National Centre for Radio Astrophysics

Internal Technical Report
GMRT/FES/001-APRIL 2014

Complete signal flow analysis of 325 MHz frontend system

Gaurav Parikh & Anil Raut

gaurav@gmrt.ncra.tifr.res.in, anil@gmrt.ncra.tifr.res.in

Objective: Comparing the Dynamic Range of existing and upgraded 325 MHz Front End System.

Revision	Date	Modification/ Change
Ver. 1.2.2	1st APRIL,2014	Final Version

Acknowledgements

We thank **Shri. S. Sureshkumar**, *(Group co-ordinator)* for giving constant support during this work. We would also like to give our sincere thanks to **Prof. Yashwant Gupta***(Dean-GMRT)*.

We are very much thankful for all those who helped in completing the assignment successfully. We wish to express our sincere gratitude to all our front-end colleagues.

INDEX

List of Figures

List of Tables

1.0 Introduction

Giant Meter wave Radio Telescope (GMRT) has been designed to operate at six frequency bands centered at 50 MHz, 150 MHz, 235 MHz, 327 MHz, 610 MHz, and L-Band extending from 1000 MHz to 1450 MHz. L-band is split into four sub-bands centered at 1060 MHz, 1170 MHz, 1280 MHz and 1390 MHz, each with bandwidth of 120 MHz . The 150 MHz, 235 MHz and 327 MHz bands have about 40 MHz bandwidth and 610 MHz band has about 60 MHz bandwidth. Lower frequency bands from 150 MHz to 610 MHz have dual circular polarization channels (Right Hand Circular and Left Hand Circular) which have been conveniently named as CH1 and CH2 respectively. The higher L-Band frequency has dual linear polarization channels (Vertical and Horizontal) and they have also been named CH1 and CH2 respectively. The receiver system has the flexibility to be configured for either dual polarization at single frequency band or single polarization at two different frequency bands. The polarization channels can be swapped whenever required. For observing strong radio sources like “SUN”, the selectable solar attenuators of 14dB, 30 dB, and 44 dB can be used. Any band of the receiver can be switched OFF, whenever not in use, with the RF on/off facility provided in the front end box. The receiver can be calibrated by injecting one of the four levels of calibrated noise viz. Low Cal., Medium cal., High Cal., Extra High Cal.; depending upon the flux density of the source being observed. To minimize cross coupling between channels, a phase switching facility using WALSH function is available at RF section of the receiver.

This report attempts to study the overall noise performance, gain and dynamic range of the upgraded 325 MHz system and compared with the the existing one. The importance of signal flow analysis is to understand receiver dynamic range, operating signal levels, etc for ensuring better receiver performance.

2.0 325 MHz Front End system

The following figure shows the block diagram of existing 325 MHz Front End system (Front end + Common box).

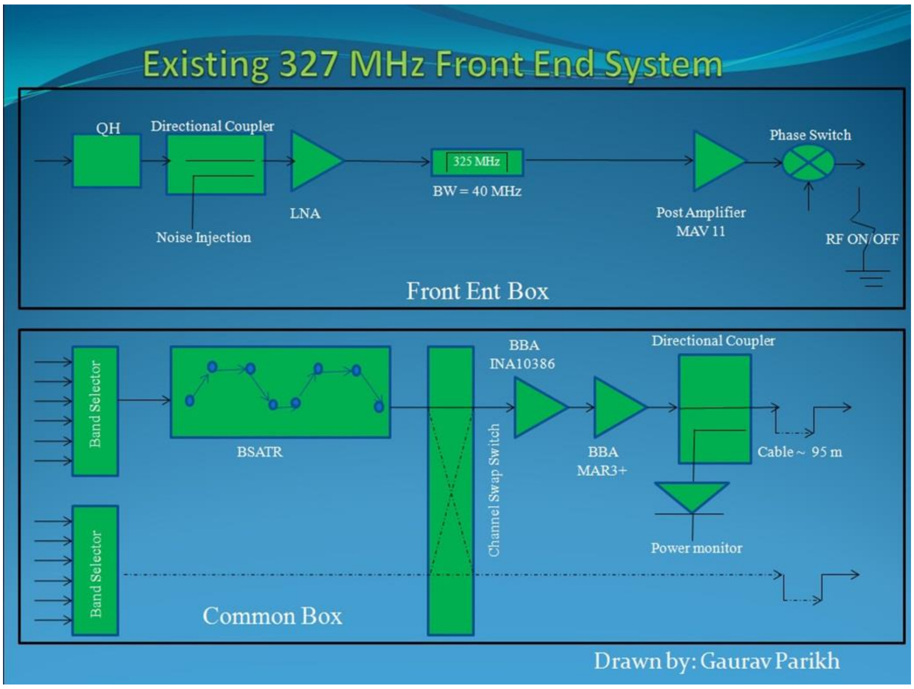

Figure-1 Existing Front End System (325 MHz Band)

