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SKA RF-IF Architecture Memo
A Procedure in Excel™ for Analysis of RF/ IF Architecture

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Version History

Nr.	Date	Changes
0.9	Jan 30, 1998	Draft Creation
0.99	Feb 03, 1998	Release for discussions in RF/ IF Meeting #13 on Feb 5, 98
1.0	Feb 11, 1998	Release
1.99	Nov 4, 1998	Revision based on RF/ IF meetings #14 to #30
2.0	Nov 10, 1998	Release

1 Goal

The aim is to create a simple computer-aided procedure for speedy analysis of RF/ IF architecture, which otherwise would involve repetitive calculation of many parameters.

In this memo, Version 1.0 of the document with the same title has been completely rewritten, based on further discussions on the topic during Feb - Aug 1998.

2 Approach

The study of RF/ IF architecture for a Radio Astronomy Receiver involves conceiving an orderly cascaded arrangement of electronic building blocks like amplifiers, attenuators, beam-formers, filters, mixers etc. These blocks process the RF signal received by an antenna in the analog domain and make it compatible for further processing in the digital back-end.

Each of the blocks is defined by specifications such as noise figure, IP2, IP3 and gain. The figure for gain of a building block like a beam-former could be different for an RF signal, an RFI signal (from terrestrial & space-borne transmitters). and incoherent receiver noise (=kTB). Blocks like feed-forward amplifiers will have an additional specification of attenuation to IM products.

A typical receiver will need a RF signal gain of around 100 dB in the analog domain. The target is to distribute the required gain among various blocks, while at the same time meeting an overall specification for (a) effective receiver temperature and (b) kTB to IM[-2 or -3] ratio, together with a (c) good RFI handling capability while maintaining linearity.

The approach taken in this memo is to aim for an RF/ IF architecture which is RFI-robust and where none of the block is dominant vis-a-vis it's inability to handle an expected RFI level.

There are many powerful commercial softwares available to help in such analysis. In the absence of such tools within NFRA at this moment, a rudimentary MircroSoft Excel™-based procedure was developed to assist in the effort of defining the RF/ IF Architecture for SKA. It is possible that the scenarios modelled might not be included in standard commercial packages.

The procedure in Version 1.0 of the memo helped in analysis and optimisation of the RF architecture. In the current version, it has been upgraded (based on discussions in the RF/ IF Architecture Meetings #14 to #30) to include:
(a) IF architecture till the base-band converter;
(b) IM2 effects and
(c) a better model for an RF beam-former.

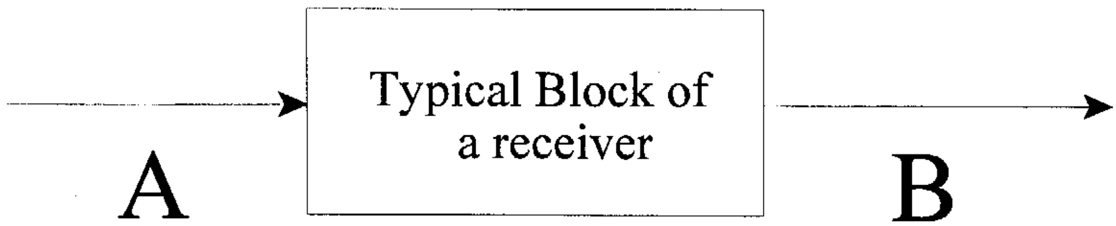
3 Description of the procedure:

A print-out of the Excel™ file SIFLANA7.XLS is enclosed as Annex 1. Note the following:

- The first column describes a receiver parameter under study. Parameters in ***BOLD ITALICS*** are user-definable inputs for all blocks. Parameters in *ITALICS* are user-definable inputs for certain blocks. The rest are computed based on standard formulae. The meaning of a parameter in a row and it's units are self-explanatory.

