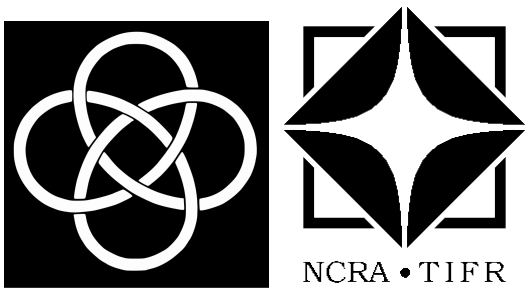
17th Radio Astronomy Winter School (RAWS) 2024



Submitted by (`Group - 3`)

Susnata Chattopadhyay
Sarthak Bondre
Udhaya Baskar
Shreya Sachdeva
Amrutha Preetha

The Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune
National Centre for Radio Astrophysics (NCRA) - TIFR, Pune

Experiment: Superheterodyne Receiver

1 Aim

We aim to understand the fundamental components of the super heterodyne receiver and study the signal flow through the receiver. This is a simplified prototype of one of the 60 channels that is used in GMRT.

2 Experimental Setup

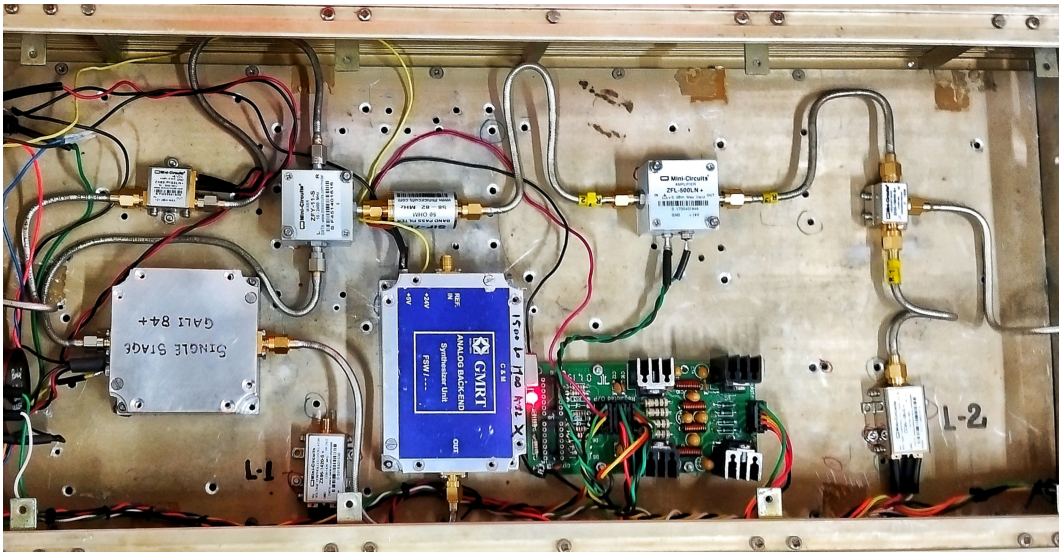


Figure 2: The setup of Superheterodyne receiver at RPL

The various components of the super heterodyne receiver are:

1. RF Signal Generator: It is used to generate signals over a wide range of frequencies. We can generate signals using this signal generator which the antenna would have collected and converted into electric signals.

2. Low Noise Amplifier: Its role is to boost the received signal a sufficient level above the noise floor so that it can be used for additional processing. It amplifies the low frequency signal without degrading its signal-to-noise ratio.

3. Frequency Mixer: Using a local oscillator, the mixer enables signals to be translated in frequency, thereby enabling signals to be converted up and down in frequency.

4. Voltage Controlled Oscillator (VCO): A Voltage controlled oscillator adjusts its oscillation frequency in response to an input voltage. 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.

5. RF Filters: They allow only desired frequency components to pass while blocking unwanted ones. These filters ensure that only relevant signals are processed further.

6. 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.

Working Principle

A superheterodyne receiver is a radio receiver that combines a locally received frequency with the carrier frequency to produce an intermediate frequency signal that can be processed more conveniently than the original carrier frequency. This conversion is called heterodyning. 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. The signal input is generated by the Signal Generator which mimics an astronomical signal (which is a weak signal). This input is passed through a low noise amplifier which boosts the input signal to a level where the amplitude and phase information can be detected and recorded. LNA amplifies its magnitude preserving its frequency and phase characteristics, while introducing minimal noise.

This amplified signal is then passed through the first frequency mixer where the RF is down converted with the principle of super-heterodyning; a Local Oscillator LO generates a frequency to mix the RF down to a value that is more convenient for further processing. This results in an Intermediate Frequency f_{IF}. The local oscillator signal is generated by the VCO in the mixer.

