



Subject:
Baseband Noise Source Design Approach,
AMiBA Intensity Mapping Project
To:
Ming-Tang Chen

Date:
2014 November 17
DK003_2014_Baseband_Noise
cc:
AMiBA routing

From:
Derek Kubo

Location/Phone:
Hilo Office/
808-961-2926

References:

- [1] [AMiBA DBE System V2](#), 2014-Oct-31
- [2] [I/Q Baseband Noise Design](#), 2014-Nov-14

I. System Description

The currently proposed design approach for the AMiBA digital correlator upgrade is described in *Fig. 1* [1]. The system begins with 7 dual linear polarization receivers, each operating over 86-102 GHz. The received signals are amplified by cryogenically cooled HEMT LNAs located in the Receiver Package then down converted in the IF/LO Module to an IF of 2-18 GHz utilizing warm sub-harmonic mixers with a fixed¹ LO frequency of 42 GHz. Unique Walsh phase switching (0, 90 degrees at 42 GHz) are applied to each of the 14 LOs for crosstalk and backend noise reduction. The IF signals are further down converted to baseband (approximately 10-2500 MHz) using an I/Q down converter that separates the signal into in-phase (I), and quadrature (Q) components. The primary advantage of the I/Q down converter over a traditional down converter is that it eliminates the need for an IF filter bank when tuning the LO to cover different ranges of the 2-18 GHz spectra. A schematic diagram of the prototype I/Q down converter is provided in *Fig. 2*.

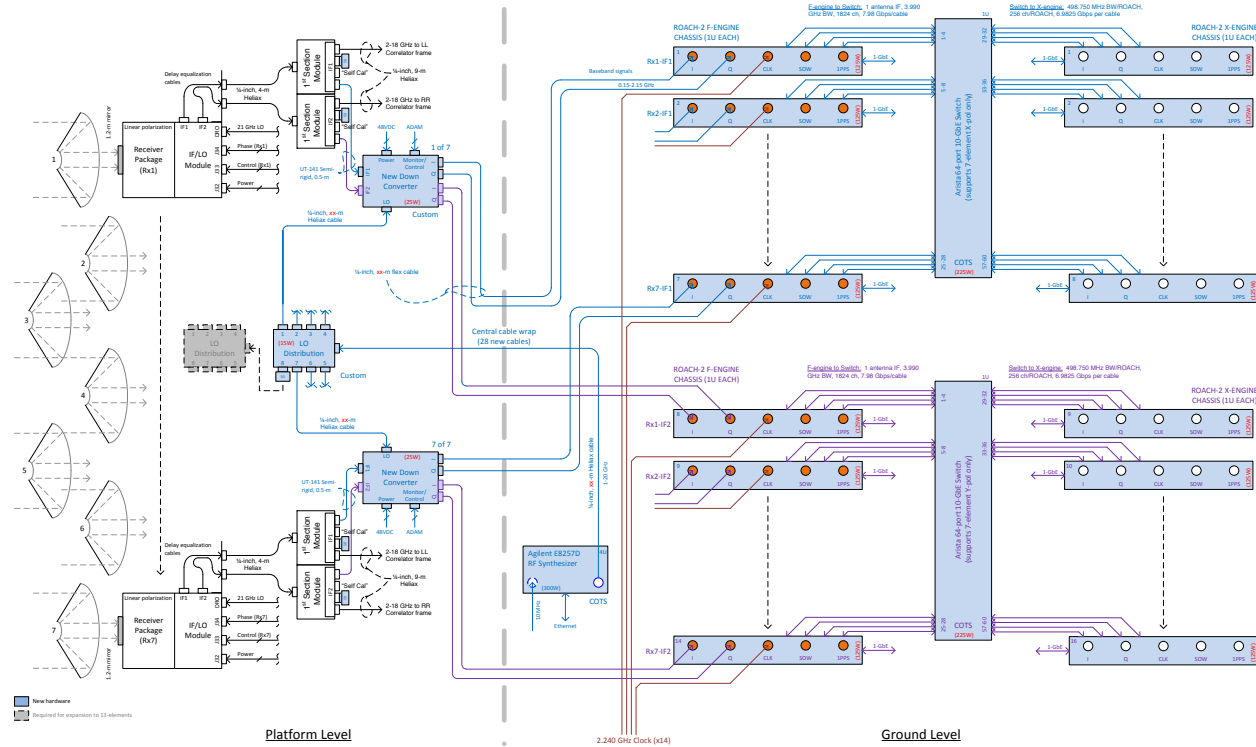


Fig. 1 System Block Diagram for Digital Correlator Upgrade. Hardware required for the digital upgrade is shown in blue. Each of the 7 New Down Converter assemblies provide I and Q baseband outputs for both X and Y polarizations. The 28 baseband signals are fed to 14 separate ROACH-2 F-Engine Chassis that provide digitization, PFB/FFT, and sideband separation functions.