Front-end:

The 325 MHz-Band front-end consists of a cross dipole / cone dipole feed to collect the radiations reflected from the parabolic dish. The signals are then converted into Left-circular and Right-circular using a wire line polarizer (QHDC) which are called CH1 and CH2 respectively. The signals are then amplified by a 2 stage low noise amplifier (LNA) designed using ATF-10135 + ATF-10136. The gain of the LNA is 34 ± 2 dB @ 325 MHz with a bandwidth (BW) of 40MHz and noise temperature of 40^{o}k ± 5^{o}k over the same frequency range. Next the signals pass through a band pass filter (BPF) centered @ 325 MHz having BW of 40 MHz. The next stage in system is the post amplifier (MAV11) and phase switching ckt (SBL_1MH) having combined gain of 4 dB.

Common Box: It consists of Band selector, to select the band of interest followed by a channel swap switch having a loss of 1 dB. This is then followed by two stage broad band amplifier giving a combine gain of 30 dB (first stage: INA-10386, second stage: MAR-3+). This is followed by the directional coupler used for power monitoring purpose. From there the signal is brought down to antenna base by two cables (one for each channel) each approx. of 95m long, and giving a loss of 7 dB @ 325 MHz.

The following block diagram shows the modification done in the upgraded sytem, wherein better LNA(two stage:ATF54143+ATF54143) and high dynamic range post amplifier (HMC-740) are used in FE box, whereas common box is same as existing one except for the broad band amplifier (high dynamic range two stage amplifier, HMC740 + HMC740).

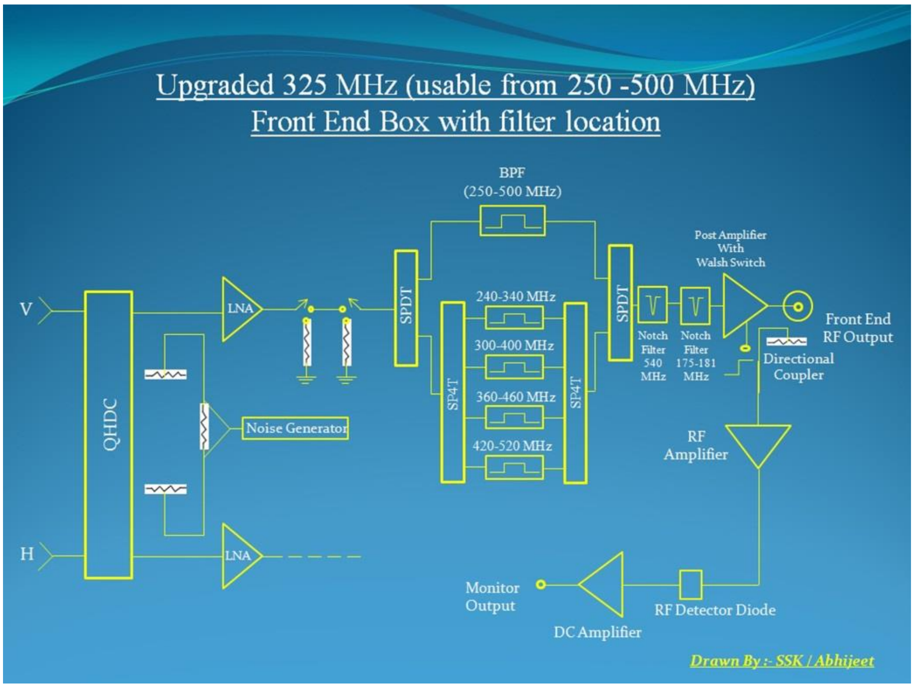

Figure-2 Upgraded Front End System (325 MHz-Band)

