RF Real-Time Video Transmission and Reception

Report

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1 Abstract

Wireless systems available for video transmission and reception have always faced a challenge of performing well in the presence of obstacles. Our research project involves the robust transmission of video in a short range (upto 70 metres), through obstacles including walls, metal, trees etc. It would be sent using frequency modulation (FM), to take advantage of the robust hardware. Also, our system will be resistant to a high level of interference and jamming, due to various filters and other measures designed for the same. The developed system, when mounted on an appropriate platform, would be very useful for the army and various defence agencies as it can provide live feed of blind spots and hence provide valuable information and early warnings. It can also be used for sports broadcasting (like umpire-cam). Its range through walls along with its resistance to jamming would help make it a valuable tool. This project thus involves RF-circuit design for wireless applications.

2 Project Objectives

- Frequency Modulation (5.8 GHz) of an analog (PAL) video signal acquired from a camera, Down-conversion, boosting power and transmission at 400 MHz.

- Reception at the receiver in a sufficiently noise and interference tolerant manner at a range of 50 meters, and then up-conversion back to 5.8 GHz.

- Frequency Demodulation of the up-converted signal and output to a screen in real-time.

3 Project Deliverable(s)

- Working FM modulator and demodulator at 5.8GHz

- Down-converting the signal to 400 MHz for transmission and then up-converting it back to 5.8 GHz at the receiver(we use 400 MHz as it can go through steel and brick walls with the least attenuation)

- Use of techniques including filtering, power amplification etc to make the system sufficiently noise tolerant.
- Real time transmission of analog at a range of 70 meters (out of line of sight).

4 Block Diagram

Our system has 4 major components: FM modulator, Mixer, PLL (for generating modulation frequency) and FM demodulator.

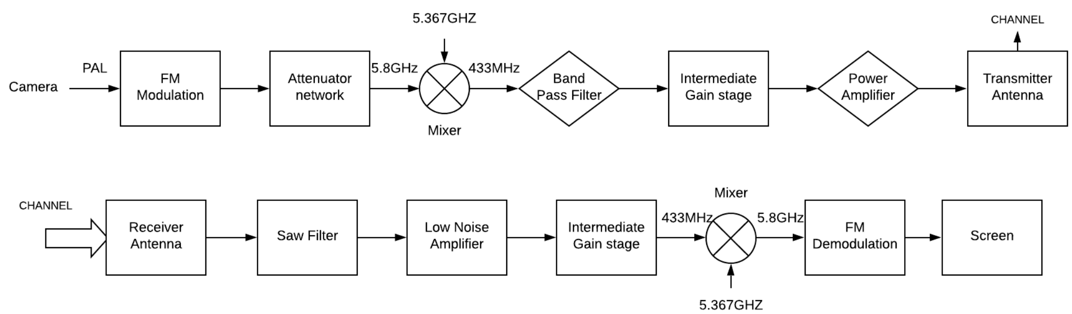

Figure 1: Block diagram of our system (Transmitter and Receiver).

5 Design Approach

Seeing the problem at hand, we needed to have a system which could also work in closed environments with obstacles. So, we zeroed in on a frequency of 400 MHz, which has the least attenuation in such an environment for the carrier frequency of our system. We also use analog video in place of digital to make it more robust.

5.1 Architecture Design

Seeing the problem at hand, we needed to have a system which could also work in environments with obstacles. So, we zeroed in on a frequency of 400

MHz, which has the least attenuation/maximum penetration in such a channel, as the carrier frequency of our system. We also use analog video(FM) in place of digital to make it more robust.We explored various modulation and demodulation architectures, including using a PLL based modulator, a 12 MHz chip and a 5.8 GHz chip. Also, we explored techniques including slope detection, quadrature demodulation etc for the demodulator. A comparison of a few major ones is given below-

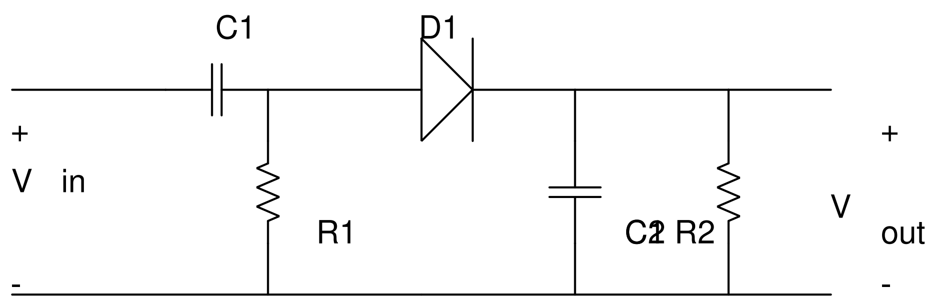

Figure 2: Slope Detector

- **PLL based demodulation**- We planned to use a PLL to demodulate our FM input,]. But, we realised that this would not be feasible as our signal is a video signal with a relatively large bandwidth of 6 MHz.Considering the practical values of loop bandwidths of PLL's available, this scheme would not work for our signal.

- **Quadrature amplitude Demodulation**-This is one of the most common demodulators for FM used today. But using this was not feasible in our case as we had to demodulate a signal at 400 MHz, and discrete AND gates, like the one required in its circuit would not work at such frequencies.Hence, we discard this idea.

- **Slope Detector**- It consists of the circuit with an almost linear response at and in a narrow band around the carrier frequency. It effectively gives a differentiated version of the input at its output. This effectively converts the FM input to an amplitude modulated output which can be detected by a simple AM demodulator. This design was rejected because of availability of better and cheaper alternatives.

- **Demodulation using a 5.8 GHz demodulator**- This was the alternative we finally zeroed in on, considering the cost effectiveness, practicality for demodulating video signals and reliability concerns.

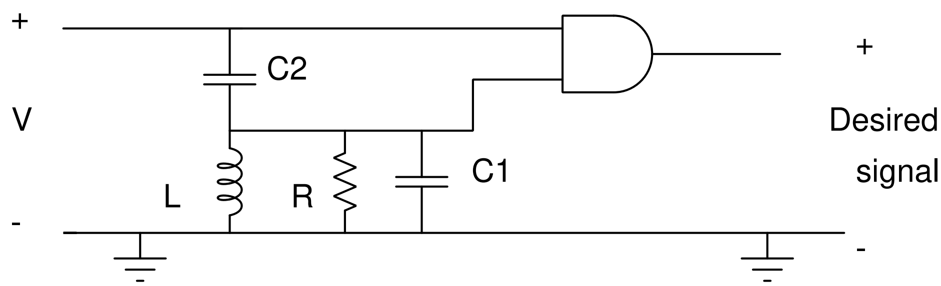

Figure 3: Quadrature amplitude demodulator

On considering the practicality of each of these for a large bandwidth (video- 6 MHz) signal and their cost effectiveness, we finalized the 5.8 GHz modulator - demodulator approach.
Also, after making a rough estimate of the attenuation at 400 MHz (and cooling limitations too) we chose a 1.6W power amplifier for our system. We also added a bandpass filter at the mixer output to prevent the mixer harmonics from entering the amplifier circuits. On considering losses in the mixer and elsewhere, we added an intermediate gain stage in both the transmitter and the receiver to achieve our target. Also, to increase our robustness to noise, we include a Surface Acoustic Wave (SAW) filter at the receiver

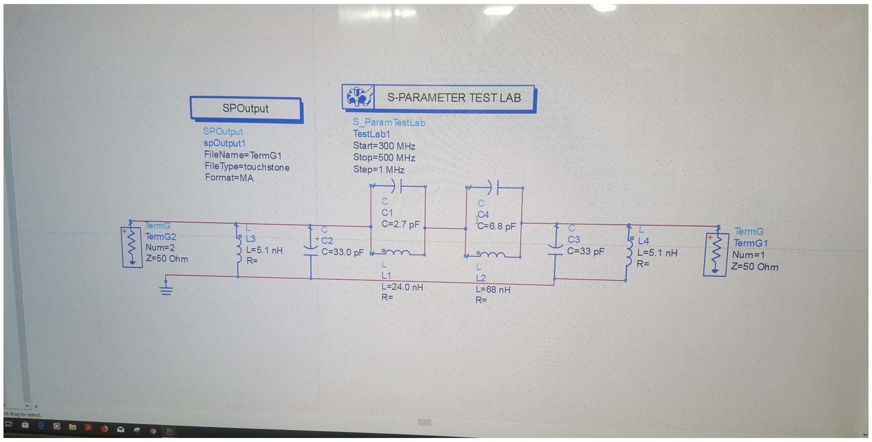

Figure 4: We used ADS simulator to simulate our designed matching circuits and filters

