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Complete signal flow analysis of L-band frontend system

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Objective: Comparing the Dynamic Range of L-Band Front End System with existing *(normal common box)* and modified *(upgraded common box)*.

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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 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 modified L-Band Front End system. The importance of signal flow analysis is to understand receiver dynamic range, operating signal levels etc for ensuring better receiver performance. In the following report the modified L-band Front End system is compared with the existing one in terms of its dynamic range, gain and noise performance.

2.0 L-Band Front End System

The following figure shows the block diagram of existing L-Band Front End system (Front end + common box).

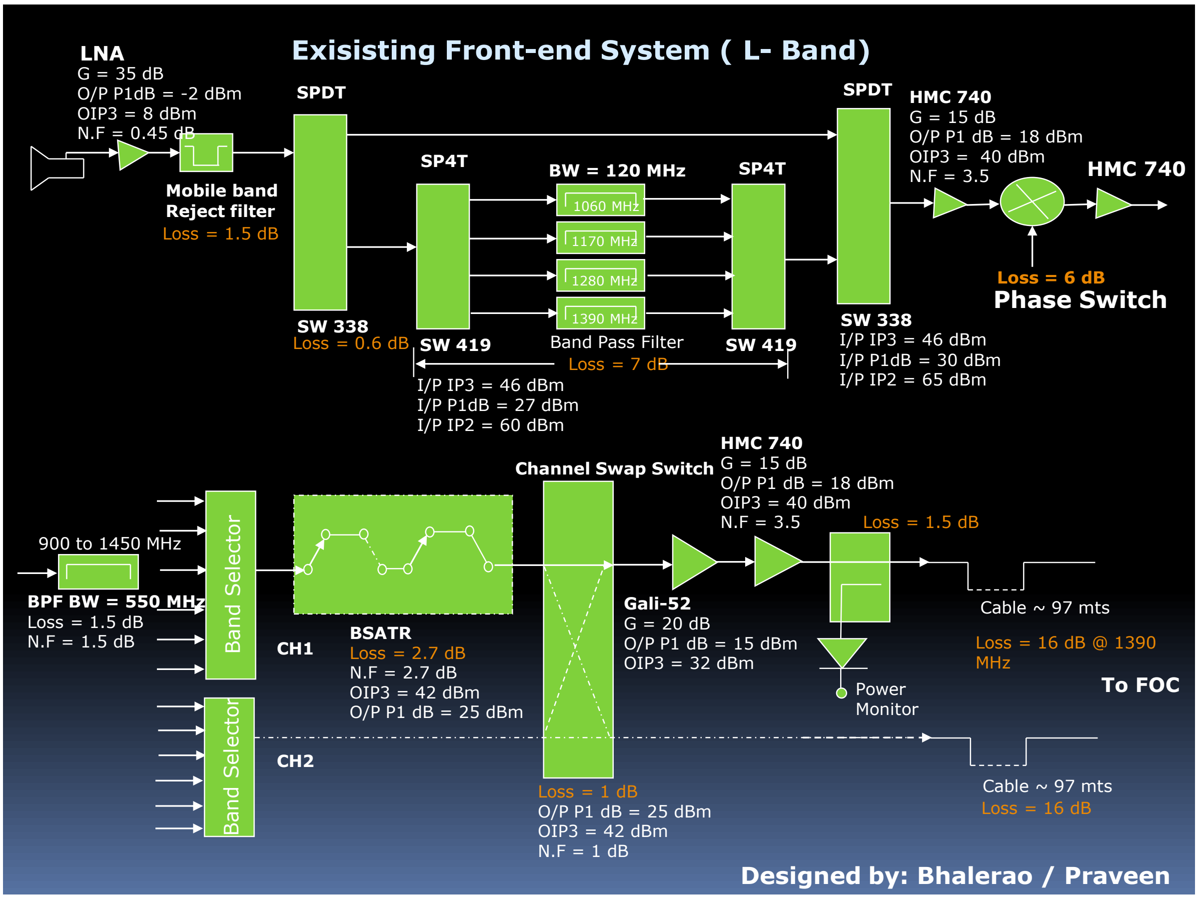

Figure.1 Existing Front End System (L-Band)