2.1 Parameters for Existing and upgraded system

unit description	Device part	Gain(dB)	NF(dB)	OP1dB	OIP3
FEED to FE input (Cable)	LDF-250 foam (1.3 m)	-0.13	0.13	1E+100	1E+100
POLARIZER(QHDC)	Wire line	-0.18	0.18	1E+100	1E+100
Directinal coupler	Micro-strip	-0.1	0.1	1000	1000
LNA	ATF10135 + ATF10136	34	0.56	-10	3.3
BPF	Lumped	-0.8	0.8	1000	1000
Post Amplifier & Phase Switch	MAV11 + SBL_1MH	4	3.55	1	3.4
FEB to CB (Cable)	RG-214 (3.3 m)	-0.6	0.6	1E+100	1E+100
BSATR	5 Nos. of SW-338, 4 Nos. of SW-239	-2.7	2.7	25	42
SWAPSW	4 Nos. of SW-239	-1	1	25	42
Attenuator		-4	4	1000	1000
Broad band Amplifier	INA10386 + MAR3+	3.08E+01	3.80E+00	6.70E+00	2.25E+01
CB output to ABR rack input (Cable)	95m	-7	7	1E+100	1E+100

Table 1: Existing 325 MHz system

unit description	Device part	Gain(dB)	NF(dB)	OP1dB	OIP3
FEED to FE input (Cable)	LDF-250 foam (1.3 m)	-0.13	0.13	1E+100	1E+100
POLARIZER(QHDC)	Sage Labs	-0.1	0.1	1E+100	1E+100
Directional coupler	Micro-strip	-0.1	0.1	1000	1000
LNA	ATF-54143 + ATF-54143	30	0.361	20.26	36.064
BPF	Lumped	-1	1	1000	1000
Post Amplifier & Phase switch	HMC740 + SBL_1MH	9.00	3.83	18	40
FEB to CB (Cable)	RG-214	-0.5	0.5	1E+100	1E+100
BSATR	5 Nos. of SW-338, 4 Nos. of SW-239	-2.7	2.7	25	42
SWAPSW	4 Nos. of SW-239	-1	1	25	42
Hittite Amplifier	HMC740	1.50E+01	3.50E+00	1.80E+01	4.00E+01
Hittite Amplifier	HMC740	1.50E+01	3.50E+00	1.80E+01	4.00E+01
CB output to ABR Rack input (Cable)	95m	-7	7	1E+100	1E+100

Table 2: Upgraded 325 (250-500 MHz) System

Note: In upgraded system, the effect of switch filter bank is not included.

3.0 Cascaded System Analysis

The concept of cascaded system analysis for High dynamic Range (HDR) receiver implies not only an ability to detect the desired signal with low distortion but 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. Cascaded system performance of 325-Band Front End was done using XLS sheet calculation and compared with results obtained in the lab tests, thereby proving the validity of the calculation method. (*please note*: In order to validate the theoretical procedure, the lab experiment was conducted, considering the initial loss before the LNA (0.5 dB) and excluding 100m cable loss)

Some of the parameters that were analyzed are Gain, Noise figure, Gain compression (also known as 1 dB compression point, P_{1dB}), Third order intermodulation products (known as third order intercept point, OIP3), Compression Dynamic Range (CDR) and Spurious Free Dynamic Range (SFDR). All these parameters help us to understand the Dynamic performance of the system.

3.1 Gain

Gain is the measure of the ability of the device to increase the power or amplitude of the signal from input to output.

3.2 Noise Figure

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. In effect, it is the amount of reduction in signal-to-noise ratio.

3.3 1 dB Compression Point

The 1-dB compression point is the measure of receiver performance that indicates the input level at which the receiver begins to deviate radically from linear amplitude response. In a linear device, for each dB of input level increase, there is a corresponding db increase in the output level. In case of the input overload, the output does not continue to increase with each input increase, but instead the output tends to limit. The input level at which the output deviates from linear response by 1 db is known as 1-dB compression point. The following figure shows the graphical measurement of 1-dB compression point.

