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Dynamic Range of the L- Band Front - End Receiver of GMRT

A. Praveen Kumar, Anil Raut, Vilas Bhalerao

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1.0 Introduction

Giant Meterwave Radio Telescope (GMRT) receiver system has been designed to operate at frequency bands centered at 150 MHz, 235 MHz, 327 MHz, 610 MHz and L-Band covering 1000 to 1450 MHz. The L-Band is split into four sub-bands centered at 1060 MHz, 1170 MHz, 1280 MHz and 1390 MHz, each with a bandwidth of 120 MHz.

The issues related with the receiver dynamic range for frequency bands 150 MHz to 610 MHz has been dealt with earlier[1]. This report reviews the dynamic range issues of the L-Band front - end and the results obtained during Lab measurements. The various dynamic ranges are defined and briefly described.

2.0 Dynamic Range Issues

The concept of High Dynamic Range (HDR) receiver implies not only an ability to detect the desired signals with low distortion and also the signals differing in amplitude by large amounts. More importantly the concept should indicate higher degree of immunity to spurious responses produced by non-linear interaction of multiple high level interfering signals.

The issues involved for characterizing the dynamic range of the receiver include Noise Figure (F), Sensitivity, intermodulation Distortion (IMD), Third-order intermodulation Products, internally generated spurious responses, Gain compression [also known as 1 dB compression point (P_{1dB})], Desensitization & blocking, Phase Noise, Cross Modulation, Reciprocal mixing etc.

2.1 Noise Figure and Sensitivity

These are fundamental to any measurement of receiver performance and are associated with the ability of a receiver to detect very weak signals. Noise figure determines the noise floor of most of the dynamic range measurements. The most common expression of noise figure is ratio in dB of the effective receiver input noise power with respect to -174 dBm / Hz.

2.2 Compression Dynamic Range (CDR)

The Compression Dynamic Range of the receiver defines the range of signal levels a receiver can process linearly. The point at which the receiver gain falls by 1 dB from the ideal for a single input signal is a figure of merit known as 1 dB

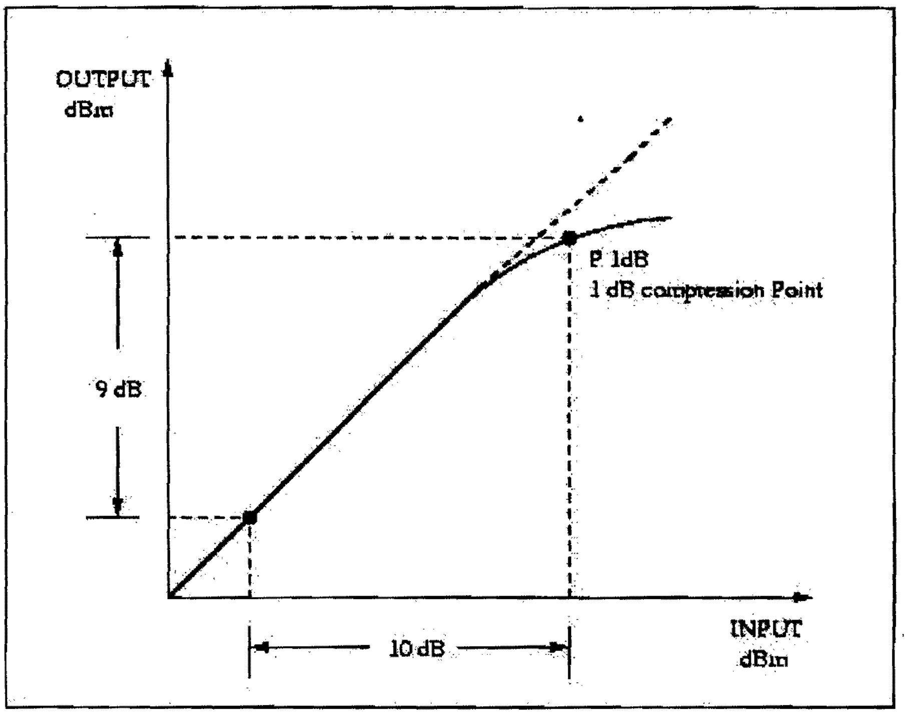


Figure – 1 : 1 dB Compression Point

compression point (P_{1dB}). It is illustrated in figure -1. Compression dynamic range (CDR) is the difference in dB between the in-band 1 dB compression point and the Minimum Discernible Signal (MDS) level. Using receiver noise floor as MDS, the compression dynamic range (CDR) can be expressed in dB as,

$$CDR = P_{1dB} - 10 \log (FkT_0 BG)$$

For an ambient temperature of 290 °K this expression can be simplified as,

$$CDR = P_{1dB} + 174 - NF - 10 \log B - 10 \log G$$

Where,

P_{1dB} - output power of receiver at 1 dB compression Point in dBm
F - Noise Figure (Noise factor)
NF - Noise figure in dB
T_0 - Ambient Temperature in °K
G - Gain of the receiver
B - Bandwidth of Receiver in Hz.
CDR - Compression Dynamic Range in dB
k - Boltzman's Constant

This dynamic range definition has an advantage of being relatively easy to measure without ambiguity but it assumes that the receiver has only single signal at its input and that the signal is desired. For specifying the performance of receivers in the presence of interfering signals other definitions of receiver dynamic range should also be considered.

2.3 Desensitization Dynamic Range (DDR)

DDR measures the receiver degradation effect due to a single dominant, out of band interfering signal. Desensitization is also called blocking. Since a large signal tends to reduce the average gain of the system & the weak signal may experience a vanishingly small gain, the receiver must be able to withstand blocking signals 60 to 70 dB greater than desired signal. To test the DDR, a signal that produces an output S/N ratio of 10 dB is injected at the receiver input and interfering sinusoidal signal is added to the input at a particular frequency offset from the desired frequency and its magnitude is increased until the output S/N ratio degrades by 1 dB. DDR is then the power ratio in dB of the undesired signal power in dBm to the receiver noise floor in dBm/Hz. DDR is expressed as,

$$DDR = P_i + 174 - NF$$

Where,

P_i - Interfering signal power in dBm
NF - Noise Figure in dB
DDR - Desensitization Dynamic Range in dB.

The DDR is strongly affected by the frequency offset of the interfering signal. At small frequency offsets, DDR is dominated by effects of phase noise and reciprocal mixing. At larger offsets, 1 dB compression due to overload may occur.