The output from the mixer is passed through an IF filter that isolates the desired IF signal by removing the unwanted frequency and other signals. It also ensures minimal amplitude losses for the signal which is required, while removing the others. Then it is passed through an IF amplifier to increase the amplitude of the filtered signal.

The amplified IF signal is then passed through a second mixer where it is combined with a LO frequency which is tuned to match with (2 Hz difference) the IF. Therefore, the signal is now changed to the baseline frequency (approximately 2 Hz), to isolate the original RF signal. We analyze the signal using a Spectrum Analyzer and characterize the change in parameters (frequency and power level) at each of the intermediate steps.

3 Theory

A *mixer* works by multiplying two signals and **beating** it to produce two waveforms of different frequency. This process, called heterodyning, works as follows

$$V_{\text{out}} = V_{\text{RF}} \times V_{\text{LO}}$$

where, V_{RF} is the input signal and V_{LO} is the desired Voltage controlled oscillator's (VCO) signal. Let,

$$V_{\text{RF}} = A\sin(2\pi f_{\text{RF}}t), \quad V_{\text{LO}} = B\sin(2\pi f_{\text{LO}}t)$$

$$\begin{aligned} V_{\text{out}} &= C\sin(2\pi f_{\text{RF}}t) \times \sin(2\pi f_{\text{LO}}t) \\ &= \frac{C}{2}\left[\cos(2\pi(f_{\text{RF}} - f_{\text{LO}})t) - \cos(2\pi(f_{\text{LO}} + f_{\text{RF}})t)\right] \end{aligned}$$

We select f_{LO} as required and remove the unwanted signals. The frequency of Intermediate Frequency (IF) is given by:

$$f_{\text{IF}} = |f_{\text{RF}} - f_{\text{LO}}|$$

In practical applications, the mixer requires input signals with sufficient power. To address this, a low-noise amplifier (LNA) is placed at the start of the circuit to compensate for any signal losses occurring in the mixer. Additionally, a filter is also introduced after the LNA and before the mixer to eliminate image interference in the mixer output. However, in this particular experiment, this filter step is omitted since the test signal used is a basic sine wave, which does not introduce image interference.

To obtain a fixed output frequency from the mixer, we need to adjust f_{LO} such that the difference $|f_{\text{LO}} - f_{\text{RF}}|$ remains constant. This can be achieved using a Voltage-Controlled Oscillator (VCO), where f_{LO} can be varied by changing the input voltage.

In an ideal mixer, both $f_{\text{LO}} + f_{\text{RF}}$ and $f_{\text{LO}} - f_{\text{RF}}$ signals are produced. However, in practical scenarios, additional signals such as $f_{\text{LO}}, f_{\text{RF}}, (2f_{\text{LO}} + f_{\text{RF}}), (f_{\text{LO}} + 2f_{\text{RF}})$, and higher-order harmonics are also generated. To address this, a bandpass filter (LPF) is placed at the mixer's output to isolate and allow only the intermediate frequency (IF) signal to pass through. The IF signal is then amplified according to the system requirements. Then this process can be repeated to further convert the intermediate frequency signal down to the baseband frequency.

Units Note that in this experiment we are measuring the power level in dBm. This is defined as

$$I(\text{dBm}) = 10\log_{10}\frac{P_2}{P_1}\bigg|_{\text{wrt 1mW}}$$

4 Data Analysis

Measurements	Frequency (MHz)	Power level (dBm)
Signal generator RF output	1420.00	-30.0
LNA (Low Noise Amplifier) output	1420.00	-20.9 (+9.1 dBm gain)
VCO(1230-1420MHz) output	1351.11	17.2
First Frequency Mixer (10-2400 MHz output)	69.08	-29.3 (8.4 dBm Conversion Loss)
LPF(Low Pass Filter)[1] with 58-82 MHz bandwidth	69.08	-29.5 (0.2 dBm loss)
IF Amplifier	69.08	-8.7 (+20.8 dBm gain)
VCO(50-MHz) output	71.57	8.2
Second Frequency Mixer (0.5-600 MHz output)	2.13	-15.5 (Total/net gain of 14.5 dBm)