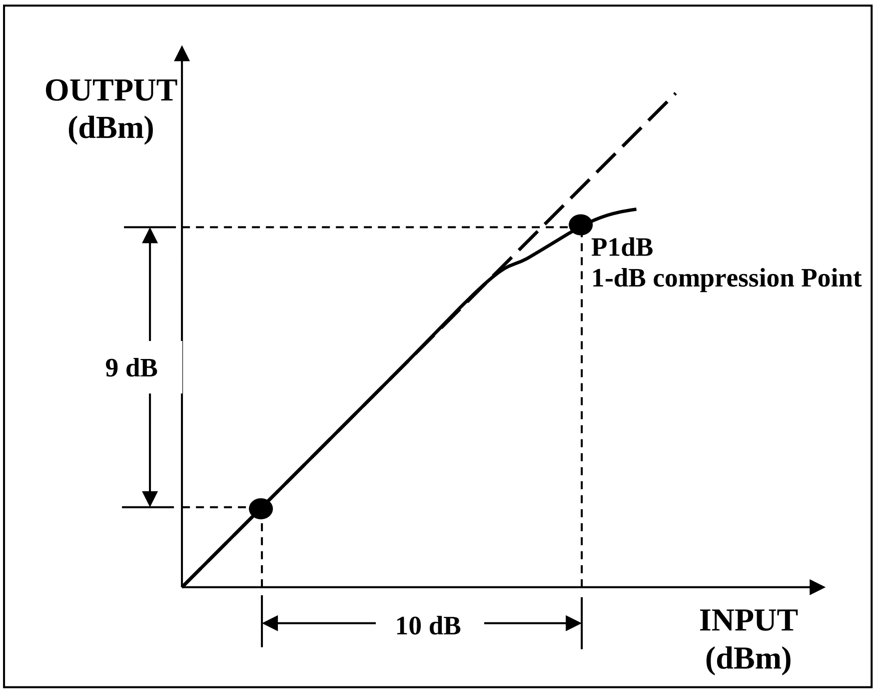

Figure-3 1-dB Compression Point

3.4 Third Order Intercept Point (TOI)

The device is fed with two sine tones with a small frequency difference. The n^{th}-order intermodulation products then appear at n-times the frequency spacing of the input tones. The presence of two or more tones at the input of a non-linear device generates inter modulation products, these products are sum and difference of multiples of fundamental tones i.e. if f_1 and f_2 which are slightly spaced fundamental frequencies then 3^{rd} order products which are $2*f_2 - f_1$ or $2*f_1 - f_2$. The typical spectrum analyzer response for calculating TOI (OIP3) is shown in figure-4.

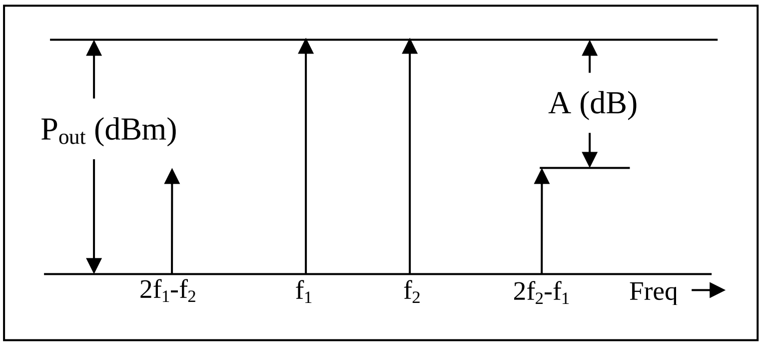

Figure-4 Spectrum Plot for OIP3

From figure-4, OIP3 is given by

$$\boxed{\mathrm{OIP3} = \mathrm{P_{out}} + \left(\frac{\mathrm{A}}{2}\right) \quad \text{dBm}}$$

Where ……… P_{out} => output signal power

A => The difference between output signal level (P_{out}) and the IMD level in dB.

3.5 Compression Dynamic Range (CDR)

The Compression Dynamic Range of the receiver defines the range of signal levels a receiver can process linearly. It’s a linear range over which a receiver can detect minimum level (Sensitivity) to the saturation level (1-dB compression point) of the input signal over the bandwidth. Using receiver noise floor as MDS, the compression dynamic range (CDR) can be expressed as

$$\boxed{\mathrm{CDR} = (\mathrm{IP_{1dB}} - \mathrm{MDS} - \mathrm{NF} - 10 * \log\mathrm{B}) \quad \text{dB}}$$

Where ……… IP_{1dB} => input power @ 1-dB compression point.