5.2 PCB Design

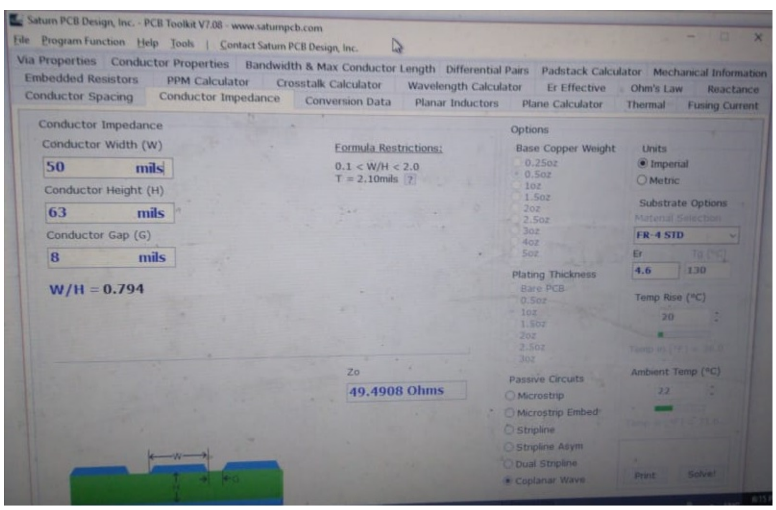

Figure 5: We used Saturn PCB toolkit to decide the trace width at different parts in our PCBs

In the design of the PCB, we had to very carefully impedance match all components of the system to **50 Ω.** We made the required matching circuits for different ICs to match them to 50 Ω. We decided to use coplanar waveguides for transmission as they have much lower inductance, and hence are

better at such high frequencies. Also, considering that we wanted to keep our system as small as possible we choose **coplanar waveguides** as they have much smaller trace widths for the same frequency (as compared to microstrip) .
We also had to consider conversion of Double ended inputs to single ended inputs and vice versa, for which we used appropriate Baluns and decoupling capacitors.Another important consideration we had was to make the differential (double ended input) traces of equal length and symmetric with the pins. They needed to be tapered carefully before connecting to the pin.
We also included a large number of **closed** vias in our board, for minimizing the parasitic inductance of the lines. Special focus was also given to maximizing their number and symmetry of placement near the 5.8 GHz trace as they would matter the most at the highest frequencies.
We also included **open** vias in the ground pads for the amplifiers and the mixers for help in effective heat dissipation. In addition, we also provided proper(large) ground pads for heat dissipation in the amplifier. Also, we adhered to a design specification of having 4 cm $\times$ 6 cm boards for the transmitter and receiver, to make them portable enough.

6 Sub Systems Developed

6.1 Transmitter

The transmitter comprised of following subparts:

- **Regulator circuit:** The mixer and Amplifier had to be isolated completely to avoid any interference so, we used an LM1117-5V regulator and isolated its output via ferrite beads and gave as power supply to the mixer and amplifier circuits. The grounds of both the power amplifier and the mixer were connected only at one node via a ferrite bead again to avoid interference.

- **Mopdulator module:** The modulator module performed FM modulation at 5.8GHz and gave us an output at 14dBm

- **Attenuator:** The maximum mixer input to prevent saturation was 11dBm, it worked best at around 2-3dBm to accommodate for that we needed to include an attenuator circuit. We used a 10dB Pi network based resistive attenuator ensuring that its input and output impedances were 50Ω

- **Mixer:** To transmit at 400MHz we had to downconvert the RF signal, we used a mixer with one input coming from our Local oscillator board (5.41GHz) and other being our RF input(5.81GHz). This gave us our 400MHz signal. Being in the critical 5.8GHz path, at all input/output nodes of the mixer IC we had to ensure that the impedance was 50Ω matched

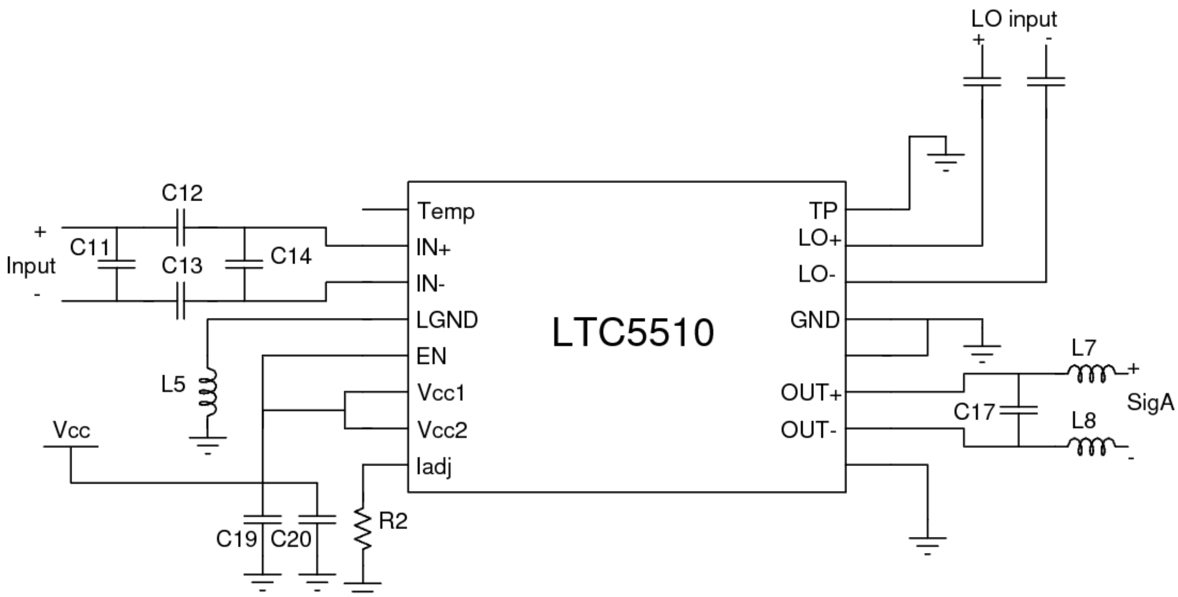

Figure 6: Mixer Circuit

- **Elliptic Bandpass filter:** The mixer output would contain a lot of harmonics of the Local oscillator (We used a 50MHz crystal) So to do away with that, we used a 3rd order elliptic bandpass filter with its passband being 350MHz to 450MHz.

- **Intermediate Gain stage:** To achieve the required output of 30dBm, we had to add an intermediate amplifier which gave us a 10dB gain and at the same time did not consume too much power (unlike the power amplifier).

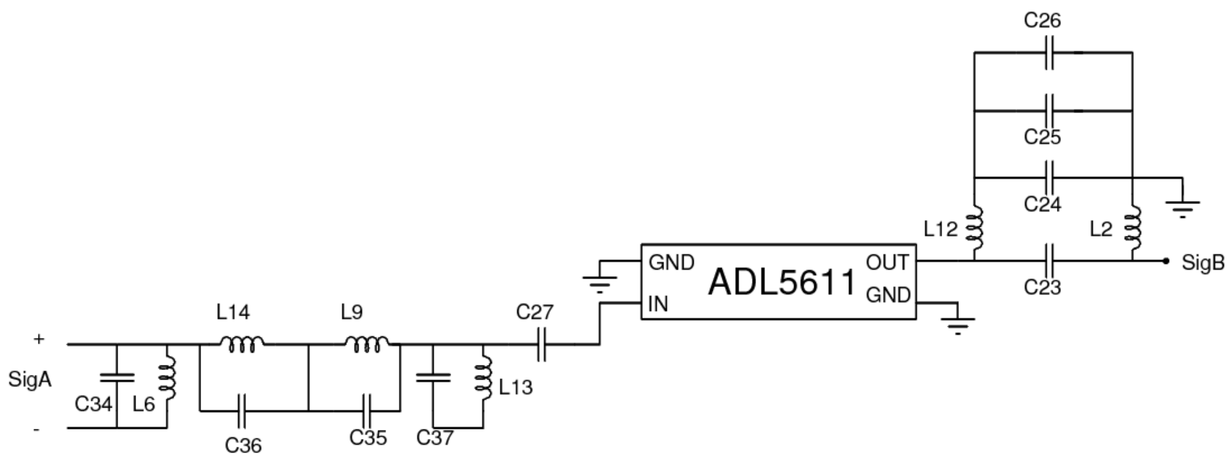

Figure 7: Intermediate gain stage circuit

- **Power Amplifier:** We needed high power at the transmitter output so we used a 1.6W power amplifier which would give us enough power to meet our range requirements. Giving us a 21dB gain at 400MHz which would give us an output higher than 30dBm.

- **Baluns:** The mixer input and output had to be double ended so we had to add Baluns to convert single-ended input to double-ended at the input side and double-ended output to single-ended output at the output of the Mixer (PA input had to be single ended). While using these baluns, being in the critical path we had to add matching circuits to ensure that our lines were 50Ω matched.