- The location of fields in other columns where users can input a number to specify a parameter for a particular block are shown in ***BOLD ITALICS.*** All other numbers are computed.

- The reference temperature for noise calculations is 290 K.
- The arrangement of input parameters to surround a block is as under:



kTB to-IM[-2 or -3] ratio at A
Practical IP3 at o/p of PREVIOUS block
Practical IP2 at o/p of PREVIOUS block
Noise figure at input of THIS block

KTB-to-IM[-2 or 3] ratio at B
Practical IP3 at o/p of THIS block
Practical IP2 at o/p of THIS block
Noise figure at input of NEXT block

Gain of THIS block for RF
Gain of THIS block for RFI
Gain of THIS block for kTB
Suppression of THIS block for IM[2 or -3] products

- The only other user-defined input parameter is the Expected level of RFI power Prfi, at the INPUT of Amp #1, which has been taken as -45 dBm, based on the memo System Specification THEA by Bart (ver 1.2 dated July 3, 1998) and further discussions with him.
- The noise temperature at a point in the receiver is computed from the user-specified noise figure data. The final figure for effective receiver temperature because of contribution by all blocks is based on <u>cumulative kTB gain till a block</u> (= 45.27 K, for the configuration in Annex 1).
- The above figure is used to compute noise (=kTB) power in a 20 MHz bandwidth at the input and various points of the receiver and forms the basis for IM[-2 or -3] specification.
- The specification for kTB-to-IM[-2 or -3] ratio at the input has been arbitrarily chosen as -50 dB.
- The definition "Gain of THIS block for RFI" is to cater to the special case of the current unit being an RFI filter, attenuating unwanted signals and passing desired RF signal with a specified loss. Using this figure for various blocks, the "Cumulative RFI gain" and "Expected RFI power at a point in the receiver" are computed.
- The definition "Gain of THIS block for kTB" is to cater to the special case of the current unit having different properties for coherent and incoherent addition of signals.
- The definition "Gain of THIS block for RF Signal" signifies the gain for coherent signals.
- The definition of "Suppression of THIS block for IM[-2 or 3] products" caters to the NEXT block being an unit with IP[-3 or 2] limitation (amplifiers and mixers) and the current block, an Inter-Modulation Rejection Unit (IMRU), which acts as a Linearizer of the next block and indirectly improves it's IP. An example of such a block is a feed-forward amplifier. It does not reduce the strength of RFI signal, per se. *It is essential to set the value of suppression to ZERO, for non-IMRU type blocks.*

- The RF Beam Form(er) is assumed to have 100 input channels. It is made of three functional blocks - A 4-bit Time Delay Unit (TDU), a 4-bit Variable Attenuator (VA) and a 100 channel Wilkinson combiner.

- The improvement of coherent signal to noise at the output of the beam-former has been included by relaxing the specification of kTB-to-IM *for stages after the block* by the same amount.

- *The correct method to define a block which is to be BYPASSED* can be seen by the manner in which AMP#3, #5 and #6 have been specified.

- While specifying IP3 for passive band-pass filters and others which do not have an IP3 limit, an arbitrary large value of 100 dB has been used. Note that in this case, those computations under the block involving IP3 have no meaning.

The Microsoft Excel 97™ file SIFLANA7.XLS dated Nov 9, 1998 is available on the Server4 Network under the directory f:\data\everyone\venkat\rf-if, for those interested.

4 Results of Analysis:

The analysis of the above inputs results in
(a) Minimum IP[-2 or -3] of a block to handle the expected RFI power at that block and
(b) Maximum RFI power allowable at a point for *PRACTICAL IP[-2 or -3] at that point.*

Using the results of (b) and the cumulative gain for RFI at a point, it is simple to compute the RFI suppression needed under IM[-2 or -3] considerations and thus find the weak link in the chain which cannot handle the expected RFI signal.