NF => Noise figure in dB

B => Bandwidth of receiver in Hz

MDS => Minimum Detectable Signal (dBm)

CDR => Compression Dynamic range in dB

This dynamic range definition has an advantage of being relatively easy to measure, but it assumes that the receiver has only single signal at its input. For specifying the performance of receiver in presence of interfering signals other definitions of receiver’s dynamic range should also be considered.

3.6 Spurious Free Dynamic Range (SFDR)

SFDR of the system is the range between the smallest signal that can be detected in a system (i.e. a signal just above the noise level of the system), and the largest signal that can be introduced into a system without generating any detectable distortions over the bandwidth. The graphical representation of SFDR is shown in figure.5.

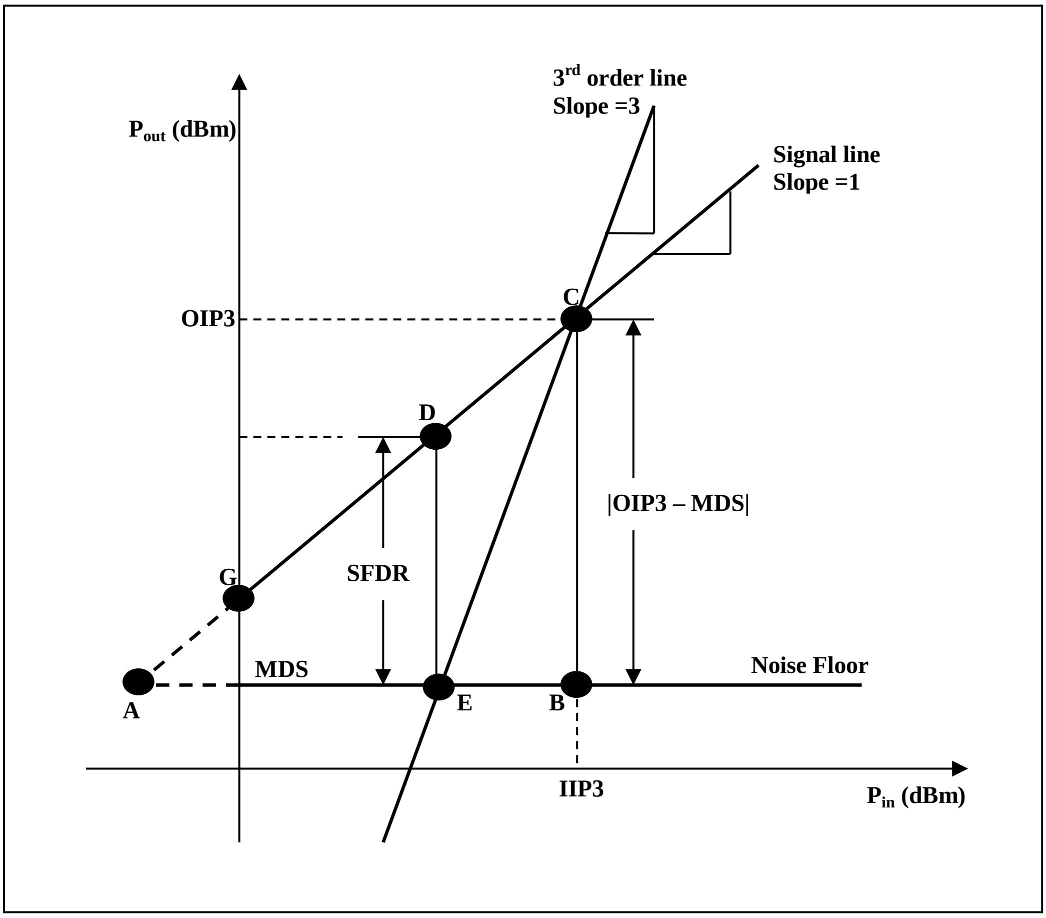

Figure-5 Graphical Representation of SFDR

Using the geometric relations shown in the figure-5, SFDR in terms of output intercept point OIP3 is

$$\mathrm{SFDR} = \left(\frac{2}{3}\right) * (\mathrm{OIP3} - \mathrm{MDS}) \quad \text{dB}$$

$$= \left(\frac{2}{3}\right) * (OIP3 + 174 - NF - 10 * \log B - G)$$

3.7 Verification of Cascaded System Analysis using Spreadsheet (XLS) calculations

While doing cascaded system analysis in XLS sheet, we need to take individual block details like gain (G in dB), noise figure (NF in dB), P1dB (in dBm) and OIP3 (in dBm). Following are the formulae used to calculate cascaded performance. Let the system be represented by the cascaded block diagram as shown in Figure-6, with all the required information.