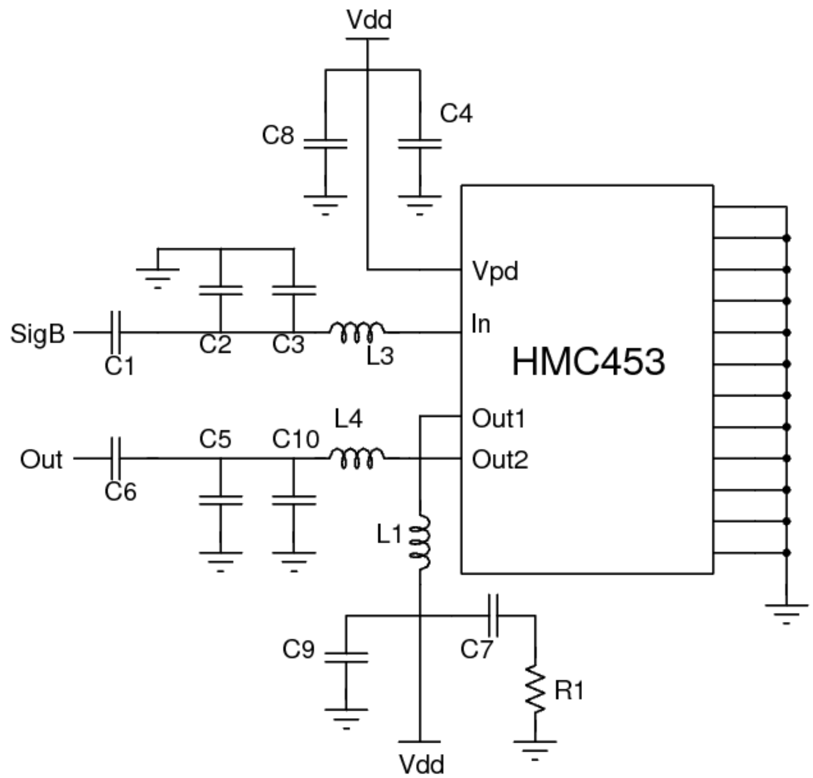

Figure 8: Power amplifier circuit

To summarize: The transmitter, includes the modulator, an attenuator, a downconverter(which uses the local oscillators output and a mixer - LTC 5510) followed by a third order filter. These are then followed by an intermediate gain stage(ADL5611) and a 2W power amplifier (HMC453QS16G).

Element	Value	Element	Value	Element	Value
C1	12pF	C2	8.2pF	C3	6.8pF
C4	100pF	C5	12pF	C6	39pF
C7	100pF	C8	2.2uF	C9	2.2uF
C10	8.2pF	C11	0.3pF	C12	0.1uF
C13	0.1uF	C14	0.05pF	C15	0.1uF
C16	0.1uF	C17	Open	C18	10nF
C19	10nF	C20	1uF	C21	10uF
C22	10uF	C23	100nF	C24	68pF
C25	1.2nF	C26	1uF	C27	100nF
R28	100Ω	R29	68Ω	R30	100Ω
C31	10nF	C32	1nF	C33	1nF
C34	3 pF	C35	6.6pF	C36	2.5pF
C37	33pF	L1	47nH	L2	40nH
L3	4.3nH	L4	4.3nH	L5	0
L6	5.1nH	L7	0	L8	0
L9	68nH	L10	FB-2.5k	L11	FB-2.5k
L12	1000nH	L13	5.1nH	L14	24nH
R1	5.1Ω	R2	$4.75k\Omega$	R3	0

Table 1: Values of elements in the transmitter
FB: Ferrite bead
0 : 0Ω resistor

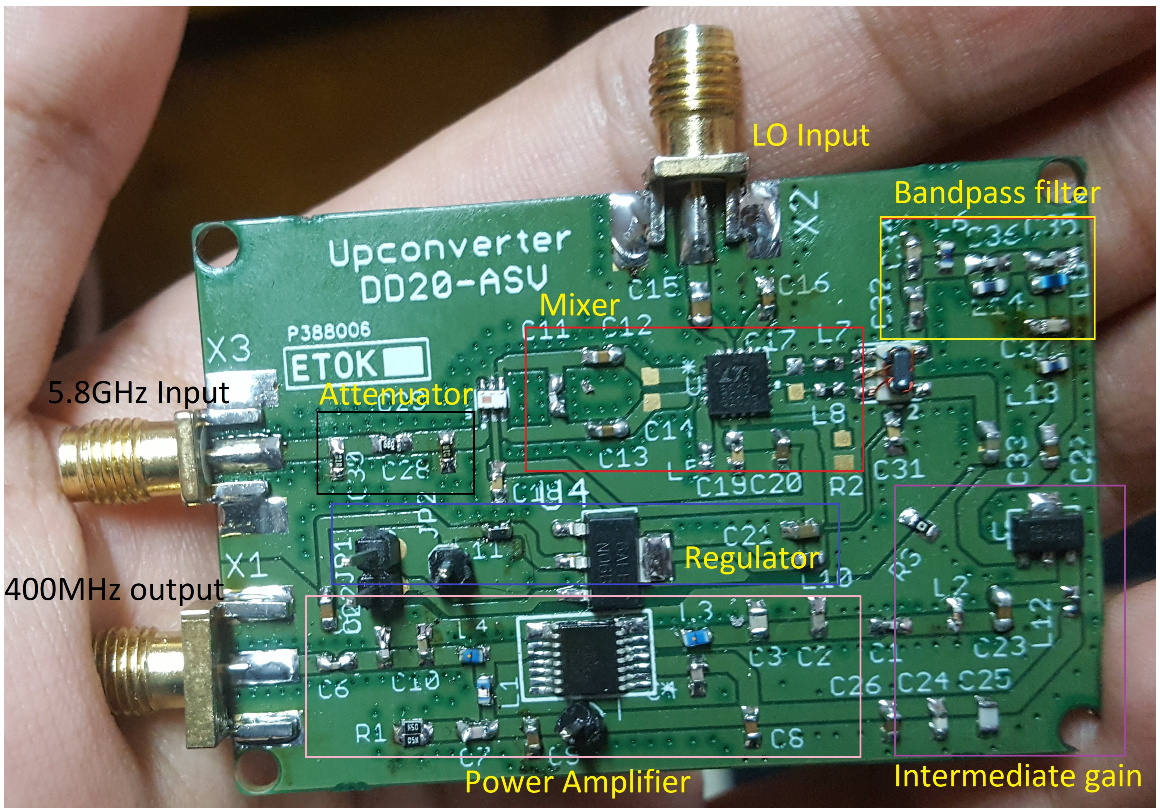

Figure 9: Power Amplifier Gain: Soldered final board

6.2 Local Oscillator

- This sub system uses a Phase Locked Loop(PLL) to generate the LO. The PLL(MAX2870) is programmed by the micro-controller (STM32F103C8T6) to generate a frequency of 5.4 GHz used in both down-conversion (at the transmitter end) and up-conversion (at the receiver end). The micro controller can be used to vary the frequency generated by the MAX2870, by writing into its registers appropriately.

- The LO goes as input to the mixer in both the transmitter and receiver PCBs and down-converts and up-converts 5.8 GHz to 400 MHz respectively. We need to do this because the penetration depth at 5.8 GHz is less and is correspondingly higher for 400 MHz. This is so because the penetration depth (δ) is inversely proportional to the frequency (f) i.e. $\delta \propto \frac{1}{f}$

- The LO board consists of three voltage regulators (LM11173.3), one each for inputs for V_{CC}s for PLL, Digital and RF. In the board the amplifier at the output end was bypassed as it was not needed.

- The loop filter was a very crucial part of the board because it helped in locking of the LO at the desired frequency (5.4 GHz in our case). The loop filter consisted for three capacitors and three resistors connected in a peculiar fashion.

- We connected the crystal externally to the board due to some issue in the existing foot-print of the PCB. The input from the crystal was given at the capacitor C9. The crystal was a 3.3V LVCMOS Surface Mount Clock Oscillator (CWX823). It has 4 ports, one each for Input, Output, Enable and Ground. The Input Pin was given a 3.3V input, the enable pin was connected to the Input pin through a $40k$ resistor and the body inherently was shorted with ground. The 3.3V was taken from the voltage regulator.

