Chapter 23

Local Oscillator and Base-band Systems

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23.1 Requirement for a Local Oscillator System at the GMRT

The GMRT Analog Receiver, in its simplest form, can be considered as a 2-terminal black box, as given in Figure 23.1.

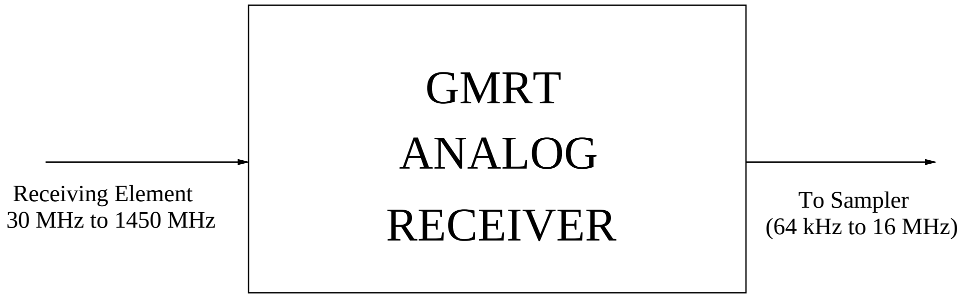

Figure 23.1: A Two-terminal representation of the GMRT analog receiver system.

The receiving element (i.e. any of the dual linearly polarised feed systems of the GMRT) is connected at the input of the black box and provides a signal consisting of:

1. Thermal noise power kTB.[1]
2. The astronomical signal, which is usually much weaker than the thermal noise power.
3. Unwanted Radio Frequency Interference (RFI), which could occur anywhere in the frequency spectrum and is often much stronger than the thermal noise power.

[1]where k is the Boltzman constant, T is the system temperature and B is the bandwidth of the signal. At the GMRT for a 32 MHz bandwidth this power is typically of the order of -100 dBm.

The output of the black box is in base-band frequency range, which is typically from DC to a maximum of 16 MHz. The upper value determines the maximum instantaneous bandwidth of GMRT. The base-band signals are then digitized by a sampler. The nominal power level needed for the sampler is 0 dBm. Since the typical input power level is -100 dBm, the gain within the black box is about 100 dB.

This large amplification has to be achieved while simultaneously providing the desired band-limiting[2] and spurious free dynamic range[3] in the presence of strong RFI. For this, the electronics system within the black box has been implemented as a heterodyne receiver, where the RF signal from the receiving element is converted to the base-band signal via different stages of frequency translation (see also Chapter 3). This frequency translation requires multiple Local Oscillator signals.

23.2 The Frequency Translation Scheme used at the GMRT

The simplified block diagram of frequency translation scheme used to convert the RF signals from each antenna of the GMRT to the base-band signals required by the sampler is given in Figure 23.2. A schematic of the typicaly used mixing scheme at the GMRT is shown in Figure 23.3.

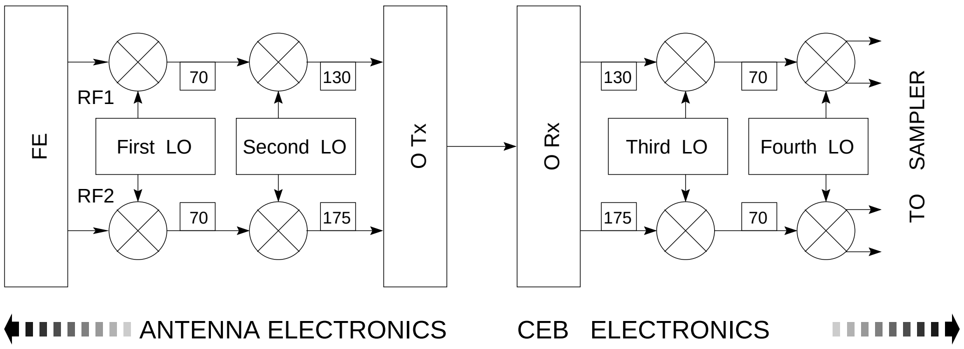

Figure 23.2: Block diagram of frequency translation Scheme at the GMRT. The numbers in the boxes are the Centre Frequency of the signal at that point.

The pair of RF signals from the Front End (FE), which are typically in the range of 30 to 1660 MHz are initially converted to a first IF signal centered at 70 MHz. The choice of the first IF frequency has been decided by the availability of commercial sharp cut-off band-pass filters with a wide choice of bandwidth at this frequency[4]. This translation from RF to the first IF needs a first LO signal, which should be tunable at least over the range of 100 to 1590 MHz. The GMRT is designed to simultaneously process two RF signals (RF1 and RF2, also called the 130 signal and the 175 signal respectively). These signals could be either (a) two polarisation signals at the same RF band, or (b) one polarisation signal in each of two different RF bands. To cater to case (b), we need two independent first LO sources.