2.4 Spurious Free Dynamic Range (SFDR)

SFDR is a very important parameter and frequently used to characterize receiver performance. The new spurious signals produced through IMD can profoundly affect the performance of the system even though they are operated well below gain compression. IMD products of significant power can appear at frequencies remote from, in or near the system passband. The worst case situation for intermodulation occurs when two or more strong signals which are very close together in frequency are received at the receiver input. In this case the resulting Third-order intermodulation Products with frequencies equal to $(2f_1 - f_2)$ and $(2f_2 - f_1)$ where f_1 and f_2 corresponds to two input signals with slightly different frequencies falling within the receiver passband. Consequently, the Third-order IMD products are often used instead of 1 dB compression point to impose an upper bound on the SFDR. The upper limit is chosen so that the input signal produces a Third-order IM products at a predetermined level below the desired output signal.

It is important to define at this stage a very useful figure of merit, the Third-order Intercept Point (IP_3). The Third-order IMD results for an input consisting of two signals f_1 and f_2, in producing new signals at ($2f_1 \pm f_2$) and ($2f_2 \pm f_1$). Under small signal conditions well below the compression, the power of a Third-order IMD product varies by 3 dB per 1 dB change in input power. This allows to derive the Third-order intercept point. We can do so by extrapolating the linear & intermodulation responses of the receiver to their point of intersection (See figure - 2).

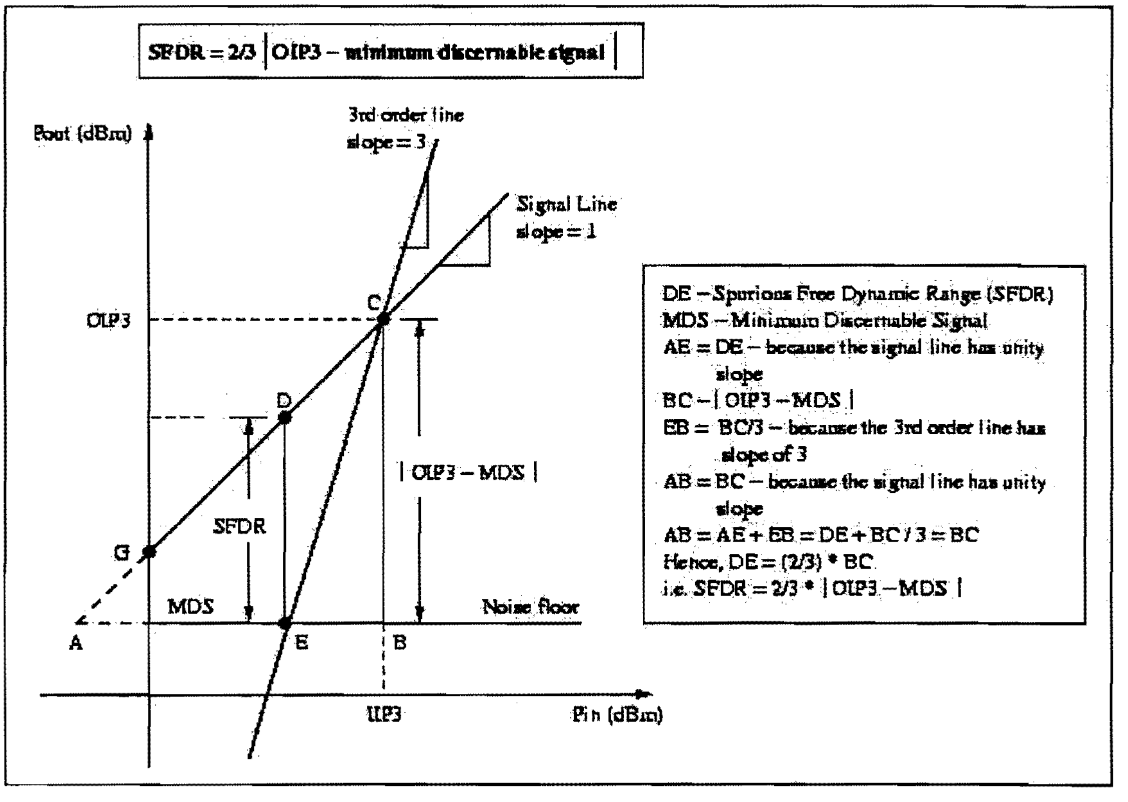


Figure – 2 : Graphical representation of Spurious Free Dynamic Range (SFDR)

This is the point where their powers will be equal if compression did not occur. Because of the system noise, there is minimum discernible signal (MDS) that limits the dynamic range at the lower end. In general the intercept point for a given IM order 'n', can be expressed, and should be characterized relative to input (IIP_n) or output (OIP_n) power. These two intercept points IIP_n and OIP_n differs by network's linear gain. For equal level test tones IIPn can be determined by

$$IIP_n = (nPf - PIM_n) / (n-1) \text{ dBm}$$

OR

$$IIP_n = [(Pout - PIM_n) / (n-1)] + PIN$$

Where,

n - Order of intermodulation product

Pf - Input power of fundamental tones in dBm

IIP_n - Input nth order intercept point in dBm

PIM_n- Power of the nth order IM product in dBm

Therefore for the third-order intercept point the equation corresponds to,

$$IIP_3 = (3Pf - PIM_3) / 2 \quad \text{dBm}$$

Using various geometric relations we can also derive a useful relationship for OIP3 as,

$$OIP_3 = Pout + (A / 2) \quad \text{dBm}$$

Where,

Pout - Output signal power level in dBm.

A - The difference between output signal level (Pout) and the IMD (PIM_3) level in dB.