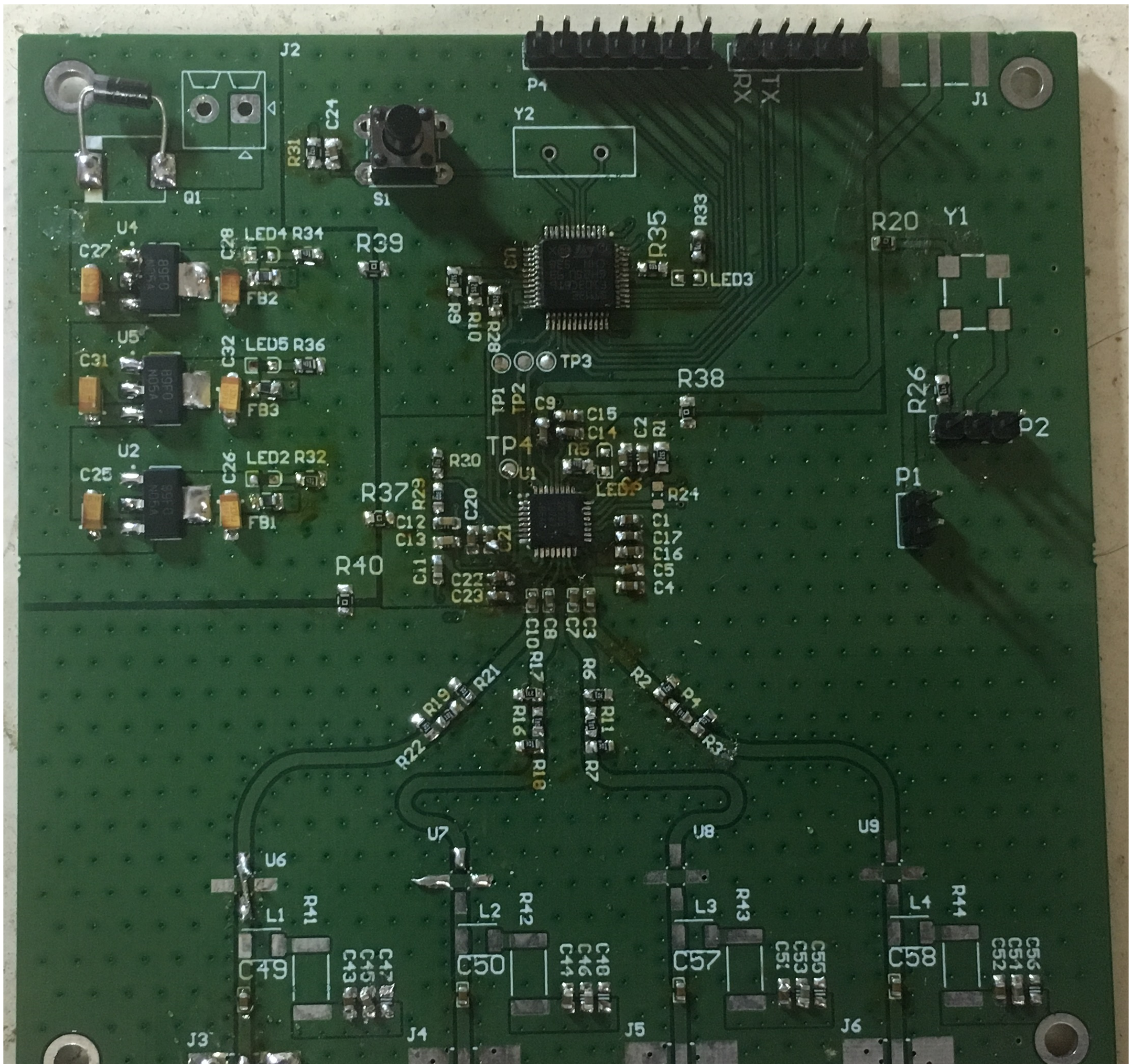

Figure 10: Local oscillator solder PCB: programmed at 5.41GHz

6.3 Receiver

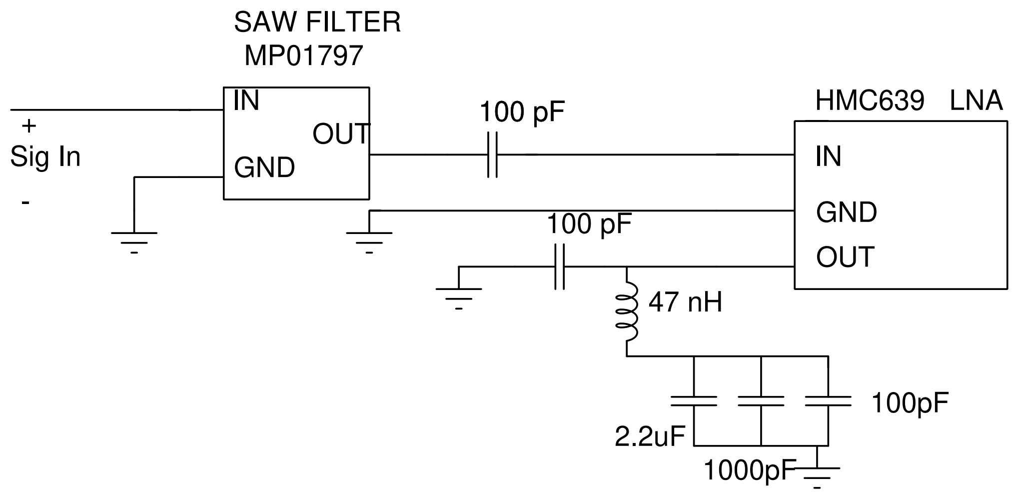

Figure 11: Low noise amplifier Circuit + Filter

The receiver includes-

- **Antenna -** A wide band 433 MHz antenna receives the signal and passes it to the SAW filter
- **SAW filter -** The MP01797 SAW filter used has a centre frequency of 402 MHz and a 1 dB bandwidth of 18 MHz, which was wide enough for our almost 6 MHz wide video signal to pass. It would also help improve the SNR by filtering out out of band noise and also remove interference.
- **Low noise amplifier-** We use the HMC639 LNA to amplify the signal before upconversion. It provides a gain of around 12 dB for the signal.
- **Intermediate gain stage-** We use an intermediate gain stage with the ADL5611 amplifier to provide a gain of around 22 dB to the signal, before upconversion and demodulation. This is required for large ranges where the incoming signal is very weak.

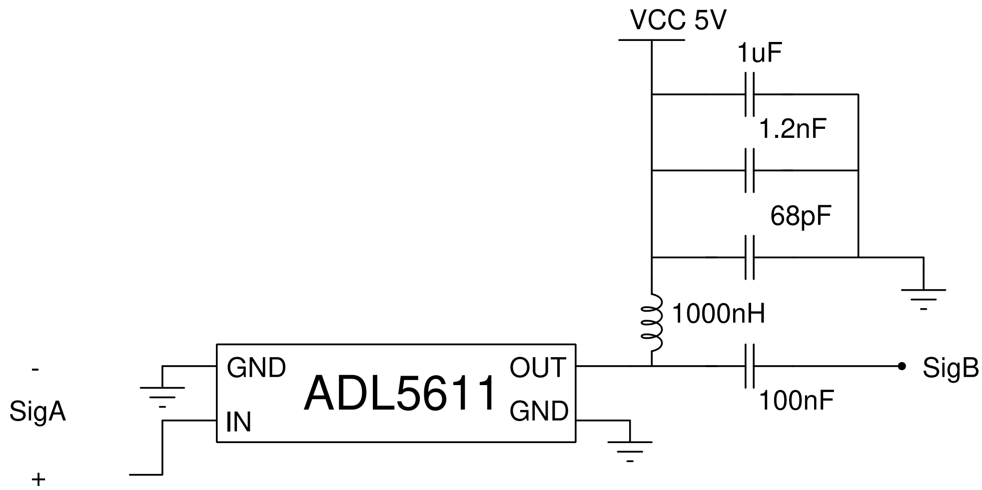

Figure 12: Intermediate gain stage circuit

- **Mixer -** We use the LTC5510 mixer to multiply the received signal at 400 MHz with the local oscillator input at 5.4 GHz. This converts the signal back to the 5.8 GHz signal which can be demodulated by the receiver block

- **Demodulator-** This block demodulates the 5.8 GHz FM signal to the required video signal.

We also have several intermediate parts, including matching circuits, blocking capacitors, baluns etc in between these sub systems to connect them.