Front-end:

The L-Band front-end consists of a corrugated horn feed to collect the radiations reflected from the parabolic dish with a quad ridge orthomode transducer (OMT) in which the waveguide mode of the signal is converted into coaxial mode. The signals are then amplified by a low noise amplifier (LNA) designed using three stages of FUJITSU HEMT's (FHX35LG). The gain of the LNA is 34 ± 2 dB over 1000 to 1450 MHz and noise temperature of 28^{o}k ± 5^{o}k over the same frequency range. The LNA is followed by mobile band reject filter, to filter out the mobile band frequencies. 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 filter bank, any 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 band pass filter is around 7 dB. The next stage in system is the post amplifier (HMC 740) with the gain of 15 dB, followed by a phase switch with insertion loss of 6 dB. This is again followed by an identical post amplifier (HMC 740). The signal is then passed through a broadband filter having bandwidth of 550 MHz centered at frequency of 1250 MHz.

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 post amplifier giving a combine gain of 35 dB (first stage: Gali-52, second stage: HMC 740). This is followed by the directional coupler used for power monitoring purpose. From there the signal is brought down to antenna base receiver (ABR) by two cables (one for each channel) each approx. of 97m long, and giving a loss of 16 dB.

The following block diagram shows the modification done in the common box in order to increase the dynamic range of the system. In this, the broad