A typical spectrum analyzer display used to calculate IP_3 is illustrated in figure - 3b. Also,

$$IM_3 = 3 \text{ Pout} - 2 \text{ OIP}_3 \quad \text{(dBm)}$$

Since, $$OIP_3 = IIP_3 + G$$

$$IM_3 = 3 \text{ Pin} - 2 \text{ IIP}_3 + G \quad \text{(dB)}$$

It is important to note that IP_3 is a fictitious power level that can be referred to the input and the output power levels as Third-order Input intercept point (IIP_3) and Third-order output intercept point (OIP_3) respectively. In figure - 3a, if all powers are in dBm and the origin of the Pin axis is 0 dBm, then the signal line will intersect the Pout axis numerically equal to the gain G. So, any Pout in the signal line is larger than the signal line by 'G'. Therefore since the IP_3 point falls on the signal line,

$$OIP_3 = IIP_3 + G.$$

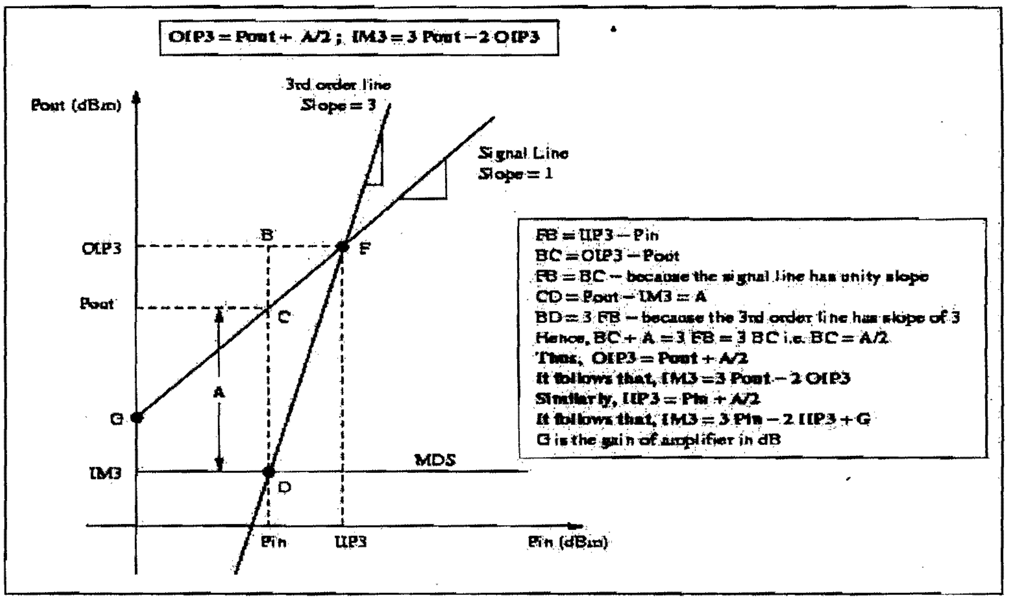


Figure – 3a : Graphical representation of the relationship between the Fundamental signal and the Third order intermodulation products (OIP3 & IIP3)

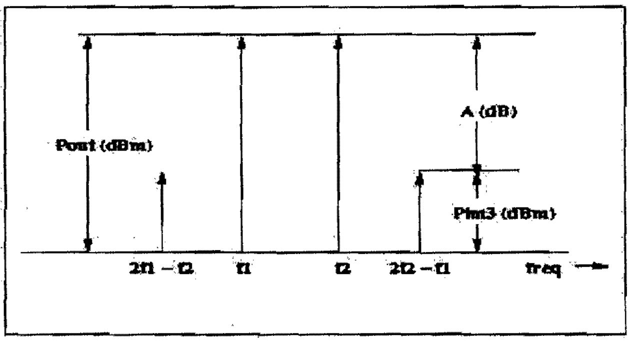


Figure – 3b : Typical Spectrum Analyser Display used to calculate the OIP3

We are now at a stage to define the SFDR. The SFDR is the difference in dB between the level of MDS and level of fundamental signal when the level of Third-order distortion product is equal to the MDS. This is illustrated in figure – 2. Maximizing the dynamic range of the receiver implies that the receiver has the maximum Third-order intercept point and minimum noise temperature. Therefore the measurement of SFDR is of paramount importance. SFDR measures the difference in power between the noise floor, and the signal power that could just cause a Third-order distortion component to emerge from the noise.

Using the geometric relations shown in the figure - 2, SFDR in terms of output intercept point OIP_3 is,

$$SFDR = 2/3 \ (OIP_3 - MDS) \quad dB$$

Where, MDS is the total noise power at the output of the receiver in dB.
Alternatively, at ambient temperature,

$$SFDR = 2/3\ (OIP_3 - (-174 + 10 \log B + NF + G))\ \ dB$$

Where,
G - Device gain in dB
B - Bandwidth of the device in Hz.

The third-order intermodulation products increase by 3 dB for every 1 dB increase in two input signals. Theoretically, the SFDR would be zero at the third-order intercept point. For every 1 dB reduction in output power there is a 3 dB reduction in the third-order intermodulation products. The result is a 2 dB improvement in SFDR.

SFDR has become a very popular specification because it seems to give a single number which can be used to compare the overall dynamic range performance of the competing receivers.

3.0 L-Band front - end

A block diagram of the GMRT RF front - end[1] is as shown in figure – 4. The block diagram and schematic diagram of the L-Band front - end receiver are shown in figure 5a and 5b respectively[2]. The L-band front - end consists of a corrugated horn feed to collect the radiations reflected from the parabolic dish with a quadridge orthomode transducer (OMT) in which the waveguide mode of the signal is converted into coaxial mode. In the OMT two linear components of the incoming signals are picked up in two perpendicular directions which are designated as V and H channels. The signals are then amplified by a low noise amplifiers (LNA[3]) designed using three stages of FUJITSU HEMT's, FHX35LG (Figure – 6). The gain of the LNA is 34 ± 2 dB over 1000 to 1450 MHz and noise temperature is 28 ± 5 deg K. over the same frequency range. The LNA is followed by a post amplifier[3] consisting of a stage of Mini-circuits MMIC amplifier MAR-3 (Figure – 7). The gain of the post amplifier is nominally 8 dB. The next stage in the system is the phase switch unit[3]. It consists of a stage of MAR-3, 4 dB attenuator, Mini Circuits SRA-2010MH double balanced mixer and two stages of MAR-3 followed by a 6 dB attenuator (Figure – 8). The gain of the phase switch unit is 13 ± 2 dB. The signals then pass through a set of switched filter bank where there is a provision to bypass the filters to get full band output. In the switched filter mode any one of the four sub-bands centered at 1060 MHz, 1170 MHz, 1280 MHz and 1390 MHz, each with a bandwidth of 120 MHz can be selected. The insertion loss of the bandpass filter is around 6 dB. At the final output a 550 MHz bandwidth band pass filter with the center frequency of 1250 MHz is incorporated.

