Super Heterodyne Receiver

Ambika S.[1], Anaya Dixit[2], Bhargava Ganesh Bhat[3],
Dhairya Kotecha[4], Pranjal Sengupta[5], Saanvi Pande[6]

[1] PSG College of Arts and Science, Coimbatore
[2] Indian Institute of Technology, Kharagpur
[3] Poornaprajna College, Udupi
[4] Indian Institute of Technology, Roorkee
[5] Indian Association for the Cultivation of Science, Kolkata
[6] Fergusson College, Pune

10th December 2025

---

1 Introduction

Astronomical signals in Radio Astronomy are processed with Superheterodyne receivers, which convert the incoming high-frequency radio signals to lower, more manageable intermediate frequencies (IF). before meaningful measurements can be made of quantities such as flux density, spectra, line intensities, and so on. This experiment aims to familiarize us with the building blocks of a radio receiver and study the signal flow through the receiver. In the process, we will also gain familiarity with test and measuring instruments.

Radio telescopes observe signals that can be in the GHz range, but processing at those frequencies is very difficult. Superheterodyne receivers solve this by first down-converting the signal to a lower intermediate frequency, where high-precision amplification, filtering, and detection are easier and more stable. Superheterodyne receivers are built into the Software Defined Radio (SDR) for processing the high-frequency RF by a computer, as the signal in its original form cannot be directly processed by it. Superheterodyne receivers find its use in various places as in Television, Radio receiver, commercial radios.

Some uses of the heterodyne receiver in daily life are as follows:

- Smart Homes: 433 MHz superheterodyne modules receive remote commands to control air conditioners or curtains.
- Industrial Monitoring: Receive wireless data from pressure/temperature sensors in factories for remote oversight.
- Security Systems: Wireless door sensors or smoke detectors transmit alerts to hosts via superheterodyne modules.

Superheterodyne receiver modules act as "signal decoders" in wireless communication, resolving the complexity of high-frequency signal processing through mature frequency conversion technology. They provide stable, efficient wireless reception solutions for IoT, consumer electronics, and industrial automation.

2 Theory

What is a Superheterodyne Receiver?

A super-heterodyne receiver contains a combination of amplification with frequency mixing, to convert a received signal to a fixed intermediate frequency (IF) which can be more conveniently processed than the original carrier frequency. This conversion is called heterodyning. The IF is then mixed again to bring the signal to baseband (0 frequency). The receiver is called super-heterodyne due to the two frequency translations.

2.1 Components

2.1.1 Signal Generator (analogous to Antenna):

Generates test signals over a range of frequencies and amplitudes. It can also provide amplitude modulated signals and signals modulated by noise. Generally this signal comes from the antenna. At GMRT, it is a 45 m parabolic dish (signal collector) and a feed (main antenna). The instrument's frequency range is from 9 KHz to 3.3 GHz.

2.1.2 Spectrum Analyzer:

A Spectrum analyzer displays intensity as a function of frequency. This spectrum helps in measurement of spectral properties of a signal and will be helpful to understand the translation of signal in both frequency and amplitude throughout the signal.

2.1.3 Low Noise Amplifier (LNA):

A low-noise amplifier is an electronic amplifier that is used to amplify signals of very low strength, usually from an antenna where signals are barely recognizable and should be amplified with minimum amount of noise addition, otherwise important information might be lost. It will give a power gain. The amplifier we are using has 10 dBm at 1 GHz and 8 dBm at 2 GHz. It is demanded that the LNA exhibits the highest possible dynamic range so that it will be able to process any signal that arrives at its input. DC Power supply is given. The working frequency range of this component is 60-3000 MHz.

2.1.4 Frequency Mixer:

Frequency mixing is a non-linear process that involves the instantaneous level of one signal affecting the level of the other at the output. This process involves the two signal levels multiplying together at any given instant in time and the output is a complex waveform consisting of the product of the two input signals. In most common applications, it produces new signals at the sum and difference of the original frequencies. Mixers are widely used to shift signals from one frequency range to another, a process known as heterodyning for convenience in transmission or further signal processing. Mixers give out conversion loss in power. The working frequency range of this component is 10-2400 MHz.

2.1.5 Voltage Controlled (local) Oscillator (VCO):

A voltage controlled oscillator is a electronic oscillator where the input tuning voltage determines the oscillation frequency. It produces a periodic signal. A tuning element called a varactor diode is used in VCOs. With the help of applied voltage to the varactor diode, the oscillator is tuned to vary the net capacitance provided to the circuit. We use 2 VCOs, one to give 70 MHz and other to cancel out and give 0 MHz. DC Power supply is given. The working frequency range of this component is 1230-1420 MHz.

2.1.6 IF Filters:

Filters form an important element within a variety of scenarios, enabling the required frequencies to be passed through the circuit, while rejecting those that are not needed. These are the band pass filters. They give power loss. The working frequency range of this component is 58-82 MHz.