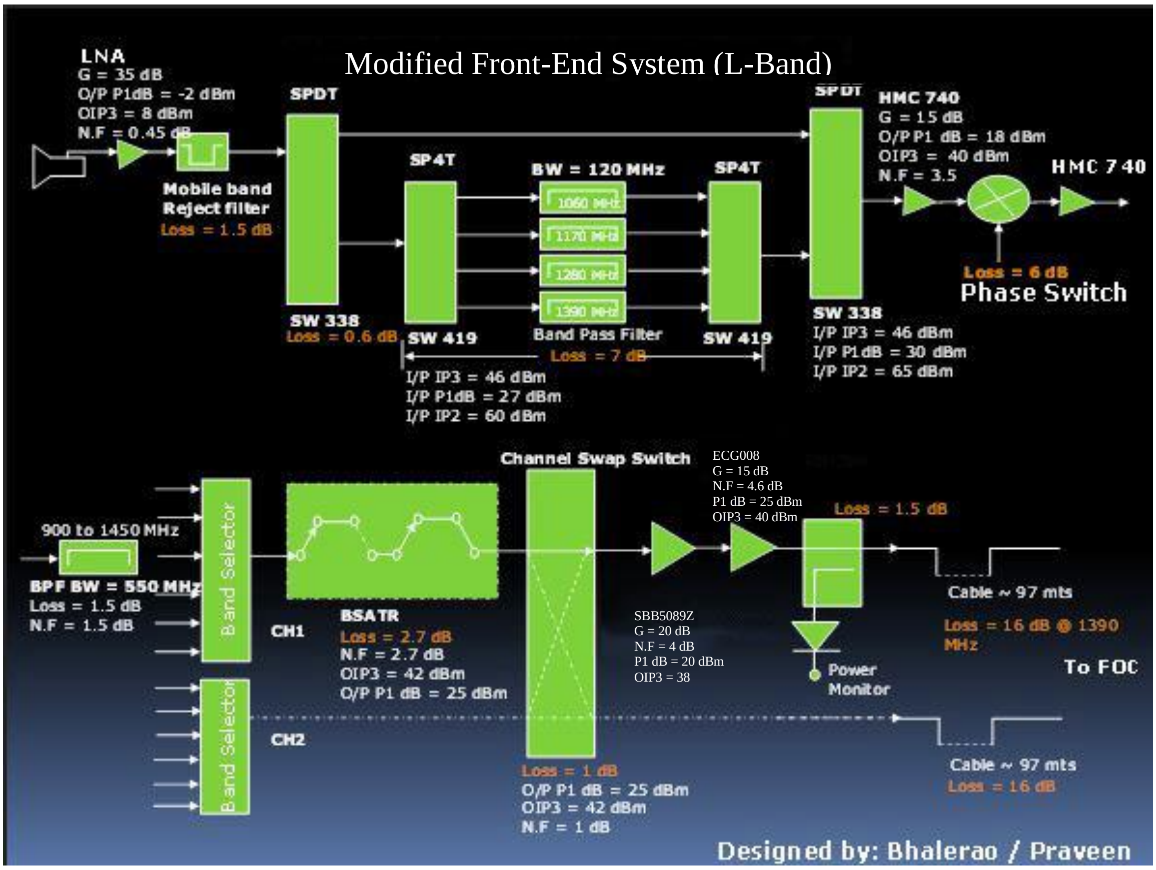

Figure.2 Modified Front End System (L-Band)

band amplifier is replaced with the two stage amplifier. The first stage is Siranza SBB5089Z with a gain of 20 dB, P1dB of 20 dBm and OIP3 of 38 dBm. The Second stage is Triquint make ECG008G with a gain of 15 dB, P1 dB of 25 dBm and OIP3 of 40 dBm.

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 L-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 (1.1 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.

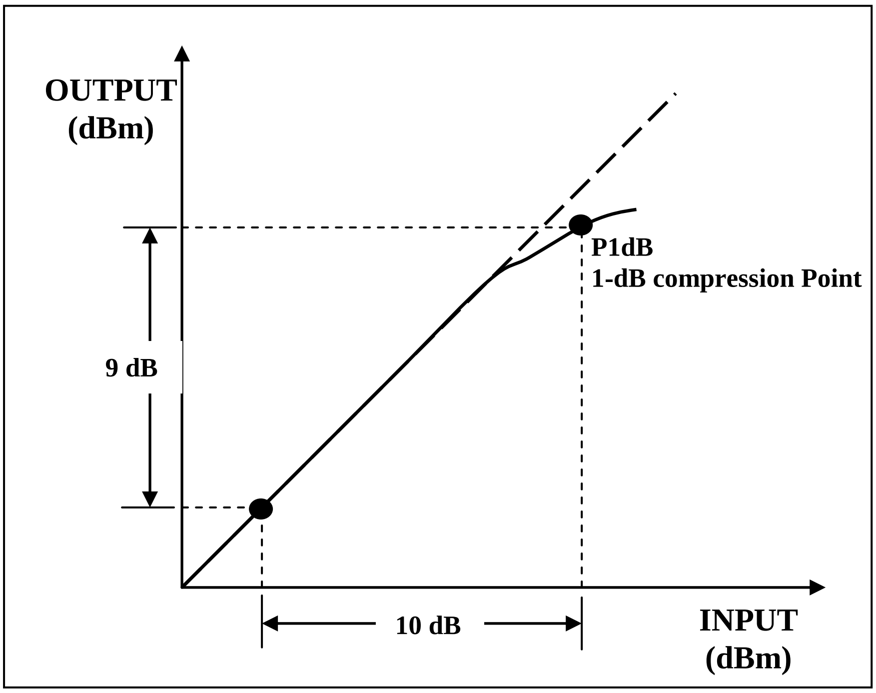

Figure.3 1-dB Compression Point

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.

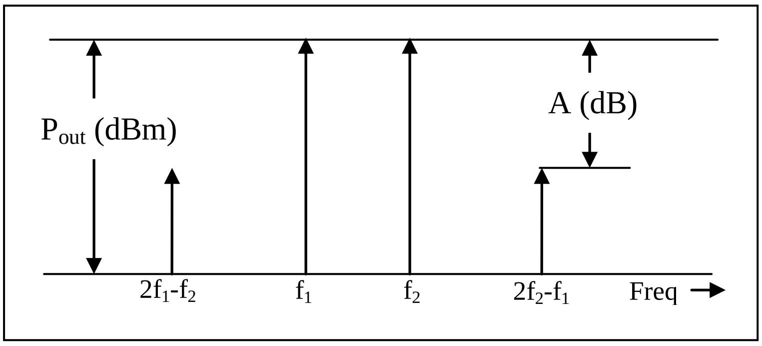

Figure.4 Spectrum Plot for OIP3

From figure.4, OIP3 is given by

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

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

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

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.