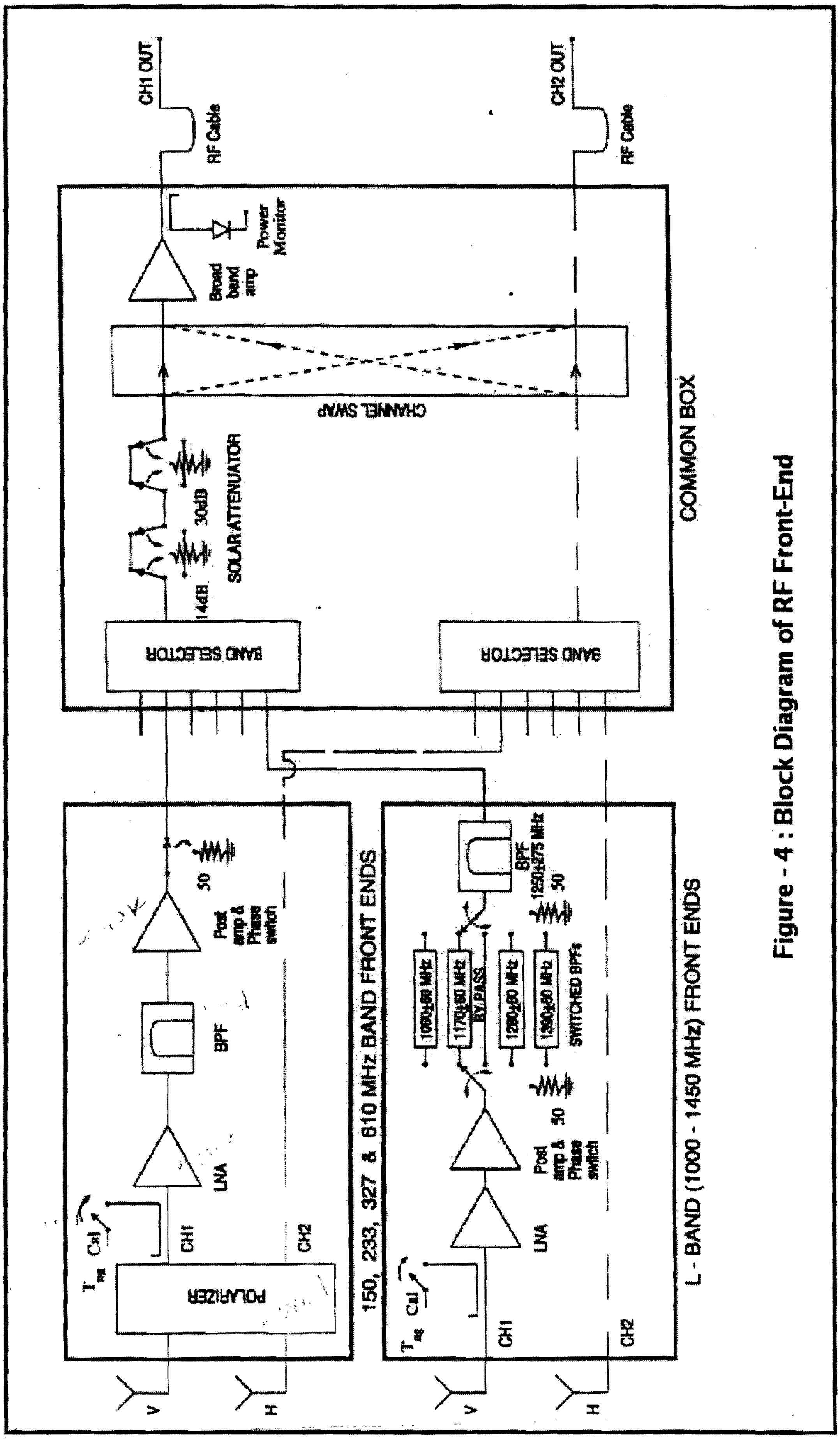


Figure - 4 : Block Diagram of RF Front-End

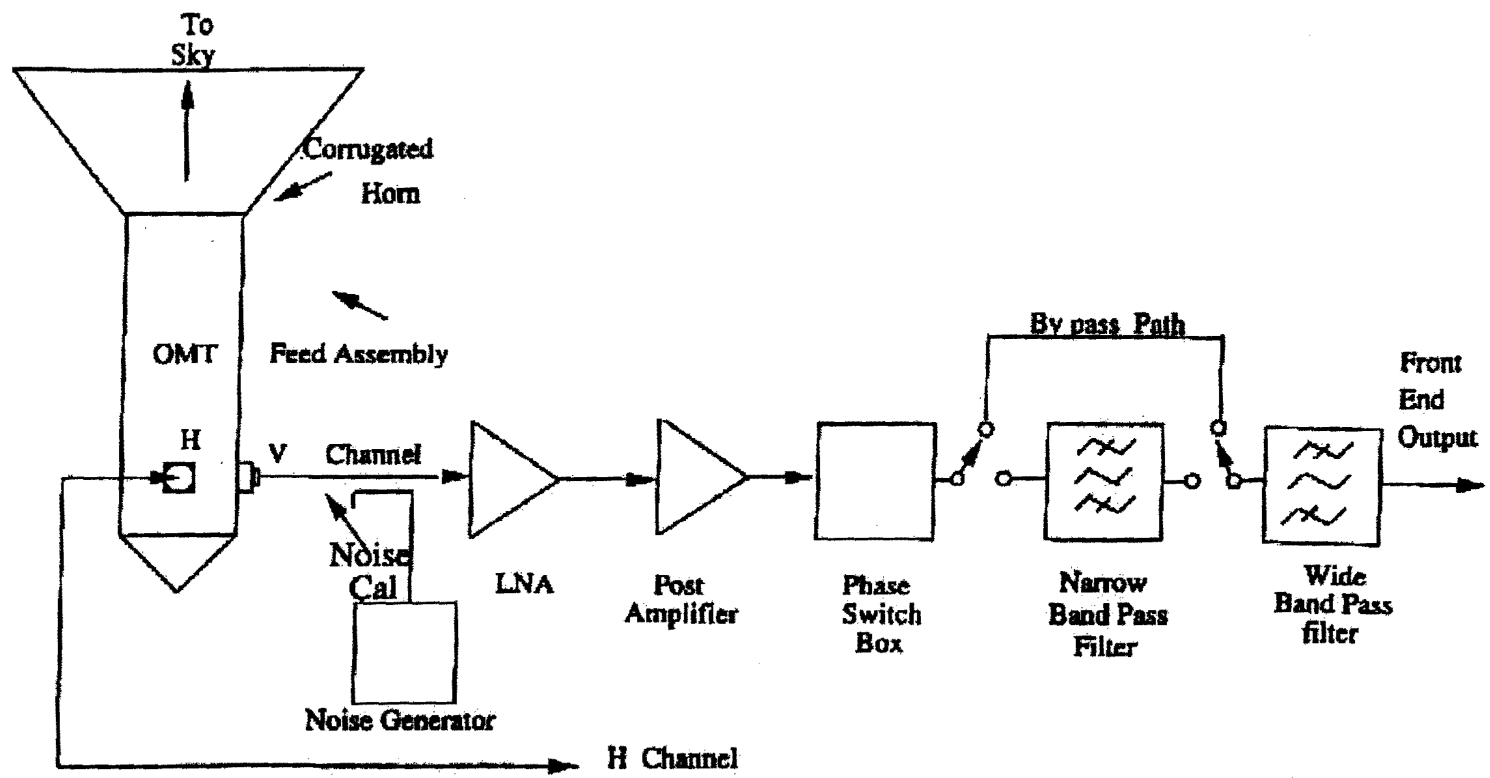


Figure - 5a : Block Diagram of L - Band Front - End

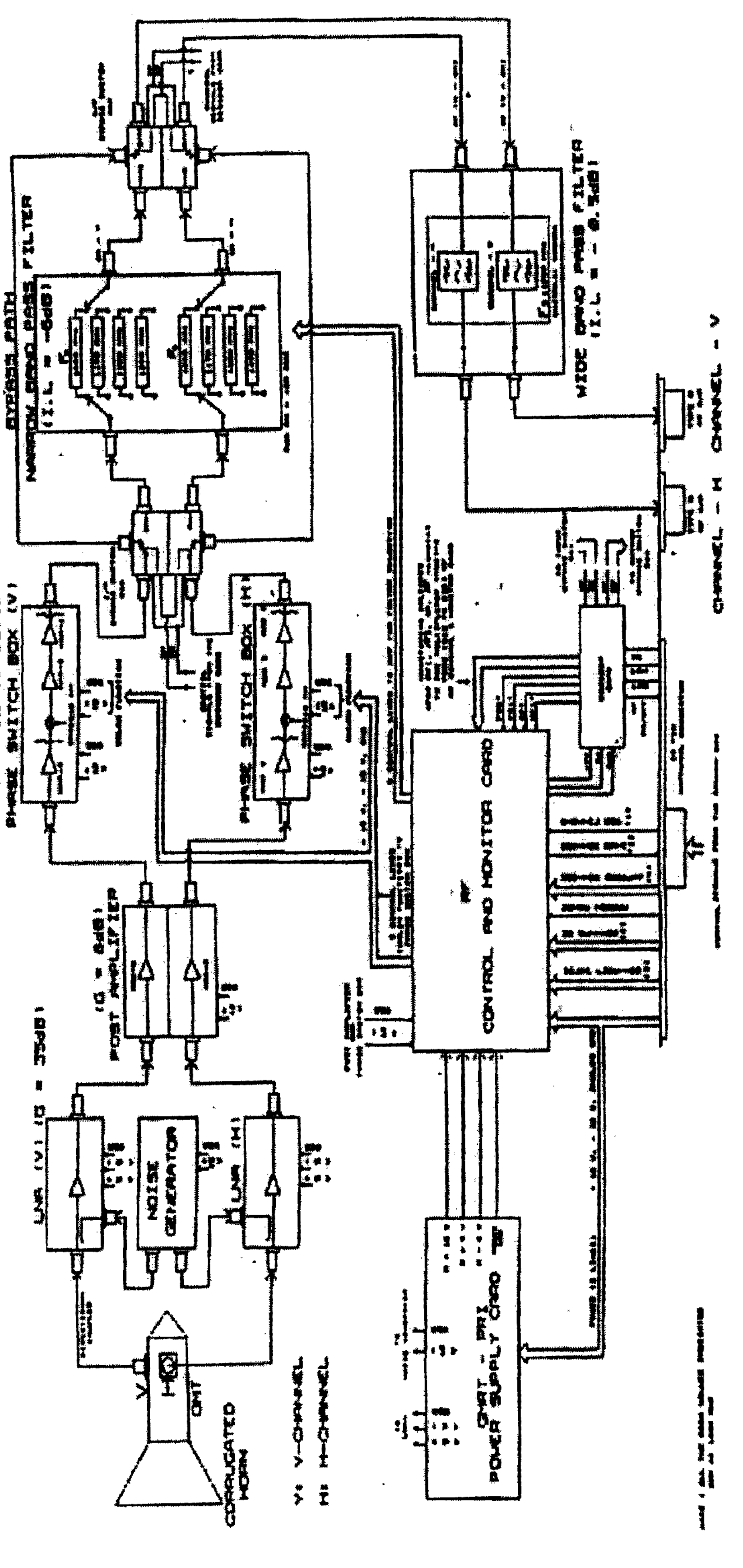


Figure - 5b : Schematic Diagram of L - Band Front - End

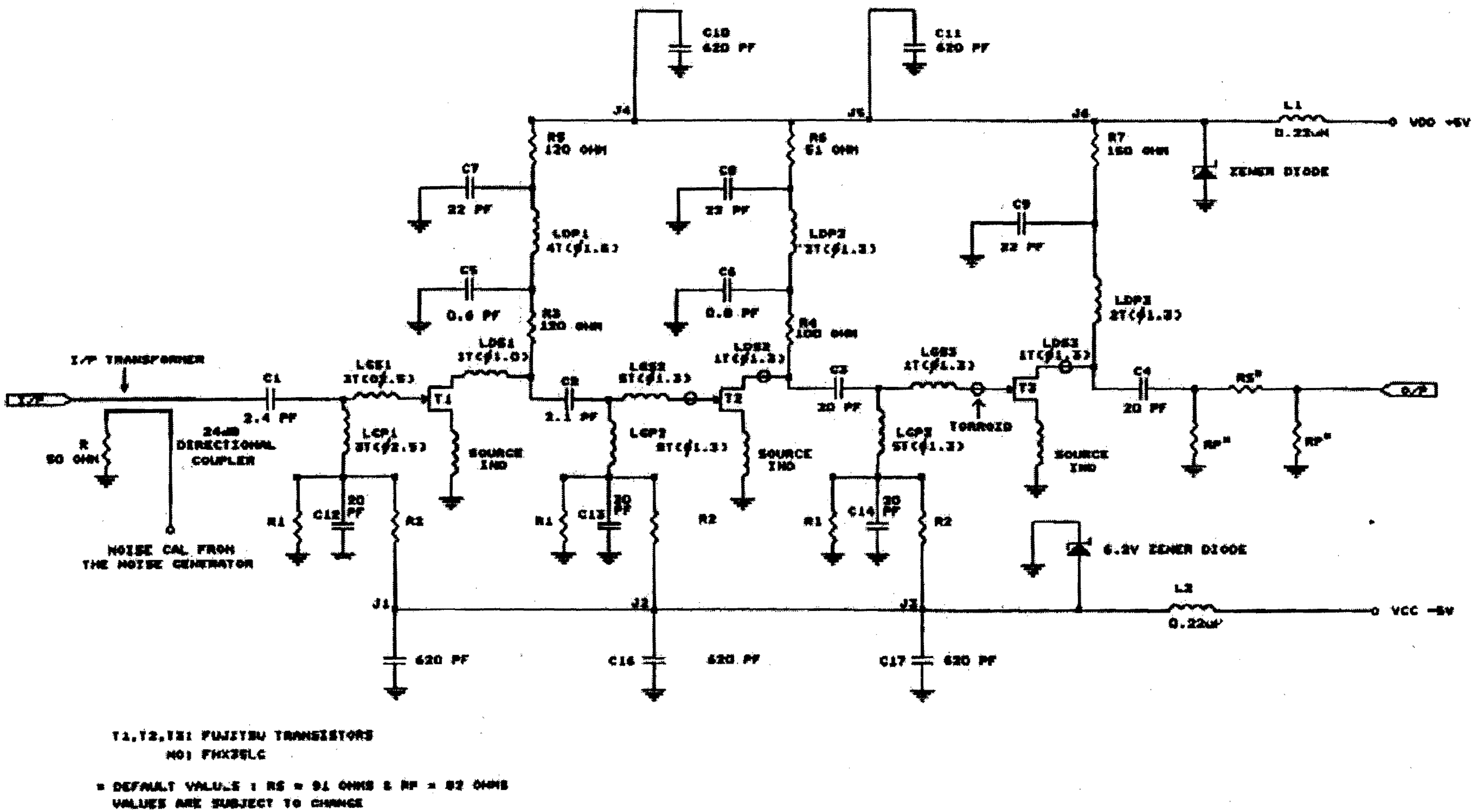


Figure - 6 : Circuit Digram of L - Band Low Noise Amplifier

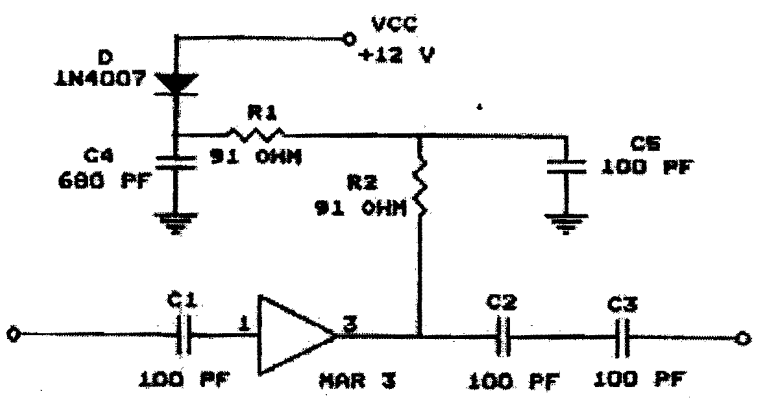


Figure - 7 : Circuit Diagram of L - Band Post Amplifier