The pair of first IF signals are brought from each antenna to the central electronics building (CEB) by a single optical fibre for further processing. Hence, we need to separate

[2]i.e. one needs to filter the signal so that only frequencies within the band of astronomical interest are accepted.

[3]i.e. one needs to ensure that the entire system is sufficiently linear so that RFI at one frequency does not produce spurious spikes at other frequencies.

[4]At the GMRT, IF bandwidths of 32, 16 and 5.5 MHz are available. See Chapter 21 for more details

the two first IF signals (centered at 70 MHz) in the frequency domain before they can be combined and fed to the optical transmitter (OTx) unit. For this, one of the first IF signals is translated to a second IF signal centered at 130 MHz and the other, to another second IF centered at 175 MHz. The choice of these centre frequencies has been decided by (a) The maximum bandwidth of the first IF signal and (b) the need to keep the overall band occupancy on the fibre to within an octave. The value for the two second LO signals chosen for the GMRT are hence 200 and 105 MHz. At the CEB the *reverse* translation is done, after the optical receiver (ORx) unit, to produce a pair of third IF signals, centered at 70 MHz. This requires two third LO signals, at 200 and 105 MHz respectively.

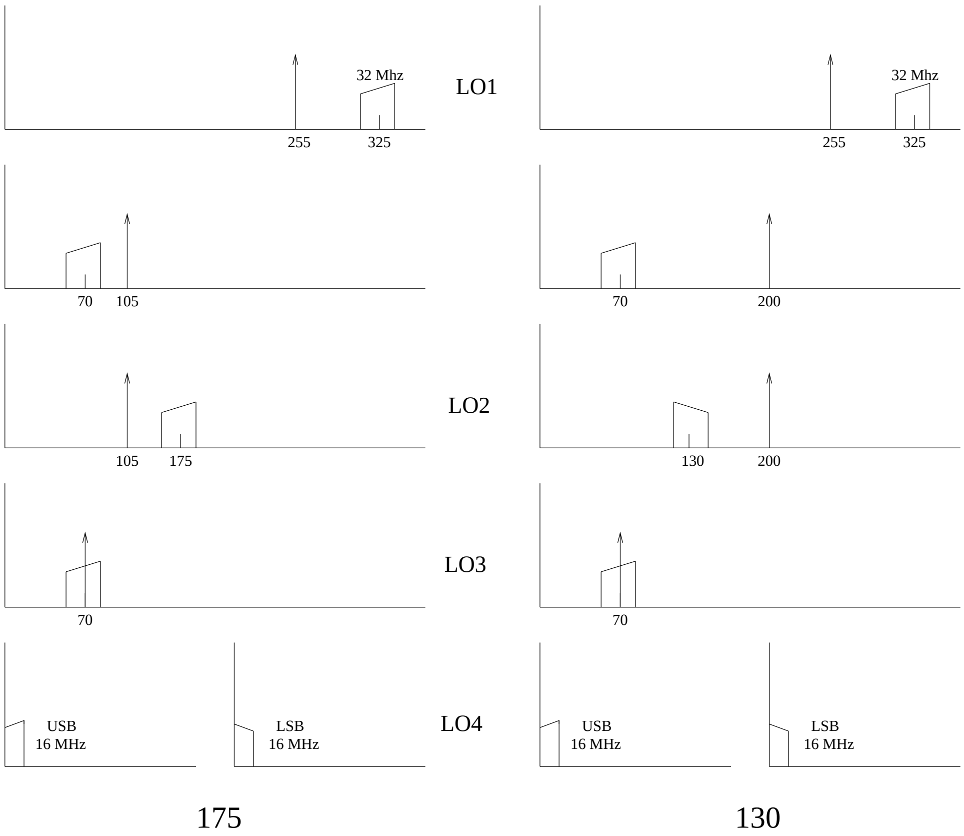

Figure 23.3: A typical mixing scheme at the GMRT. LO1 is tunable in the range 30 - 1590 MHz, in steps of 1 MHz below 350 MHz and 5 MHz above that. LO2 and LO3 are not tunable. LO4 is tunable in the range from 50 - 90 MHz, in steps of 100 Hz. As can be seen from the figure, if $\nu_{LO1} > \nu_{RF}$ then the sky frequency increases with correlator channel number for the USB and decreases with increasing correlator channel number for LSB. This is true for both the 175 and the 130 signals. If $\nu_{LO1} < \nu_{RF}$, then for both 175 and 130 signals, the sky frequency decreases with increasing correlator channel number for USB and increases with increasing channel number of LSB.