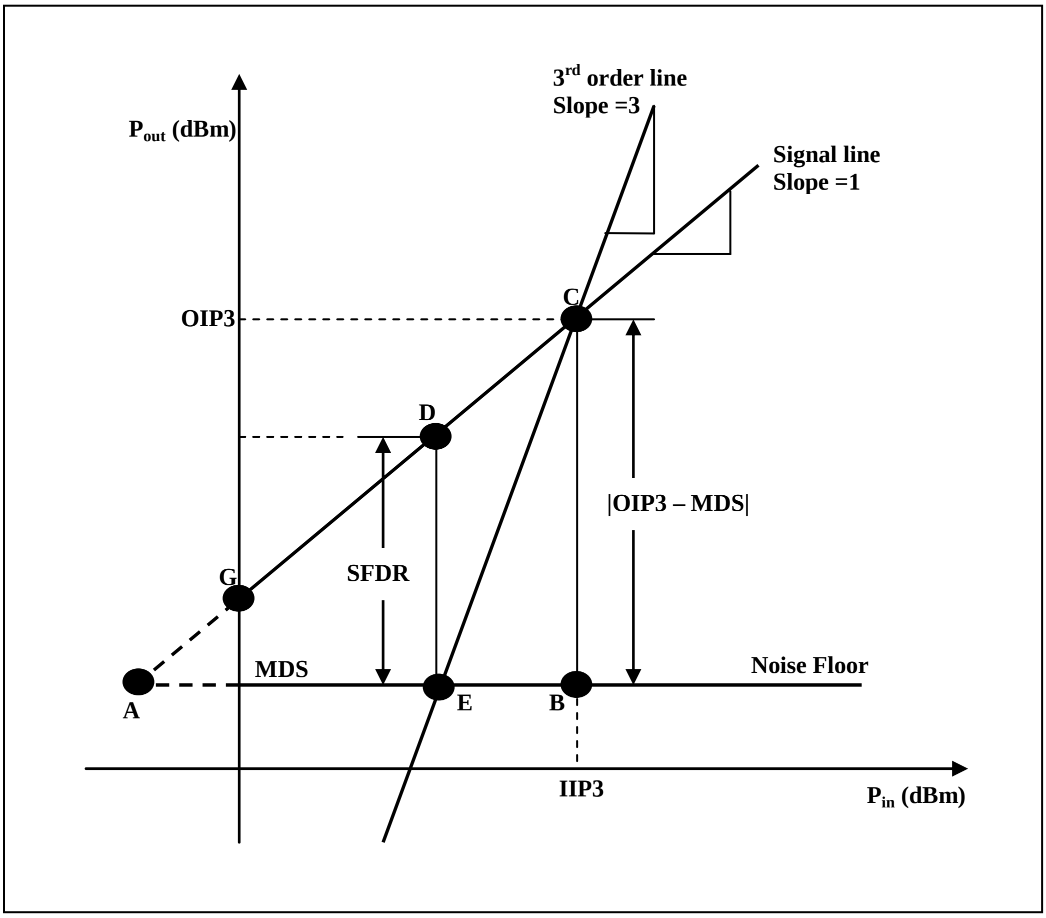

Figure.5 Graphical Representation of SFDR

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

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

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

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.