The aim of the designer of the system would be to make a judicious compromise with specifications like overall system temperature and kTB-to-IM ratio, to see whether it is possible to make the RFI suppression needed at a point reach a figure of *Less-Than-Or-Equal-To-Zero* throughout the chain, so that no block in the chain is dominant. For this purpose, the designer could choose blocks with better practical specifications (if possible) with due considerations for cost OR "invent" new functional blocks. Conversely, if the number at a point is "too negative", the specifications of the block at that point CAN be relaxed.

It has been concluded after detailed discussions in the RF/ IF Architecture meetings that IP3 is the determining factor in the receiver chain AFTER Mixer #1 and IP2, BEFORE Mixer #1.

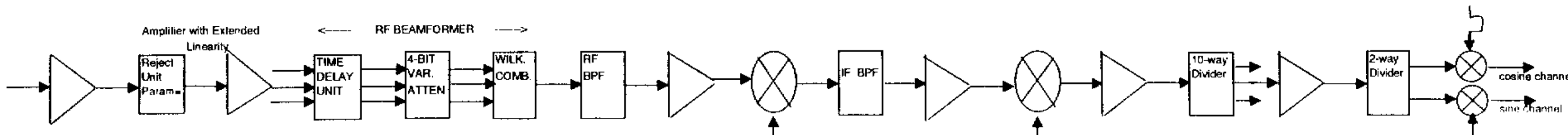
5 Scope for further work:

(A) Noise contribution due to ADC has not been included in the absence of information at this stage.

(B) The figure for attenuation to IM products by the beamformer has been taken as Zero. In practice, this will be non-zero and will depend, among other factors, on the order of IM product. This has to be suitably modelled and included in the analysis.

6 Conclusion:

A general purpose mosaic for designing the RF/ IF Architecture of a receiver system for a radio telescope has been developed and explained. The System Designer can use the mosaic to conceive an optimal and practical architecture to handle a specified level of RFI and simultaneously achieve the best possible figures for system temperature and kTB-to-IM ratio. The mosaic is of immediate relevance in the design of the architecture for THEA.



PARAMETER UNDER STUDY		Amp#1	IMRU	Amp#2					Amp#3	mixer#1		Amp#4	mixer#2	Amp#5	"Band Split"	Ampl #6		mixer#3
BASIC SPECS:																		
kTB-to-IM[2-or-3] Ratio (dB)	***-50.00***	-50	-50	-50	-50	-50	-30	-30	-30	-30	-10	-10	-10	-10	-10	-10	-10	10
Practical IP3 at output (dBm)		***20***	***100***	***20***	***30***	***30***	***100***	***100***	***100***	***3***	***100***	***20***	***12***	***100***	***100***	***100***	***100***	***15***
Practical IP2 at output (dBm)		***32***	***100***	***32***	***42***	***42***	***100***	***100***	***100***	***25***	***100***	***32***	***25***	***100***	***100***	***100***	***100***	***47***
Noise Figure at input (dB)	***0.5612***	***1***	***1.287***	***4***	***2***	***6***	***1***	***0***	***8.5***	***1***	***3***	***8.5***	***0***	***10***	***0***	***3***	***8.5***	***3***
Gain for RF Signal (dB)		***17***	***-1***	***33***	***-4***	***-2***	***14***	***-1***	***0***	***-8***	***-1***	***43***	***-8***	***0***	***-10***	***0***	***-3***	***-8***
Gain for RFI (dB)		17	***-1***	33	-4	-2	***-14***	-1	0	-8	-1	43	-8	0	-10	0	-3	-8
Gain for KTB (dB)		17	***-1***	33	-4	-2	***-6***	-1	0	-8	-1	43	-8	0	-10	0	-3	-8
Attenuation for 2nd, 3rd IM Products (dB)		***0***	***32***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***
Cumulative Gain at a Point:																		
Cumulative RF Signal Gain (dB)	***0***	17	16	49	45	43	57	56	56	48	47	90	82	82	72	72	69	61
Cumulative RFI Gain (dB)	***0***	17	16	49	45	43	29	28	28	20	19	62	54	54	44	44	41	33
Cumulative kTB Gain (dB)	***0***	17	16	49	45	43	37	36	36	28	27	70	62	62	52	52	49	41
POWER AT A POINT (in dBm):																		
kTB power in a 20 MHz bw (eff kTB NT taken)	-109	-91.97	-92.97	-59.97	-63.97	-65.97	-71.97	-72.97	-73	-80.97	-81.97	-38.97	-46.97	-46.97	-56.97	-56.97	-59.97	-67.97
IM[2-or-3] spec=P_{kTB} - {kTB-to IM[2-or-3] Ratio}	-159	-142	-143	-77.97	-114	-116	-102	-103	-103	-111	-91.97	-48.97	-56.97	-56.97	-66.97	-66.97	69.97	77.97
Expected Prfi at a point in receiver	***-45***	-28	-29	4	0	-2	-16	-17	-17	-25	-26	17	9	9	-1	-1	-4	-12
Min IP3 to handle Expected Prfi		28.985	27.985	44.985	56.985	54.985	26.985	25.985	25.99	17.985	6.9052	49.985	41.985	41.985	31.985	31.985	28.985	20.985
Max Prfi allowable for Practical IP3		-33.99	19.01	-12.66	-17.99	-18.66	32.677	32.343	32.34	-34.99	36.01	-2.99	-10.99	47.677	44.343	44.343	43.343	-15.99
Min IP2 to handle Expected Prfi		85.97	84.97	85.97	113.97	111.97	69.97	68.97	68.97	60.97	39.97	82.97	74.97	74.97	64.97	64.97	61.97	53.97
Max Prfi allowable for Practical IP2		-54.99	-21.49	-22.99	-35.99	-36.99	-0.985	-1.485	-1.49	-42.99	4.0148	-8.485	-15.99	21.515	16.515	16.515	15.015	15.49