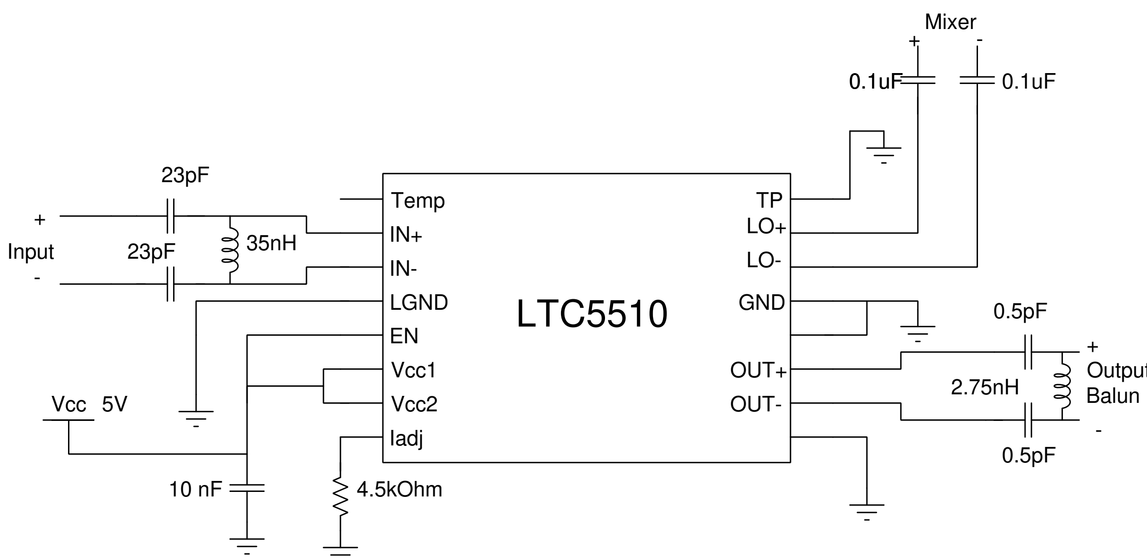

Figure 13: Mixer circuit

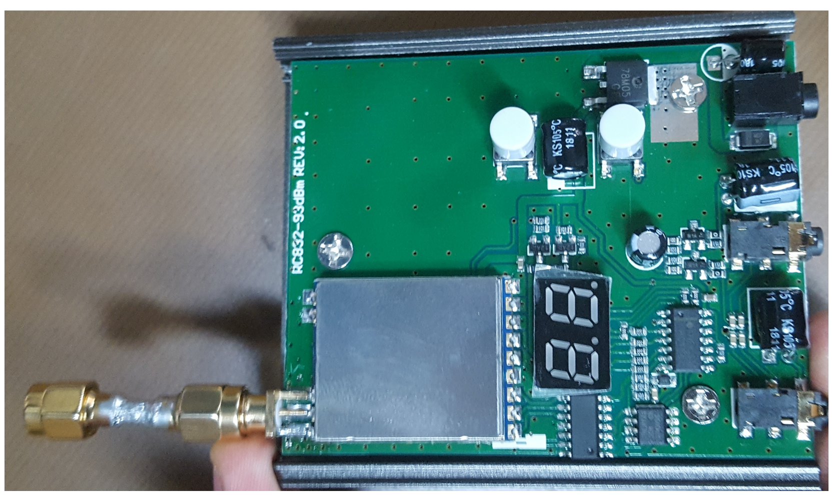

Figure 14: Our receiver module

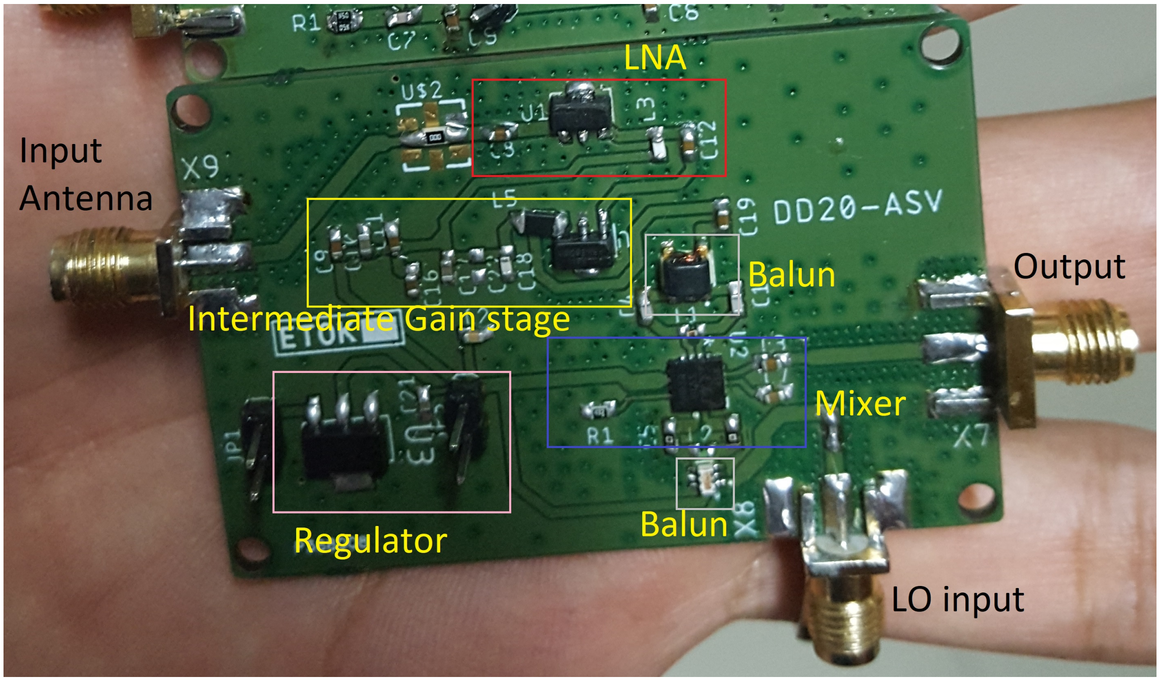

Figure 15: Receiver soldered PCB

7 Test Results

- We finished our work on 2 LO (Local oscillator) PCB boards, each consisting of a MAX 2870 (PLL IC) and micro-controller (STM32F103C8T6). The frequency of the board is variable). We successfully tested it with an RF source of 50MHz as input,set to generate a frequency of 5.4 GHz.

- We made EAGLE footprints for the components we ordered including the mixer (LTC 5510), power amplifier (HMC453QS16G), LNA (HMC639ST89) and the baluns.

- We also tested our analog (PAL) screen and camera after making adequate powering and transmission circuits for the same.

- We tested the range of our modulator, demodulator (both at 5.8 GHz), our screen and camera without use of a power amplifier. In our tests,we got a range of around 30 meters in line of sight.

- We tested our LO board with and without the crystal (in the case of without the crystal we gave input from the RF source). The peak of the PLL was 5.4 GHz, as was expected.

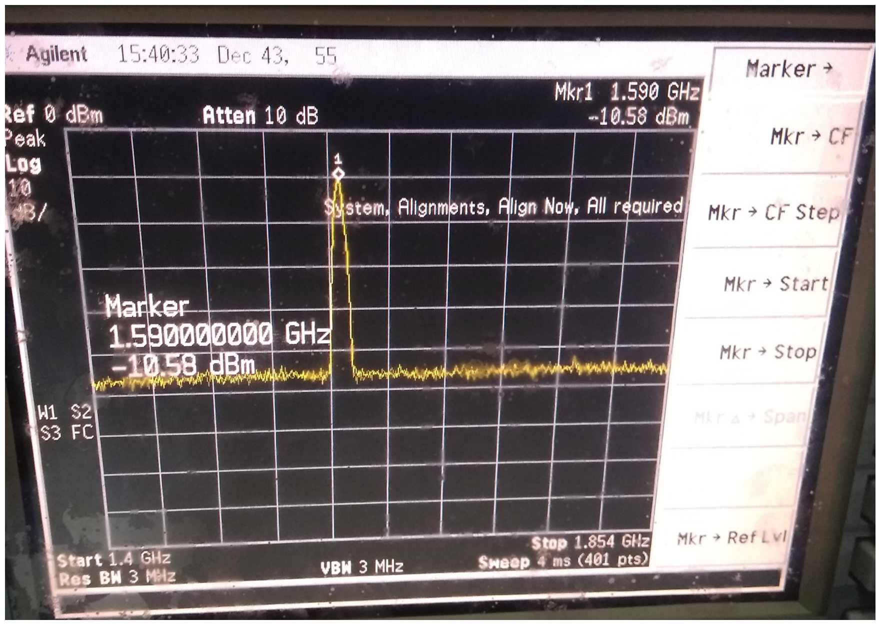

Figure 16: PLL getting locked at 1.59 GHz

- We also tested our modulator and demodulator using a Vector signal analyzer, to check its response at various frequencies.
- We tested our LO board with a 50 MHz crystal, and ensured that it was locking at the correct frequency
- We tested our downconverter+ transmitters output spectrum. We observed its power and FM modulation, as seen in the figure. We also observed that its signal was received even 2 floors below, using a portable spectrum analyzer.
- In line of sight we were able to achieve very large distances for the transmitter module. (we tested till around 300m)
- We also tested our upconverter and LNA boards output spectrum, and verified that we get a peak at 5.8 GHz of the required power on giving an input of 400 MHz and LO frequency of 5.4 GHz.

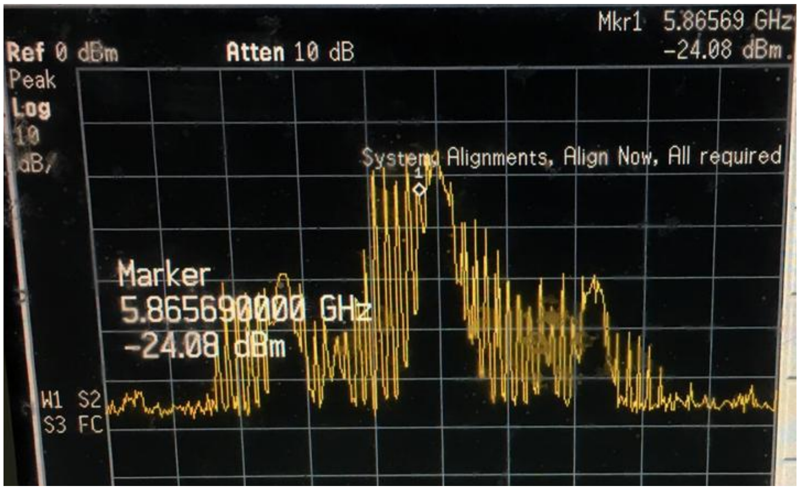

Figure 17: Transmitter output: Spectrum of the video signal at 5.8GHz

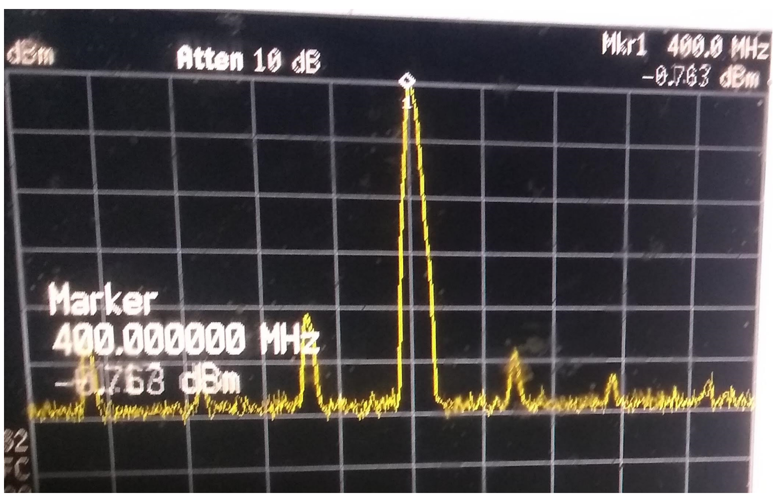

Figure 18: Power Amplifier Gain: with a large span (zoomed out)