4.0 Dynamic Range Measurement

Following dynamic range measurements were carried out to estimate the dynamic performance of the L-band front - end receiver in the presence of an external interference, both in-band and out of band. Compression, blocking and spurious free dynamic ranges were estimated.

4.1 Blocking or desensitization Dynamic Range Measurements

First, the output noise power in the filter bypass mode (full band) at L-Band receiver output is measured with carrier OFF. Then the carrier at 1.8 GHz is injected into the receiver at LNA input and the power of the carrier is increased gradually till the front - end output power was dropped by 1 dB with respect to the measured noise power when the carrier was not present.

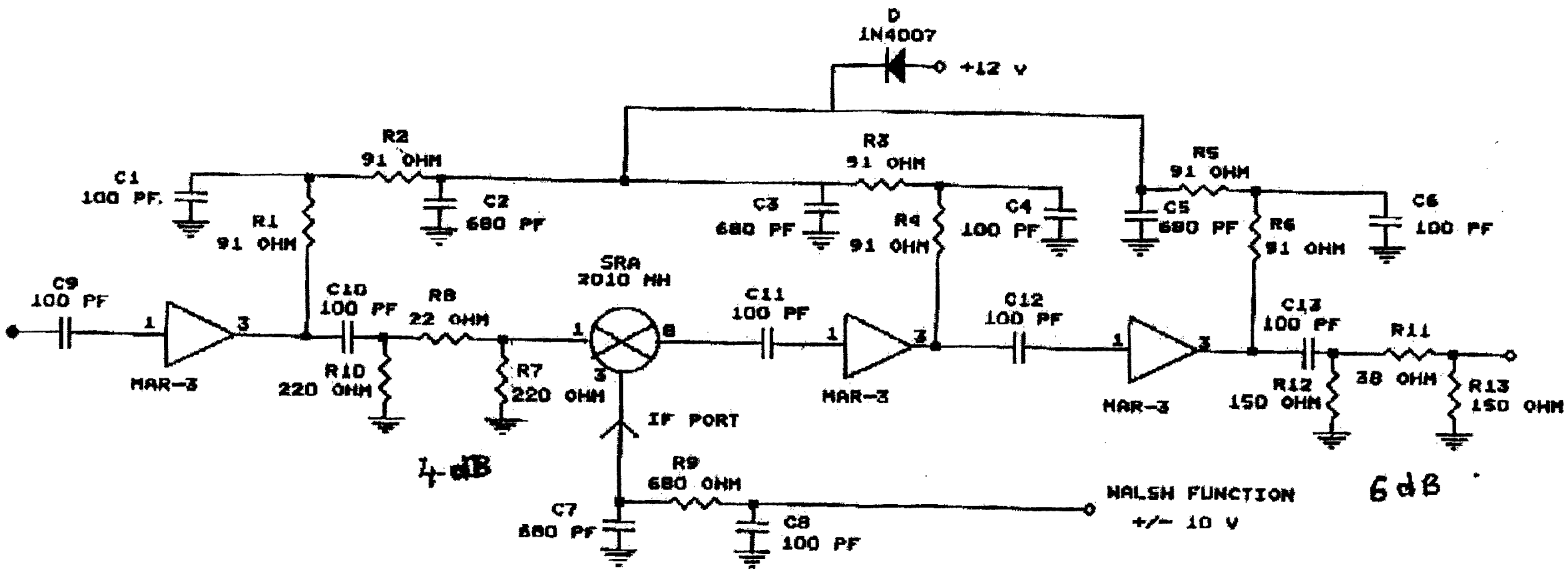
Two sets of readings were taken, First at the output of L-Band receiver and the second at the output of phase switch (before band pass filter). Brief details about the results obtained are as follows.