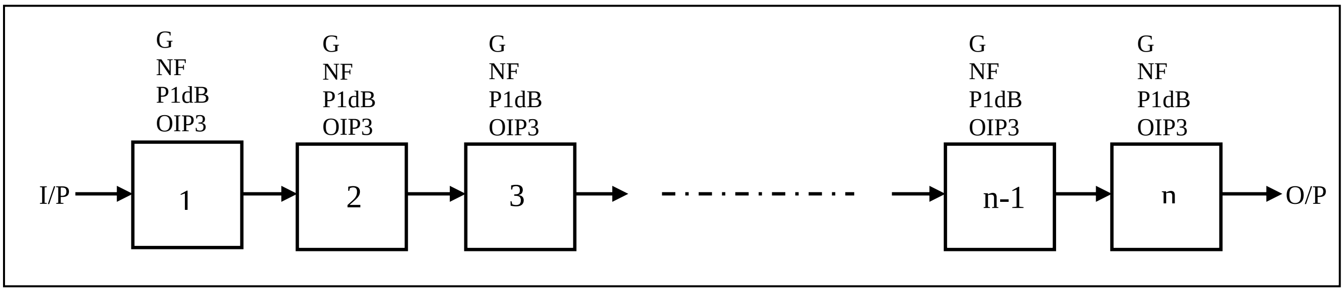

Figure-6 Cascaded System Block diagram

Basic relationship between linear and dB scale are as follows

Linear scale	**dB scale**
$g = 10^{\frac{G}{10}}$	$G = 10\log(g)$
$f = 10^{\frac{NF}{10}}$	$NF = 10 * \log(f)$
$p1dB = 10^{\frac{P1dB}{10}}$	$P1dB = 10 * \log(p1dB)$
$oip3 = 10^{\frac{OIP3}{10}}$	$OIP3 = 10 * \log(oip3)$

Formulae for cascaded system analysis

a. Gain

$$\text{Overall gain} = g_1 * g_2 * g_3 * \cdots\cdots\cdots\cdots\cdots\cdots * g_{(n-1)} * g_n$$

Or

$$\text{Overall gain (dB)} = G_1 + G_2 + G_3 + \cdots\cdots\cdots\cdots\cdots + G_{(n-1)} + G_n$$

b. Noise Figure

$$\text{Noise Factor(f)} = f_1 + \frac{f_2 - 1}{g_1} + \frac{f_3 - 1}{g_1 * g_2} + \cdots\cdots\cdots\cdots\cdots + \frac{f_n - 1}{g_1 * g_2 * \cdots\cdots * g_{(n-1)}}$$

And

$$\text{Noise Figure (NF) in dB} = 10 * \log(f)$$

c. P1dB @ output

$$\frac{1}{p1dB} = \frac{1}{p1dB_n} + \frac{1}{g_n * p1dB_{n-1}} + \cdots\cdots\cdots + \frac{1}{g_n * g_{n-1} * \cdots\cdots * g_2 * p1dB_1}$$

And

$$\text{P1dB (dBm)} = 10 * \log(p1dB)$$

d. OIP3 @ output

$$\frac{1}{oip3} = \frac{1}{oip3_n} + \frac{1}{g_n * oip3_{n-1}} + \cdots\cdots\cdots + \frac{1}{g_n * g_{n-1} * \cdots\cdots * g_2 * oip3_1}$$

And

$$\text{OIP3 (dBm)} = 10 * \log(oip3)$$

Using the above formulae for cascaded system analysis, first the methodology is verified using lab test and results obtained theoretically on existing as well as upgraded 325 MHz system

Resolution Bandwidth	300 KHz	
	Lab Test	XLS Sheet
Minimum Input power(dBm)	-118	-116
Output power(dBm)	-57	-57.4
Gain(dB)	61	58.6
Noise Figure(dB)	1.0	1.3
P1dB(dBm)	3.8	5.62
OIP3(dBm)	15.7	19.8
CDR(dB)	59	63
SFDR(dB)	47.3	51.4
Head Room(dB)	62	64