Our expected was 30dBm, The image shows -0.763dBm as the output power this is after attaching a 30dB attenuator (so as to not damage the spectrum analyser). So, we managed to achieve the required gain

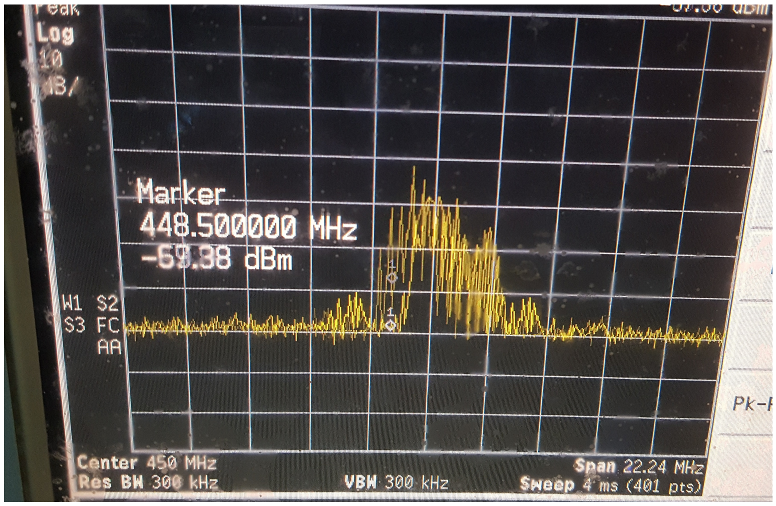

Figure 19: RF output: Spectrum of the transmitted signal at 433MHz (after attenuators)

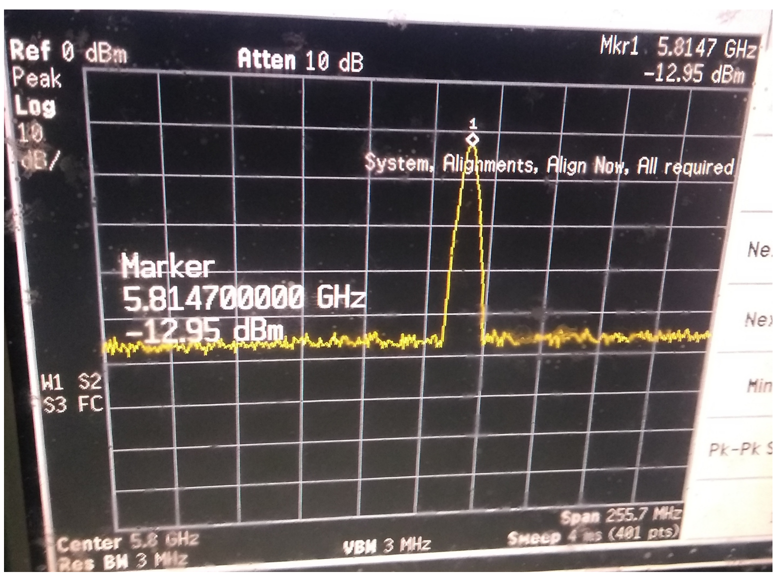

Figure 20: Receiver output (with large span) we achieved a gain of 18dB

8 Final Demo

- We demonstrated a fully working transmitter module with an LO (PLL board), a 5.8 GHz modulator, a mixer for down-conversion (from 5.8 GHz to 400 MHz), a power amplifier for amplifying the signal and an antenna.
- We also demonstrated a fully working 400 MHz receiver block, with an LO (PLL board), Low noise amplifier (LNA), mixer for up-conversion (to 5.8 GHz), a 5.8 GHz demodulator and an antenna.
- In addition to demonstrating the individual working of these blocks, we transmitted a camera's analog video output in real time at a frequency of 400 MHz and successfully received and demodulated it. This was done for an out of line of sight mode of transmission.

Figure 21: Line of sight range testing: We could receive the signal beyond Civil department from the Communications Lab for our transmitter module

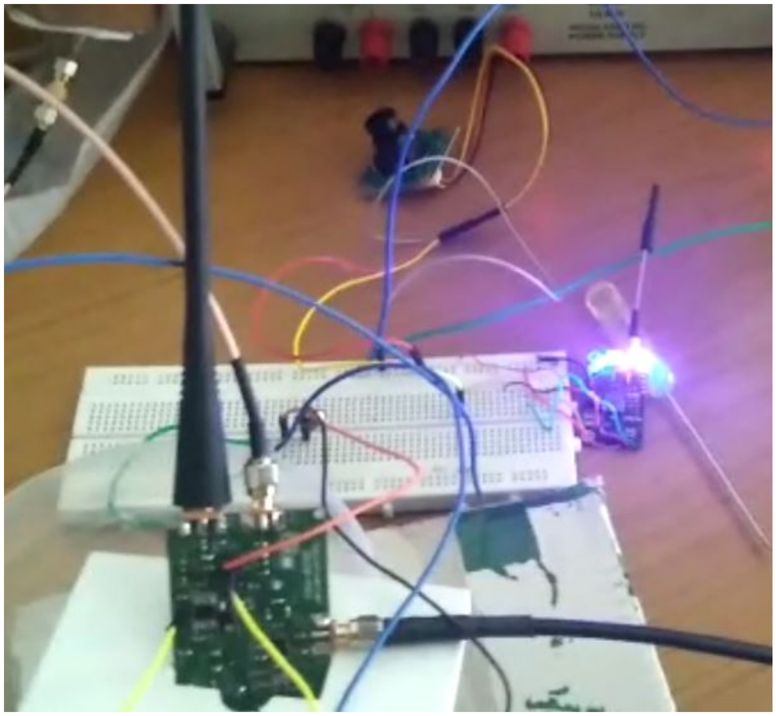

Figure 22: Transmitter Setup in WEL-5

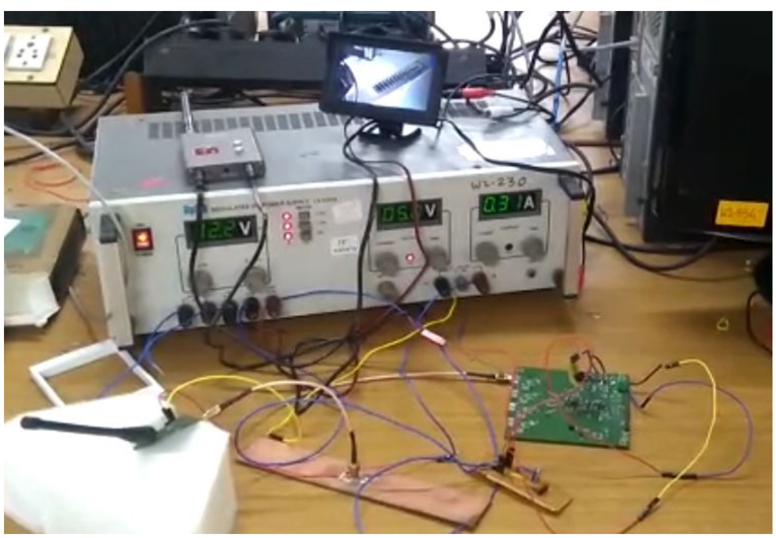

Figure 23: Receiver Setup in WEL-4: Video being displayed on the LCD

9 Problems faced

- We did not know about the specific points to be taken care of in designing an RF PCB board, like having closed vias, tapered lines etc. We had to search a lot about how to include these in our EAGLE design.

- We were not familiar with SMD soldering and that consumed a lot of our time.

- There was some issue with the Loop Filter which was causing the PLL to not lock at the desired frequency (5.4 GHz). The error in the Loop Filter was not evident and we found out about it after much deliberations.

