Improvement of GMRT Receiver for better Dynamic Range

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Improvement of GMRT Receiver for better Dynamic Range

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1.0 Introduction

1.1 General

Giant Meterwave 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 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 150 MHz, 235 MHz and 327 MHz bands have about 40 MHz bandwidth and the 610 MHz band has about 60 MHz bandwidth. The low noise receiving system of GMRT has been designed to receive dual polarization. Lower frequency bands from 150 to 610 MHz have dual circular polarization channels (Right Hand Circular and Left Hand Circular polarization) which has been conveniently named as CH1 and CH2, respectively. The higher frequency L-Band has dual linear polarization channels (Vertical and Horizontal polarization) and they have been named CH1 and CH2 respectively. The receiver system has flexibility to be configured for either dual polarization observation at a single frequency band or single polarisation observation 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 14 dB, 33 dB or 44 dB can be used. The front end has RF termination facility also. Any band of the receiver can be switched OFF, whenever not in use, with the RF on/off facility provided in the front end. The receiver can be calibrated by injecting one of the four levels of calibrated noise named Low cal, Medium cal, High cal and 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 functions is available at RF section of the receiver.

The first synthesized local oscillator converts the RF band to an IF band centered at 70 MHz. The synthesized local oscillator has a frequency range of 100 MHz to 1795 MHz. 100 MHz to 600 MHz is covered by synthesizer-1 and 605 MHz to 1795 MHz is covered by synthesizer-2. The local oscillator frequencies from 100 MHz to 354 MHz can be set with a step size of 1 MHz and the frequency range from 355 MHz to 1795 MHz can be set with a step size of 5 MHz. The IF bandwidths of either 5.5 MHz, 16 MHz or a full RF bandwidth of 32 MHz can be selected. The IF at 70 MHz is then translated to a second IF at 130 MHz and 175 MHz for CH1 and CH2 respectively. The maximum bandwidth available at this stage is 32 MHz for each channel. This frequency translation is done so that they can be transported to the Central Electronics Building (CEB) over a single fiber-optic cable. Two sets of 0 to 30 dB programmable attenuators are incorporated in the IF chain in each channel, which can be varried in steps of 2 dB. An automatic level control (ALC) facility is provided at the output stage of IF which can be bypassed whenever required (e.g. For Pulsar Observations).

The IF signals at 130 and 175 MHz along with telemetery and LO round trip phase carriers directly modulate a laser diode operating at 1300 nm wavelength which is coupled to a single mode fiber-optic cable link between the receiving antennas and the CEB. At the CEB, these signals are recovered with a PIN photodiode detector and suitably amplified. The 130 MHz and 175 MHz signals are then separated out and sent for baseband conversion. There is a monitor port available at the fiber-optic receiver front panel at CEB, where all the received signals can be monitored.

The baseband (BB) converter section converts 130 and 175 MHz IF signals to 70 MHz using 3rd LO (200 MHz & 105 MHz respectively). The 70 MHz signals are then converted to baseband consisting of upper and lower sidebands for each polarization channel using a tunable LO which can be set from 50 MHz to 90 MHz in steps of 100 Hz. The BB system bandwidths can be set to any of the bandwidths out of 62.5 KHz, 128 KHz, 256 KHz, 512 KHz, 1 MHz, 2 MHz, 4 MHz, 8 MHz and 16 MHz as per the user's requirement. An ALC is incorporated at the output of BB converter that can be bypassed manually using key switch in the BB rack in receiver room at the CEB.

1.2 Scope

The purpose of this report is to closely look at the present GMRT receiver system and modify the same in order to improve the dynamic range using pin to pin compatible components and by doing minimal changes in the system. With this modifications we can expect an improvement of about 25 dB in Compression Dynamic Range (CDR) and about 15 dB in Spurious Free Dynamic Range (SFDR). This is not meant for major up-grade of the receiver system which is being planned to be executed during the tenth plan. This proposal is aimed at improvements for sustaining the current phase of GMRT with the existing interference scenario. Also, this report does not suggest any improvements in the baseband system since there is a proposal for modifying it. We do not propose any changes in the L-band feed-front end system as the existing dynamic range is not causing any limitation in its performance with limited Radio frequency interferences (RFIs) in this band. Only the system temperature reduction for the L-band is given a consideration in brief.

The tables containing the components incorporated with their specifications for the existing and proposed receiver configuration are included.

The report also contains the simulated results of the dynamic range related parameters at every stage of the receiver chain and compares the receiver performance of existing receiver, modified receiver with new ALC unit proposed by S.J.Pandharpure et al, and proposed high dynamic range receiver, both with and without the incorporation of the new ALC unit.

A comparison of the few possible configurations of the 150 MHz front end and the best approach is highlighted.

The various dynamic range related issues are also covered in the report with a fair amount of details.

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 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 as

$$CDR = P_{1dB} - 10 \log (FKT_0 B)$$

For an ambient temeperature of 290 degree kelvin this expression can be simplified as,

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

Where,

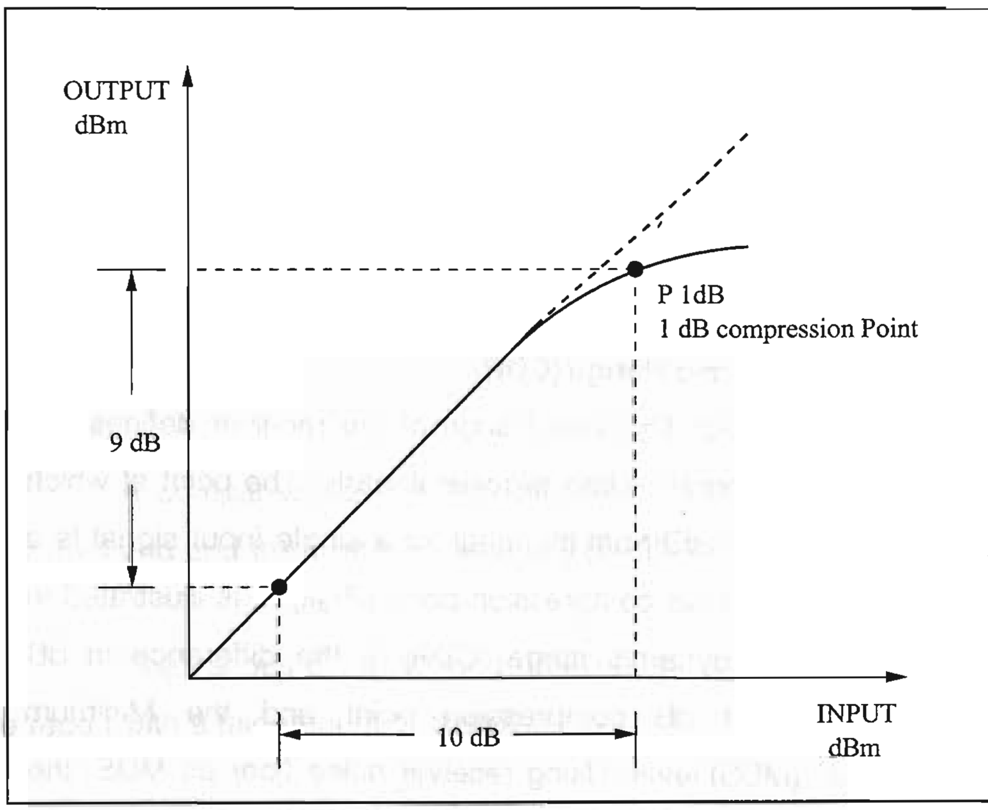


Figure – 1 : 1 dB Compression Point

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 degree Kelvin

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,

$$DDR = P_i + 174 - NF \quad (dB)$$

Where,

P_i - Interfering signal power in dBm

NF - Noise Figure in dB

DDR - De-sensitization Dynamic Range in dB.

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.

Receiver phase noise is a measurement of phase and frequency perturbations added to the input signals by the receiver frequency conversion oscillators. Because of phase noise, the undesired out of band signals mix with the oscillator phase noise and produce in-band noise that degrades receiver sensitivity. This effect is called reciprocal mixing. receiver phase noise performance is the product of both the oscillator phase noise and receiver filtering. Consequently, the phase noise performance is strongly affected by the frequency offset from the tuned frequency. A typical receivers phase noise might be specified at offsets of 100 Hz, 1 KHz, 10 KHz, 100 KHz, 1 MHz and 10 MHz.

Because of the above frequency effects, it is necessary to specify the DDR at several different offset frequencies. More attention should be given to obtaining a good DDR at large frequency offsets.

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 (2f1 - f2) and (2f2 - f1) where f1 and f2 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 f1 and f2, in producing new signals at $(2f_1 \pm f_2)$ and $(2f_2 \pm f1)$. 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). 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 IIP_n can be determined by

$$IIP_n = (nP_f - P_{IMn}) / (n-1) \ \text{dBm}$$

<u>OR</u>

$$IIP_n = [(P_{out} - P_{IMn}) / (n-1)] + P_{IN}$$

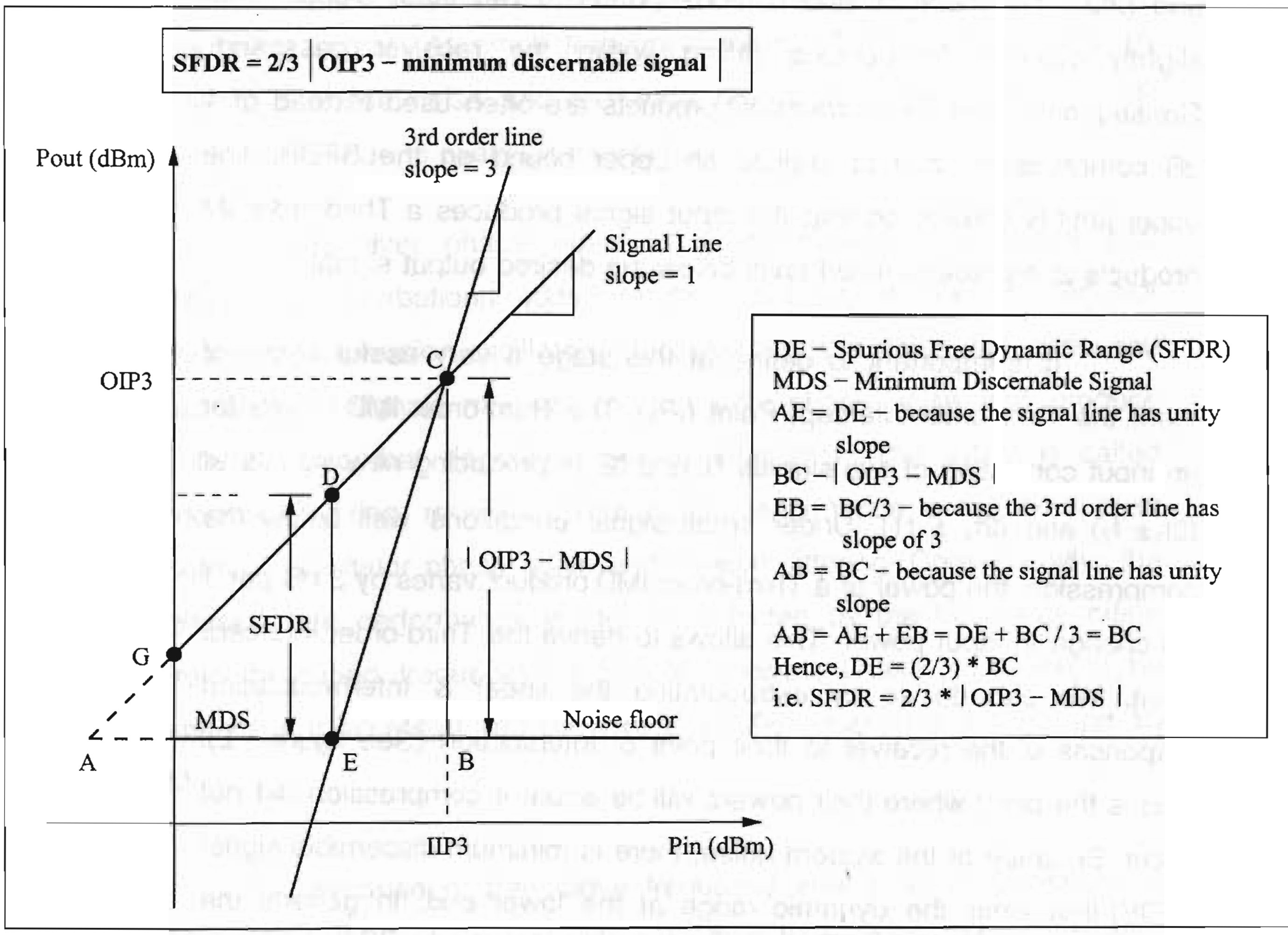


Figure – 2 : Graphical representation of Spurious Free Dynamic Range (SFDR)

Where,

n - Order of Intermodulation product

P_f - Input power of fundamental tones in dBm

IIP_n - Input n^{th} order intercept point in dBm

P_{IMn} - Power of the n^{th} order IM product in dBm

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

$$IIP_3 = (3P_f - P_{IM3}) / 2 \quad \text{dBm}$$

Using various geometric relations we can also derive a useful relationship for OIP_3 as,

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

Where,

P_{out} - Output signal power level in dBm.

A - The difference between output signal level (P_{out}) and the IMD (P_{IM3}) level in dB.

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

Also,

$$IM_3 = 3\,P_{out} - 2\,OIP_3 \text{ (dBm)}$$

Since, $OIP_3 = IIP_3 + G$

$$IM_3 = 3\,P_{in} - 2\,IIP_3 + G \quad \text{(dB)}$$

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

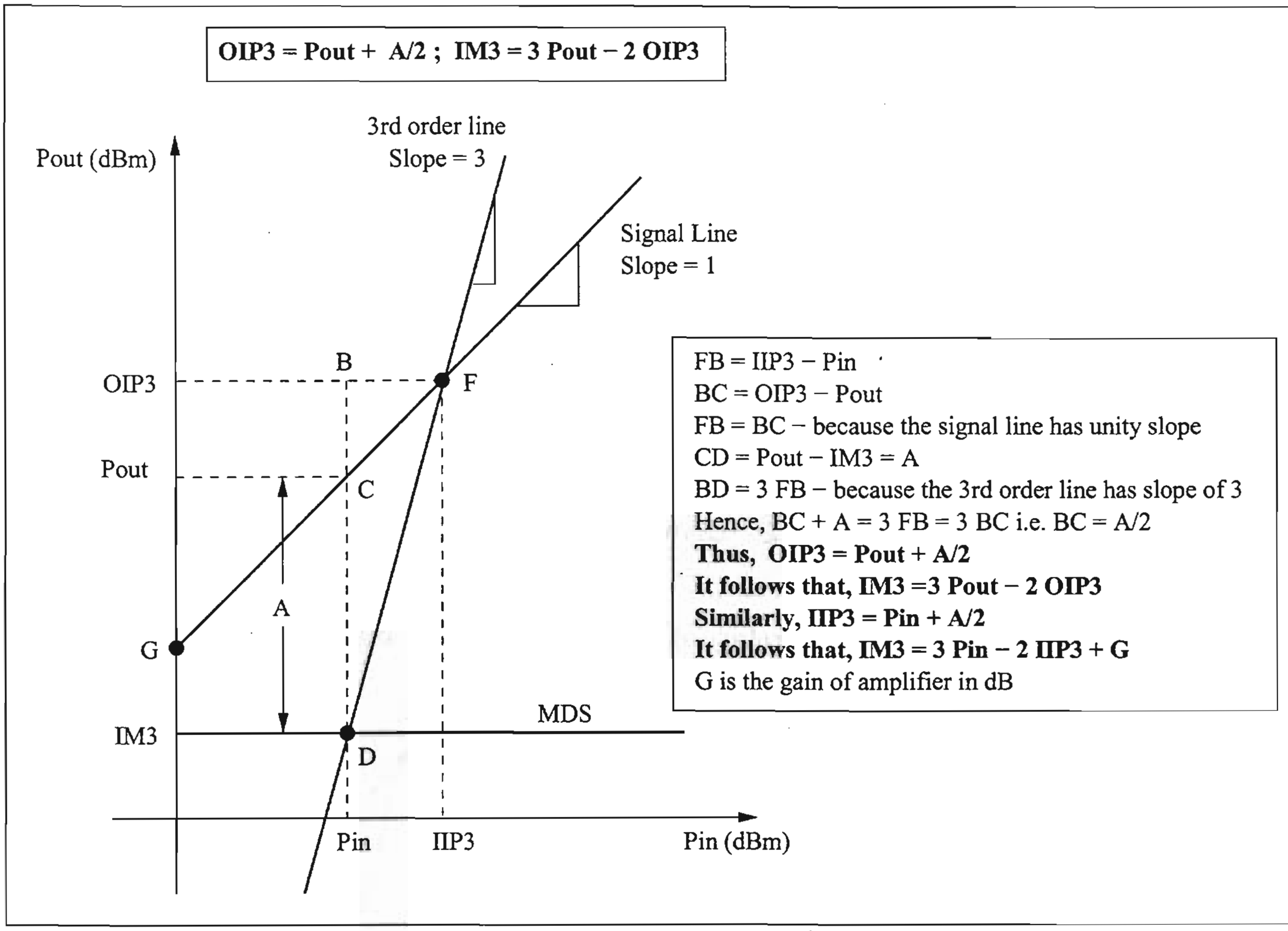


Figure – 3a : Graphical representation of the relationship between the Fundamental signal and the Third order intermodulation products (OIP3 & IIP3)

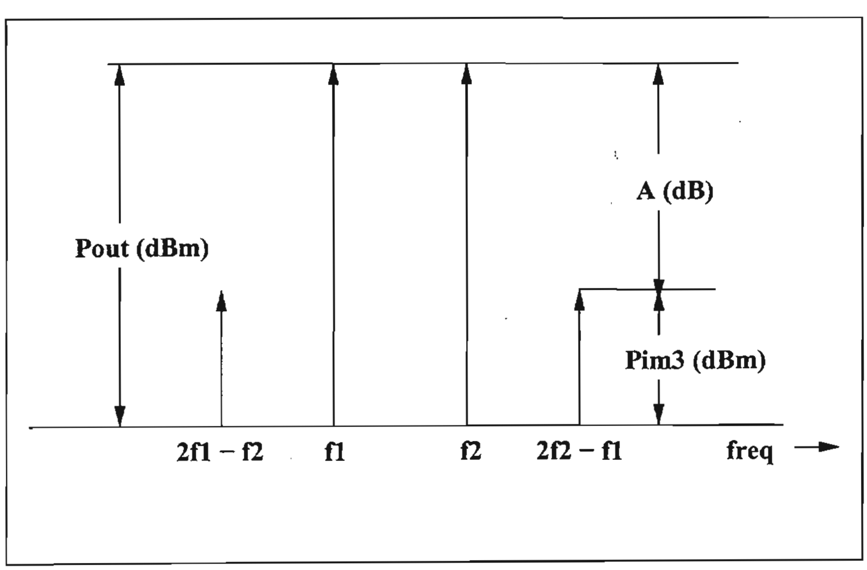


Figure – 3b : Typical Spectrum Analyzer Display used to calculate the OIP3

P_{IN} axis is 0 dBm, then the signal line will intersect the P_{OUT} axis numerically equal tothe gain G. So, any P_{OUT} in the signal line is larger than the signal line by 'G'. Therefore since the IP_3 point falls on the signal line, $OIP_3 = IIP_3 + G$.

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,

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

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. Theoritically, the SFDR would be zero at the third 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. Unfortunately the specification overlooks several important factors as described below, that influence the dynamic range.

1. It Attempts to model interference by just using two interfering signals but real signal environment is usually populated by multitude of signals.
2. It does not reveal the effect of reciprocal mixing or compression like the DDR test.
3. It does not effectively test the effects of receiver input filtering pre-selection).
4. It considers only the Third-order distortion.

Inspite of these limitations, SFDR is popular as it gives a simple method of testing and comparing the receiver dynamic range performance.

2.5 Cascading devices with known IP3 and Noise Figure

The noise performance of the receiver will never be better than the input stage noise temperature and the distortion performance will never be better than the final stage output IP_3. When designing a receiver chain, it can be difficult to know where to put effort into improving IP_3 and noise temperature. Although it is obvious that the noise temperature of first stage is crucial, we need to estimate how much we can allow the noise temperatures of subsequent stages to deteriorate, without greatly degrading the overall noise performance of the receiver. By the same token, although we realize that the distortion perfomance of the final stage is crucial in setting the overall distortion performance of the receiver, we need to know what distortion performance is required of the earlier stages in the chain. A cascade connection of amplifiers is shown in figure - 4. The overall noise temperature (T) of such a cascaded amplifiers is given by,

$$T = T_1 + T_2 / G_1 + T_3 / G_1 G_2 + T_4 / G_1 G_2 G_3 + \text{------}$$

Alternatively the overall noise figure of a cascade connection of amplifier is given by,

$$F = F_1 + (F_2 - 1) / G_1 + (F_3 - 1) / G_1 G_2 + (F_4 - 1) / G_1 G_2 G_3 + \text{----}$$

The worst case output Third-order intercept point (OIP3) of such a cascaded amplifiers is given by,

$$1 / OIP3 = 1 / OIP3_n + 1 / OIP3_{n-1} G_n + 1 / OIP3_{n-2} G_n G_{n-1} + \text{---} + 1 / OIP3_1 (G_n G_{n-1} \text{---} G_2)$$

All the "OIP3" values are in watts and all the gains "G" are power gain factors.

We now have a fair picture of all the issues involved in the estimation and measurement of dynamic range of the receiver. The important parameters to be estimated and measured are the noise figure, P_{1dB} and IP_3. We are now at a stage where we can look at the above parameters in the existing receiver chain and propose modifications with devices having better parameters wherever required.

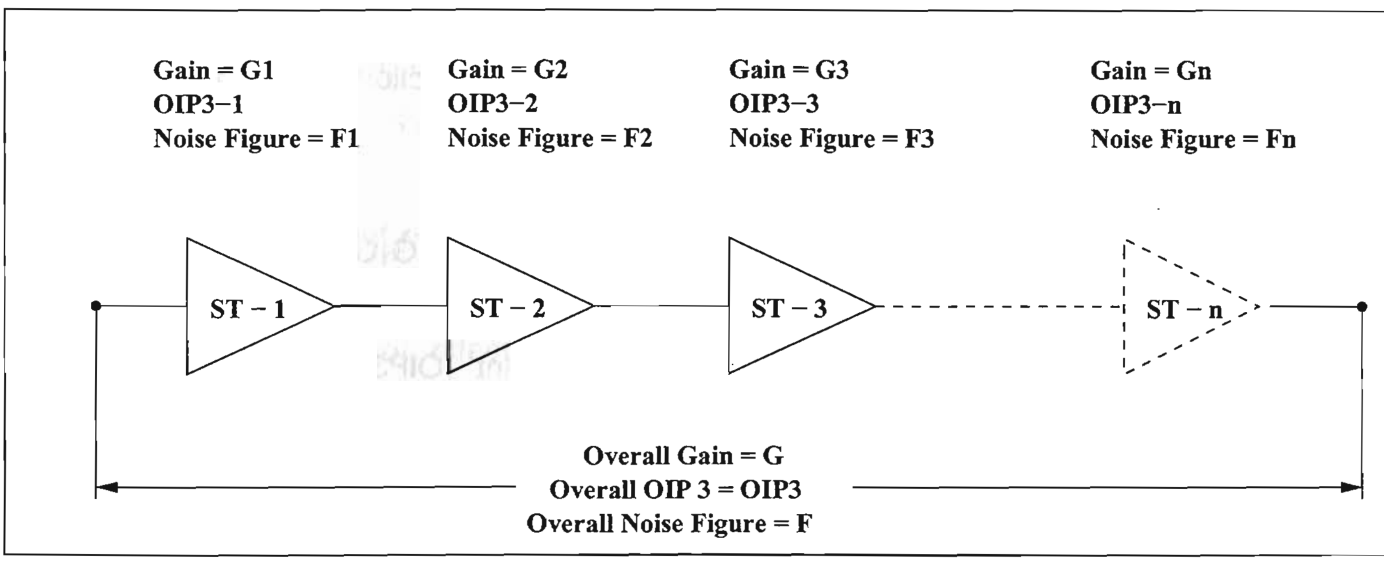


Figure – 4 : Cascade Connection of Amplifiers

3.0 Brief description of the proposed modifications in GMRT Receiver

In this section we will briefly go through the existing GMRT receiver system, estimate the dynamic range, highlight the devices which limit the dynamic range and propose alternative devices which are compatible in package for changing in the existing receiver without PCB modifications. This will improve the dynamic range and comparison between the existing and the proposed receiver chain is being tabulated.