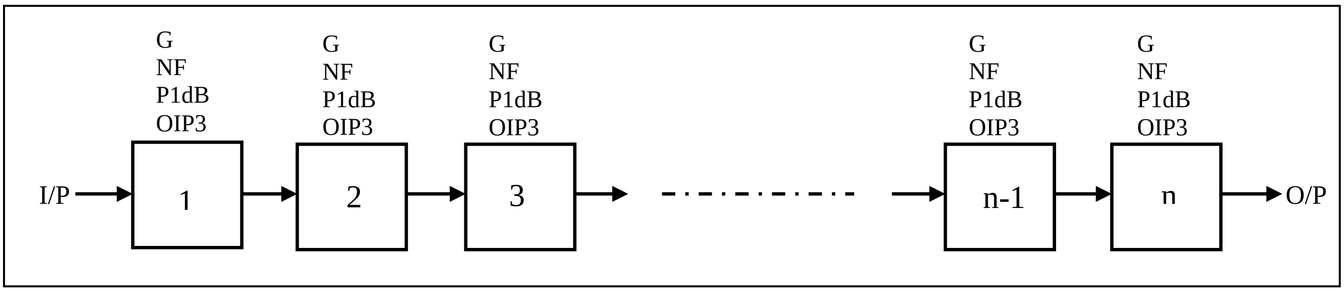

Figure.6 Cascaded System Block diagram

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

$$\frac{1}{p1dB} = \frac{1}{p1dB_1} + \frac{1}{g_1 * p1dB_2} + \cdots\cdots\cdots\cdots + \frac{1}{g_1 * g_2 * \cdots\cdots * g_{n-1} * p1dB_n}$$

And

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

d. OIP3 @ output

$$\frac{1}{oip3} = \frac{1}{oip3_1} + \frac{1}{g_1 * oip3_2} + \cdots\cdots\cdots\cdots + \frac{1}{g_1 * g_2 * \cdots\cdots * g_{n-1} * oip3_n}$$

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 L-Band with old Common Box. The results are tabulated below in table. 1

Resolution Bandwidth	300 KHz	
	Lab Test	XLS Sheet
Minimum Input power(dBm)	-115	-116
Output power(dBm)	-43	-43.09
Gain(dB)	72	72.91
Noise Figure(dB)	1.61	1.61
P1dB(dBm)	16	15.90
OIP3(dBm)	9.03	8.19
CDR(dB)	59.98	59.71
SFDR(dB)	33.62	34.00
Head Room(dB)	60	59.72

Table.1 Comparison between calculated & measured parameters

Note: For these calculations the loss of 1.1 dB before the LNA was considered (done in the lab), which contributes to higher noise figure (1.6 dB). Also the 100m cable loss of 16 dB was not accounted for (as this was done in the lab). Thereby giving higher overall system gain (72 dB).

From the above table, 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 block diagram of Existing and Modified L-Band Front End with all the information fed into the XLS sheet was carried out, the results are tabulated in table. 2. These calculations take into account 16 dB RF cable loss.

Parameters	100 MHz Bandwidth		200 MHz Bandwidth		400 MHz Bandwidth	
	Existing	Modified	Existing	Modified	Existing	Modified
Minimum Input power(dBm)	-92.18	-92.18	-89.17	-89.17	-86.16	-86.16
Output power(dBm)	-34.1	-34.1	-31.09	-31.09	-28.08	-28.08
Gain(dB)	58.08	58.08	58.08	58.08	58.08	58.08
Noise Figure(dB)	0.72	0.72	0.72	0.72	0.72	0.72
P1dB(dBm)	0.21	6.95	0.21	6.95	0.21	6.95
OIP3(dBm)	9.08	9.08	9.08	9.08	9.08	9.08
CDR(dB)	35.31	42.05	32.30	39.05	29.29	36.04
SFDR(dB)	28.79	28.79	26.78	26.78	24.77	24.77
Head Room(dB)	35.31	42.05	32.30	39.05	29.29	36.04

Table.2 Cascaded system analysis of L-Band with Existing & Modified Common Box

Note: Summary of Results

1. Since L-Band electronics is the same in both existing and modified systems, the OIP3 is same even though we have used better amplifiers in Common box. This indicates that OIP3 is limited by the L-Band LNA, (which also confirms from the LNA datasheet).
2. Thus using better amplifiers in common box, only helps in increasing CDR, which is confirmed from datasheet as well as from the results obtained.
3. The actual system consists of 0.22 dB loss before the LNA.

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 show that by replacing post amplifier in common box with high dynamic range amplifier, (with same gain as existing post amplifiers) indeed increases the dynamic range (CDR) of the cascaded system by 7.0 dB, while maintaining the same overall gain of around 60.0 db.

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 modified common box with L-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

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