1. **At the output of L-Band Receiver**

   Carrier Frequency : 1.8 GHz
   Input Carrier power : -38 dBm
   Output Carier power : - 38 dBm
   L-Band power output at 1200 MHz with carrier OFF : - 69 dBm
   L-Band power output at 1200 MHz with carrier ON : - 70 dBm

2. **At the output of Phase switch (Before the BPF)**

   Carrier Frequency : 1.8 GHz
   Input Carrier power : -38 dBm
   Output Carrier Power : - 8 dBm
   L-Band power output at 1200 MHz with carrier OFF : - 67 dBm
   L-Band power output at 1200 MHz with carrier ON : - 68 dBm



1) MAR 3: PIN NOS: 2 AND 4 ARE GND PINS

2) SRA 2010 MH: PIN NOS: 2,5,6,7 ARE GND PINS,
4 IS OPEN

Figure - 8 : Circuit Diagram of Phase Switch Unit

The measured input carrier power is the upper limit of the blocking dynamic range. The lower limit of the blocking dynamic range is the system noise floor which is $kT_{sys}B$. Where 'B' is the bandwidth and T_{sys} is the receiver noise temperature.

For the L-band receiver, the T_{sys} is taken to be 80 °K and for one Hz bandwidth the system noise floor is calculated as -180 dBm. The input carrier power at which the 1 dB blocking occurs is -38 dBm. Therefore the blocking dynamic range is 142 dB/Hz for an interfering signal at 1800 MHz.

The L – band front - end was reconfigured by shifting the switched filter bank after the post amplifier unit. The phase switch unit was incorporated after the switched filter bank. With this configuration the blocking signal level was measured choosing 1390 MHz sub-band. Under this condition it was found that 1.8 GHz carrier of – 21.5 dBm power at the LNA input causes 1 dB blocking of the L – band RF signal.

Next, the switched filter bank was incorporated immediately after the LNA with post amplifier and phase switch unit after the switched filter bank. Under this condition the 1 dB blocking occurred for 1.8 MHz carrier of - 20 dBm power at the LNA input.

From the above measurements it can be concluded that shifting of the switched filter bank just after the post amplifier is the best option in order to improve the blocking performance of the L – band front - end. **It gives about 16 dB improvement in the blocking dynamic range compared to the existing system configuration.**

4.2 1-dB Compression Point Measurement

For this measurement, a carrier at a frequency of 1420MHz is fed to the RF input port of the LNA in L-Band receiver and carrier power at the output of the L-band receiver is measured by varying input carrier power progressively. The L-band receiver was set to operate in the 1390 MHz sub-band. The measurement results are as follows.

Input Carrier Power (dBm)	Output Carrier Power (dBm)
- 100	- 59.0
- 90	- 49.0
- 80	- 39.0
- 70	- 29.0
- 60	- 19.5
- 59	- 18.5
- 58	- 17.5
- 57	- 16.5
- 56	- 15.6
- 55	- 14.7

Input Carrier Power (dBm)	Output Carrier Power (dBm)
- 54	- 13.8
- 53	- 13.0
- 52	- 12.0
- 51	- 11.4
- 50	- 10.7
- 49	- 10.1
- 48	- 9.6
- 47	- 9.2
- 46	- 8.8
- 45	- 8.5
- 44	- 8.3
- 43	- 8.1
- 42	- 8.0
- 41	- 8.0
- 40	- 8.0