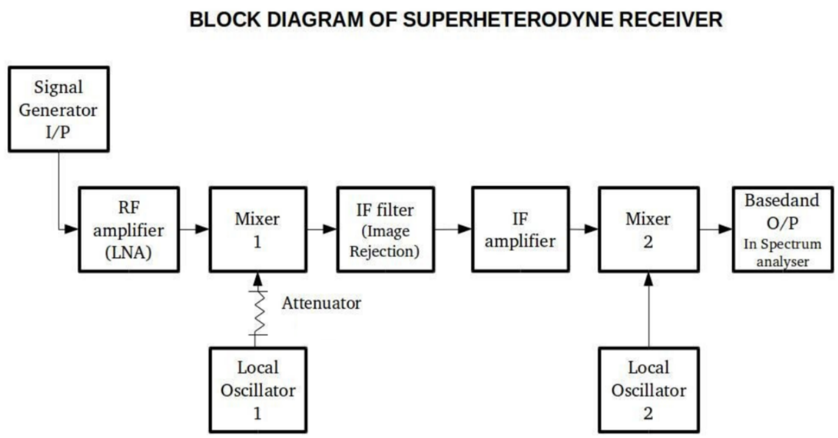

Figure 1: Block diagram

2.2 Block Diagram

3 Observations and Calculation:

The following table shows the frequency response of the cable.

Signal Generator		Spectrum Analyser	
Frequency (MHz)	Power (dBm)	Frequency (MHz)	Power (dBm)
100	0.0	100	-1.3
500	0.0	500	-2.2
1000	0.0	1000	-2.9
1500	0.0	1500	-3.8
2000	0.0	2000	-3.9
2500	0.0	2500	-4.9
3000	0.0	3000	-5.7

The frequency response of the cable was plotted in a graph as shown in the following image.

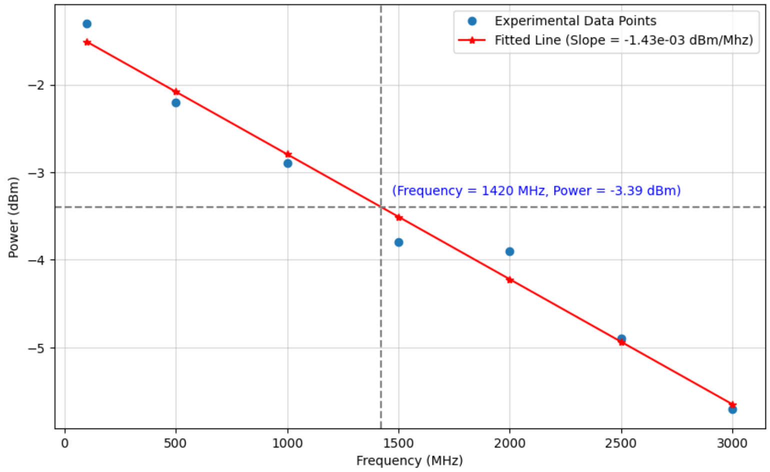

Figure 2: Cable Characteristics (Frequency Response)

The minimum and maximum frequency that could be generated by the two VCOs were probed. It was found that the **VCO 1 (Local Oscillator 1)** could generate signals with a minimum frequency of **1170 MHz** at **19.2 dBm** and a maximum frequency at **1420 MHz** at **18.6 dBm** and was set at **1350 MHz** at **18.9 dBm**. The **VCO 2 (Local Oscillator 2)** could generate signals with a minimum frequency of **44 MHz** at **19.2 dBm** and a maximum frequency at **111 MHz** at **6.7 dBm**. The second VCO was set at **64 MHz** at **7.9 dBm**.

The next table shows the power level of the signal at the various stages of the process. The final signal has been brought down to a **baseband signal**.

Measurement	**Frequency (MHz)**	**Power Level (dBm)**
Signal Generator RF output	1420	$-30 - 3.4 = -33.4$
LNA output (50-3000 MHz)	1420	-20.9
VCO (1230-1420 MHz) Output	1350	18.9
First Frequency Mixer (10-2400 MHz) Output	70	-29.7
LPF (DC-140MHz) Output	70	-29.9
Amplifier (0.1-500 MHz) Output	70	-7.5
VCO (50 - 100 MHz) Output	64	7.9
Secondary Frequency Mixer (0.5 - 600 MHz) Output	6	-13.7

4 Results

From the observations, it can be seen that the RF signal at 1420 MHz was successfully first down-converted to a 70 MHz intermediate frequency and then subsequently to a baseband signal near 6 MHz, with the measured power levels at each stage matching the expected behaviour of the LNA, mixers, filters, and amplifiers in the chain.

5 Interpretation

This experiment involved characterizing the behaviour of RF components in a two stage **Supreheterodyne Receiver** operating around the 1420 MHz Hydrogen line frequency. Each stage of the receiver was tested individually, and the observed power levels and frequencies were compared with theoretical explanation.