- The Crystal CWX823 had to be connected externally to the LO Board due to some issue with the foot-print on the PCB. We had a lot of problem adjusting the external crystal because the crystal output wire, which was connected to the capacitor C9, would come out quite frequently and would somehow rip the capacitor connected at C9 into pieces.

- The footprints for the power amplifier and the mixer were hard to modify. They had an erroneous ground pad which had to be corrected.

- We had to continuously monitor the temperature of the transmitter boards because they consisted of components like voltage regulators and power amplifiers which tend to heat up a lot. We would turn off the boards once they would reach $60^{o}C$. To overcome this we used an external mini-fan which would continuously cool down the setup. This method was quite effective in combating the 'heating-up' issue. Adding a heat sink is a part of future work.

- We didn't have RP (Reversed Polarized) SMA (the 5.8 GHz modulator and demodulator had RP SMAs and not the usual SMAs) to a normal SMA connector hence we had to use antennas for the same. This led to a serious two fold (one at the transmitter end and the other at the receiver end) attenuation.

10 Conclusion

We were able to successfully demonstrate 'RF Real Time Video Transmission'. We have handed over our project in Communication Lab for its further use and improvement.

11 Acknowledgements

We would like to extend our sincerest gratitude to **Prof. Shalabh Gupta** for giving us the opportunity to do this project and for his constant guidance and support throughout the project.
We would like to express our deep gratitude to **Ajay Maurya, Punit Jain and Salil Tembe** (from the Communication Lab) and **Maheshwar Sir and Shekhar sir** (from WEL Lab) for their immense support and help. We would also like to thank **Ms. Rinkee** from the Antenna Lab for lending her own antennas and the Lab's RF Source for our demo.

12 Appendix

This section contains EAGLE circuit diagrams for circuits which were previously shown. We also show the routing diagram for the PCBs.