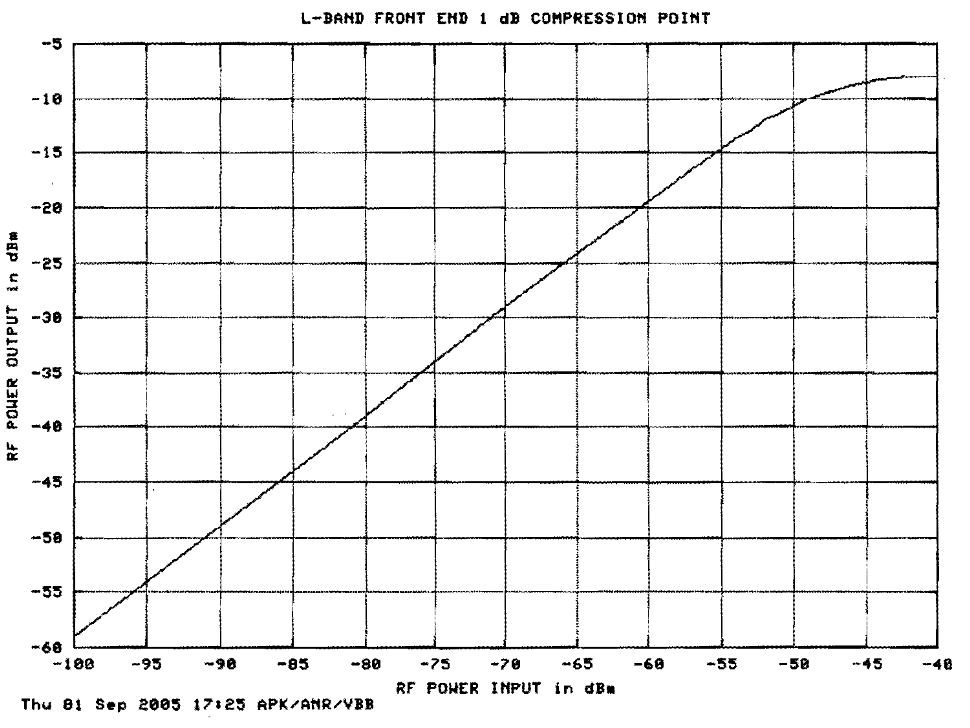


Figure – 9 : Input Carrier power Vs Output Carrier Power

The plot for input carrier power vs output carrier power is shown in figure – 9. It can be seen that the 1 dB compression point (output power level at 1 dB compression) is about - 15 dBm. The linear gain of the system was measured as described below. A 1420 MHz input signal is fed at the input of the LNA and the output of the L-band front - end was measured using a spectrum analyzer. At the spectrum analyzer output the carrier power is set to - 60 dBm by varying the input power. The input power level is noted down which is - 99.2 dBm . Afterwards the receiver was bypassed and the signal generator output is directly fed to the spectrum analyzer through the interconnecting cables. The signal generator power was increased till the spectrum analyzer reads - 60 dBm carrier power. The corresponding input signal power was noted down, which is - 57.2 dBm. The difference between these two power levels is, (- 57 - (- 99.2)) = 42 dB is the actual linear power gain 'G'. In the previous section we have estimated the noise floor for 1 Hz bandwidth of the receiver as -180 dBm at the input of the receiver. Therefore the output noise floor for 1 Hz bandwidth is, (- 180 + 42) = - 138 dBm. The compression dynamic range (CDR) for the L-band front - end is thus (-15 - (- 138)) = 123 dB/Hz. For 120 MHz bandwidth the compression dynamic range is works out to 42 dB.

4.3 Measurement of Spurious Free Dynamic Range (SFDR)

The third order intermodulation products required for estimation of SFDR were generated at the output of the L-band front - end by injecting two carrier tones at 1390 MHz and 1400 MHz. Figure – 10 shows the spectrum of the fundamental and intermodulation products. The measurement results are as below.

Power level of the fundamental carriers at the output (Pout)	= - 22 dBm
Power level of the intermodulation (IMD) products (IM_3)	= - 67 dBm
Difference in dB between the fundamental and IMD product levels (A)	= 45 dB

The output third order intercept point (OIP_3) in dBm is given by,

$$OIP_3 = Pout + (A/2)$$
$$= -22 + (45/2)$$
$$\sim 0 \text{ dBm}$$

SFDR in dB is given by,

$$SFDR = 2/3\ (OIP_3 - kT_{sys}BG)$$
$$= 2/3\ (0 - (-180 + 42))$$
$$= 92 \text{ dB (for 1 Hz bandwidth.)}$$

For 120 MHz bandwidth the SFDR is,

$$SFDR = 2/3\ (0 - (-180 + 81 + 42))$$
$$= 2/3\ (0 + 57)$$
$$= 38 \text{ dB}$$

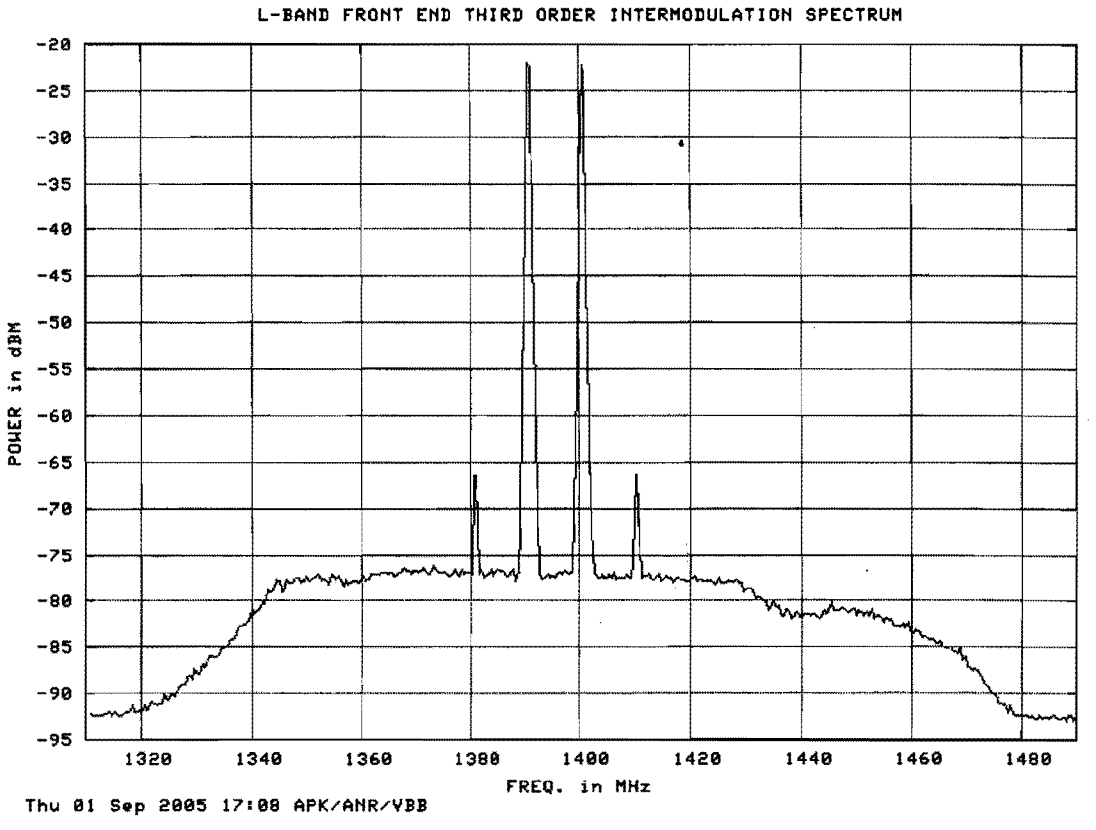


Figure – 10 : Third order Intermodulation spectrum

5.0 Conclusions

In this report we have attempted to review the issues associated with the dynamic range of the L-band front - end receiver system of GMRT. The concepts of various dynamic ranges were described in detail. Lab measurements were carried out to estimate the desensitization, compression and spurious free dynamic ranges. The desensitization (blocking) dynamic range has been measured for a single dominant interfering carrier located at 1800 MHz. This has been done to analyze the system performance in the presence of interference caused by the GSM mobile communication system operating in the region at 1800 MHz band. It has been found that 1800 MHz signal level of the order of – 38 dBm causes the L-band front - end receiver gain compression by 1 dB. In case the blocking dynamic range has to be increased, the switched filter bank in the system has to be located before the phase switch unit. This configuration gives an improvement of about 16 dB in th blocking dynamic range.

References

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