3.1 Multi-frequency RF Front-end

A schematic of the front-ends are shown in figure - 5a and 5b. In this system, all the low noise amplifiers will be retained as such since they are not restricting the dynamic range. There is a scope for replacing the existing band-pass filters (BPF) with higher band width BPFs matching with the feed band width or switchable filter banks. Already, there is a provision for incorporating four filter banks which can be switched in each channel. The post amplifier with phase switch, at present use one stage of Mini circuits MAR-3 amplifier for 150 MHz to 327 MHz bands and MAR-6 amplifier for 610 MHz band. For L- band system, three stages of MAR-3 amplifiers are used as post amplifier. We propose to change MAR-3 devices in 150 MHz to 327 MHZ bands with single stage of Mini Circuits MAV - 11 amplifier. A MAR-6 device in 610 MHz band can be changed with a cascade consisting of MAV-11, phase switch and another MAV-11 stage. MAR-3 has P_{1dB} of +10 dBm and OIP_3 of +23 dBm. It has a frequency response from DC to 2 GHz and gain of 12 dB. *MAV-11 is a high dynamic range MMIC amplifier with similar gain of 12 dB. It has a high P_{1dB} of the order of +17.5 dBm and OIP_3 of +30 dBm. At the same time it has a low noise figure of 3.6 dB. It is a very useful device for a frequency range of 50 to 1000 MHz. We propose to use this device as a replacement for most of the devices used within this frequency range.*

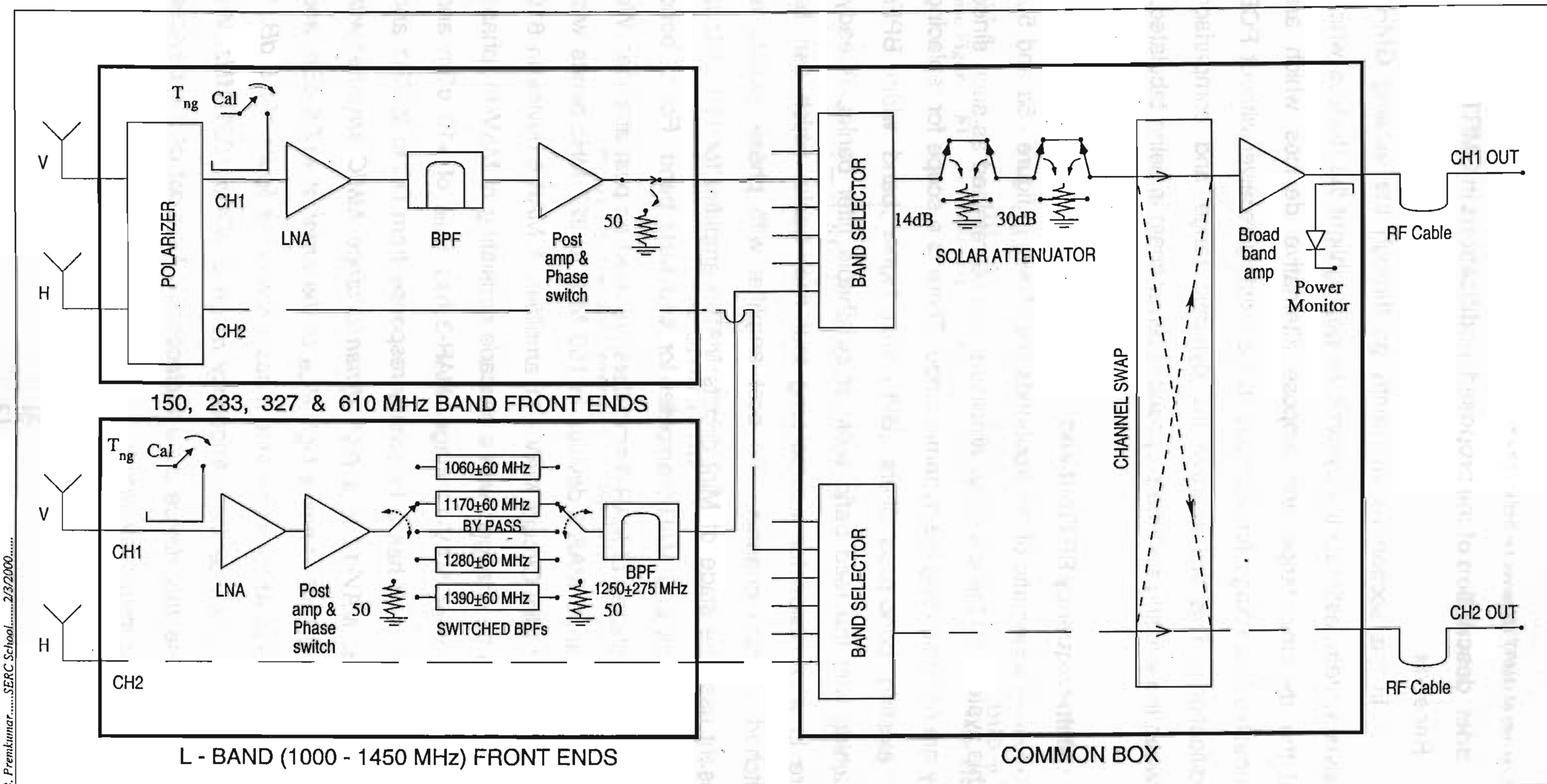
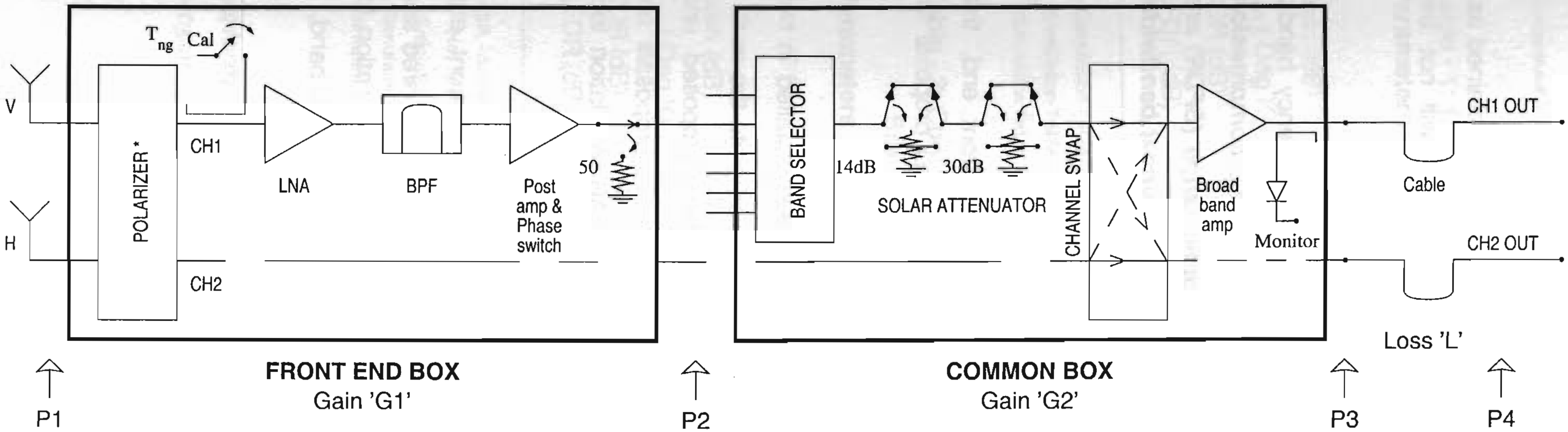

V
H
Tng Cal
POLARIZER
CH1
CH2
LNA
BPF
Post amp & Phase switch
50
150, 233, 327 & 610 MHz BAND FRONT ENDS
1060±60 MHz
1170±60 MHz
BY PASS
1280±60 MHz
1390±60 MHz
SWITCHED BPFs
BPF 1250±275 MHz
L - BAND (1000 - 1450 MHz) FRONT ENDS
BAND SELECTOR
14dB
30dB
SOLAR ATTENUATOR
CHANNEL SWAP
Broad band amp
Power Monitor
RF Cable
CH1 OUT
CH2 OUT
COMMON BOX

FIG. 5a



FREQ. BAND (MHz)	T_{sys} (K)	P1 (dBm)	G1 (dB)	P2 (dBm)	G2 (dB)	P3 (dBm)	L (dB)	P4 (dBm)
150	580	- 96	34	- 62	28	- 34	8	- 42
233	234	- 100	37	- 63	27	- 36	9	- 45
327	108	- 103	38	- 65	27	- 38	11	- 49
610	101	- 104	35	- 69	26	- 43	15	- 58
1060	83	- 104	50	- 54	25	- 29	22	- 51
1170	77	- 105	49	- 56	24	- 32	23	- 55
1280	74	- 105	49	- 56	23	- 33	24	- 57
1390	72	- 105	47	- 58	23	- 35	26	- 61

Note : Power levels are over 32 MHz BW; with 0dB solar attenuator - * The L-Band (1000 - 1400 MHz) FE does not have the polarizer

FIG. 5b

All the mixers used as phase switching units will be retained as such. Also, the RF on/off switch SW-239 of M/A-COM will not be changed.

The following sections deal with the various frequency bands along with simulated results and comparison tables. ***The compression dynamic range (CDR) and spurious free dynamic range (SFDR) are calculated for the bandwidth of 32 MHz which is the largest bandwidth available at present in GMRT.***

3.1.1 150 MHz System

Table - 1 illustrates the existing 150 MHz front end, the recently modified front end by Mr. S. Sureshkumar and our proposal for modification to a high dynamic range front end.

The recently implemented front end has been installed in two GMRT antennas C12 and C14. Both the proposals incorporate the multi - notch filters and a set of high and low pass filters proposed and designed by Mr. B. Ajithkumar. The existing and the two proposals are compared for their performance results using MATLAB simulation tool (Simulink) and are summarised in table -1.

The overall performance of these three types of front end boxes when integrated with common box (CB) are again compared and the results are as illustrated in table - 2. This table contains the option for using 14 dB solar attenuator as a default setting for the 150 MHz band.

Table - 1: 150 MHz Front End Box (FEB) Comparison

Parameters	Existing[1] FEB	Proposed[2] FEB	Recently Implemented[3] FEB
Gain (dB)	33	36	20
T_{eff} (Deg K)	264	264	266
CDR (dB)	65	74	77
SFDR (dB)	51	54	60

1 - Simulation Table - 1
2 - Simulation Table - 6
3 - Simulation Table - 6A

Table - 2: Comparison table for 150 MHz FEB integrated with Common Box (CB).

Parameters	Existing[2] FEB + CB		Proposed[3] FEB + CB		Recently Implemented[4] FEB + CB	
	SA[1]	No SA[1]	**SA[1]**	No SA[1]	SA[1]	No SA[1]
Gain (dB)	47	61	**50**	64	NA	49
T_{eff} (Deg K)	306	265	**294**	265	NA	306
CDR (dB)	58	44	**63**	4	NA	55
SFDR (dB)	43	34	**50**	42	NA	45

1 - SA - Solar Attenuator, 14 dB.
NA - Not applicable
2 - Simulation Table - 1
3 - Simulation Table - 6
4 - Simulation Table - 6A

It is obvious from the above comparison table that the best performance for 150 MHz front end is obtained while using the proposed modification with 14 dB solar attenuator.

The overall performance of complete front end (FE) systems, existing and proposed, integrated with corresponding ABR systems and the recently implemented front end with existing ABR, is illustrated in table - 3.

Table - 3: 150 MHz Front End (FE) and Antenna Base Receiver (ABR) integrated performance.

Parameters	Existing[1] FE + ABR		Proposed[2] FE + ABR		Recently Implemented[3] FE + ABR	
	SA	No SA	SA	No SA	SA[1]	No SA
Gain (dB)	76	76	**76**	NA	NA	75
T_{eff} (Deg K)	306	266	**295**	NA	NA	307
CDR (dB)	15	15	**38**	NA	NA	38
SFDR (dB)	18	16	**29**	NA	NA	29

1 - Simulation Table - 3 and 4
2 - Simulation Table - 9
3 - Simulation Table - 7

From the comparison table - 3, it is noticed that the performance of the proposed receiver with 14 dB solar attenuator is identical in all respects except for a marginal improvement in the effective receiver temeprature. However at the first mixer output, the dynamic ranges are better by about 3 dB than the receiver with recently implemented front end without solar attenuator in combination with the proposed ABR. Therefore we recommand to implement the proposed front end with the proposed new ABR without ALC to achieve high dynamic range performance. 14 dB solar attenuator has to be used. Default IF attenuator values are, Pre-attenuator = 16 dB and Post-attenuator = 4 dB.

The detail list of components used in the 150 MHz front end boxes with their performance figures are outlined in table - 1A and Table -

TABLE - 1A : Components for Existing and proposed 150 MHz front end box.

Sub System	Component Name	Char of Existing Components					Char of Proposed Components				
		Device Name	Gain (dB)	P (1dB)	OIP3 (dBm)	NF (dB)	Device Name	Gain (dB)	P (1dB)	OIP3 (dBm)	NF (dB)
Front End Box 150 MHz	**Feed to FE Cable**	RG - 214	-0.2			0.2	RG - 214	-0.2			0.2
	Two Way Combiner	PSC 2-1	- 0.4			0.4	PSC 2-1	- 0.4			0.4
	Polarizer (QHDC)	"Wireline"	-0.4			0.4	"Wireline"	-0.4			0.4
	LNA	Si Bipolar MMIC INA 02184	31.0	11.0	23.0	1.8	Si Bipolar MMIC INA 02184	31.0	11.0	23.0	1.8
	BPF	Coupled Resonator	-0.5			0.5	HPF + Notch Filter + LPF	-2.5			2.5
	Post Amp	MAR - 3	12.0	10.0	23.0	6.0	MAV-11	12.5	17.5	30.0	3.6
	Ph sw / Mixer	SBL-1MH	-4.0	9.0	24.0	5.0	SBL-1MH	-4.0	9.0	24.0	5.0
	RF Switch	SW-239	-0.5	25.0	42.0	0.5	SW-239	-0.5	25.0	42.0	0.5
	Attenuator	Resistive "Pi" Type	-4.0			4.0					
FEB to CB Cable	**Flexible Coaxial Cable**	RG - 214	-0.3			0.3	RG - 214	-0.3			0.3

TABLE - 1B : Components for recently implemented and proposed 150 MHz front end box.

Sub System	Component Name	Char of recently implemented Components					Char of Proposed Components				
		Device Name	Gain (dB)	P (1dB)	OIP3 (dBm)	NF (dB)	Device Name	Gain (dB)	P (1dB)	OIP3 (dBm)	NF (dB)
150 MHz Front End Box	Feed to FE Cable	RG - 214	-0.2			0.2	RG - 214	-0.2			0.2
	Two Way Combiner	PSC 2-1	- 0.4			0.4	PSC 2-1	- 0.4			0.4
	Polarizer (QHDC)	"Wireline"	-0.4			0.4	"Wireline"	-0.4			0.4
	LNA	Si Bipolar MMIC INA 02184	31.0	11.0	23.0	1.8	Si Bipolar MMIC INA 02184	31.0	11.0	23.0	1.8
	BPF	HPF + Notch Filter + LPF	-2.5			2.5	HPF + Notch Filter + LPF	-2.5			2.5
	Attenuator	Resistive "Pi" Type	-3.0			3.0	MAV-11	12.5	17.5	30.0	3.6
	Ph sw / Mixer	SBL-1MH	-4.0	9.0	24.0	5.0	SBL-1MH	-4.0	9.0	24.0	5.0
	RF Switch	SW-239	-0.5	25.0	42.0	0.5	SW-239	-0.5	25.0	42.0	0.5
FEB to CB Cable	Flexible Coaxial Cable	RG - 214	-0.3			0.3	RG - 214	-0.3			0.3

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1B. Table - 1A gives the components for existing and proposed front ends and Table - 1B gives the components for recently implemented and proposed front ends.

3.1.2 235 MHz System

In the 235 MHz band, the modification proposal is exactly like the 150 MHz band proposal and 14 dB solar attenuator will be used like the existing arrangement in the front end.

The existing and proposed schemes are compared for their performance using MATLAB simulation tool (Simulink) and the results are illustrated in comparison table - 4.

From table - 4, we can conclude that the performance of the proposed front end with 14 dB solar attenuator gives the better dynamic range.

Table - 4: 235 MHz Front End System system performance

Parameters	**Existing FE**		**Proposed FE**	
	SA[1]	**No SA[2]**	**SA[3]**	**No SA[4]**
Gain (dB)	52	66	**57**	71
T_{eff} (Deg K)	114	100	**106**	100
CDR (dB)	57	43	**58**	46
SFDR (dB)	40	32	**43**	38

1 - Simulation Table - 12
2 - Simulation Table - 10
3 - Simulation Table - 16
4 - Simulation Table - 14

The overall performance of these existing and proposed front ends, when integrated with the antenna base receiver are compared and the results are illustratted in table - 5.

Table - 5: 235 MHz Integrated FE and ABR performance

Parameters	Existing FE + ABR		Proposed FE + ABR	
	SA[1]	No SA[2]	SA[3]	No SA[4]
Gain (dB)	79	79	**80**	80
T_{eff} (Deg K)	114	101	**106**	100
CDR (dB)	15	15	**38**	36
SFDR (dB)	17	15	**28**	26

1 - Simulation Table - 13
2 - Simulation Table - 11
3 - Simulation Table - 17
4 - Simulation Table - 15

As we can see from the above tables the proposed system with 14 dB solar attenuator gives the best dynamic range performance. The default IF attenuator values for pre and post attenuators are 18 dB and 4 dB respectively.

The detail list of components used in the 235 MHz front end boxes with their performance figures are outlined in Table - 2A. The table gives components for existing and proposed front ends.

3.1.3 327 MHz System

In the 327 MHz band front end, the post amplifier will be changed to MAV - 11 and the 4 dB attenuator at the output of the front end will be retained. Table - 6 shows the comparison between existing and the proposed front end systems.

The overall performance of the existing and proposed front ends, when integrated with the corresponding ABR are tabulated in table - 7.

TABLE - 2A : Components for Existing and proposed 235 MHz front end box.

Sub System	Component Name	Char of Existing Components					Char of Proposed Components				
		Device Name	Gain (dB)	P (1dB)	OIP3 (dBm)	NF (dB)	Device Name	Gain (dB)	P (1dB)	OIP3 (dBm)	NF (dB)
Front End Box 235 MHz	Balun	Coaxial Balun	-0.25			0.25	Coaxial Balun	-0.25			0.25
	Balun to FE Cable	RG - 214	-0.30			0.30	RG - 214	-0.3			0.30
	Polarizer (QHDC)	"Wireline"	-0.25			0.25	"Wireline"	-0.25			0.25
	LNA	GaAsFET's ATF 10135 ATF 10136	36.00			0.48	GaAsFET's ATF 10135 ATF 10136	36.0			0.48
	BPF	Coupled Resonator	-0.80			0.80	Coupled Resonator	-0.8			0.80
	Post Amp	MAR - 3	12.00	10.0	23.0	6.00	MAV-11	12.5	17.5	30.0	3.6
	Ph sw / Mixer	SBL-1MH	-4.00	9.0	24.0	5.00	SBL-1MH	-4.0	9.0	24.0	5.00
	RF Switch	SW-239	-0.50	25.0	42.0	0.50	SW-239	-0.5	25.0	42.0	0.50
	Attenuator	Resistive "Pi" Type	-4.00			4.00					
FEB to CB Cable	Flexible Coaxial Cable	RG - 214	-0.40			0.40	RG - 214	-0.4			0.40

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Table - 6: 327 MHz Front End System Performance

Parameters	Existing FE[1]	Proposed FE[2]
Gain (dB)	66	67
T_{eff} (Deg K)	53	53
CDR (dB)	45	53
SFDR (dB)	32	40

1 - Simulation Table - 18
2 - Simulation Table - 20

Table - 7: 327 MHz Integrated FE and ABR performance

Parameters	Existing FE + ABR[1]	Proposed FE + ABR[2]
Gain (dB)	83	83
T_{eff} (Deg K)	53	53
CDR (dB)	15	38
SFDR (dB)	14	26

1 - Simulation Table - 19
2 - Simulation Table - 21

Here again the proposed FE and ABR combination gives better dynamic range of the order of 38 dB in CDR and 26 dB in SFDR. The default IF attenuation values for pre and post attenuators are 22 dB and 6 dB respectively.

The detail list of components used in the 327 MHz front end boxes with their performance figures are outlined in Table - 3A. The table gives components for existing and proposed front ends.

3.1.4 610 MHz System

In the 610 MHz band front end, the post amplifier and the phase switch unit will be changed to the stages consisting of MAV - 11

TABLE - 3A : Components for Existing and proposed 327 MHz front end box.

Sub System	Component Name	Char of Existing Components					Char of Proposed Components				
		Device Name	Gain (dB)	P (1dB)	OIP3 (dBm)	NF (dB)	Device Name	Gain (dB)	P (1dB)	OIP3 (dBm)	NF (dB)
Front End Box	Feed to FE Cable	Andrew Heliax LDF 2-50	-0.13			0.13	Andrew Heliax LDF 2-50	-0.13			0.13
	Polarizer (QHDC)	"Wireline" & Microstrip	-0.18			0.18	"Wireline" & Microstrip	-0.18			0.18
	LNA	GaAsFET's ATF 10135 ATF 10136	36.00			0.41	GaAsFET's ATF 10135 ATF 10136	36.0			0.41
	BPF	Coupled Rasonator	-0.80			0.80	Coupled Rasonator	-0.8			0.80
	Post Amp	MAR - 3	12.00	10.0	23.0	6.00	MAV-11	12.5	17.5	30.0	3.6
	Ph sw / Mixer	SBL-1MH	-4.00	9.0	24.0	5.00	SBL-1MH	-4.0	9.0	24.0	5.00
	RF Switch	SW-239	-0.50	25.0	42.0	0.50	SW-239	-0.5	25.0	42.0	0.50
	Attenuator	Resistive "Pi" Type	-4.00			4.00	Resistive "Pi" Type	-4.0			4.00
FEB to CB Cable	Flexible Coaxial Cable	RG - 214	-0.60			0.60	RG - 214	-0.6			0.60

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followed by phase switch SRA - 2010 MH and then another stage of MAV - 11, for satisfying the requirement of higher gain. The 4 dB attenuator at the output of the front end will be retained. This front end will be integrated with the proposed common box and the following table - 8 shows the comparison between existing and the proposed front end systems.

Table - 8: 610 MHz Front End System performance

Parameters	**Existing FE[1]**	**Proposed FE[2]**
Gain (dB)	66	**71**
T_{eff} (Deg K)	58	**58**
CDR (dB)	46	**50**
SFDR (dB)	32	**38**

1 - Simulation Table - 22
2 - Simulation Table - 24

The overall performance of the existing and proposed front ends, when integrated with the corresponding ABR are tabulated in table - 9.

Table - 9: 610 MHz Integrated FE and ABR performance

Parameters	**Existing FE + ABR[1]**	**Proposed FE + ABR[2]**
Gain (dB)	84	**84**
T_{eff} (Deg K)	58	**59**
CDR (dB)	15	**38**
SFDR (dB)	13	**25**

1 - Simulation Table - 18
2 - Simulation Table - 20

Here again the proposed FE and ABR combination gives better dynamic range of the order of 38 dB in CDR and 25 dB in SFDR.

The default IF attenuation values for pre and post attenuators are 24 dB and 4 dB respectively.

So far, we have not described the details of the modifications in the common box and ABR as they are common to all the frequency bands. They are covered in the subsequent sections.

The detail list of components used in the 610 MHz front end boxes with their performance figures are outlined in Table - 4A. The table gives components for existing and proposed front ends.