12.1 Transmitter

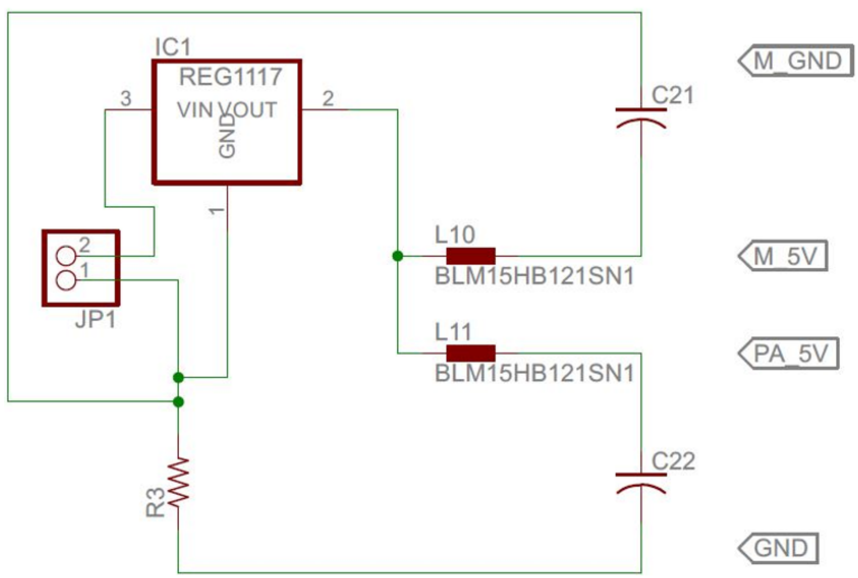

Figure 24: Transmitter Voltage Regulator

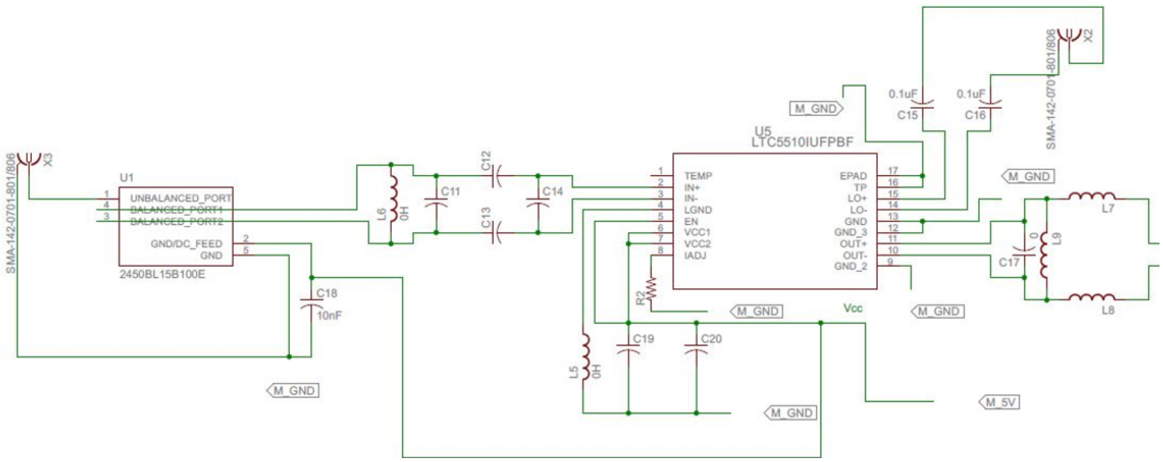

Figure 25: Transmitter Mixer

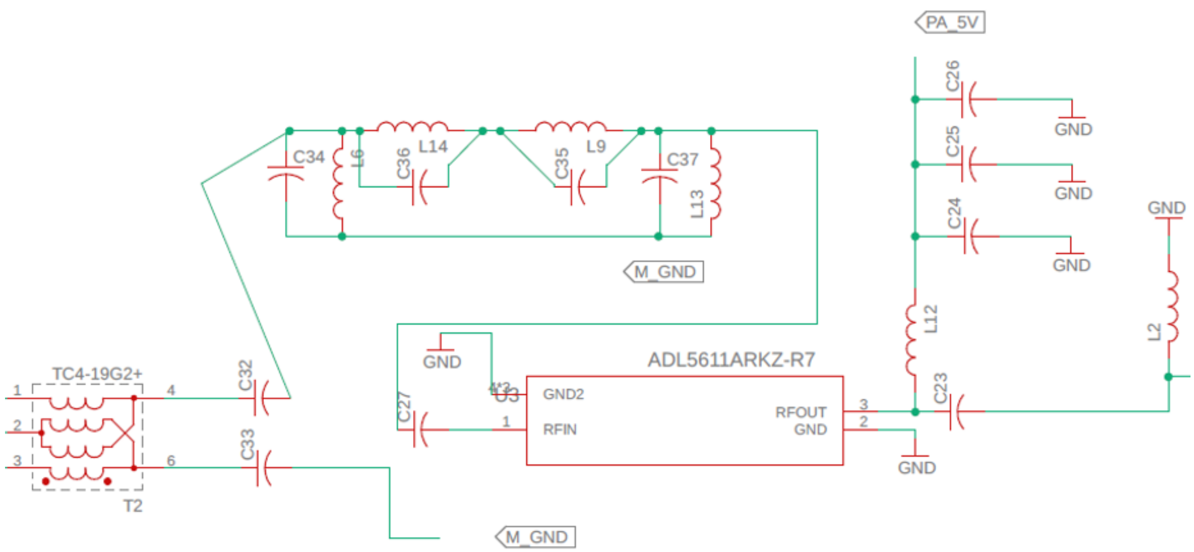

Figure 26: Transmitter Intermediate Gain Stage

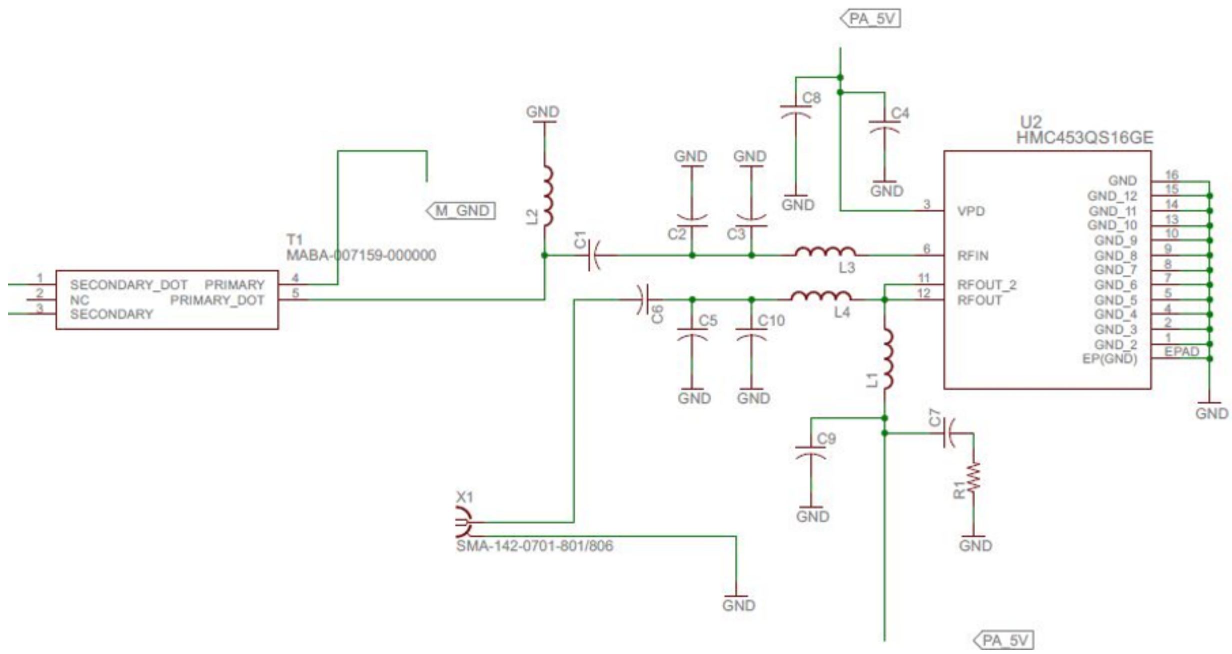

Figure 27: Transmitter Power Amplifier

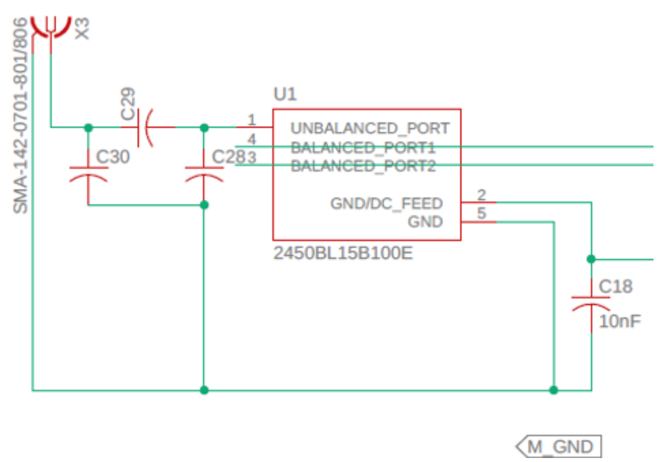

Figure 28: Transmitter Attenuator Circuit

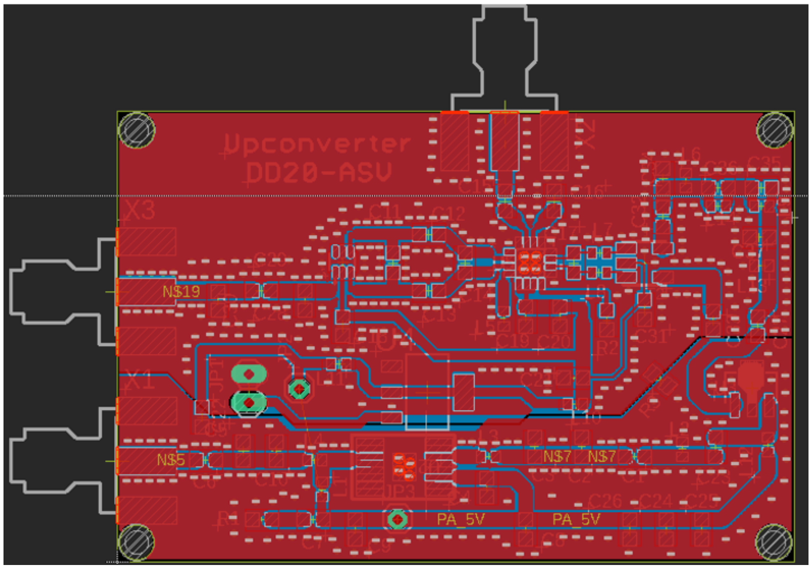

Figure 29: Transmitter PCB Routing

12.2 Receiver

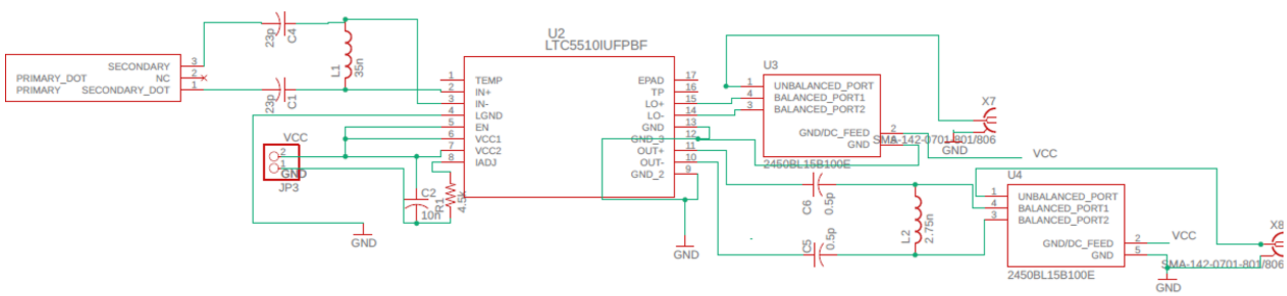

Figure 30: Receiver Mixer

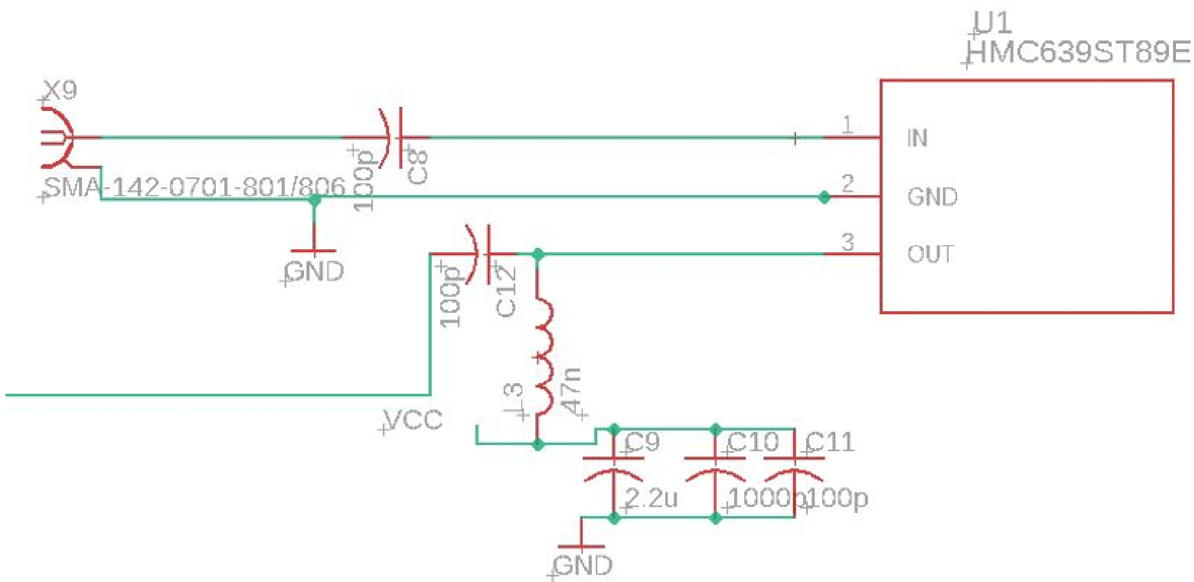

Figure 31: Receiver Low Noise Amplifier (LNA)

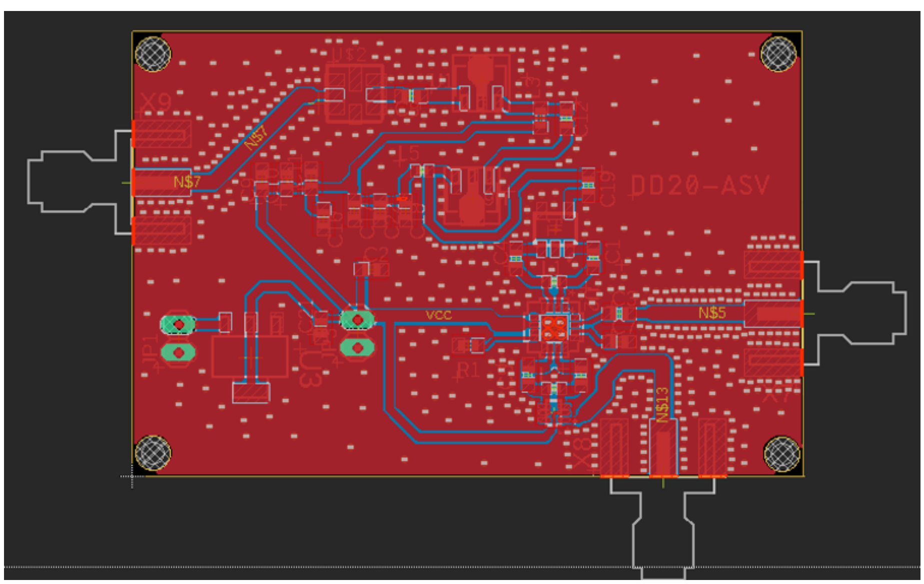

Figure 32: Receiver PCB Routing