RESULTS OF ANALYSIS

POWER REF TO INPUT (in dBm):																		
Prfi ref. To I/p of receiver (IM3 consideration)		-50.99	3.01	-61.66	-62.99	-61.66	3.68	4.34	4.34	-54.99	17.01	-64.99	-64.99	-6.32	0.34	0.34	2.34	-48.99
Prfi ref. To I/p of receiver (IM2 consideration)		-71.99	-37.49	-71.99	-80.99	-79.99	-29.99	-29.49	-29.5	-62.99	-14.99	-70.49	-69.99	-32.49	-27.49	-27.49	-25.99	-48.49
RFI suppress. needed at I/p (IM3 consideration)		5.9901	-48.01	16.657	34.99	32.657	-48.68	-49.34	-49.3	9.9901	-62.01	19.99	19.99	-38.68	-45.34	-45.34	-47.34	3.9901
RFI suppress. needed at I/p (IM2 consideration)		26.985	-7.515	26.985	52.985	50.985	-15.01	-15.51	-15.5	17.985	-30.01	25.485	24.985	-12.51	-17.51	-17.51	-19.01	3.4852
NOISE TEMPERATURE T (in K):																		
At a point in the receiver chain	40.00	75.088	100.03	438.45	169.62	864.51	75.088	0	1763	75.088	288.63	1763	0	2610	0	288.63	1763	288.63
Contribution at input(kTB gain considered)	45.27	1.4982	2.5126	0.0055	0.0054	0.0433	0.015	0	0.443	0.119	0.5759	0.0002	0	0.0016	0	0.0018	0.0222	0.0229

Scenario: Generalised Format for Study of RF/ IF Architecture.

(Template based on RF/IF Architecture meetings till #30)

Numbers in **BOLD *ITALICS*** are User-definable input parameters

Parameter in *italics* is definable and the rest are computed.

Venkat Nov 9, 1998 18:30 hrs c:\myfiles\rfifana\xana\siflana7.xls