors to set the output voltage. The required power outputs from the board is:

- 3V : Frequency divider
- 3.3V: SGL0622Z LNA
- 4.5V: IQ demodulator Board
- 5V : Arduino, Crystek LNA, and LTC5510 Mixer
- 5.5V to 6.5V : Power Amplifier

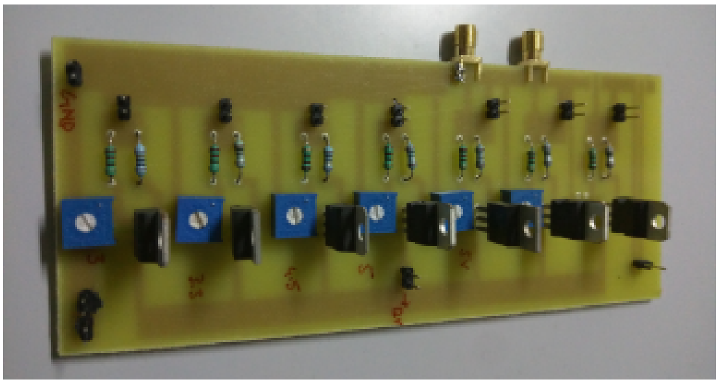


Figure 39: Power Supply Board

As 0.2 Ohm resistors weren't available in WEL, we replaced 0.2 Ohm with 1 Ohm and 2.4 k Ohm with a 5k Ohm pot. This reduced the output voltage range to 1.25 - 11.5V.

3.12 Shielding

In RF systems almost every board/wire becomes an antenna or a receiver, and the spurious signals they inadvertently receive or transmit can degrade the overall performance of the RF subsystem. Hence it was very important to shield the transmitter side ICs from each other as well as from the receiver antennas. Aluminium foil was used to shield the transmitting side ICs from each other. This provided an isolation of 20dB and also improved the performance of the filters. A GI box which further provides an isolation of 20dB was made to place the transmission side circuit.

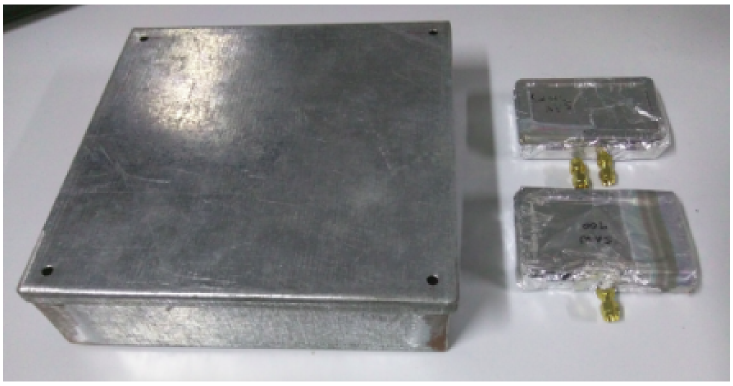


Figure 40: Shielding

4 Performance Evaluation

All the components as indicated in the block diagram have been made. However some of them are functioning as intended and some aren't. We have been able to successfully observe the generated harmonics from a non-linear junction on using some lab equipments like the signal generator and the spectrum analyser. On transmitting 10dBm power, and placing a multimeter right on top of the antennas, we received a 2nd harmonic signal at around ¡insert¿ dBm. There are a lot of problems which we faced, and many of them are still outstanding. Issues specific to our current implementation are:

- Radiation from the various components in the transmitter chain is an issue. All the components here - PLL, filters, power amplifier - radiate some amount of harmonics, and these are lot stronger than what we intend to receiver from a junction to be detected. This requires us to have excellent shielding both between the components and from the outside world. We have tried placing each component in a separate box and covered it with aluminium foil which is grounded. This provided an isolation of 20dB. Placing the components in a GI box further reduced it by 20dB. However the metal box is much smaller in dimensions that required and thus we aren't able to place the PLL, power amplifier, and filters in it at the same time. This is preventing us from detecting the reflected harmonics while using our setup.