3.2 Common Box

In the Common Box, the band selectors and channel swap units need not be changed as all the switches incorporated in these units have high OIP_3. The broad band amplifier with a frequency range of 10 MHz to 2.0 GHz is used for amplifying signals received from all the bands. The broadband amplfier consists of two stages of amplification. The First stage is a silicon bipolar MMIC, INA 03184 (Agilent make)..This device has 1 dB compression point (P_{1dB}) of -2 dBm and output IP_3 (OIP_3) of +7 dBm. This device has a frequency response from DC to 2.5 GHz and a gain of about 25dB. *We propose to change this device with Agilent Technologies Inc. make silicon bipolar MMIC amplifier, INA 10386, which has P_{1dB} of +10 dBm and OIP_3 of +23 dBm. This device has a frequency response from DC to 1.8 GHz and gain of about 26 dB. The second stage device is MAR-3 of mini circuits, which can be changed with ERA-6 of mini circuits. ERA-6 MMIC has a P_{1dB} of +18 dBm and OIP_3 of +36 dBm. It has a frequency response from DC to 4 GHz and gain of 11 dB.* Thus the upper cut-off frequency of the common box will be 1.8 GHz, which is adequate for the frequency bands covered by GMRT.

TABLE - 4A : Components for Existing and proposed 610 MHz front end box.

Sub System	Component Name	Char of Existing Components					Char of Proposed Components				
		Device Name	Gain (dB)	P (1dB)	OIP3 (dBm)	NF (dB)	Device Name	Gain (dB)	P (1dB)	OIP3 (dBm)	NF (dB)
Front End Box 610 MHz	Balun + 20 cm balun to Probe cable	Coaxial Balun + 0.141" semirigid cable	-0.22			0.22	Coaxial Balun + 0.141" semirigid cable	-0.22			0.22
	Polarizer (QHDC)	Branchline Coupler	-0.15			0.15	Branchline Coupler	-0.15			0.15
	LNA	GaAsFET's ATF 10135 ATF 10136	29.0			0.41	GaAsFET's ATF 10135 ATF 10136	29.0			0.41
	LNA to BPF Cable	RG - 214	-0.6			0.60	RG - 214	-0.6			0.60
	BPF	Coupled Rasonator	-1.4			1.40	Coupled Rasonator	-1.4			1.40
	Post Amp - 1	MAR - 6	20.0	2.0	14.0	3.00	MAV-11	12.5	17.5	30.0	3.6
	Ph sw / Mixer	SRA 2010 MH	-4.0			5.00	SRA 2010 MH	-4.0			5.00
	Post Amp - 2						MAV-11	12.5	17.5	30.0	3.6
	RF Switch	SW-239	-0.5	25.0	42.0	0.50	SW-239	-0.5	25.0	42.0	0.50
	Attenuator	Resistive "Pi" Type	-4.0			4.00	Resistive "Pi" Type	-4.0			4.00
FEB to CB Cable	Flexible Coaxial Cable	RG - 214	-0.5			0.50	RG - 214	-0.5			0.50

The detail list of components used in the common box with their performance figures are outlined in Table - 5A. The table gives components for existing and proposed front ends.

3.3 Front End to ABR Cables

The first version of the coaxial cables from front end to ABR for both the channels consisted of,

a. 9 m of RG-214 cable from common box output to the top of the quadripod through stainless steel flexible hose wrapped around a set of horizontal steel tubes within the feed cage.
b. 46 m of Andrew *Heliax* make foam cable LDF 2-50 from quadripod top to apex of the dish.
c. 40 m of RG-214 cable from dish apex to ABR rack.

The above cable combination had a total attenuation as shown in table - 10.

Table - 10 : Front end to ABR cable attenuation with old cable set

Frequency Band (MHz)	Attenuation (dB)
150	8
235	9
327	11
610	15
1060	22
1170	23
1280	24
1390	26

TABLE - 5A: Components for Existing and proposed common box

Sub System	Component Name	Char of Existing Components					Char of Proposed Components				
		Device Name	Gain (dB)	P (1dB)	OIP3 (dBm)	NF (dB)	Device Name	Gain (dB)	P (1dB)	OIP3 (dBm)	NF (dB)
Common Box	**Band Selector**	SW - 338					SW - 338				
	+ Solar Attr	SW - 239	-2.7	25.0	42.0	2.7	SW - 239	-2.7	25.0	42.0	2.7
	Swap Switch	SW - 239	-1.0	25.0	42.0	1.0	SW - 239	-1.0	25.0	42.0	1.0
	Attenuator	Resistive "Pi" type	-4.0			4.0	Resistive "Pi" type	-4.0			4.0
	BB Amp										
	Stage 1	INA 03184	25.5	-2.0	7.0	2.6	INA 10386	26.7	10.0	23.0	3.7
	Stage 2	MAR - 3	12.0	10.0	23.0	6.0	ERA-6	11.0	18.0	36.0	8.4
	Directional Coupler	PDC 10-5	-1.5			1.5	PDC 10-5	-1.5			1.5

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At present, the cable configuration has been modified as follows.

a. 3.3 m of LMR-400 Ultraflex foam cable from common box output to the top of the quadripod through PVC flexible hose.
b. 46 m of Andrew *Heliax* make foam cable LDF 2-50 from quadripod top to apex of the dish.
c. 43.5 m of LMR-400 Ultraflex foam cable from dish apex to ABR rack.

The measured attenuation details for this new cable combination is as shown in table -11.

These changes in the cables resulted in an improvement of around 10 dB in the signal levels at higher frequencies.

Table - 11: Front End to ABR cable attenuation with low loss cable set

Frequency	Attenuation (dB)			
Band (MHz)	**3.3 m LMR-400**	**46 m LDF 2-50**	**43.5 m LMR-400**	**Total**
150	0.3	2.53	2.3	5.13
235	0.3	2.87	3.1	6.27
327	0.3	3.27	3.8	7.37
610	0.4	4.37	5.4	10.17
1060	0.6	5.83	7.5	13.93
1170	0.6	6.06	7.9	14.56
1280	0.6	6.26	8.3	15.16
1390	0.6	6.61	8.7	15.91

3.4 Antenna Base Receiver (ABR)

3.4.1 Converter - 1 (RF Frequencies to 70 MHz IF)

In the antenna base receiver (ABR), for the first two stages of amplification, MAR-3 MMIC's of mini circuits are used in the existing receiver (C41 PIU). *We propose to replace these devices with a single ERA-6 amplifier for the reasons highlighted in the common box modification.*

After this stage of amplification, the first mixer SRA-2010MH of Mini circuits is used to convert RF frequencies into an IF frequency centred at 70MHz. SRA-2010MH is a level 13 frequency mixer with the frequency range of 10 to 2000 MHz. It uses LO drive level of +13 dBm and can handle RF levels only upto +9 dBm. *This device can be changed with Mini circuits SAY-11 double balanced, level 23 mixer. The RF signal handling capability of this mixer is very high of the order of +20 dBm. This has a frequency range of 10 to 2400 MHz. It requires LO drive level of +23 dBm therefore 1st LO level has to be boosted to +23 dBm.*

The third-order intercept point of this mixer is of the order of +35 dBm for lower frequency ranges and + 30 dBm for mid and higher frequency bands.

Following the 1st mixer, a single stage of MAR-3 amplifier has been incorporated in the present receiver chain. *This can be replaced with a high dynamic range MMIC amplifier MAV-11 of the same gain.*

The next stage in the chain is a 0 to 30 dB programmable Pre-IF attenuator AT001D4-25 which is left unchanged since it has high head room (P_{1dB} = +14 dBm, OIP_3 = +32 dBm).

The next unit in the chain is a 70 MHz SAW filter. This unit has at present MAR-3 followed by 70 MHz SAW filter banks and MAR-6 amplifier. *This can be modified as MAV-11 followed by 70 MHz SAW filter* *banks and MSA 3111 amplifier of Agilent technologies. which has a gain of 24 dB, P_{1dB} of +9 dBm, OIP_3 of +23 dBm and noise figure of 3.5 dB. It has a frequency range of DC to 500 MHz.*

3.4.2 Converter - 2 (70 MHz IF to 130 / 175 MHz IF)

The 70 MHz IF output from both polarization channels are converted to 130 MHz (CH-1) and 175 MHz (CH-2) IF in the PIU C42 and C43 respectively. The first stage in both the channels is MAR-3 amplifier. *This can be replaced with MAV-11 amplifier.*

Following this amplifier, is a 2nd Mixer SBL-1MH of mini circuits, which is a level 13 frequency mixer for a frequency range of 1 to 500 MHz and can handle RF signal level upto +9 dBm. The LO drive required is +13 dBm (2nd LO). *We propose to use a level 23 frequency mixer SAY-1 of mini circuits which has frequency range of 0.1 to 500 MHz and can handle RF signal level upto +20 dBm. It requires +23 dBm LO drive. Therefore an additional LO amplification is required. The third-order intercept point will be of the order of +35 dBm.*

Following this, two stages of MAR-4 amplifiers are used. The first MAR-4 stage is left unchanged. *After that, an IF post attenuator AT001D4-25 with an attenuation range of 0 to 30 dB can be incorporated.* Th second *MAR-4 stage is replaced with MAV-11.* After this unit we have SAW bandpass filter units for 130/175 MHz. In this the first stage is Agilent's MSA-0520 which has very high dynamic range capability. Therefore it can be left unchanged. After the saw filter module, a MAR-6 amplifier is used. *This can be changed to a single MAV-11 amplifier.*

The next stage in the existing receiver is a post IF attenuator

AT001D4-25 with an attenuation range from 0 to 30 dB. *This can be removed as it has been shifted to an earlier stage as described in the previous paragraph.*

The ALC amplifier used at present IVA 05208 of HP make, limits the dynamic range of IF system since it has a P_{1dB} of -3 dBm. Therefore the CDR at the output of the IF system is limited to +14 to +15 dBm which is very low. Also, the SFDR is limited to around 15 dB only. *In the new arrangement we propose to eliminate the ALC amplifier itself. Instead, at the begining of observations the right attenuation settings may be done using Pre and Post attenuators and no ALC be used. The final output stage of the IF can be a combination of a MAV-11 and MSA-1023 power amplifier which has a gain 8.5 dB, P_{1dB} of +27 dBm, and OIP_3 of +37 dBm.*

Alternatively, if the ALC is required, the new ALC unit designed by Shri. S. J. Pandharpure, consisting of MAR-4 amplifier, Analog devices make AD 8367 variable gain amplifier and a MSA-0520 amplifier can be used. This improves the CDR to about +28 dBm and SFDR to +33 dBm. However from the MATLAB simulated results (Simulation Table - 26, 27 and 28), it can be seen that the ALC unit pulls down the dynamic range considerably. Therefore we tend to gain a lot by not incorporating ALC in the IF chain.

The two polarization channels at 130 and 175 MHz are combined with LO round trip carriers 200 MHz and 105 MHz along with a provision for spare port. A 5-way combiner PSC 5-1 of mini circuit with frequency range 1 to 300 MHz and insertion loss of 7.5 dB is used for combining these signals. This combiner and the final low pass filter with a cut 0ff of 205 MHz can be left unchanged.

A schematic of the existing ABR (IF chain) system is shown in figure - 6. The detail list of components used in the ABR (IF system) with their performance figures are outlined in Table - 6A. The table gives components for existing and proposed front ends.

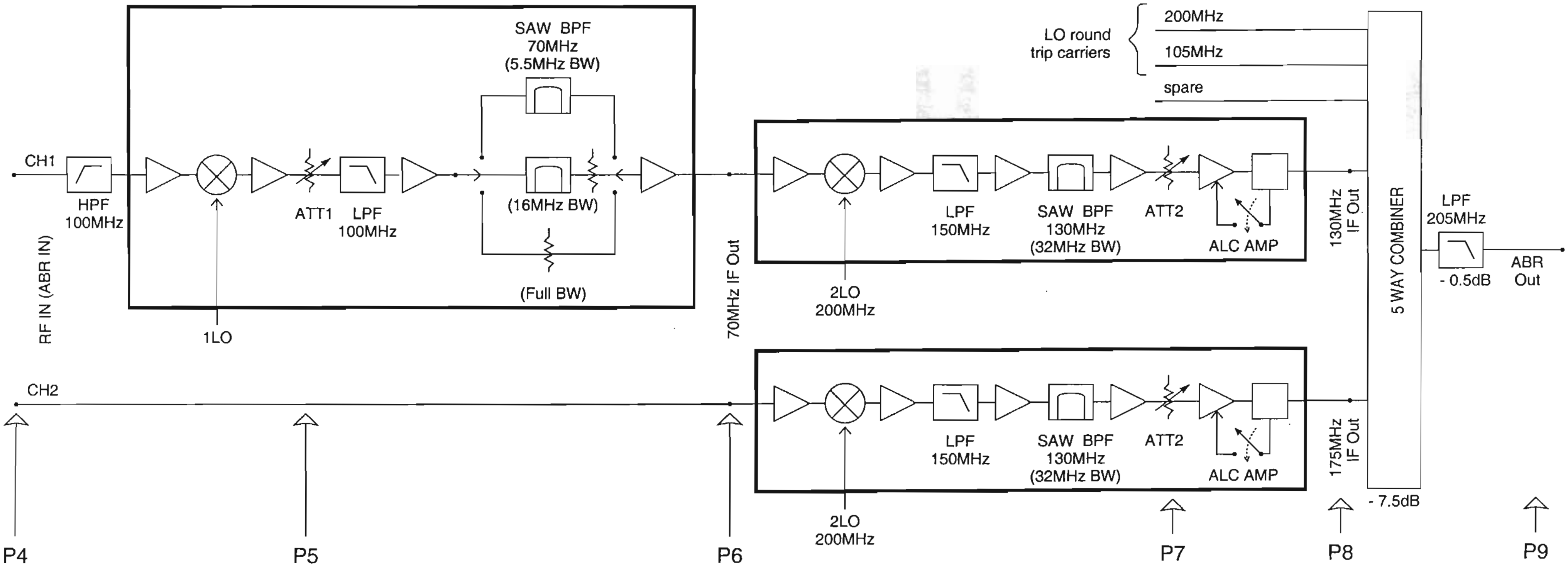
3.4.3 Optimum IF operating power level

The ABR operating output power level is found to be optimum at -20 dBm. From figure - 7 and the equivalent system noise temperature table - 12 associated with it, we can see that the equivalent input noise (EIN_{OFS}) for a 32 MHz bandwidth, varies from -54 dBm to about -41 dBm for the optical loss variation from 0 dB to 11 dB encountered in the present GMRT fiber optic link. So, we can take the worst case EIN_{OFS} to be -40 dBm and fix the IF operating level at -20 dBm so that the signal to noise ratio is not degraded by less than 1% for the farthest antenna.

3.5 Local Oscillator (LO) System

For the LO system, an appropriate choice of additional amplifier in order to drive the level 23 mixers recommanded in this proposal can be Agilent make MMIC MSA-1023. The incresed LO drive level to these mixers with finite isolations could lead to higher levels of LO leakage to the RF and IF ports of the mixer. Th LO leakage to RF ports will result in self mixing and consequently DC offsets at the IF port. The DC offsets could be eliminated by AC coupling, high pass filters etc. The LO leakage to the IF port and the Intermodulation products at the IF port can be removed by the existing Low pass filters. If further rejection is required this low pass filters could be improved.

The front end performance and the receiver performance for various frequencies and various options, described above, are summarised in Table - 7A and 7B respectively.



FREQ. BAND (MHz)	P4 (dBm/32MHz)	P5 (dBm/32MHz)	ATT1 (dB)	P6 (dBm)	P7 (dBm)	ATT2 * (dB)	P8 (dBm)	P9 (dBm)
150	- 42	- 17	18	- 34	- 17	16	- 12	- 20 in each channel or - 17 total power
233	- 45	- 20	16	- 35	- 18	16	- 12	
327	- 49	- 24	12	- 35	- 18	16	- 12	
610	- 58	- 34	10	- 43	- 26	8	- 12	
1060	- 51	- 28	10	- 37	- 20	14	- 12	
1170	- 55	- 33	10	- 42	- 25	8	- 12	
1280	- 57	- 35	10	- 44	- 27	6	- 12	
1390	- 61	- 40	8	- 47	- 30	4	- 12	

Note 1. Atenuation for ALC mode: (For Non-ALC mode operation add 6dB more attenuator to get - 12dBm a P8)

2. Channels 16 & 20 of MCM #9 should read 131 (± 5) counts, to indicate proper ALC setting. For quick check, adding 4dB more attn. in the above setting will cause the MCM channels (16 & 20) counts to read 215 (± 5) showing that operating point is just under for AGC.

Table - 6A : Antenna Base Receiver (ABR) Components

Sub System	Component Name	Char of Existing Components					Char of Proposed Components				
		Device Name	Gain (dB)	P (1dB)	OIP3 (dBm)	NF (dB)	Device Name	Gain (dB)	P (1dB)	OIP3 (dBm)	NF (dB)
PIU C-41	Amp St -1	MAR - 3	12	10	23	6	ERA 6	11	18	36	8.4
RF to 70	Amp St - 2	MAR - 3	12	10	23	6	------				
MHz IF	Mixer	SRA 2010MH	-8	9	24	9	SAY -11	-8	20	35	9
Converter	Amp.	MAR - 3	12	10	23	6	MAV 11	12	17.5	30	3.6
	Pre - Attr	AT001D4-25	0 to -30	14	32		AT001D4-25	0 to -30	14	32	
	Filter	LPF (100MHz)	-1			1	LPF (100 MHz)	-1			1
	Amp.	MAR - 3	12	10	23	6	MAV 11	12	17.5	30	3.6
	Saw Filter	SAW (70MHz)	-27			27	SAW (70MHz)	-27			27
	Amp.	MAR - 6	20	2	14	3	MSA 3111	24	9	23	3.5
PIU C-42	Amp.	MAR - 3	12	10	23	6	MAV 11	12	17.5	30	3.6
70 MHz IF	Mixer	SBL - 1MH	-7	9	24	8	SAY - 1	-7	20	35	8
to 130/175	Amp.	MAR - 4	8	12.5	25.5	6.5	MAR - 4	8	12.5	25.5	6.5
MHz IF	Amp.	MAR - 4	8	12.5	25.5	6.5	AT001D4-25	0 to -30	14	32	
Converter							MAV 11	12	17.5	30	3.6
	Filter	LPF (150 & 200 MHz)	-1			1	LPF (150 & 200 MHz)	-1			1
	Amp.	MSA 0520	8	23	33	6.5	MSA 0520	8	23	33	6.5
	Saw Filter	SAW (130 & 175 MHz)	-28			28	SAW (130 & 175 MHz)	-28			28
	Amp.	MAR - 6	20	2	14	3	MAV 11	12	17.5	30	3.6
	Post - Attr	AT001D4-25	0 to -30	14	32		------				
	VCA	1VA 05208	0 to 30	-3		9	MAV 11	12	17.5	30	3.6
	Amp	MAR - 3	12	10	23	6	MSA 1023	8.5	27	37	7.0
	2 Way Divider		-6.0			6.0					
	5 Way Combiner	PSC 5-1	-7.5			7.5	PSC 5-1	-7.5			7.5
	Filter	LPF (205 MHz)	-0.5			0.5	LPF (205 MHz)	-0.5			0.5

Table - 7A

Summary of Front End performance for various frequency bands for Existing and Proposed schemes

Frequency Band (MHz)	System Noise Temp. Tsys (K)	CDR (dB)	SFDR (dB)	Front End Gain (dB)	Front End to ABR Cable Loss (dB)	Input RF Power Level* to ABR (dBm)
150						
Existing						
With SA	626	58	43	47	5	-54
Without SA	586	44	34	61	5	-40
Proposed						
With SA	**615**	**63**	**50**	**50**	**5**	**-51**
Without SA	585	49	42	64	5	-37
Recently Implemented						
Without SA	627	55	45	49	5	-52
233						
Existing						
With SA	245	57	40	52	6	-54
Without SA	232	43	32	66	6	-40
Proposed						
With SA	**237**	**58**	**43**	**59**	**6**	**-50**
Without SA	231	46	38	71	6	-36
327						
Existing	106	45	32	66	7	-44
Proposed	**106**	**53**	**40**	**67**	**7**	**-43**
610						
Existing	100	46	32	66	10	-48
Proposed	**101**	**50**	**38**	**71**	**10**	**-43**

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*** Power levels are calculated for 32 MHz band width**

Table - 7B

Summary of Receiver performance for various frequency bands for Existing and Proposed scheme.

Frequency Band (MHz)	Receiver Noise Temp. (Tr) (Deg. Kelvin)	Ground Ground (Tgnd) (Deg. Kelvin)	Sky Temp. (Tsky) (Deg. Kelvin)	System Temp. (Tsys) (Deg. Kelvin)	CDR (dB)	SFDR (dB)	Receiver Gain (dB)
150							
Existing							
With SA	306	12	308	626	15	18	76
Without SA	266	12	308	586	15	16	76
Proposed							
With SA	295	12	308	615	38	29	76
Recently Implemented							
Without SA	307	12	308	627	38	29	75
233							
Existing							
With SA	114	32	99	245	15	17	79
Without SA	101	32	99	232	15	15	79
Proposed							
With SA	106	32	99	237	38	28	80
Without SA	100	32	99	231	36	26	80
327							
Existing	53	13	40	106	15	14	83
Proposed	53	13	40	106	38	26	83
610							
Existing	58	32	10	100	15	13	84
Proposed	59	32	10	101	38	25	84

CDR and SFDR are calculated for 32 MHz band width
SA - Solar Attenuator, 14 dB in front end

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3.6 Fiber Optic System (Return link)

In the fiber optic receiver, the output of the InGaAs PIN photo diode goes to the pre-amplifier INA 2170 with a noise figure of 2 dB, gain of 31.5 dB, P_{1dB} of +11 dBm and OIP_3 of +23 dBm. After the pre-amplifier there is a unit incorporating a fixed attenuator that varies from antenna to antenna and another stage of INA-2170 (see figure - 8). At present the noise floor at the output of the amplifier is -10 dBm. This will result in a small compression dynamic range of only 21 dB. *Therefore it is advised that the second stage amplifier can be changed to an amplifier consisting of two MAV-11 stages.* This will improve the compression as well as the spurious free dynamic range. *Also, the fixed attenuator between two receiver amplifiers can be changed with a programmable attenuator (0 to 30 dB).*

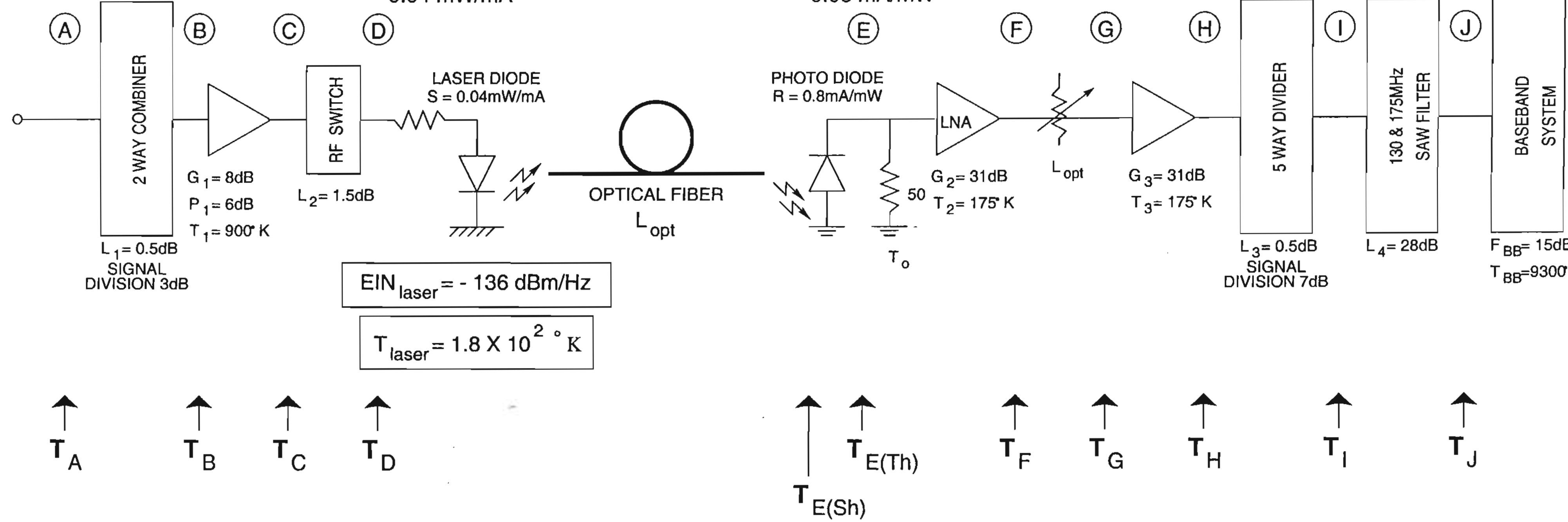
At present we are using a Fabry-Perot type laser diodes with 1 mW optical power rating. It is advisable to *change the laser diode to Distributed feedback (DFB) laser diodes with 10 mW operating optical power. With this modification, the dynamic range could be improved to match with the high dynamic performance achieved upto the ABR output. These laser diodes have about 41 dB OIP_3 with third order intermodulation distortion products at the level of about -53 dBc. With 5 times higher slope efficiency, the optical to electrical and electrical to optical conversion loss will be reduced by about 12 dB. The currently available DFB laser diodes with the above characteristics have about 2 GHz analog bandwidth and lower Relative Intensity Noise (RIN). But, it may not be advisible to procure and change in all the antennas since the next upgrade might require different design approach.*

4.0 Conclusion and future plans

This report highlighted the areas in which the present receiver system could be improved without much change in hardware so that the

F.O. RETURN LINK - EQUIVALENT SYSTEM NOISE TEMPARATURE

S = SLOPE RESPONSIVITY OF LASER 0.04 mW/mA   R = RESPONSIVITY OF PHOTODIODE 0.08 mA/mW



L_S = LINK ELECTRICAL LOSS

= $(SR\alpha/2)^2$

L_{opt} = OPTICAL LOSS

q = ELECTRONIC CHARGE = 1.6×10^{-19} COULOMBS

P_O = AVG. OPTICAL POWER = 0.5mW

I_d = PHOTODIODE DARK CURRENT = 5nA

α = OPTICAL TRANSMISSION FACTOR = $1/L_{opt}$

T_O = AMBIENT TEMP. = 300 °K

$T_{E(sh)}$ = THERMAL NOISE TEMP. AT (E)

$T_{E(th)}$ = SHOT NOISE TEMP OF PHOTODIODE AT (E)

FIG. 7

GMRT FIBER - OPTIC RETURN LINK

TABLE - 12 .