Table.3 Validation for existing 325 MHz system

Resolution Bandwidth	300 KHz	
	Lab Test	XLS Sheet
Minimum Input power(dBm)	-118	-116.5
Output power(dBm)	-54	-53.8
Gain(dB)	64	62.7
Noise Figure(dB)	0.76	1.0
P1dB(dBm)	19	17.35
OIP3(dBm)	37	39.3
CDR(dB)	71.5	70.9
SFDR(dB)	59.6	61.9
Head Room(dB)	74	72

Table.4 Validation for Upgraded 325 MHz system

Note: For these calculations the signal generator to FEB i/p cable loss of 0.5 dB before the LNA was considered (done in the lab), which contributes to higher noise figure. Also the 100m cable between CB output to ABR i/p contributing loss of 7 dB was not accounted for (as this was done in the lab). The spectrum analyzer setting for this test were RBW of 300kHz, VBW of 3kHz.

From the above tables, we see that the lab test and XLS calculation are in close agreement. Thus verifying the XLS calculation. So now this method can be used for signal flow for other modified/upgraded system.

3.8 Cascaded System Analysis using XLS calculation

The cascaded system analysis of existing and upgraded 325MHz-Band Front End system using XLS sheet was carried out. The results are tabulated in table-5. These calculations take into account 7 dB RF cable loss of nearly 100m cable.

Parameters	100 MHz Bandwidth (CW signal)		200 MHz Bandwidth (CW signal)		400 MHz Bandwidth (CW Signal)	
	Existing	Upgraded	Existing	Upgraded	Existing	Upgraded
Minimum Input power(dBm)	-91.30	-91.8	-88.3	-88.8	-85.3	-85.7
Minimum-Output power(dBm)	-39	-35.3	-36	-32.3	-33	-29.2
Gain(dB)	52.3	56.5	52.3	56.5	52.3	56.5
Noise Figure(dB)	0.98	0.74	0.98	0.74	0.98	0.74
Input P1dB(dBm)	-52.2	-44.62	-52.2	-44.62	-52.2	-44.62
O/P P1dB(dBm)	-0.9	10.85	-0.9	10.85	-0.9	10.85
Input OIP3 (dBm)	-39.1	-23.63	-39.1	-23.63	-39.1	-23.63
OIP3(dBm)	13.24	32.84	13.24	32.84	13.24	32.84
CDR(dB)	37.83	45.65	34.82	42.64	31.81	39.63
SFDR(dB)	34.64	45.1	32.64	43.1	30.63	41.1
Head Room(dB)	39.1	47.2	36.1	44.2	33.1	41.1

Table-5 Cascaded system analysis of existing and upgraded 325 MHz FE System

Note: Summary of Results

1. The upgraded system has gain of 56.5 which is around 4 dB more than existing system.
2. The upgraded system has better noise figure as compared to existing one.
3. P1dB of the upgraded system is 10.85 dBm which is around 11 dB more than the existing system.
4. Similarly OIP3 of the upgraded system has become 33 dBm which is around 20 dB more than the existing system.
5. This helps in increasing the overall dynamic range of the system as confirmed from the table.

4.0 Summary

The results calculated using MS-Excel (XLS) sheet were first verified with the lab tests. Both of them are in close agreement with each other. Thereby proving the correctness of cascaded system analysis methodology. The results clearly shows an improvement in the overall dynamic range by around 7.0 dB and better noise performance by using better LNA.

5.0 Conclusion

Signal flow analysis is a very powerful method to tune / characterize the dynamic range and operating power levels of the signals. The above method can be further extended for characterizing the complete receiver performance by using calculation/simulation. The existing and upgraded 325 MHz band Front End system was studied for various RF parameters like dynamic range, gain and noise performance for the complete cascaded system.

6.0 References

1. A. Praveen Kumar, Anil N. Raut and Vilas Bhalerao, *Dynamic Range of the L-Band Front End Receiver,* GMRT Internal Technical Report, Sept. 2005.
2. A. Praveen Kumar and Anil Raut, *Improvement of GMRT Receiver for better Dynamic Range,* GMRT Internal Technical Report, Nov. 2003.
3. Arunkumar Heddallikar and S. Sureshkumar, *Signal Flow Analysis of Broad Band Analog Fiber Optic system for GMRT Upgrade,* GMRT Internal Technical Report, Feb. 2012.
4. RF cafe: http://www.rfcafe.com