The last stage of frequency translation is to base-band, using a fourth LO signal, which can be set to any frequency from 50 to 90 MHz in 100 Hz steps. The step size is determined by the need to incorporate online doppler tracking, so that a spectral line under observation can be confined to a specified channel in the correlator throughout the entire observation.

23.3 Generation of Phase-Coherent Local Oscillator Signals

The GMRT is generally used in the interferometric mode where the correlation between the electric field vectors received by each feed element is measured. To maintain the relative phase between the electric field vectors incident on different antennas, it is essential that the local oscillators used must be phase-coherent[5]. This implies that the frequency of the LOs at the various antennas must be identical and the variation of phase of the LO at a given antenna (with respect to the phase of some reference antenna) must be precisely known during an observation so that necessary correction can be made in real time. This is acheived by having all the local oscillator signals be generated from a single reference frequency source using phase-locked loop (PLL) techniques.

In detail, the third and fourth LO signals are generated in the CEB from an ultra-high stable and pure quartz oscillator at 5 MHz. The second LO generation uses a voltage controlled crystal oscillator (VCXO) in a PLL, while the first LO needs a phase-coherent frequency synthesiser. Signals at 106 MHz and 201 MHz are broadcast from the CEB to each antenna, and these are used at the antennas to generate the 105 MHz and 200 MHz second LOs. The 105 MHz second LO signal is in turn used to generate the first LO. In this way the phase coherence of all the LOs at all the antennas is maintained.

Despite being derived from a common signal, there are still phase variations of the LOs at the different antennas for a variety of reasons. The physical length of the optical fibre link to various antennas varies from a few hundred meters to about 20 kms. As the temperature coefficient for expansion of the fibre is not zero, there will be a variation of the phase of LO signal broadcast from CEB and received at an antenna. The receiver system in each antenna is housed in an air-conditioned environment and undergoes independent cyclic variation in temperature. This also causes the LO phase between antennas to vary in a random manner. All of this would make it desirable to have a system for estimation of phase of the LO signals at all antenna locations. This could be achieved by bringing back the second LO signals from each antenna to the CEB and comparing its phase with that of the signal originally generated at CEB. From this information, the phase variation introduced by the transmission process could be estimated. Of course, this needs the pair of optical fibre to an antenna to be reciprocal and non-dispersive, which has been independently confirmed. However, this scheme is not yet fully implemented.

23.4 Noise Calibration and Walsh Switching

As discussed in Chapter 21, all the GMRT receivers have the facility for noise injection. By injecting noise of known power the system temperature can be measured. The noise at any antenna can be switched on and off (on sub second time scales) according to a pre-determined pattern, which is encoded in PROMs in the Antenna Based Receiver (ABR). By synchronously measuring the total power, it is possible to calibrate the system temperature. The synchronous total power measurment however has not yet been implemented.

Signals from one antenna could leak into another antenna at various points along the signal flow chain. This is normally referred to as *cross-talk*. This would cause a spurious corrrelation between the base-band signals from these two antennas. This leakage can be minimized by switching the phase of the RF signal of each antenna by a pattern that

[5] i.e.the phase difference between the LO signals at antenna i and antenna j should be constant with time for all antennas i, j. If this is not acheivable, then at least the phase difference between the LOs at different antennas should be calibratable in real time.

is ortho-normal to the pattern used for all other antennas. At the correlator the exact reverse phase switching is done for each antenna so that the original phase is recovered just before the cross-correlation is done. Such a scheme would greatly reduce the cross-talk at all points between the RF amplifier and the base-band. Typically the ortho-normal functions used are Walsh functions, and this scheme is called Walsh Switching. The required Walsh patterns for each antenna are also encoded in PROMs situated at the ABR. However the Walsh demodulation at the correlator is yet to be implemented.

23.5 The Base-band System

The base-band system of GMRT processes the IF signals received from the antennas and makes them compatible for the correlator.