EQUIVALENT SYSTEM NOISE TEMPERATURES

EIN_{OFS} (32MHz) dBm	T_A $X10^6$ °K	T_B $X10^6$ °K	T_C $X10^6$ °K	T_D $X10^6$ °K	L_S dB	L_{opt} dB	T_{ORX} °K	$T_{E(sh)}$ °K	$T_{E(th)}$ °K	T_F $X10^4$ °K	L_{att} dB	T_G °K	T_H °K	T_I °K	T_J °K
-54.0	9.00	4.02	25.38	17.97	-36	**0**	4062	116	3946	437	22	27182	34×10^6	6057300	9300
-53.7	9.61	4.29	27.06	19.16	-38	**1**	2751	92	2659	275	20				
-53.3	10.55	4.71	29.69	21.02	-40	**2**	1922	73	1849	173	18				
-52.8	12.07	5.39	34.04	24.10	-42	**3**	1407	58	1349	110	16				
-52.0	14.36	6.41	40.47	28.65	-44	**4**	1069	46	1023	68.6	14				
-51.0	18.10	8.08	50.96	36.08	-46	**5**	861	37	824	43.9	12				
-49.8	23.74	10.60	66.90	47.36	-48	**6**	722	29	693	27.5	10				
-48.4	32.44	14.48	91.39	64.70	-50	**7**	629	23	606	16.5	8				
-46.8	46.99	20.98	132.38	93.72	-52	**8**	580	18	562	11.0	6				
-45.1	70.76	31.59	199.32	141.11	-54	**9**	555	14.6	540	8.2	4				
-43.3	106.74	47.65	300.62	212.82	-56	**10**	530	11.6	518	5.5	2				
-41.5	160.94	71.85	453.34	320.94	-58	**11**	506	9.2	497	2.7	0				

$$T_A = T_{OFS} = 2.24\ T_B + (L_1 - 1)\ T_0$$

$$T_B = \frac{T_C}{G_1} + T_1 \approx T_C / G_1$$

$$T_C = L_2 T_D + (L_2 - 1)\ T_0 \approx L_2 T_D$$

$$T_D = L_S T_{ORX} + T_{laser}$$

$$T_{ORX} = T_{E(th)} + T_{E(sh)}$$

$$T_{E(th)} = T_0 + T_2 + T_F / G_2$$

$$T_{E(sh)} = \frac{25q(RP_0 \alpha + T_0)}{K}$$

$$T_F = L_{att}\ T_G + (L_{att} - 1)\ T_0$$

$$T_G = \frac{T_H}{G_3} + T_3$$

$$T_H = 5.6\ T_1 + (L_3 - 1)\ T_0$$

$$T_1 = L_4\ T_{BB} + (L_4 - 1)\ T_0$$

$$T_J = T_{BB}$$

$$L_s = (SR\ \alpha/2)^2$$

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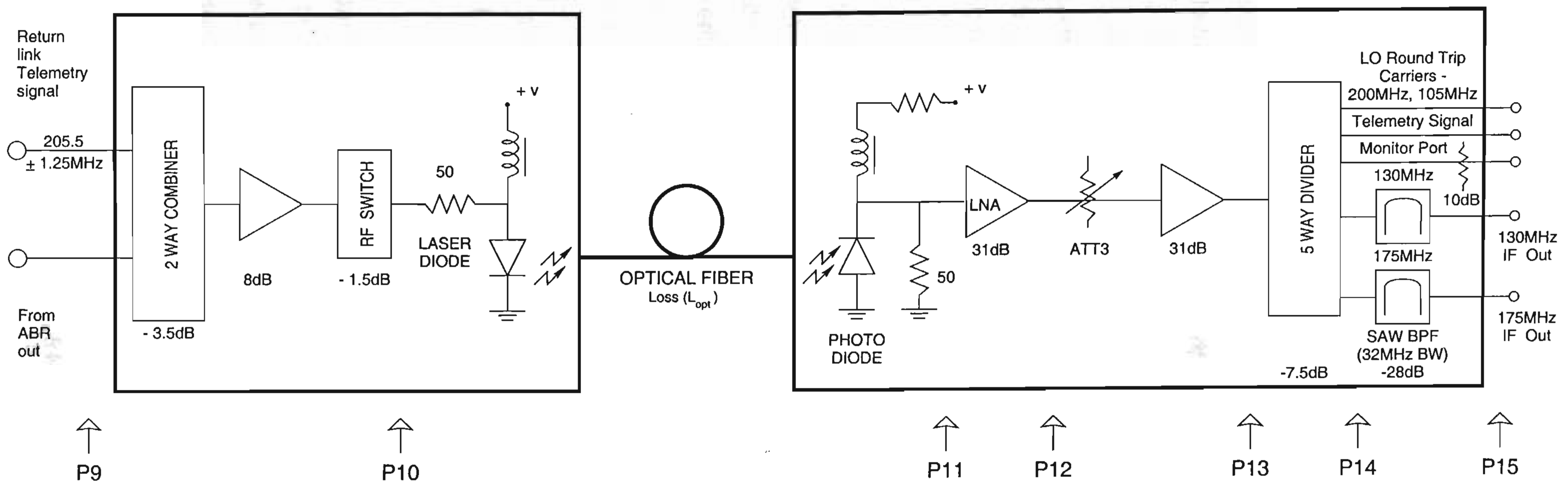
FIBER OPTIC RETURN LINK



P9 (dBm)	P10 (dBm)	L_{opt} (dBm)	P11 (dBm)	P12 (dBm)	ATT3 (dBm)	P13 (dBm)	P14 (dBm)	P15 (dBm)
- 17 (- 20 per ch.)	- 14 (- 17 per ch.)	0	- 50	- 19	22	- 10	- 17.5 (- 20.5 per ch.)	~ - 49 @ 130MHz & 175MHz Outputs
		5	- 60	- 29	12			
		10	- 70	- 39	2			
		11	- 72	- 41	0			

Note : 0dB Nett gain in the optical fiber link means P9 to P14 GAIN is 0dB

FIG. 8

system can remain linear over a wide range of input signals. The present day receivers are often subject to high levels of interference with growing use of spread spectrum systems and cellular radio phones. So the receiver should not produce Intermodulation products above a certain limit acceptable for astronomical observations. Therefore the improvement proposed has been configured to increase the compression and spurious free dynamic range of the receiver chain. An introduction to various issues involved in the defining the dynamic range of the receiver is included. A comparison table consisting of the specifications of the existing and proposed devices giving their dynamic range performance is included for easy reference. Also the content of this report compares the various options proposed for the 150 MHz band receiver and highlights the best option.

This proposal is meant for short term performance improvement of the receiver and not meant for the planned futuristic receiver. For future upgrade, various colleagues have made proposals for continuous frequency coverage from 50 to 1500 MHz. As it stands now, the feeds will cover the frequency range in the following bands.

1. 120 - 230 MHz
2. 200 - 400 MHz
3. 400 - 900 MHz
4. 900 - 1500 MHz

For covering 900 - 1500 MHz band, the existing L-band feed with a corrugated horn and OMT prapogating signals in the HE-11 mode will be used as such. This system has a system temperature of the order of 65 to70 degree kelvin, out of this figure, 23 degree kelvin ($T_{see\text{-}through}$ = 15 Deg kelvin, $T_{spillover}$ = 8 deg kelvin) is contributed by the ground noise radiations. LNA contribution is 30 degree kelvin and OMT contributes about 10 degree kelvin. Since cooling schemes seem to be not feasible and the cassegrain system has some limitations, decreasing of ground contribution seems to be the only feasible solution (as hilighted by A. Raghunathan of RRI, see ref. no. - 11). The use of ground shield below the main reflector and within the radial ribs of the dish will reduce the $T_{see\text{-}through}$ from 15 degree kelvin to 5 degree kelvin, thereby reducing the T_{sys} from 65 degree kelvin to 55 degree kelvin. Incorporation of these changes may lead to change in mechanical load distribution and the decision requires involvement of mechanical / structural experts. A large ground shielding mesh spread over the ground below the antenna structure has been proposed and its feasibility study has to be done.

Designing a new LNA using new range of Pseudomorphic HEMTs for the L-band and incorporating them will result in about 50 degree kelvin system temperature.

For RF front ends, the various types of low noise Pseudomorphic HEMTs have been identified for building low noise amplifiers (LNAs) which can give noise temperatures in the range of 15 - 18 degree kelvin in the L-band (900 - 1500 MHz), 18 - 20 degree kelvin for 400 - 900 MHz, around 20 degree kelvin for 200 - 400 MHz and 50 - 70 degree kelvin for 120 - 230 MHz band. While designing the new feeds for 200 - 400 MHz and 400 - 800 MHz, there is a scope for reduction of the ground noise contribution, which at present is about 32 degree kelvin for 610 and 233 MHz bands.

All the above amplifiers have very high P_{1dB} in the range of +20 to +29 dBm and OIP_3 in the range of +36 to +46 dBm. The appropriate sub-bands / main band for these front ends have to be worked out. The whole front end system will be designed with a very high dynamic range. The front end signals will be brought to the antenna shell with the existing low loss cables and suitably amplified to the required level.

The current trend in receiver design is to establish the foundation for increasing the content and capability of digital signal processing (DSP). Therefore the analog - digital boundary is moving closer to the antenna. The signals should be digitized with high speed and high-performance ADCs at the antenna base itself, thereby performing the variety of receive functionalities in the digital domain. This ensures ease of design, flexibility, reconfigurability and programmability. With digitizing the signals at the base of antenna, high dynamic range also can be ensured. The digital signals can be brought to CEB through digital fiber-optic links and the received digital signals can be processed at the CEB. The implementation of DSP using advanced hardware technologies like Field Programmable Gate Arrays (FPGA) and other emerging technologies have variety of potential benefits like implementation of algorithms as efficiently as possible using minimal hardware in terms of cost, size, performance and power consumption. With these techniques, the elimination of signals corresponding to (intentional or unintentional) interferers can be done more flexibly. In traditional RF systems, the cancellation of these signals is done on the basis of frequency spectrum alone with the use of narrow band filters / filter banks, notch filters at RF, IF and Base-band. They will lead to simplified testing and troubleshooting, possibly with system self test.

The second option for bringing the signals with high dynamic range could be to bypass the ABR (IF chain). The RF signals in two polarization channels can directly modulate the optical carriers around

1550 nm wavelength. These optically modulated signals can be transported through the return link fiber to CEB using wavelength division multiplexing (WDM) techniques. The return LO and telemetry carriers can also be routed throuh the same link using WDM techniques. The laser diodes for this application could be 1550 nm DFB lasers with 10 mW optical operating power levels. The wavelengths can be selected from the standard ITU - T grid specifications. The wavelength spacings have to be sufficiently large since direct modulation of the laser diode results in dynamic chirping and by this, the cross talk between channels can be minimised.

The former option (digital) seems to be the better option in terms of flexibility, configurability and possibility for future upgrades.

5.0 Acknowledgements

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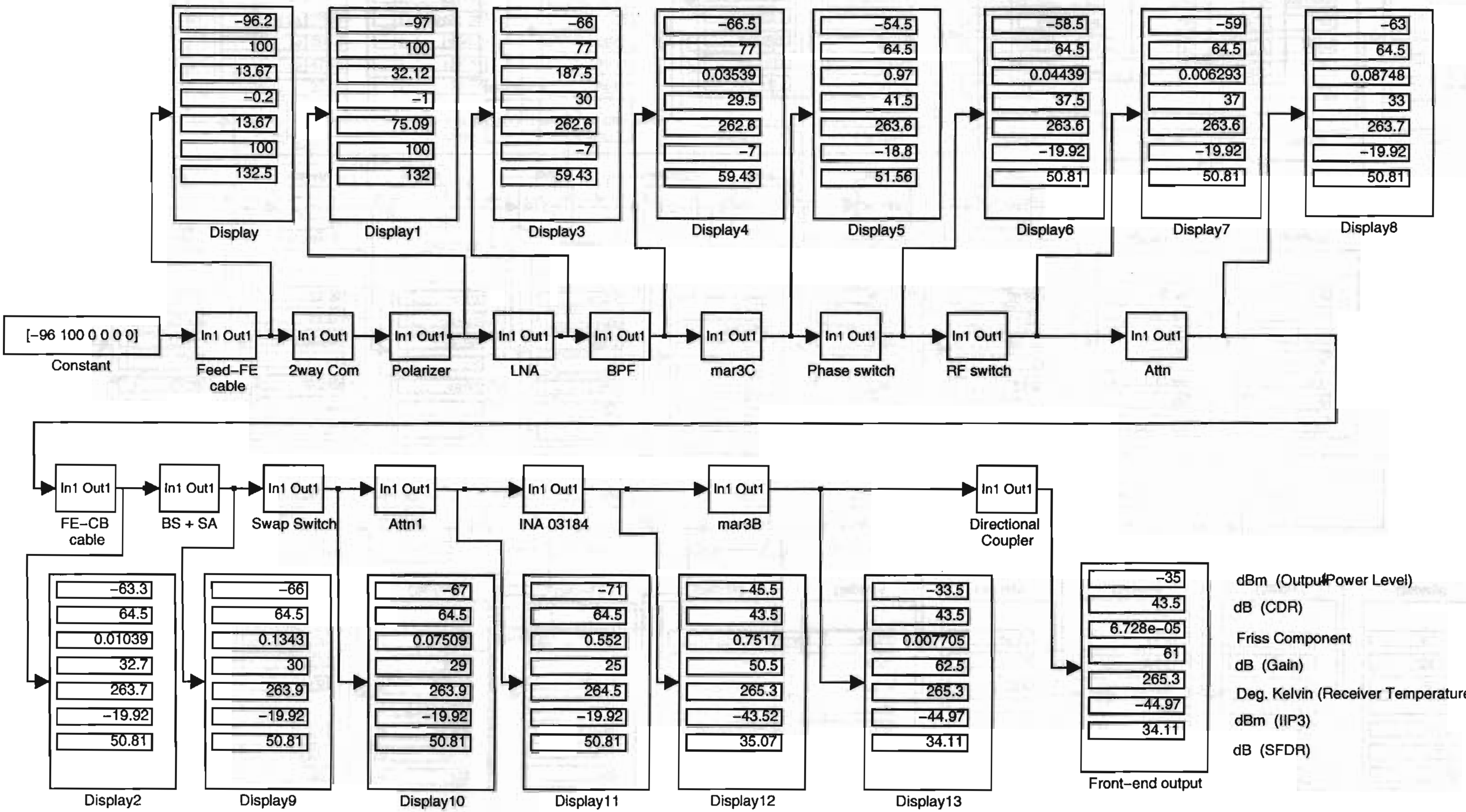
APPENDIX - A