- Placing filters in cascade isn't working as intended. We designed low pass filter to filter out the harmonics generated by the PLL and power amplifier. However, it was insufficient to suppress the transmitted harmonics upto a desired extent. So we placed two such filters (as we had an extra PCB board for it printed and sending out a new design to be printed would have consumed a lot of time) in cascade in hope of getting our task done. Though individually each suppressed the harmonics by around 55 dB, when placed in cascade we got an additional suppression of just 3 dB. This could be due to some sort of coupling between the two.

- We aren't able to generate exact 885 MHz from the MAX2870 Evaluation Kit (It was however possible to obtain it from the IQ modulator board). We could only get 870, 880, 890 MHz etc frequencies generated. Even when we are programming it for 885 MHz or any other nearby frequency, it is only generating one of the above stated frequencies. We are currently unaware of the reason behind this.

- The LNA which we prepared for use is showing instability. It is producing an output at around 470 MHz (11 dBm) and the harmonics of the same. Possible reason for this could be improper isolation between the input the output ports.

- Also the gain provided by the LNA is much less than expected. We are getting less than 6dB gain whereas it is expected to be 28dB. Possible reason behind this could be improper grounding of the IC. Doing the thermal grounding directly using a via beneath the IC can help.

- The RF switches which we got aren't providing sufficient isolation at the required frequencies - isolation drastically reduces with input frequencies. We are getting just 10 dB isolation against the 20 dB specified. The isolation as promised in the datasheet is only obtained at very high RF input powers (20 dBm or above).

- Our boards are currently having microstrip based transmission lines and insufficient ground vias to prevent surface waves on the substrate. This could be the reason for the bad isolations that we are getting. The way to improve on this is to have coplanar waveguides and lots of vias on the PCB.

5 Conclusion

We have been able to demonstrate the working of an NLJD at a proof of concept level. All the components have been made and we understand the complete theory behind them. Many initial hurdles like PCB guidelines for RF circuits; usage of software like eagle, ghostview; designing and simulating antennas using CST and IE3D; simulating filters etc have been overcome. Also a lot of issues have been brought to our notice, like proper isolation between the components, proper shielding etc. The journey to the final product is still long. It involves considering many more practical issues at play. The following list attempts to specify the scope of future work to be done:

- Carrying out a frequency sweep in the beginning to figure out silent bands and decide on the frequency of operation. Having broader bands of operation for antennas and filters to allow for a range of frequencies to be used.

- Make all the components on a single board and use coplanar waveguides in the design. This will lead to a compact device and allow for proper packing of the final product.

- Modulating the transmit signal with some sort of signature so that its not easy for someone to fool the detector by flooding the region with the harmonics.

- Evaluation boards of some of the ICs (IQ demodulator and MAX2870) are being used. It is required to design our own boards for them.

- Make circularly polarized antennas instead of the linearly polarized one currently being used.

- Make a single antenna for both transmitting and receiving and use a diplexer in between. This will lead to further compaction of the device.

- Allow for automatic control over the transmit power depending on the strength of the received harmonics. This prevents false detection of a genuine p-n junction as a metal-metal junction. This is because on transmitting very high power, if the IIP3 levels of the circuit to be detected get exceeded, the received signal will contain greater third harmonic content.

- Having pulse mode transmission also instead of just continuous mode. This will lead to power savings and extend the duration for which the battery lasts. Pulse mode can be used when the user wishes to have display in the screen. Continuous mode is on the other hand preferred when using headphones. It is not possible to do away with continuous mode as light coming out from LCD display during night time operations in naxalite infested areas can give away the location of the troops.

- A speaker for receiving the audio signals from the microprocessor control circuit and producing audible sounds corresponding to the audio signals, whereby an operator may listen to the audible sounds and distinguish between different types of non-linear junctions based on the differences in the audible sounds.

- Use a microcontroller other than Arduino. One which will allow for greater processing power as now we would like to have control over the gain provided by the power amplifier, carry out frequency sweeps during startup, display on LCD screen, generate audio signals.

- A battery management system which keeps track of the current charge left in the battery. Also the power supply and management can be improved upon.

- Have better shielding than what is currently being obtained. This can also involve placing RF absorbers around the circuit to prevent radiation.