Table 1: Observed Results at each stage of the experiments

4.1 Block diagram

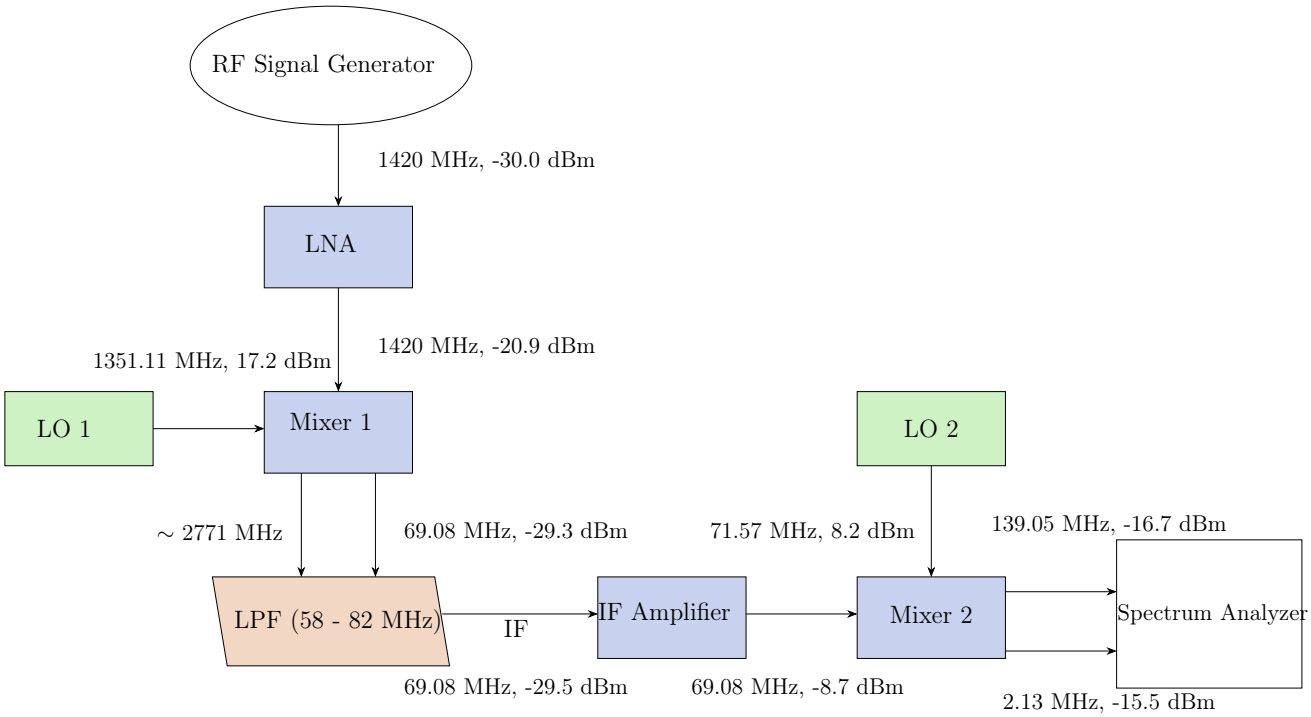


Figure 3: The variation of power level of input signal (RF) across the superheterodyne receiver. Abbreviations: LNA - Low Noise Amplifier, LO - Local Oscillator, IF - Intermediate Frequency signal.

5 Error Analysis

In this table we summarise the relative errors between the expected and observed output frequencies in each of the devices.

Devices	Expected (MHz)	Observed (MHz)	Error (%)
LNA (1)	1420.00	1420.00	0
Mixer 1	68.89	69.08	1
Mixer 1	2771.11	-	-
LPF	69.08	69.08	0
IF Amp (2)	69.08	69.08	0
Mixer 2	140.65	139.05	1.14
Mixer 2	2.49	2.13	14.46

Sources of Error The major source of error was the varying capacitance values and thermal noise in the circuit which hindered a particular output frequency to be measured (The output of Mixer 2 was very noisy and peaks were not constant with varying power levels). Tiny voltage fluctuation/ imperfect calibration in spectrum analyzer also limited the accuracy of measuring the actual output signal.

6 Conclusion

We successfully studied the working and signal flow through a superheterodyne receiver, and also identified possible sources of error in our measurements. We also concluded that the loss in signal power in wires is proportional to the length of the wire and also the frequency of the input signal. That is a higher frequency signal will experience more loss than a lower frequency one.

7 Discussion

By carefully analyzing the changes to the input signal at each stage of the circuit, we gained a clear understanding of the role and effects of each component whether it was frequency conversion, filtering, attenuation, or amplification. Ultimately, this allowed us to comprehend the overall functioning of the superheterodyne receiver. The objective of this experiment was not to measure any specific physical quantity. Since all measurements were taken using the spectrum analyzer, there was limited scope for a quantitative error analysis. Instead, we focused on identifying the precautions to be taken and challenges encountered during the process.

We ensured that all connections were properly secured, the input frequency remained within the operating range of the instruments, and all power supplies shared a common ground. Special attention was given to detecting short circuits, as these would cause the power supply to drop to zero, requiring a careful recheck of the connections. Despite these precautions, some difficulties were encountered during the experiment, primarily due to substandard or faulty mixers, which caused drift in the output spectrum. Specifically, the peak frequency of the output spectrum shifted over time, making it challenging to report consistent results.

In addition to the frequency drift, the output signal contained noticeable noise, likely caused by low-quality components. These challenges highlighted the importance of using reliable, high-quality equipment and carefully managing the experimental setup to ensure accurate and stable results.