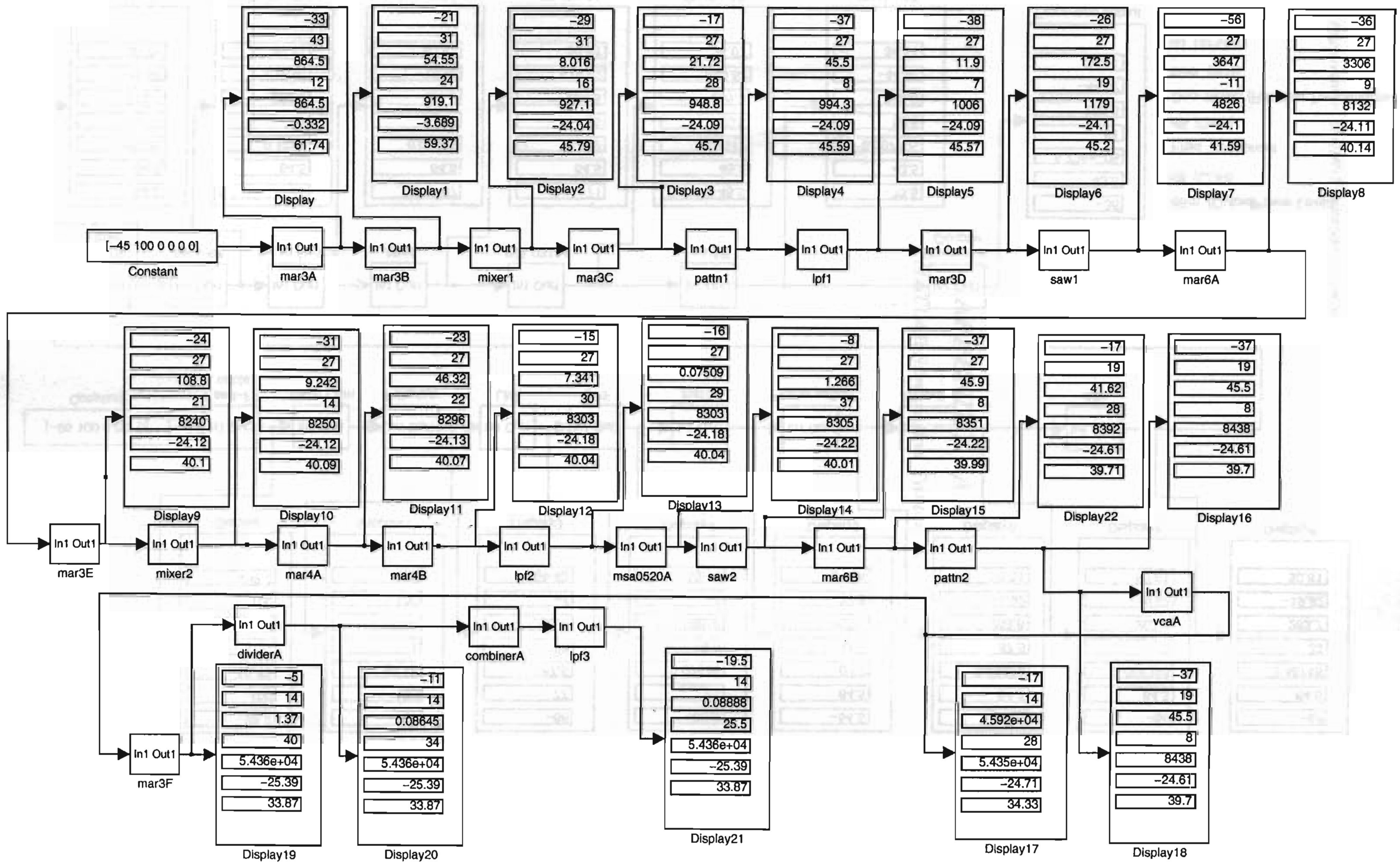
MATLAB Simulation Tables

Existing 150 MHz Front End



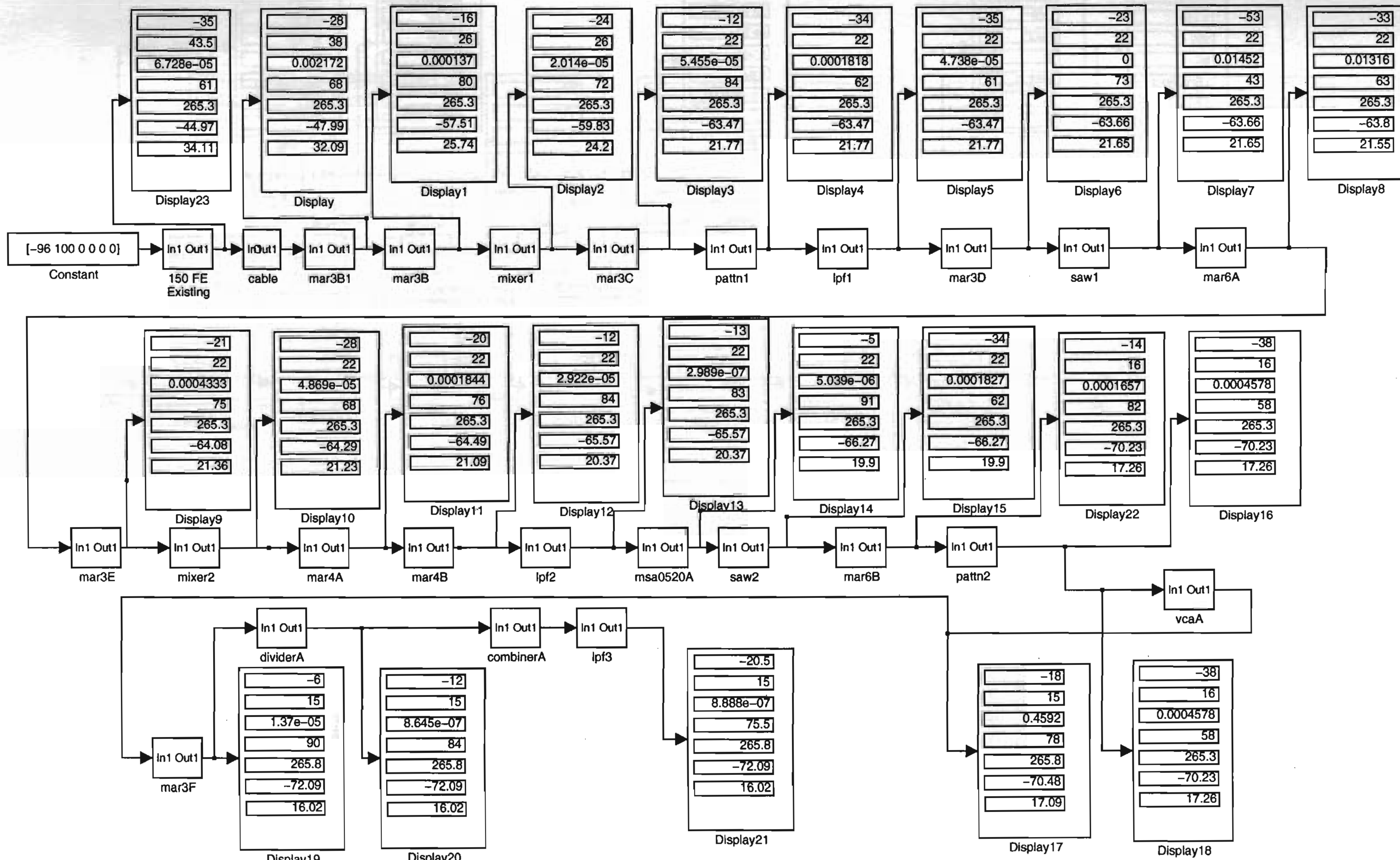
Simulation Table – 2

Existing ABR for 327 MHz band

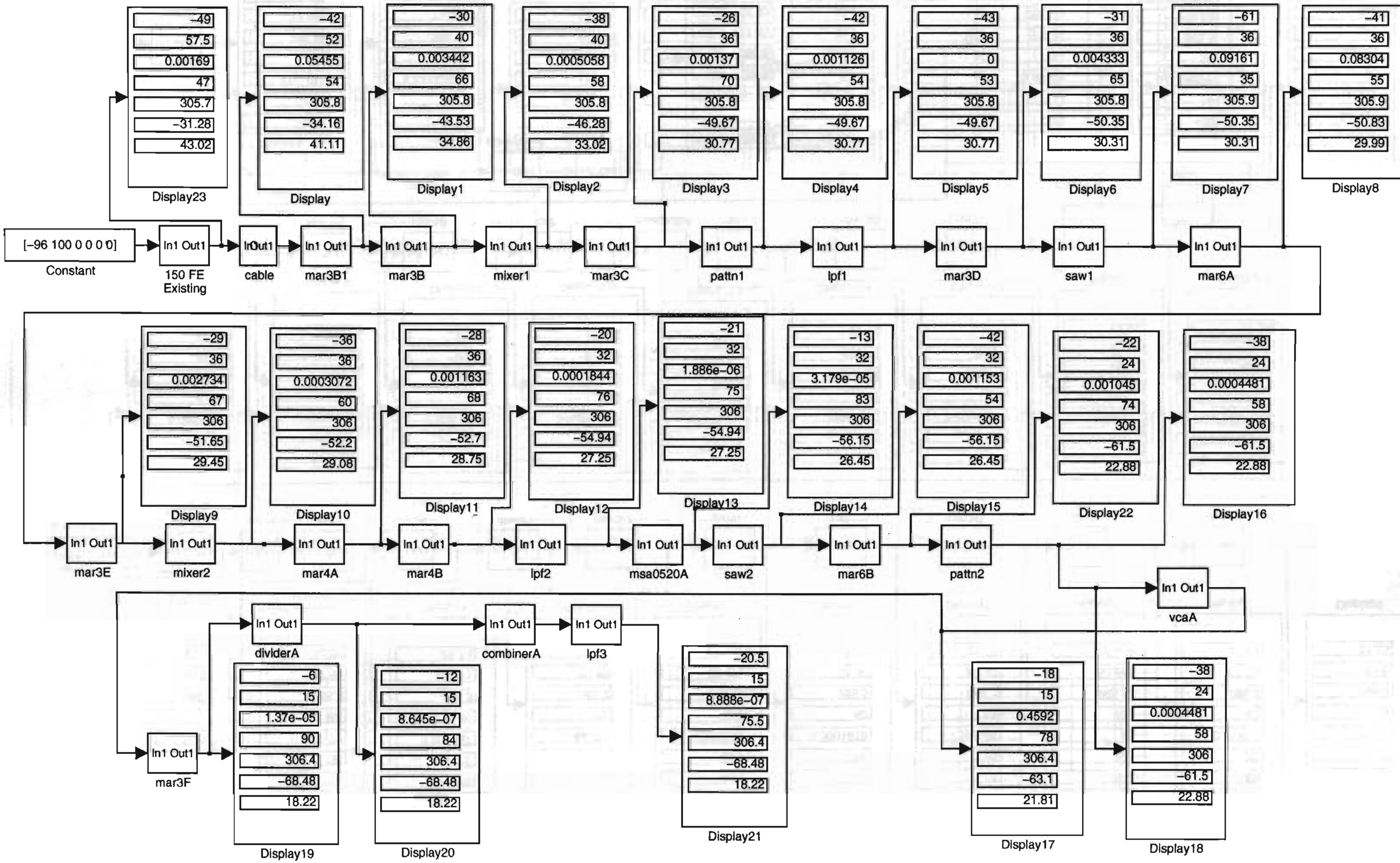


Simulation Table – 3

Existing 150 MHz Receiver

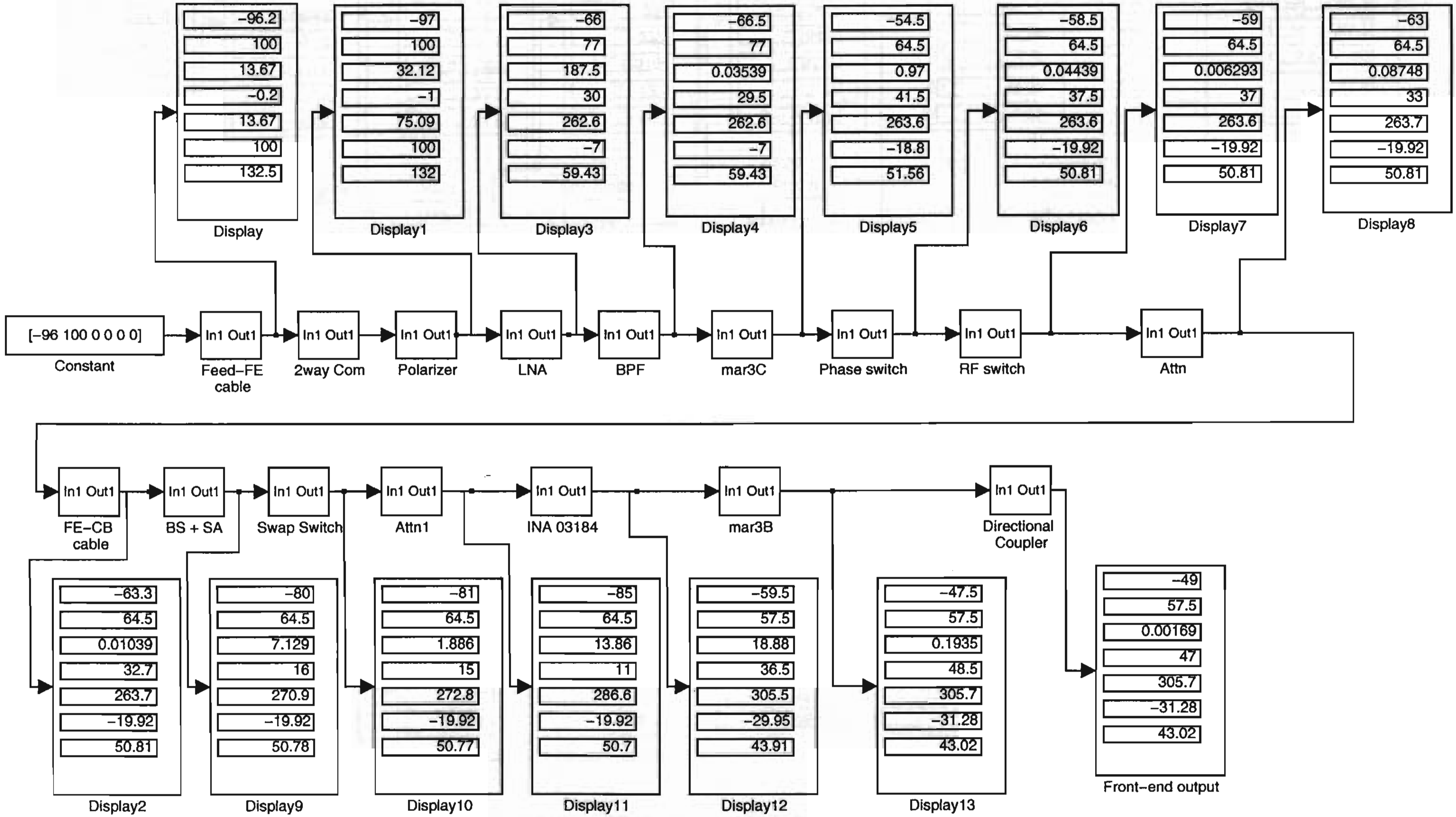


Existing 150 MHz Receiver with 14 dB solar attenuator



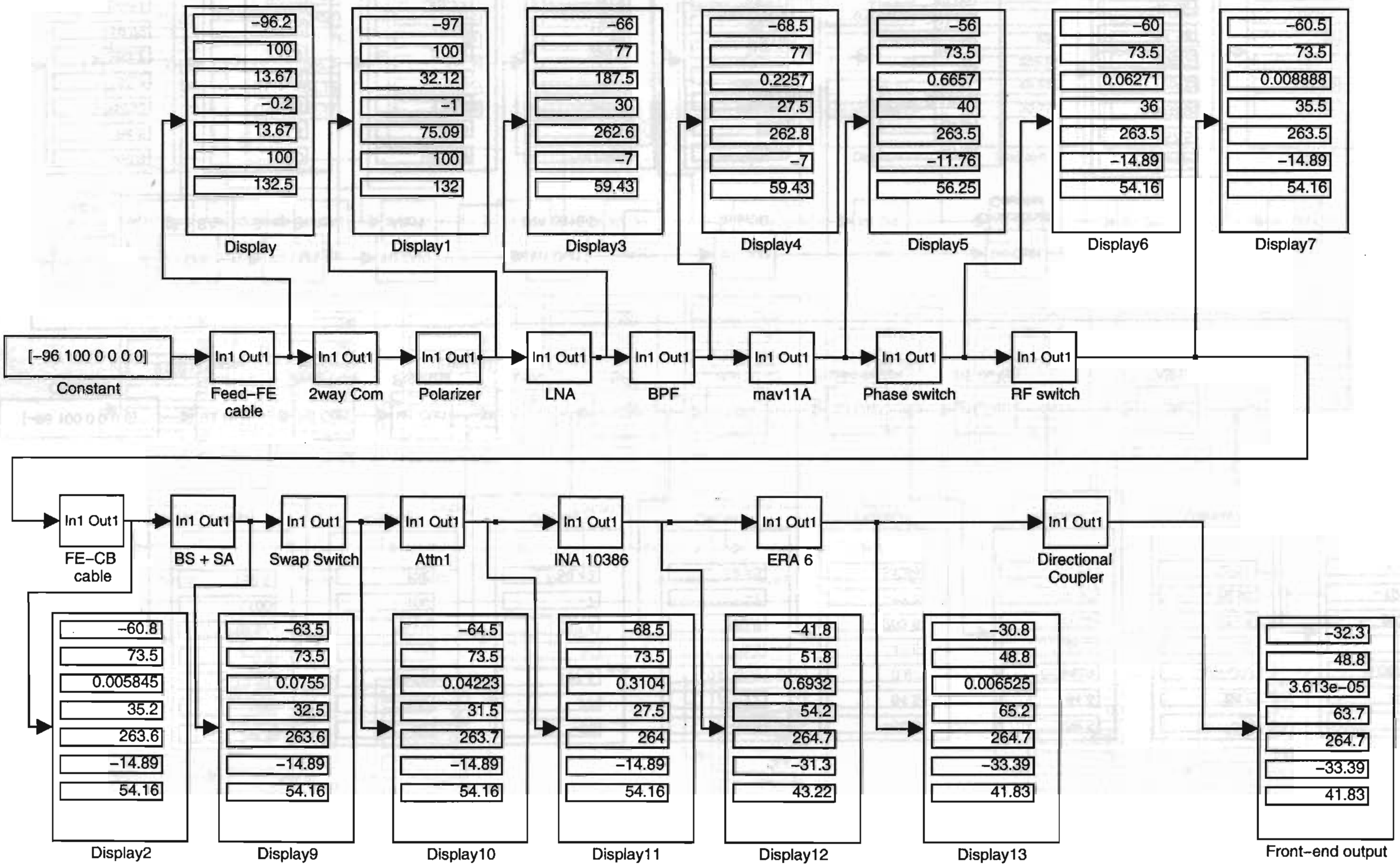
Simulation Table – 5

Existing 150 MHz Front End with 14 dB solar attenuator



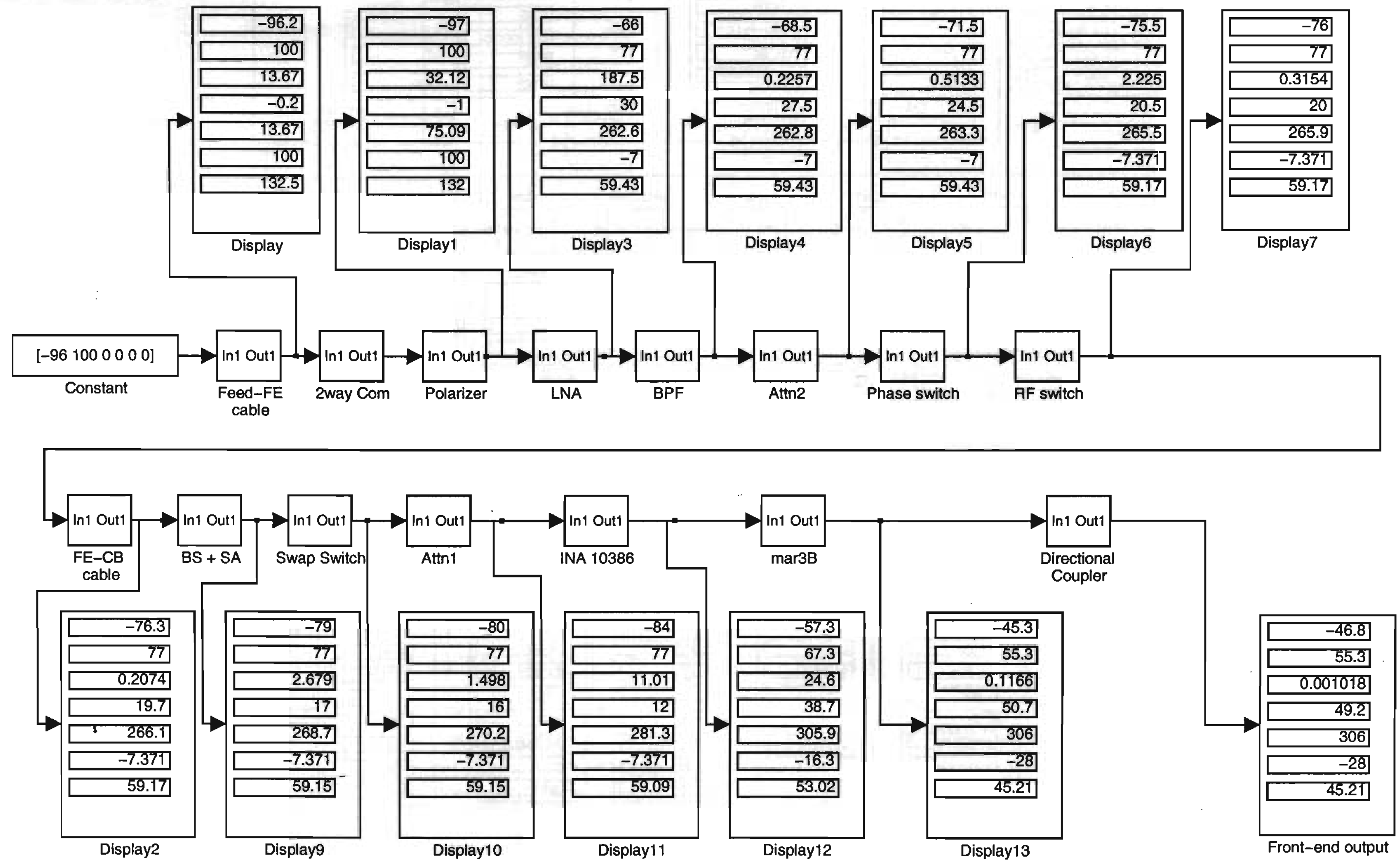
Simulation Table – 6

150 MHz Front End System – Modified for High Dynamic Range and with Multi-Notch Filter



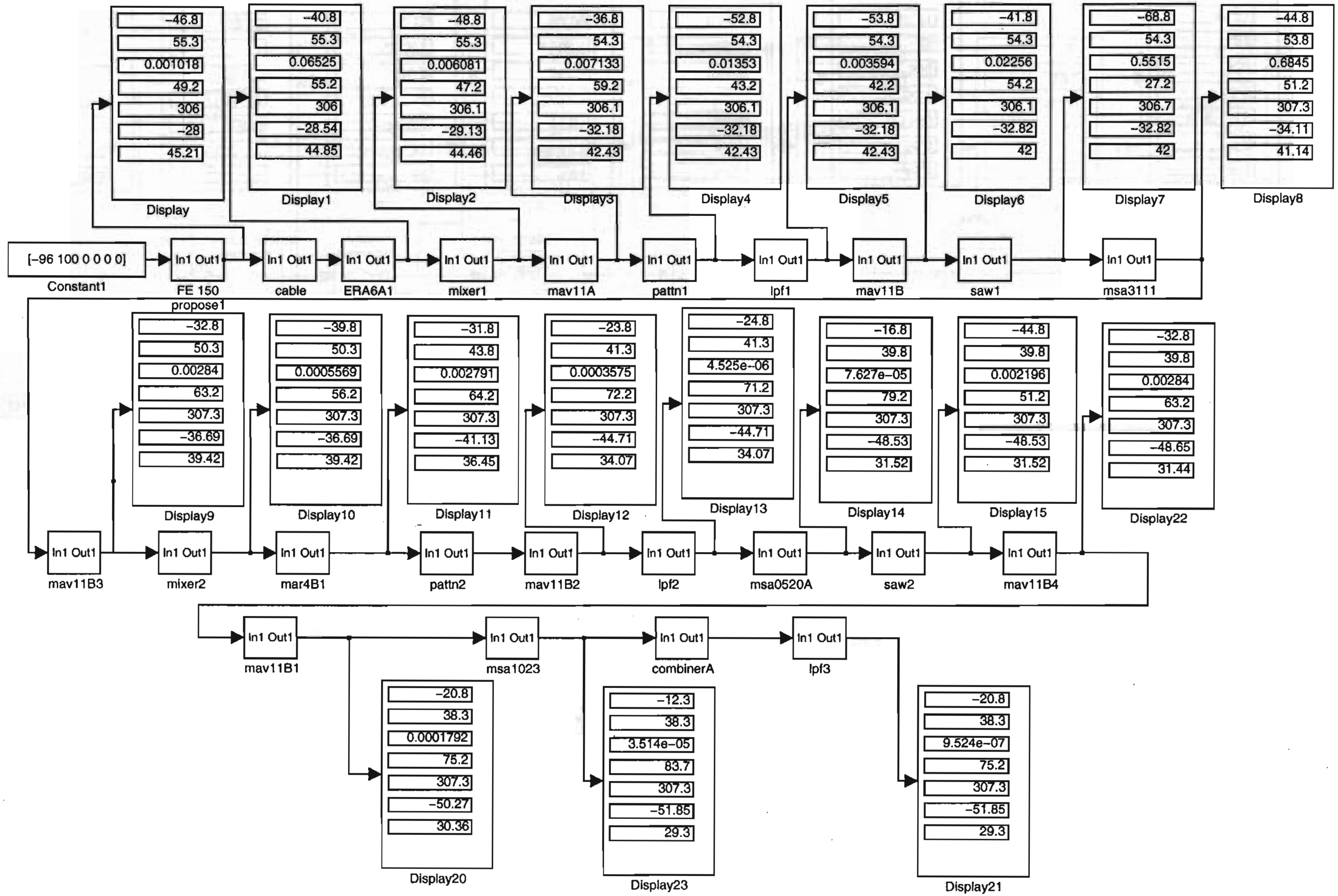
Simulation Table - 6A

150 MHz Front End System - Recently Modified with Multi-Notch Filter



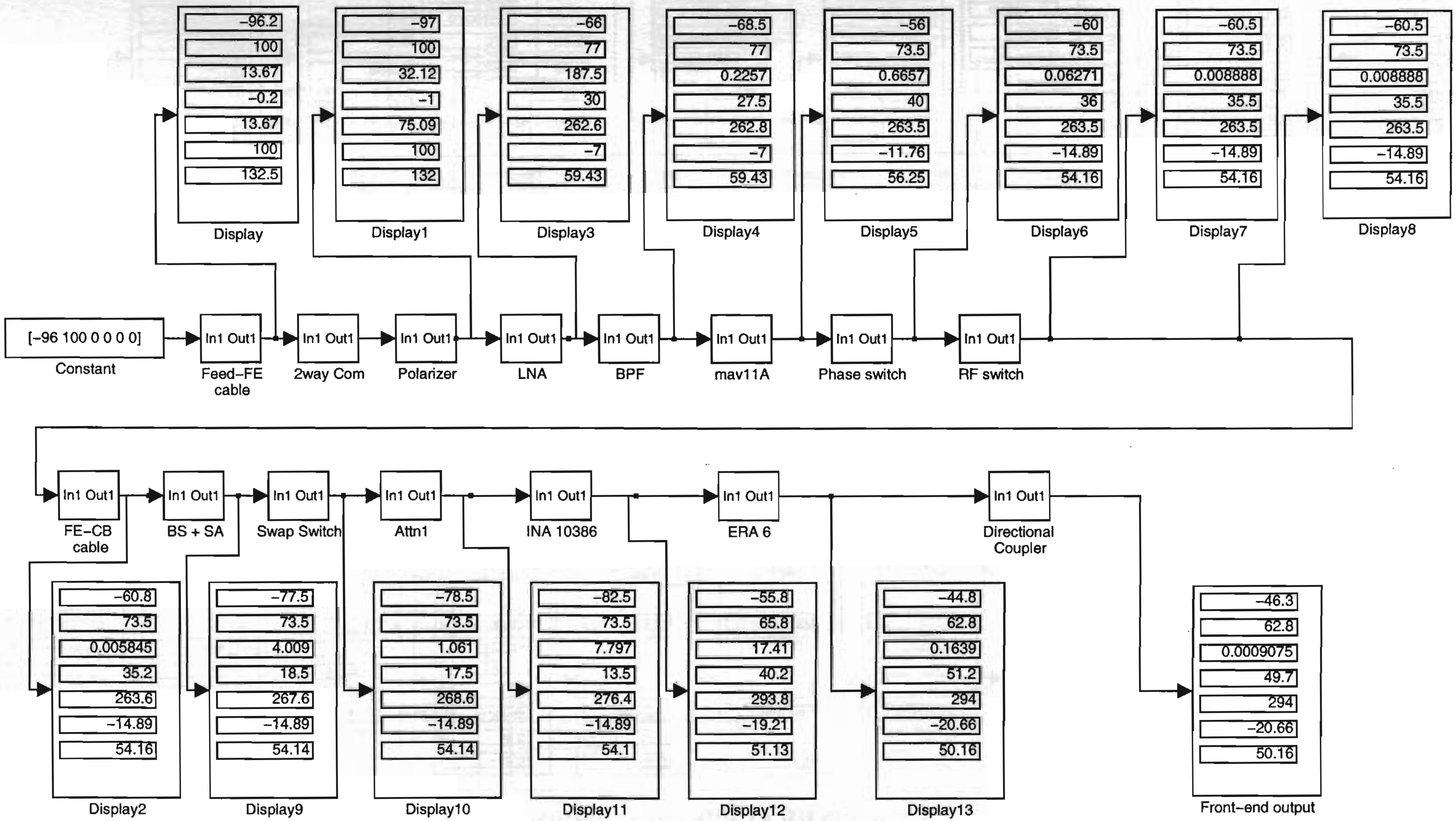