5.1 Cable Characteristics

The measured cable response shows a clear consistent increase in attenuation with frequency, ranging from -1.3 dB at 100 MHz to -5.7 dB at 3 GHz. Intermediate points follow the same monotonic trend.
These results match the expected behaviour of coaxial RF cables, where at higher frequencies it experiences greater skin effect and dielectric losses.
One data point at 2.5 GHz was observed to be unusually close to the 2 GHz value and did not follow the trend of the surrounding measurements. This was considered likely to be a measurement or processing artifact. To maintain a physically accurate curve, we treated this point as an outlier and excluded it from the calculations.

5.2 Signal Generator (SG)

The Signal Generator was used as a primary RF source for the Superheterodyne Receiver and was set to transmit a continuous signal at 1420 MHz frequency. Although the procedure specifies an output level of -10 dBm, the effective level set during the experiment was -30 dBm.
Before connecting the SG to the receiver chain, a seperate calibration check was performed with the generator set to 0 dBm. The measured level at the spectrum analyzer showed a loss of 3.4 dBm, which corresponds to the combined system attenuation of the cable, connectors, and analyzer input path. This calibration measurement aligns closely with the independently measured cable loss value near the operating frequency. Because of this, the SG power level used in the subsequent gain and loss calculations is taken as -30 dBm, which accurately reflects the real RF level delivered into the LNA input during the experiment.

5.3 Low Noise Amplifier (LNA)

The input signal from the Signal Generator was -30 dBm, and the measured output for the LNA was -20.9 dBm, giving a gain of $+9.1$ dBm.
This is within the expected operating range of the 1420 MHz LNA module and confirms that the amplifier enhanced the weak RF signal with minimal added noise.

5.4 Voltage Controlled (Local) Oscillator (VCO-1)

The first voltage controlled oscillator generated a stable output at 1350 MHz with a measured power of -18.9 dBm. The output frequency varied smoothly with the applied tuning voltage, confirming the correct VCO operation. This signal was used as the local oscillator for the first mixing stage. The output power was sufficient to drive the mixer without distortion. The stability of the VCO ensure accurate and repeatable frequency conversion.

5.5 First Mixer

The first mixer combined the 1420 MHz RF signal with the 1350 MHz LO from VCO-1. A clear output at 70 MHz, corresponding to the difference in the frequencies, was observed. The measured IF power was -29.7 dBm, indicating a conversion loss of approximately 8.8 dB. This value lies within the expected range for passive RF mixers. The mixer therefore performed effective frequency down conversion.

5.6 IF Low Pass Filter

The low pass filter allowed the 70 MHz IF to pass while suppressing higher frequency mixing products. The output power changed only slightly from -29.7 dBm to -29.9 dBm, corresponding to an insertion loss of about 0.2 dB. This confirms that the IF lies well within the filter passband. The filter effectively cleaned the IF spectrum without significant signal loss.

5.7 IF Amplifier

The IF amplifier increased the signal level from -29.9 dBm to -7.5 dBm, providing a gain of approximately 22.4 dB. This gain is consistent with the expected performance of the amplifier module. The amplified IF ensured sufficient signal strength for the second mixing stage. The amplifier operated linearly and without observable distortion.

5.8 Voltage Controlled (Local) Oscillator (VCO-2)

The second VCO produced a stable output at 64 MHz with a power level of -7.9 dBm. This signal served as the local oscillator for the second frequency tuning was smooth and stable with applied voltage. The output power was smooth and stable with the applied voltage. The output power was appropriate for efficient mixer operation. VCO-2 therefore functioned correctly as a low frequency local oscillator.

5.9 Second Mixer

The second mixer combined the 70 MHz IF with the 64 MHz LO from VCO-2. The resulting output was 6 MHz corresponds to the expected difference in frequencies. The measured output power of -13.7 dBm indicates a conversion loss of approximately 6.2 dB. This is consistent with typical passive mixer behaviour. The final low frequency output confirms successful second stage down conversion.

5.10 Final Interpretation

The experiment successfully demonstrated the operation of a two stage superheterodyne receiver at the 1420 MHz band. The RF signal was amplified, down converted to an intermediate frequency, filtered, amplified, and further converted to a low frequency output, with all observed frequencies matching theoretical expectations. Measured gains and losses at each stage were consistent with standard RF compared behaviour once cable attenuation was accounted for. Overall, the results confirm the practical implementation of superheterodyne receiver principles used in radio astronomy.

6 Acknowledgements

We would like to express our sincere gratitude to Prof. Subhashis Roy, Dr. Prakash Arumugaswamy and Mr. Navnath Shinde for helping us get valuable insights in this particular experiment. We also thank IUCAA and NCRA TIFR and the entire organising committee of RAWS 2025 for their support and providing us with the opportunity to perform this experiment.

7 Contributions

Introduction and Results - Dhairya Kotecha[4]
Theory - Anaya Atul Dixit[2] and Saanvi Pande[6]
Observations - Ambika S[1]
Calculations and Data plotting - Pranjal Sengupta[5]
Interpretation - Bhargava Ganesh Bhat[3]

8 Reference

electronicscoach.com, cdebyte.com, wikipedia.org,
Pozar, D.M., Microwave Engineering, 4th Edition, Wiley, Manual