The maximum bandwidth of the IF signal is 32 MHz. Considering the fact that the correlator system can run at a maximum clock speed of around 40 MHz, a Single Side-Band (SSB) conversion with image rejection approach is used in the base-band. This results in two base-band signals, (the Upper Side Band, (USB) and the Lower Side Band (LSB)) each with a maximum bandwidth of 16 MHz, for each of the third IF signal. There are hence 120 base-band outputs resulting from 60 third IF signals (typically one from each of two polarizations) from 30 antennas of the GMRT. A simplified block diagram for the system to handle one of the third IF signals is given in Figure 23.4

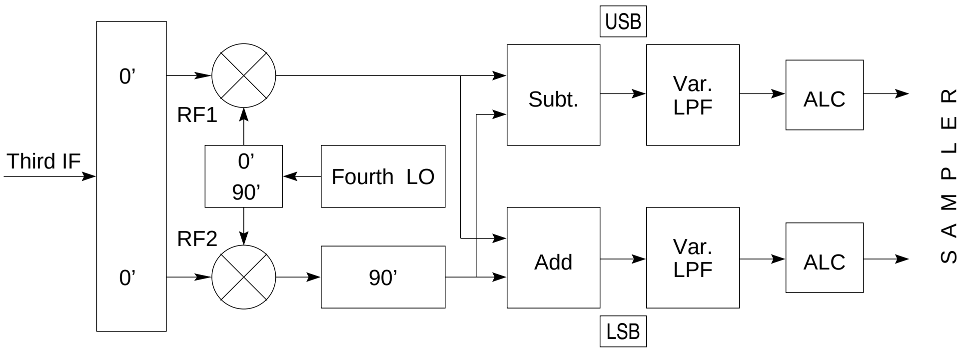

Figure 23.4: A simplified block diagram of the base-band processing at the GMRT.

The input third IF signal at 70 MHz is converted to two base-band signals, the Upper Side Band (USB) corresponding to $70+16$ MHz and Lower Side Band (LSB), to $70-16$ MHz. This single side-band mixers are based on in-phase and quadrature-phase power dividers for the third IF and fourth LO as well as a broadband quadrature network in the base-band. The typical image rejection which has been achieved is 25 dB.

The base-band system has facility for a wide choice for bandwidth, from 62.5 kHz to 16 MHz, in octave steps. This is achieved in the variable low pass filter block. The power output from the system is kept constant by automatically increasing, the gain as the bandwidth is decreased, to keep the product constant. In addition the ALC stage ensures that the sampler is supplied with a constant power. For some applications (eg. Pulsar observations) however, the finite time constant of the ALC produces undersireable distortions of the astronomical signals. For these observations, the ALC can be switched off.

23.6 A Summary of Important Specifications

23.6.1 Array Frequency Reference

Model used	Frequency and Time Standard (FTS) make 1000B Quartz TCXO
Output frequency	5 MHz, 2 Hz, (adjustable externally)
Aging per day	1×10^{-10}
Short-term Stability over 1 to 100 sec	1×10^{-12}
SSB Phase noise	-116 dBc/Hz at 1 Hz offset -140 dBc/Hz at 10 Hz offset -150 dBc/Hz at 100 Hz offset
Harmonics	-40 dBc
Spurious	-100 dBc

23.6.2 First LO Synthesiser

Frequency Coverage	100 MHz to 1795 MHz
Step Size	1 MHz from 100 MHz to 354 MHz 5 MHz from 350 to 1795 MHz
Power output	$+11$ dBm -3 dB
Harmonics	Better than -20 dBc
Spurious	Better than -60 dBc
Phase Noise	Better than −60 dBc/ Hz at 10 kHz offset, (corresponding to a peak-to-peak phase jitter of better than 0.1 deg in time scales of 0.1 msec)
Line Frequency modulation	Better than -20 dBc

23.6.3 Second and Third LO Sources and Offset Frequency Sources

Oscillator circuit	Transistorised VCXO with 5th overtone crystals for sources around 105 MHz and 7th overtone crystal for 200 MHz., operating in a PLL with loop bandwidth of 70 Hz.
Maximum frequency deviation	2 kHz for 10 V range.
Spurious	Better than -50 dBc
Harmonic	Better than -70 dBc
Phase jitter	Less than 1 nsec
SSB Phase noise	Better than -90 dBc/Hz at 100 Hz offset.

23.6.4 Fourth LO Synthesiser

Frequency Coverage	50 to 90 MHz
Step Size	100 Hz
Inband spurious	Better than -60 dBc
Phase noise	−80 dBc/ Hz at 1 kHz offset

23.6.5 Base-band System

Lower cut-off frequency	~ 10 kHz
Choice for Upper cut-off frequency	62.5 kHz, 125 kHz, 250 kHz, 500 kHz, 1 MHz, 2 MHz, 4 MHz, 8 MHz and 16 MHz
Pass-band ripple	$<$ 0.5 dB
Stop band rejection	48 dB/octave
Image Rejection	minimum 20 dB
Fourth LO leakage to output	Better than 60 dB
Third IF input level	-65 dBm to -55 dBm
Base band output power level	0 dBm (ALC ON mode)
Typical Third IF level in ALC OFF mode:	-50 dBm, to give 0 dBm output.