Simulation Table – 7

150 MHz Receiver – Recently Modified with Multi-Notch Filter in the Front End and High Dynamic Range ABR



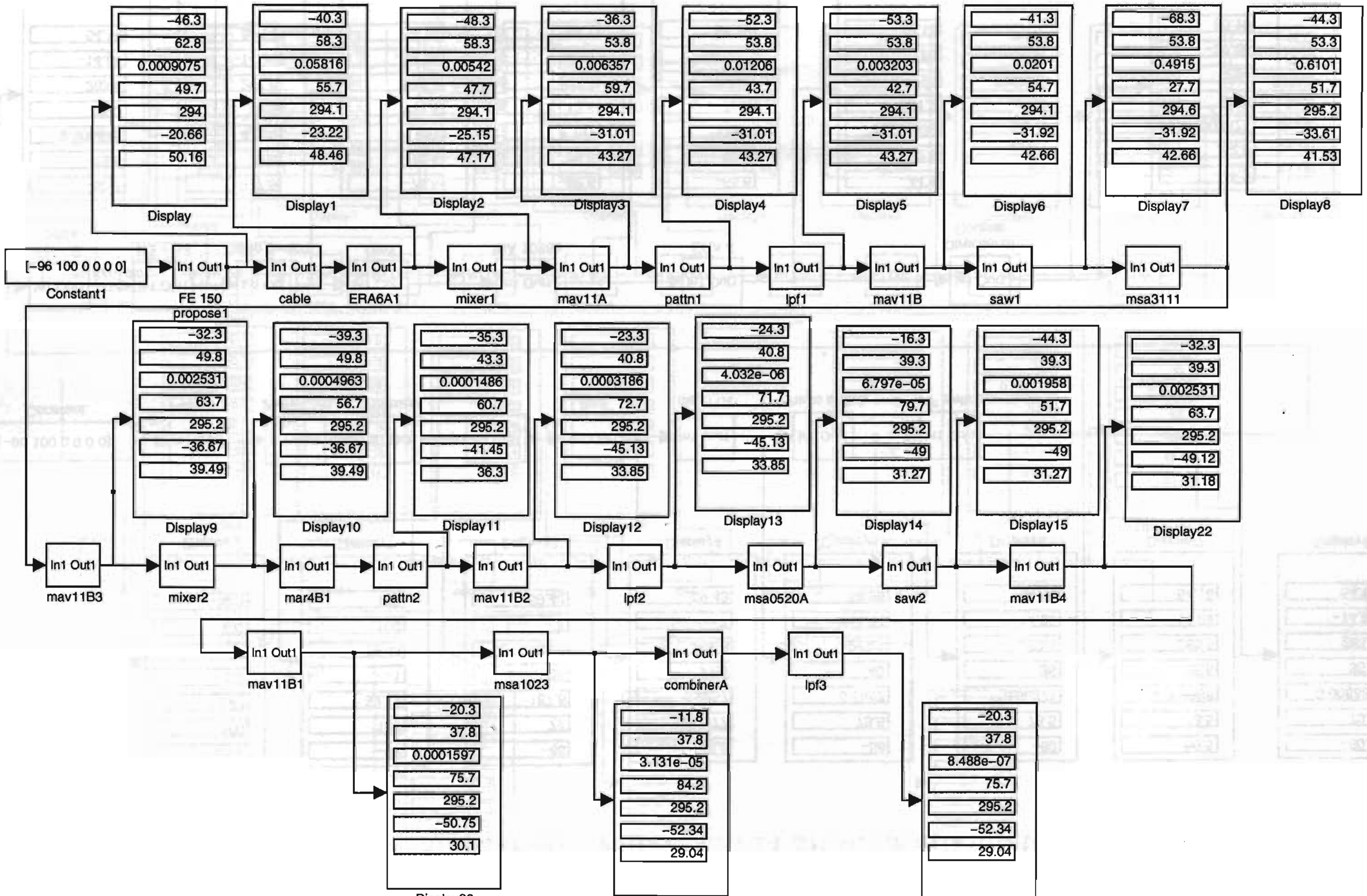
Simulation Table – 8

150 MHz Front End System – Proposed with High Dynamic Range, Multi–notch Filter and 14 dB solar attenuator

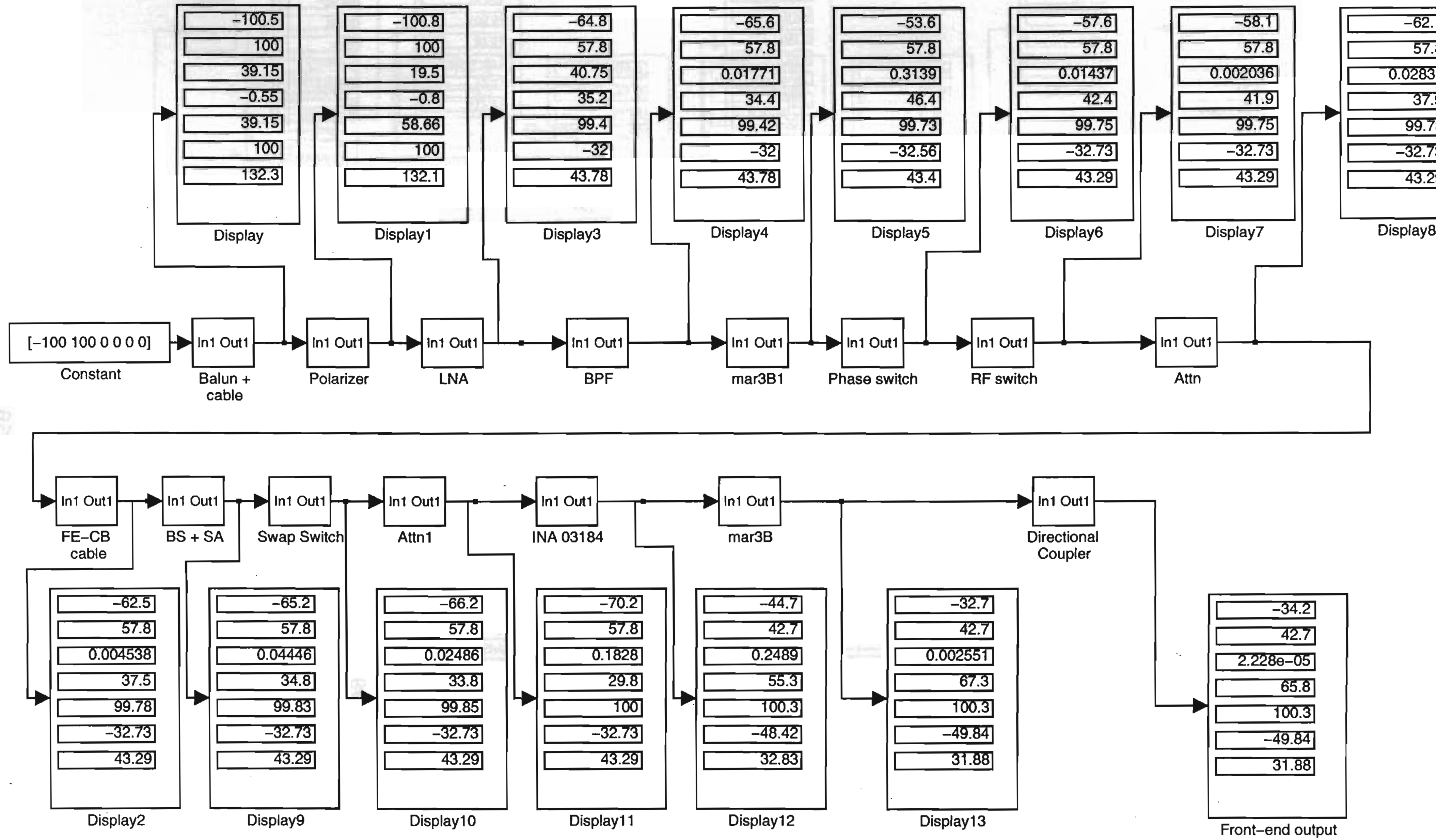


Simulation Table – 9

150 MHz Receiver Chain – Proposed with High Dynamic Range, Multi-Notch Filter and 14 dB solar Attenuator



Existing 235 MHz Front End



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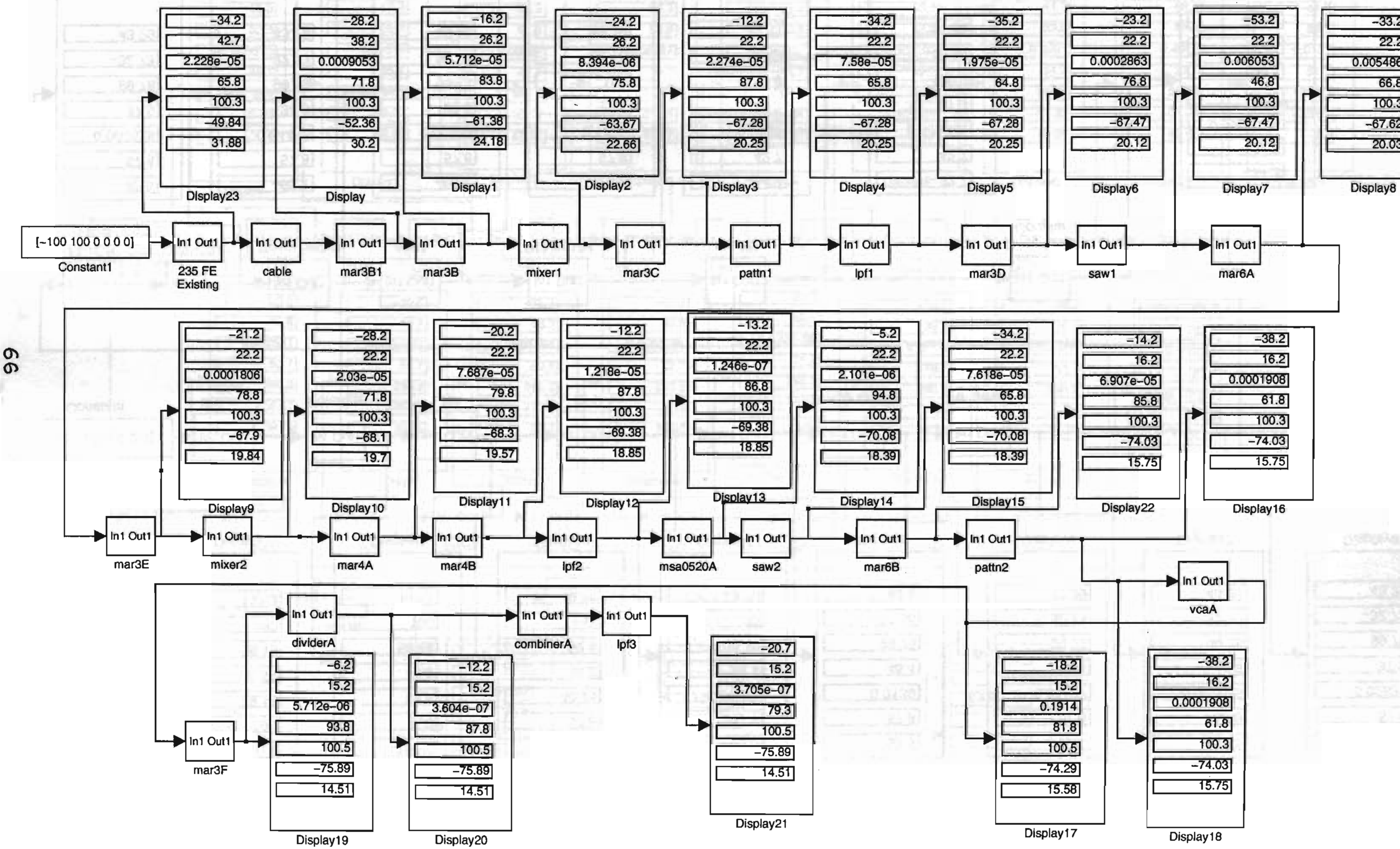
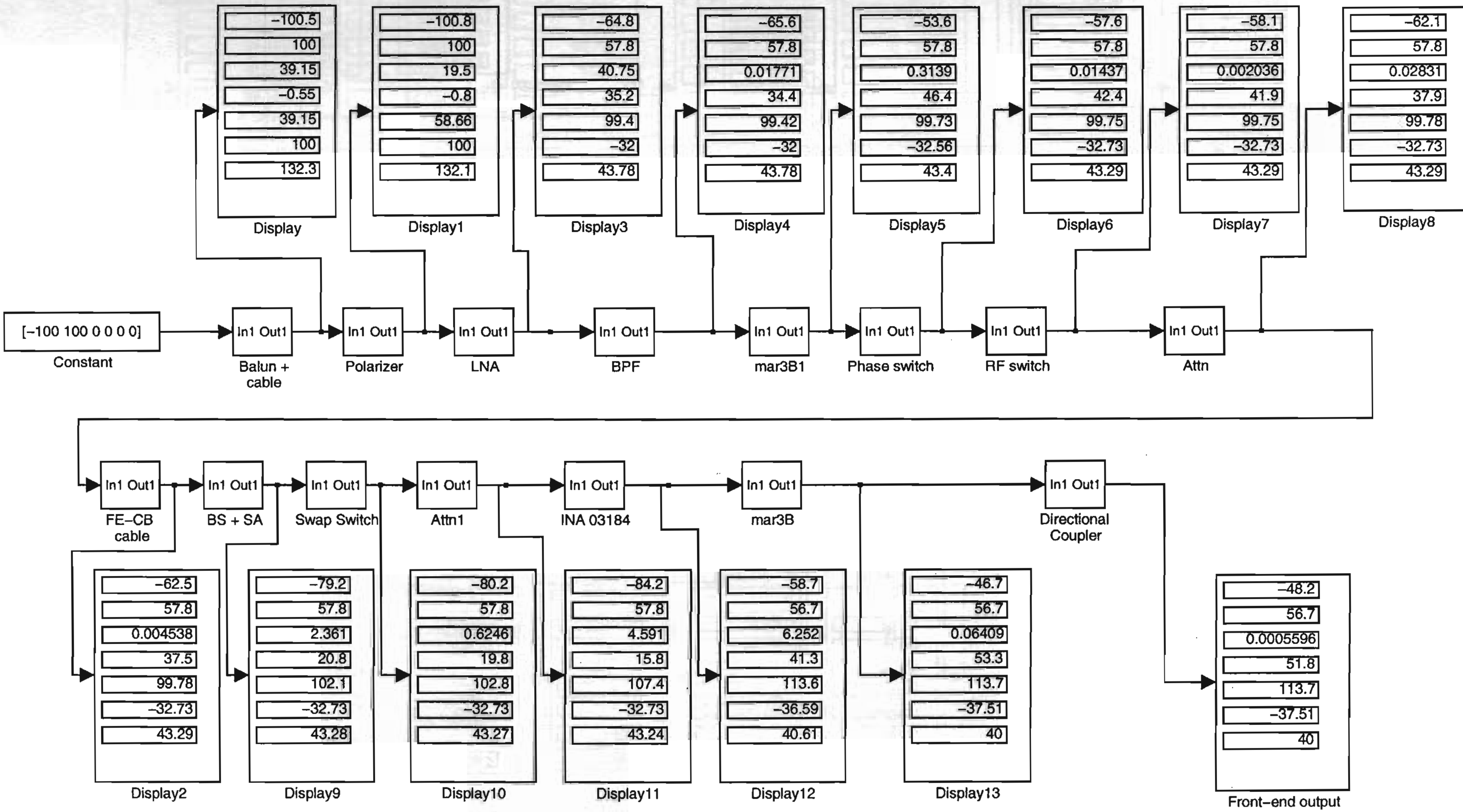
Simulation Table – 11

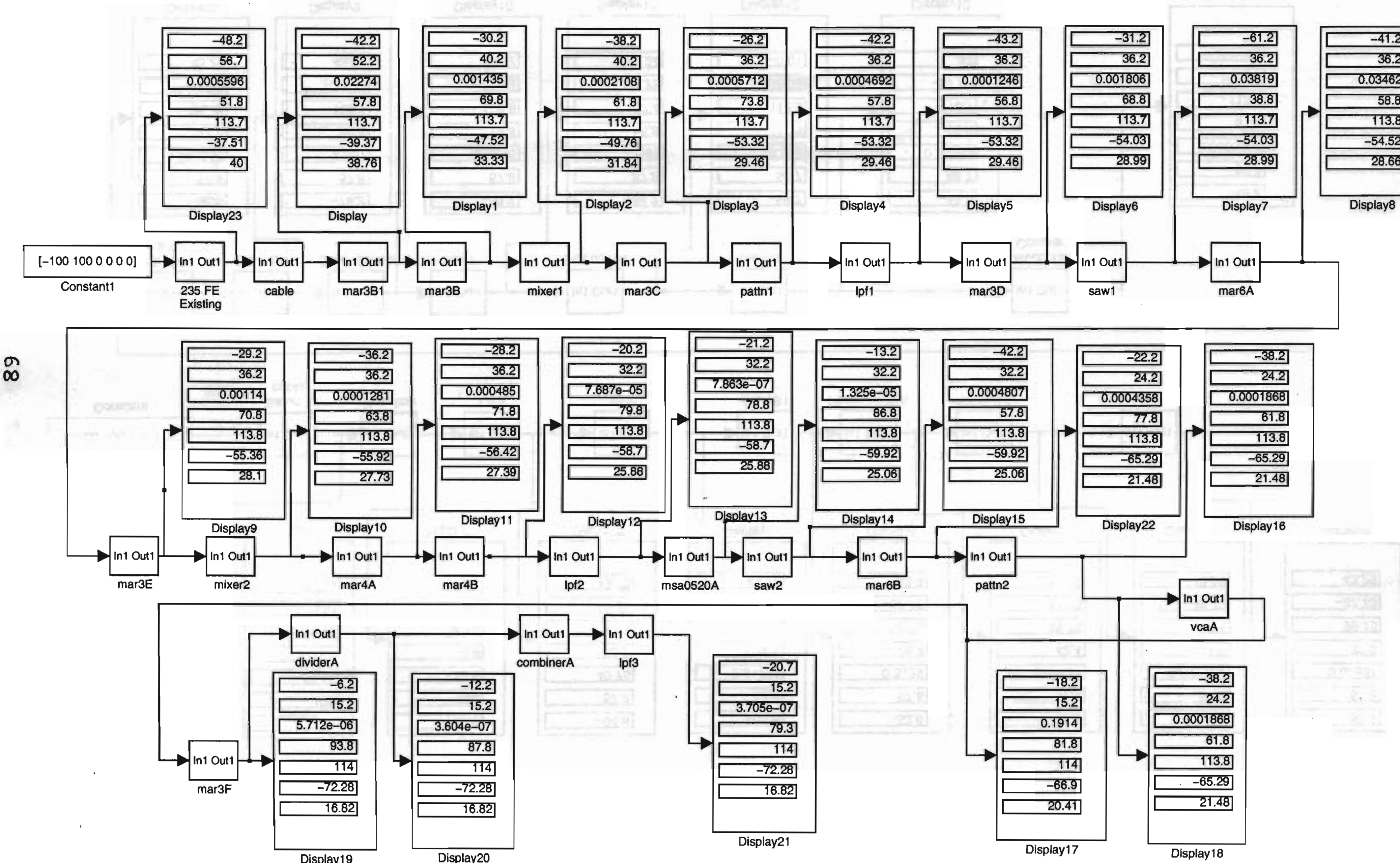
Existing 235 MHz Receiver



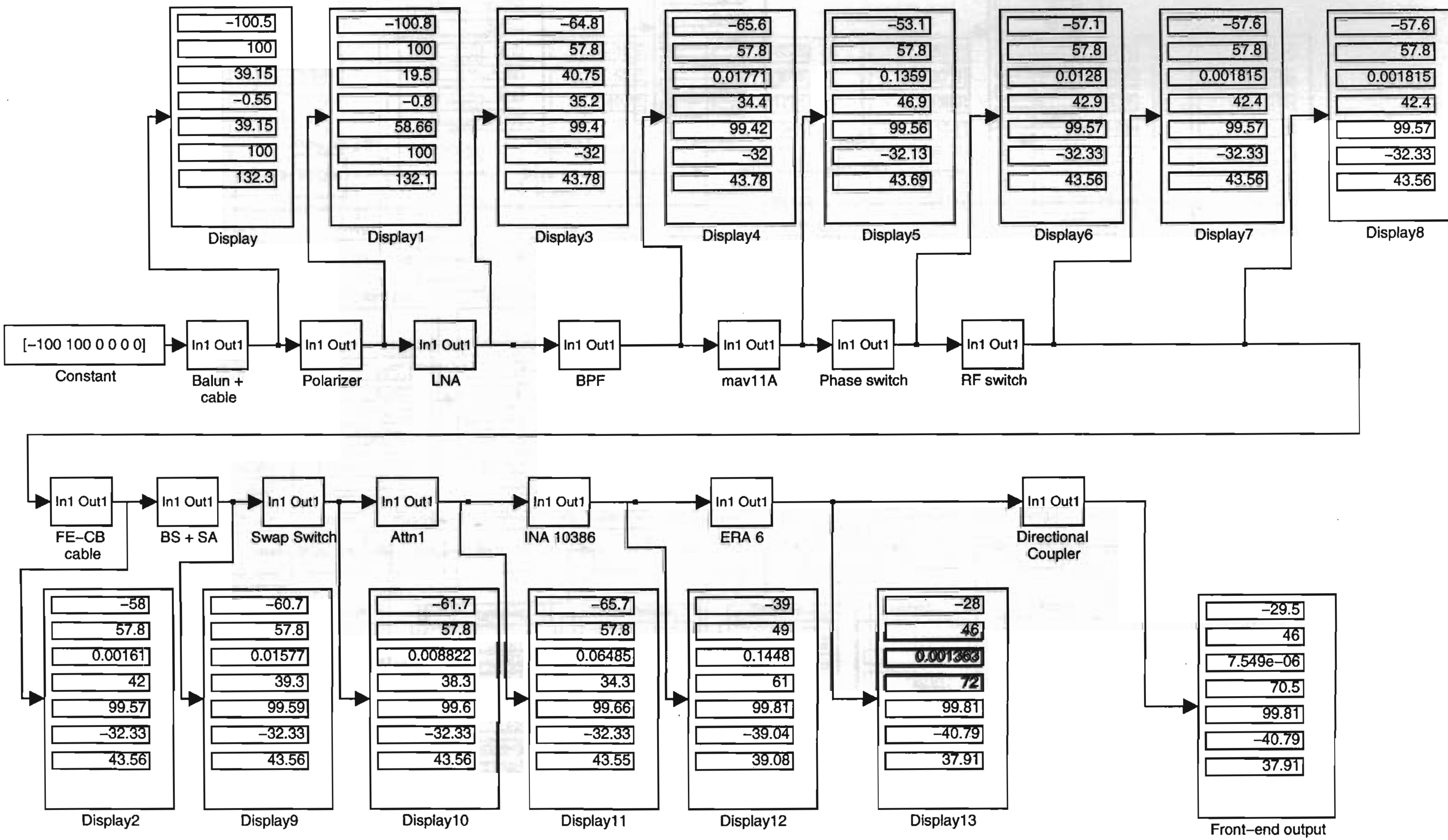
Existing 235 MHz Front End with 14 dB solar attenuator



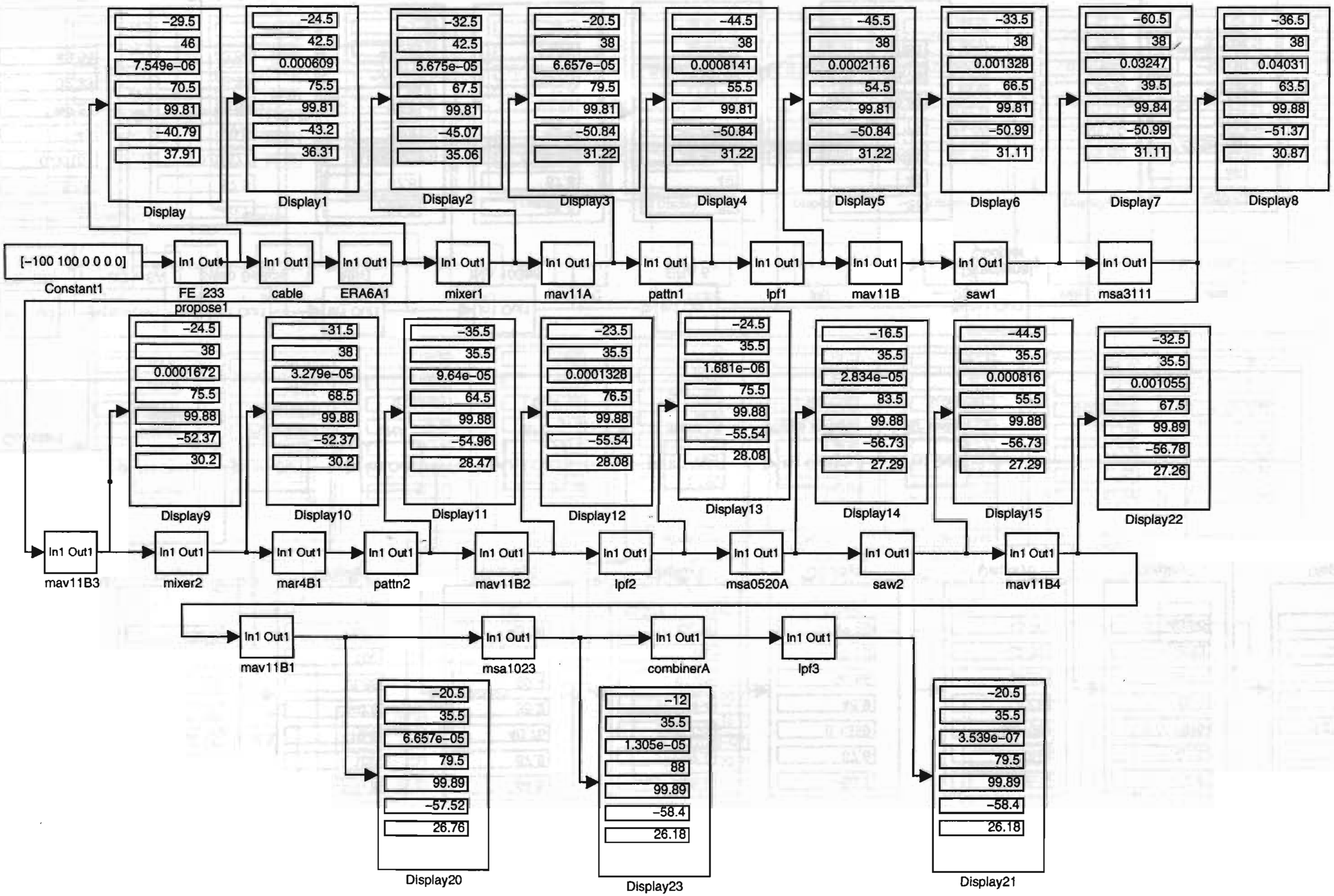
Existing 235 MHz Receiver with 14 dB solar attenuator



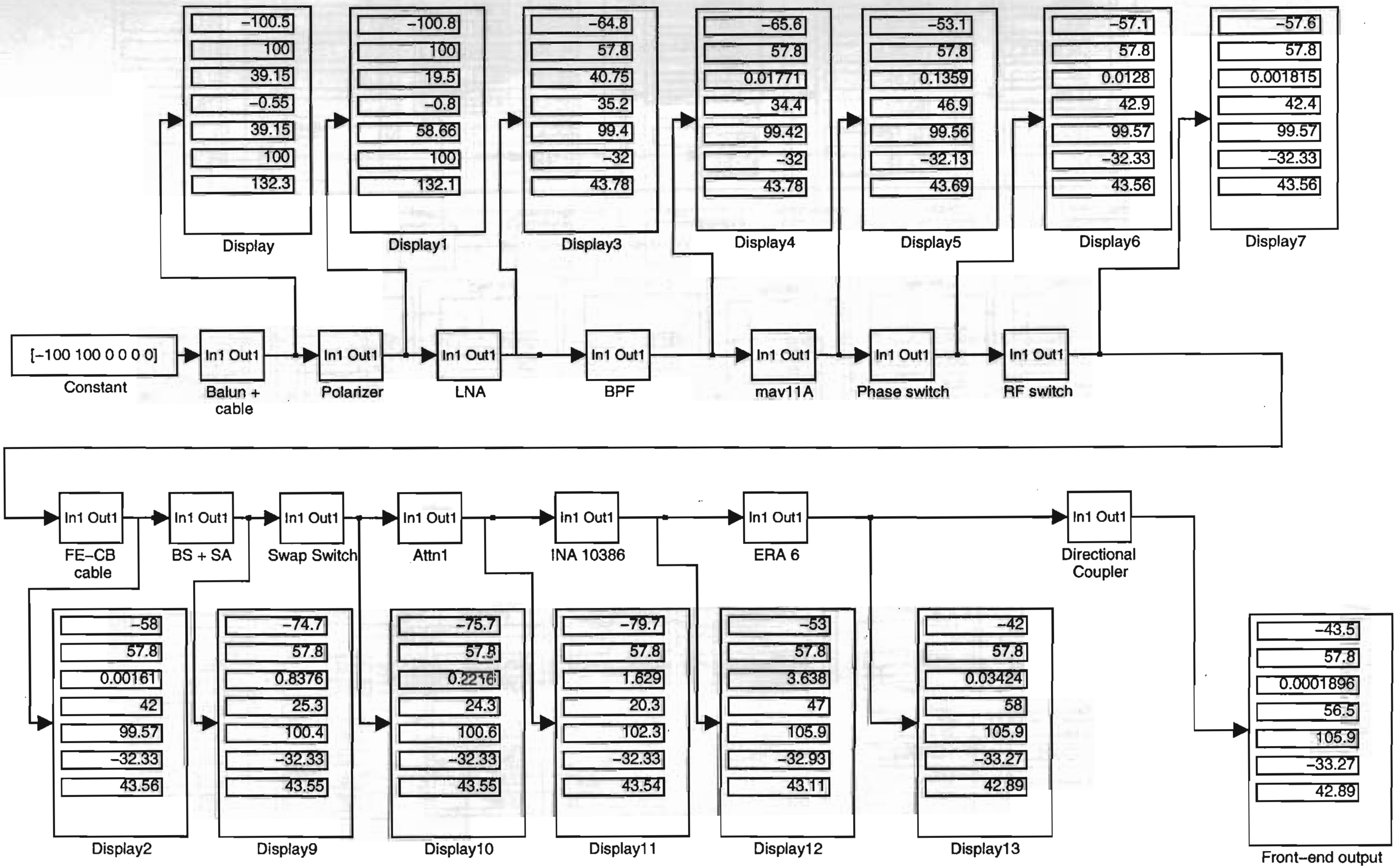
233 MHz Front End System – Proposed for High Dynamic Range



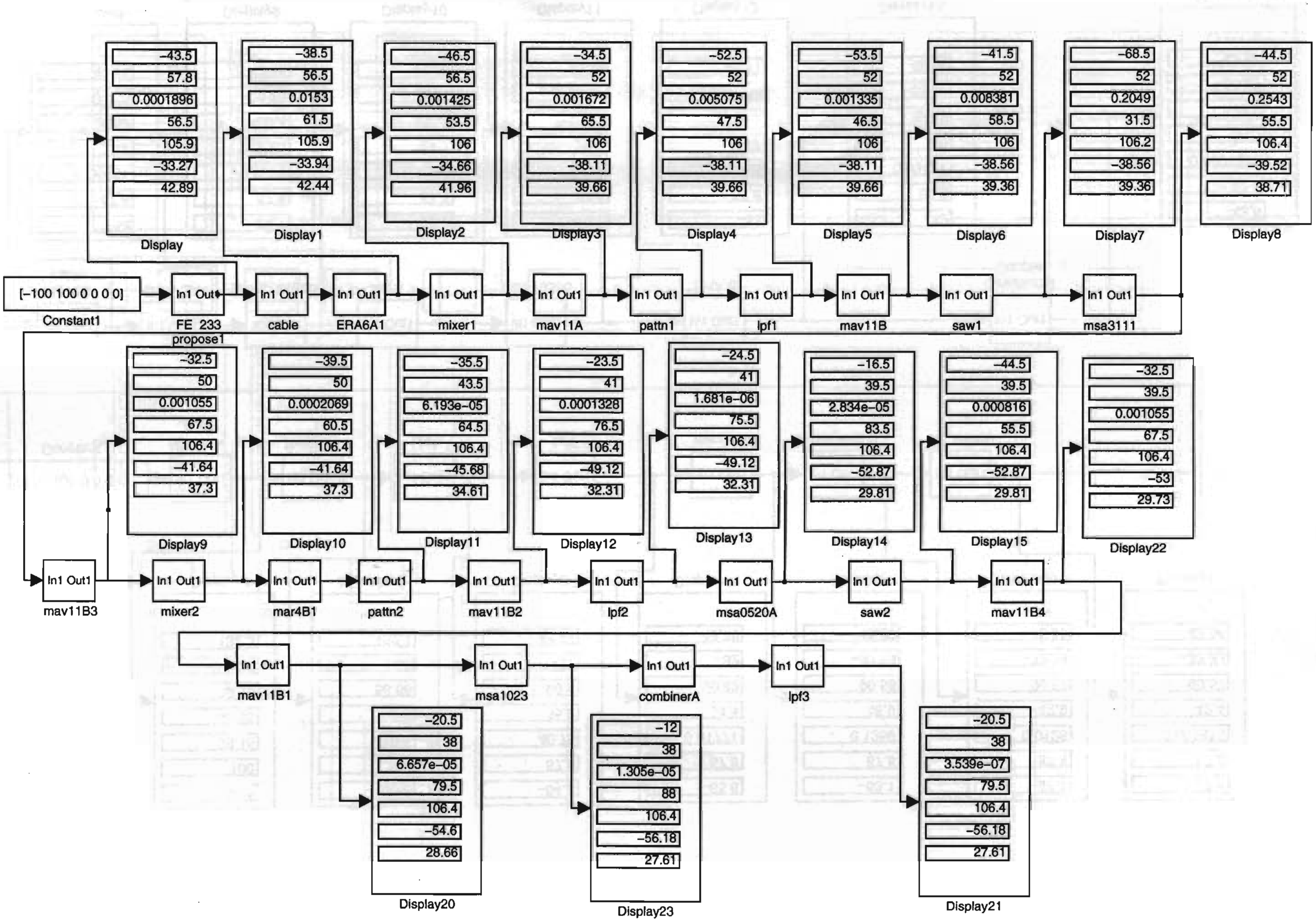
233 MHz Receiver – Proposed for High Dynamic Range



233 MHz Front End System – Proposed for High Dynamic Range with 14 dB Solar Attenuator

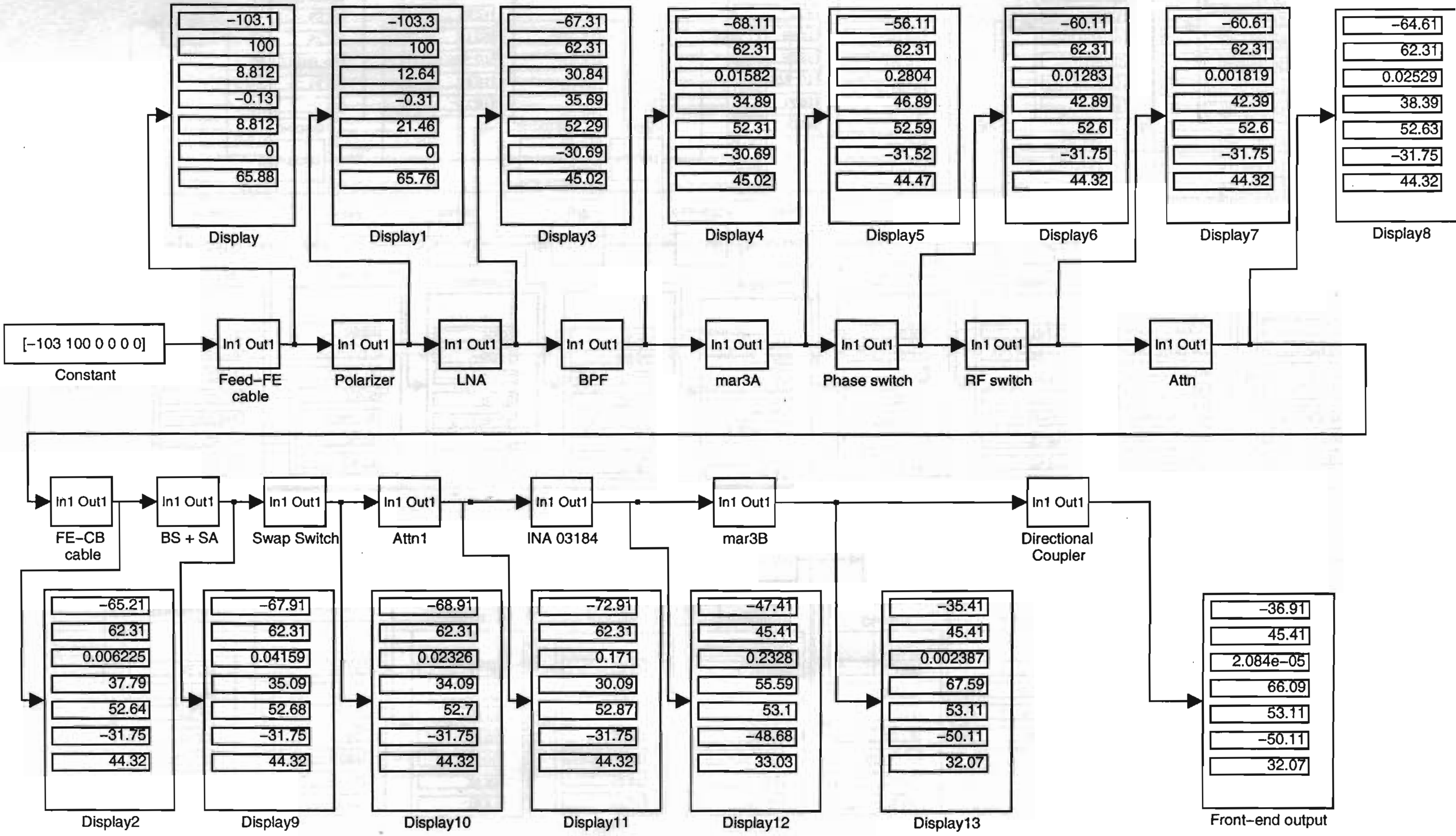


233 MHz Receiver – Proposed for High Dynamic Range with 14 dB Solar Attenuator



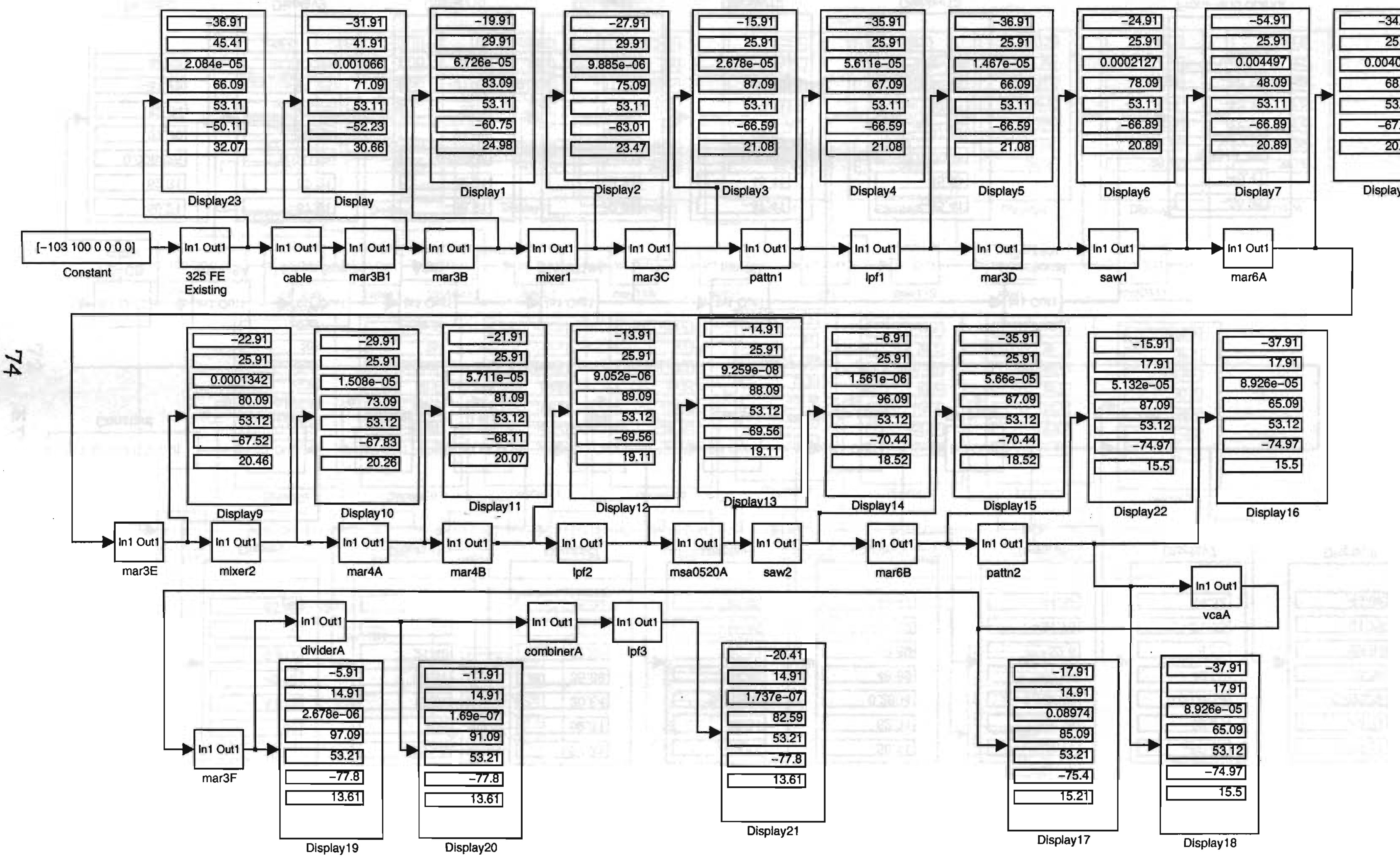
Simulation Table - 18

Existing 327 MHz Front End

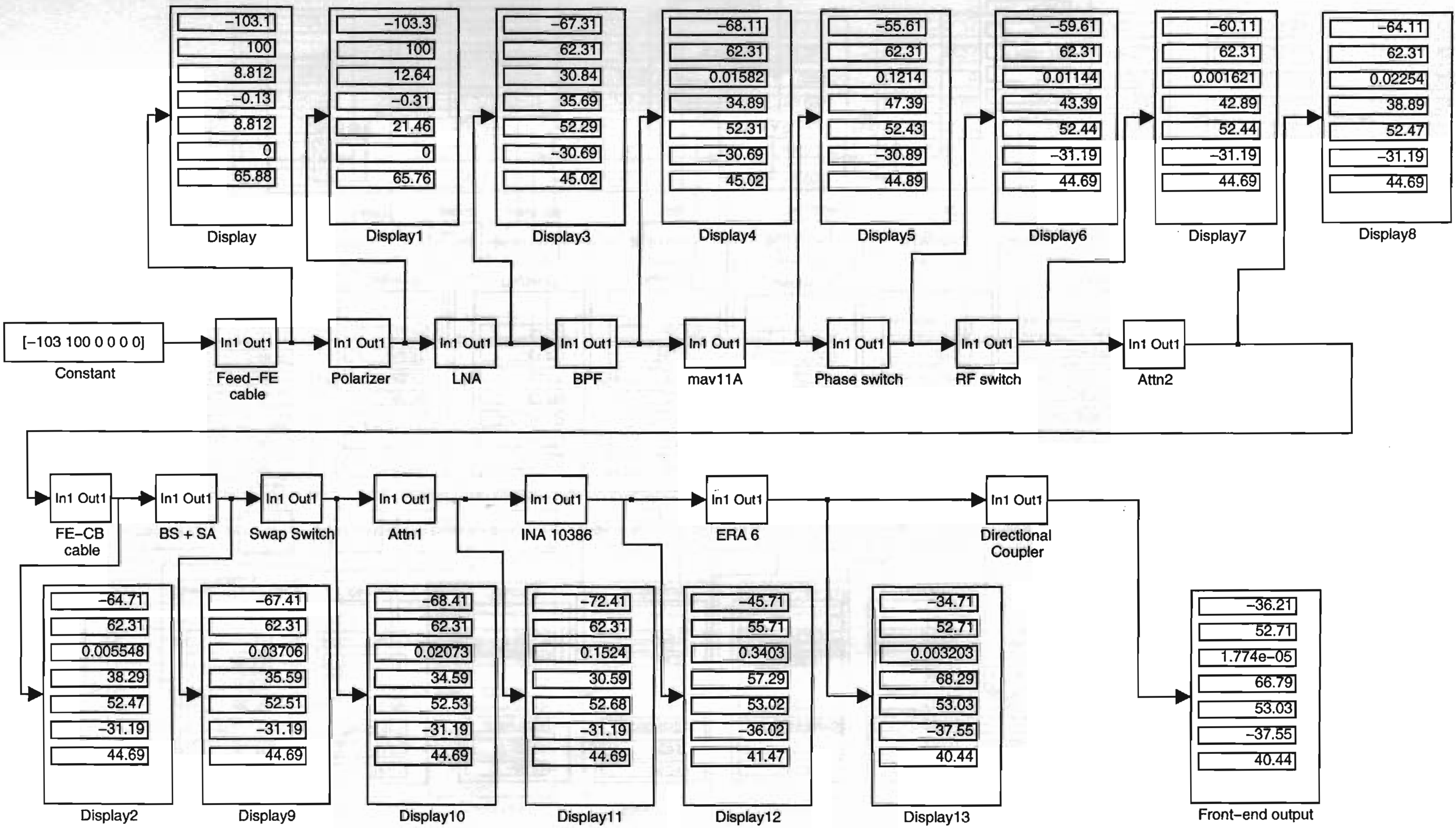


Simulation Table – 19

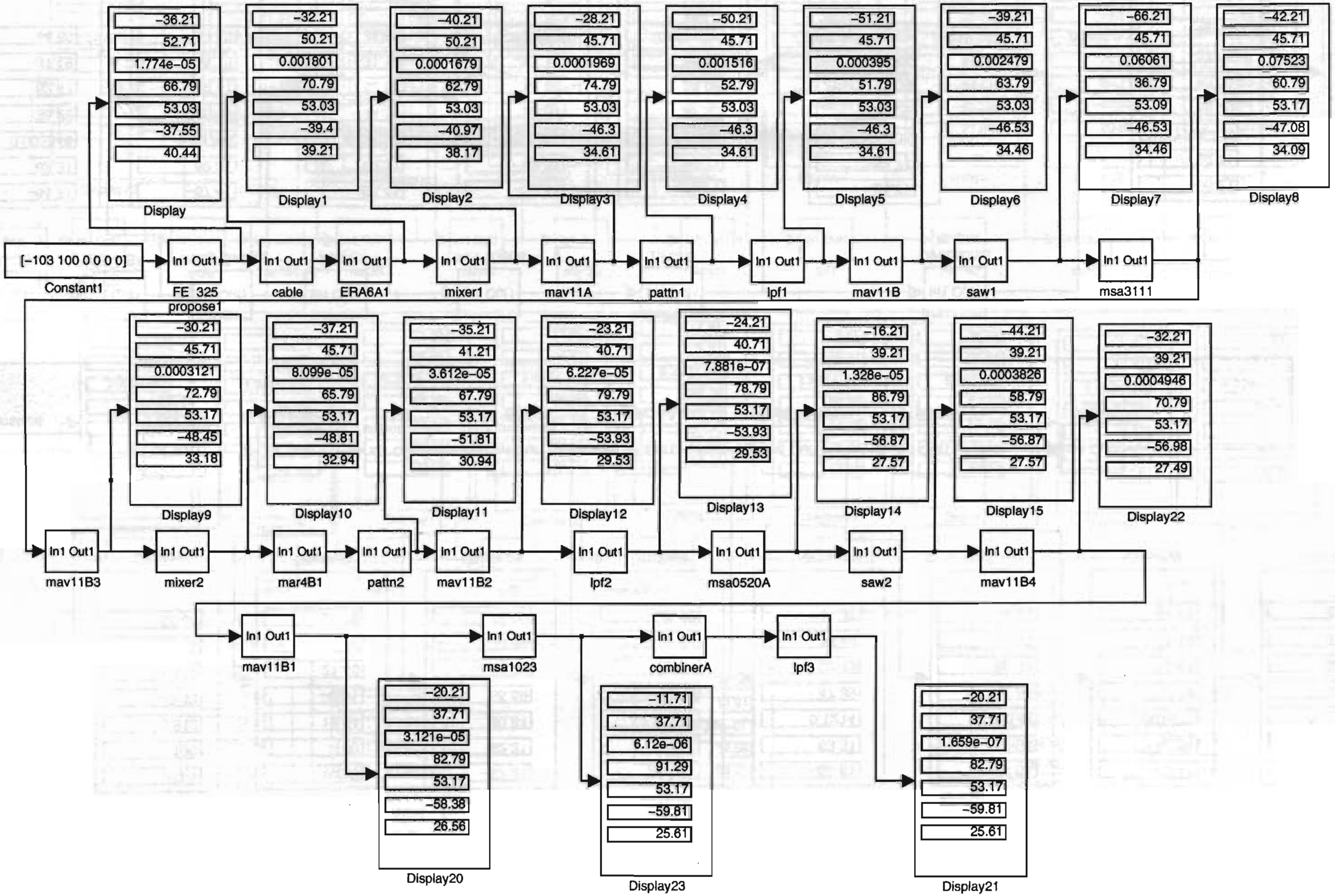
Existing 327 MHz Receiver



327 MHz Front End - Proposed for High Dynamic Range

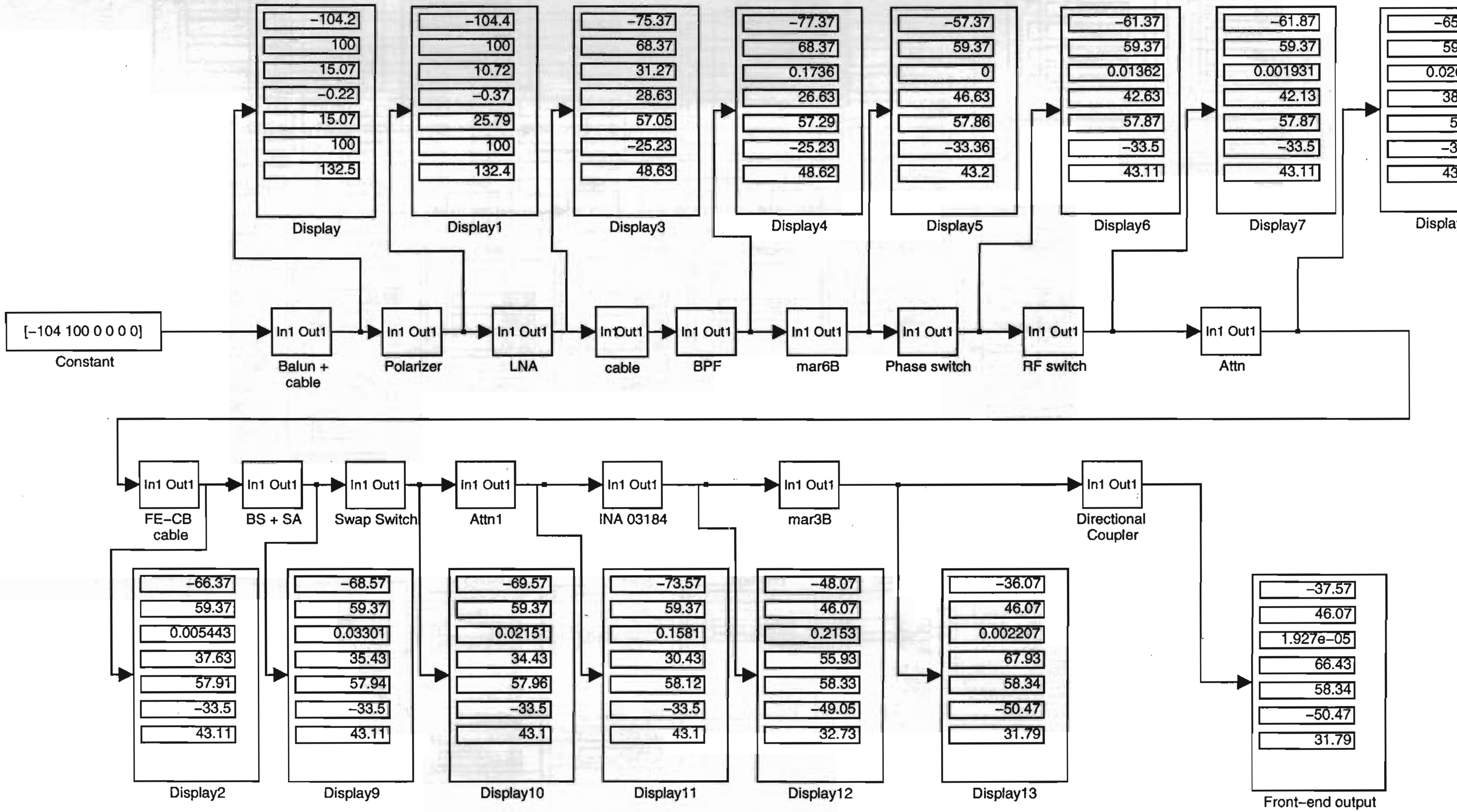


325 MHz Receiver – Proposed for High Dynamic Range

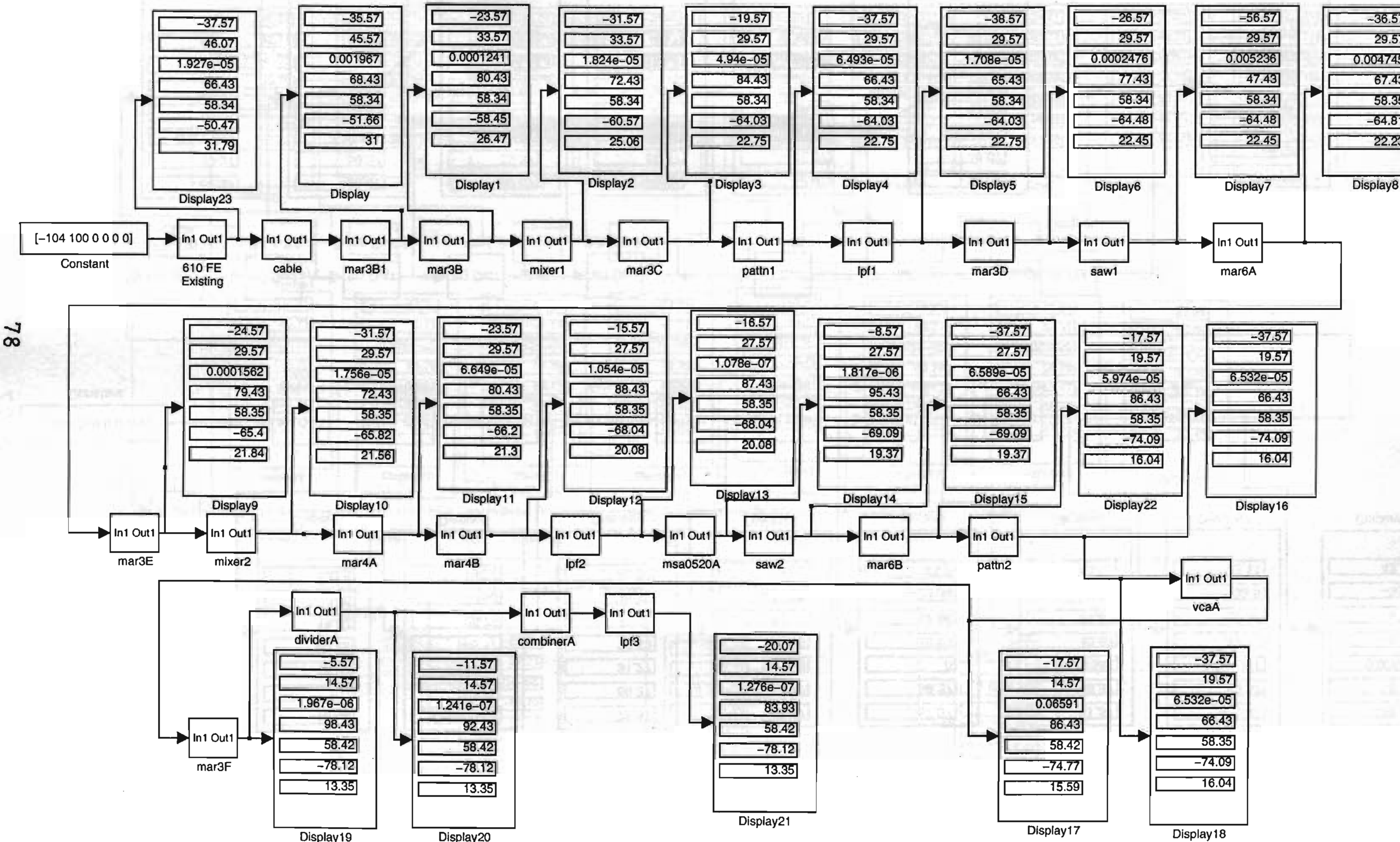


Simulation Table – 22

Existing 610 MHz Front End



Existing 610 MHz Receiver



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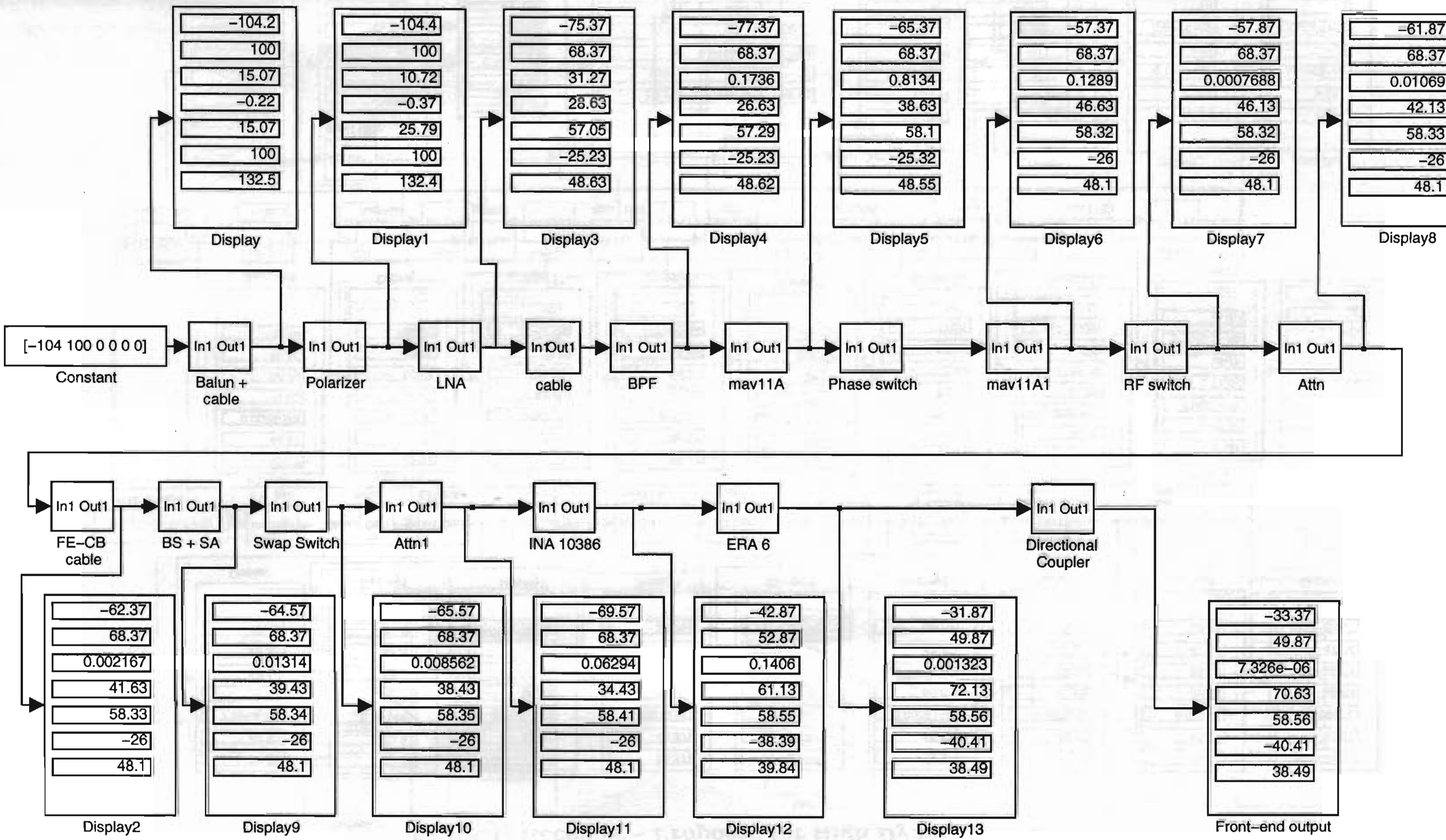
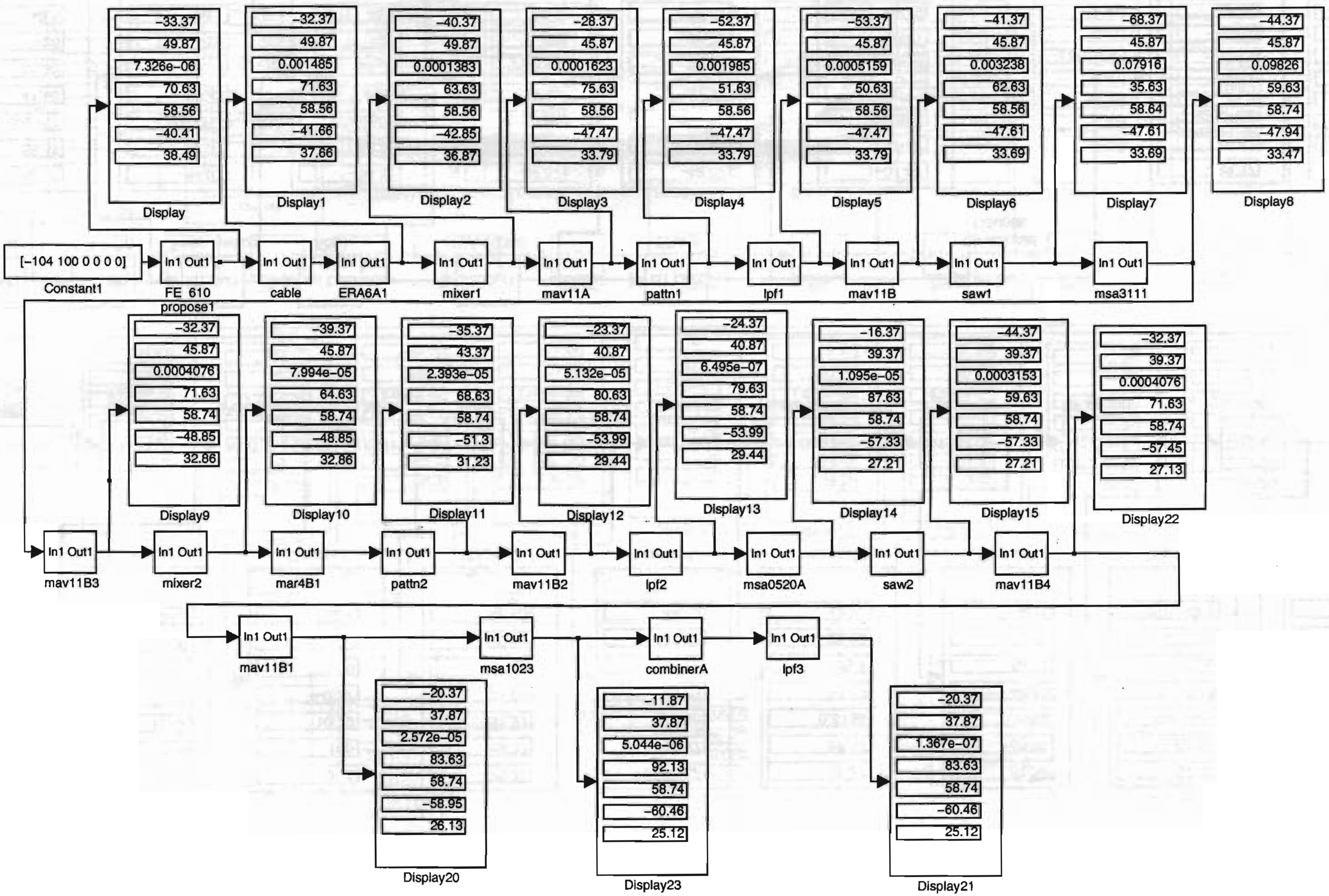
610 MHz Front End – Proposed for High Dynamic Range

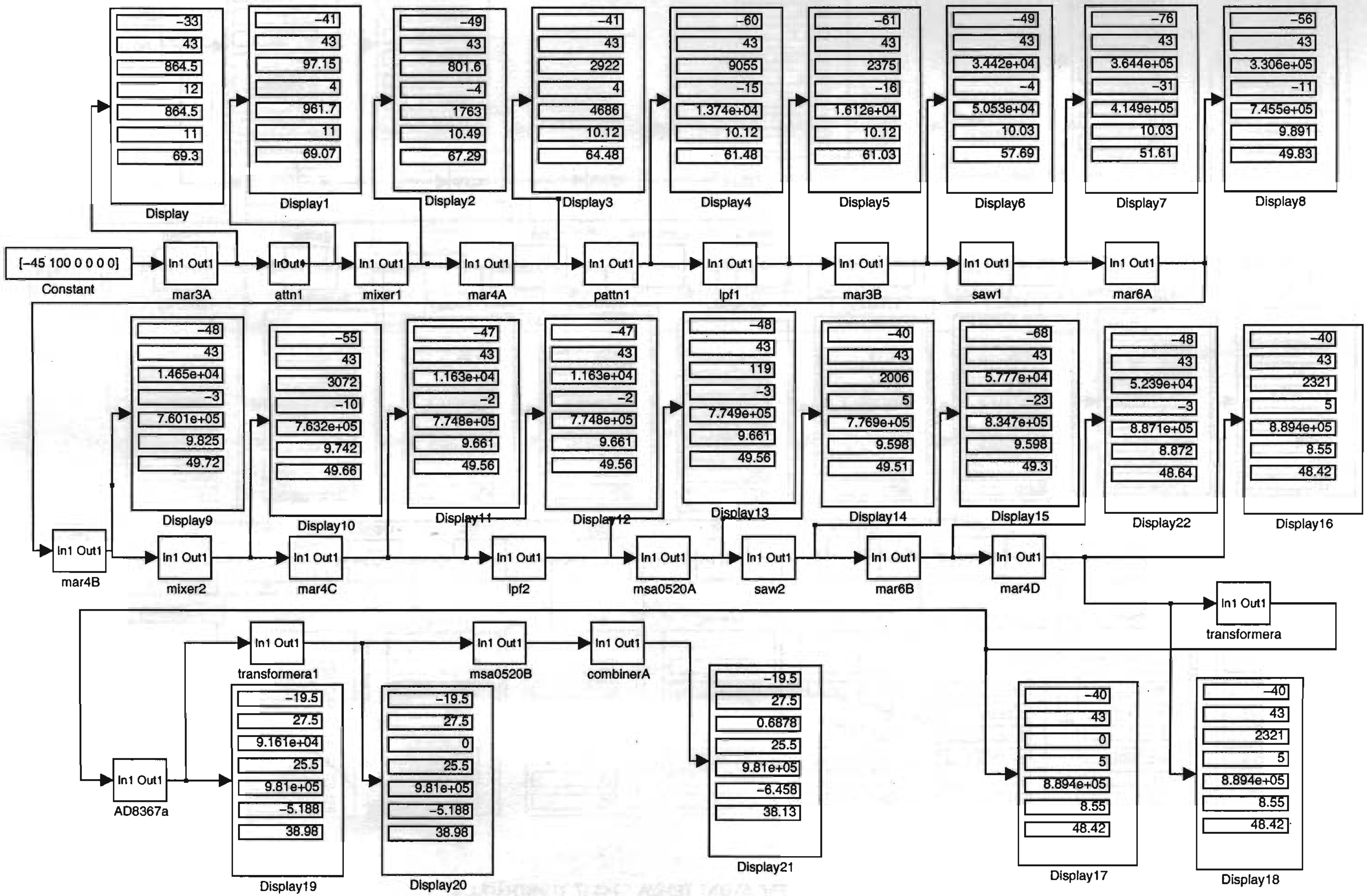


Simulation Table – 25

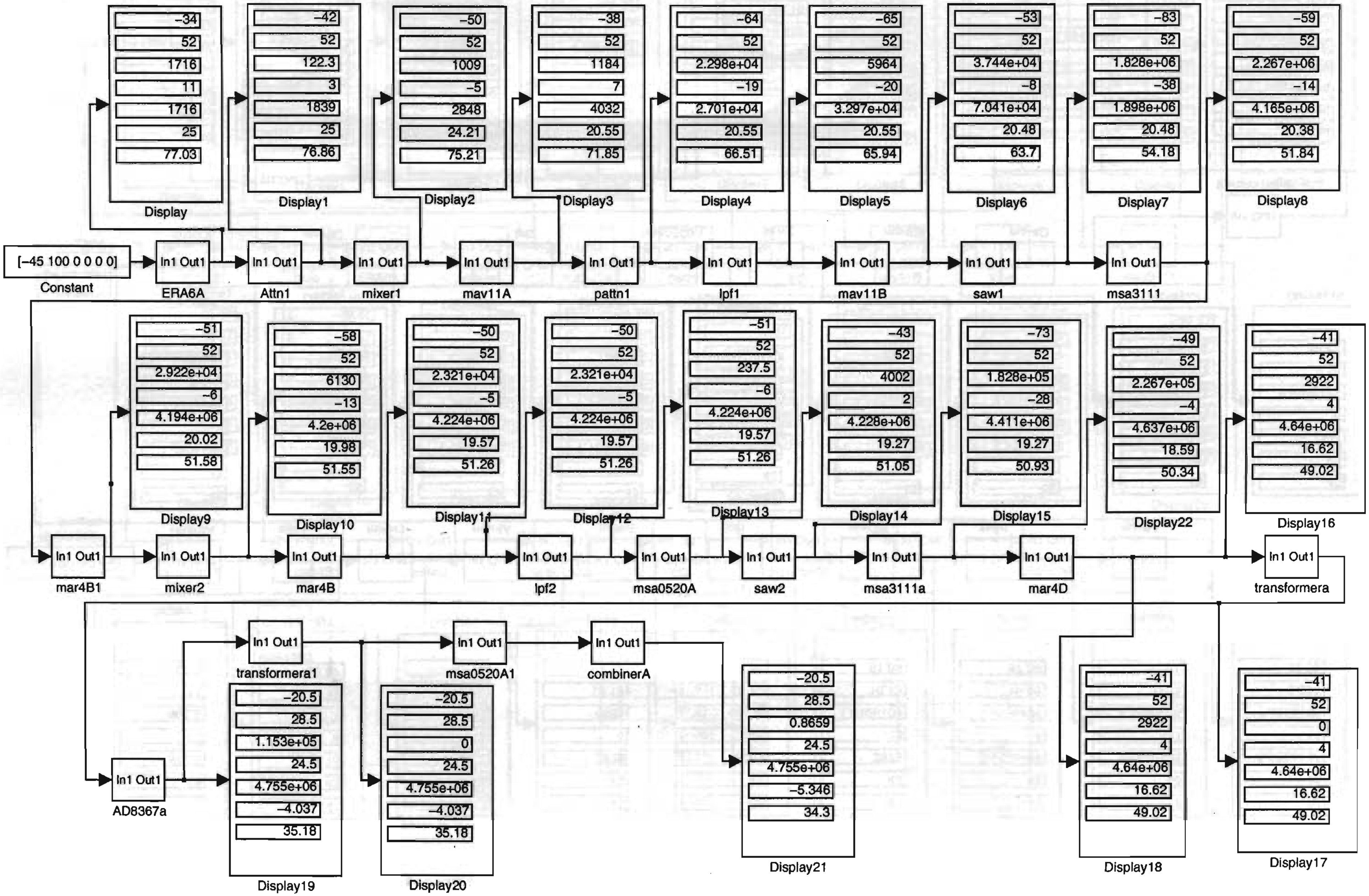
610 MHz Receiver – Proposed for High Dynamic Range



Existing ABR with New ALC for 327 MHz



Proposed ABR with New ALC for 327 MHz



Simulation Table – 28

Proposed ABR without ALC for 327 MHz