¹ 42 GHz LO cannot be changed in frequency due to the phase switching method employed.

The New Down Converters will be located on the platform next to their respective 1st Section Modules along the outer perimeter of the platform. Long flexible low loss coaxial cables will carry the 28 baseband signals (14 receivers x I & Q-ch) down to the ROACH-2 F-engine chassis located within 2 racks at the ground level.

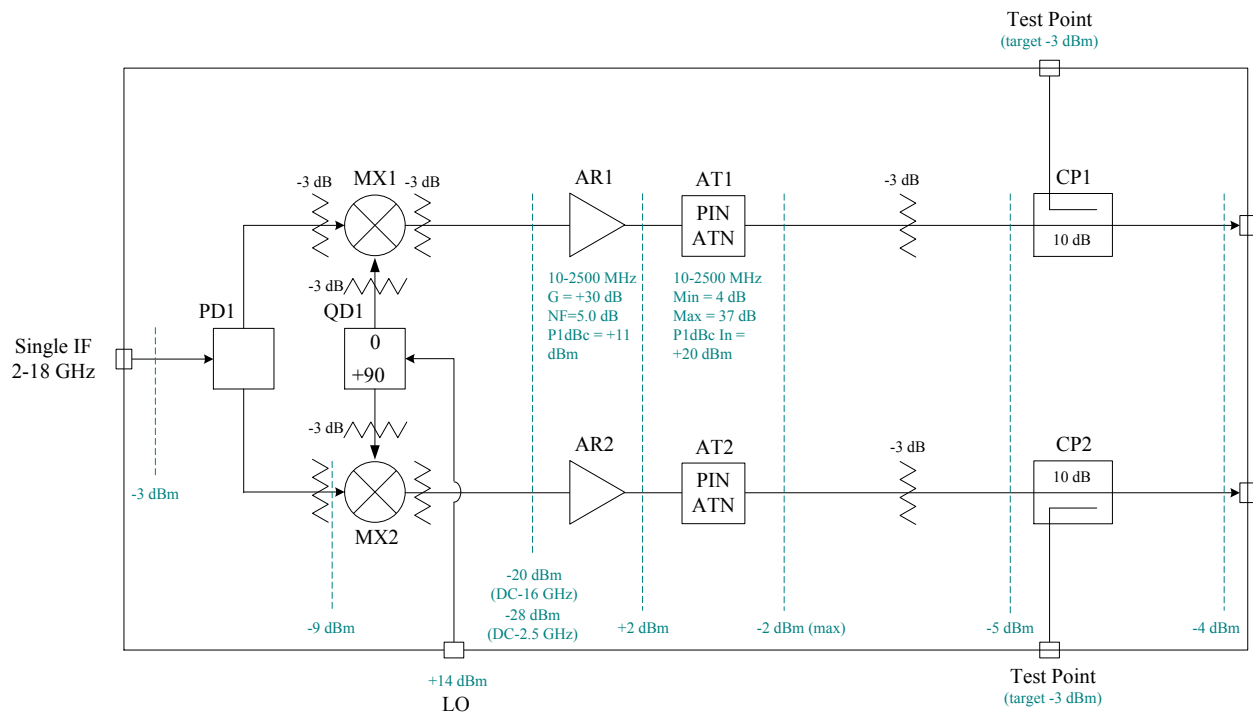


Fig. 2 Prototype Single Polarization I/Q Down Converter. The wideband IF input signal is presented to an in-phase power divider, PD1, which provides identical signals at mixers, MX1 and MX2. An LO tunable over 4-16 GHz is fed to a quadrature hybrid which produces 0 and 90 degree LOs to the mixers. The baseband outputs of MX1 and MX2 contain the folded over IF spectra and are amplified by AR1 and AR2, and leveled by PIN diode attenuators AT1 and AT2. In the final design, the PIN attenuators, 3 dB pads, and directional couplers will be relocated downstream into the Interface Panels located in the F-engine racks.

II. Noise Calibration Goals and Requirements

The primary goals for noise calibration are as follows:

1. *Magnitude and phase vs. frequency calibration for each of the 42 baseline products (21 X-pol, 21 Y-pol). The artificial noise must be flat, preferably with a Gaussian distribution, and be injected as early as possible at the antenna feed or equivalent at W-band (86-102 GHz). The calibration for the present analog correlator is being performed by periodically looking at astronomical sources during the track and takes into account Z-direction antenna movement caused by platform deformation. This astronomical calibration is still viable for the digital correlator upgrade.*
2. *Delay calibration for the ROACH-2 correlator. The ROACH-2 correlator chassis currently power up with arbitrary delays between the ADCs and causes a large number of phase wraps in the phase vs. frequency cross correlation product. A strong artificial correlated noise source is required to provide initial phase unwrapping. This noise source can be performed at W-band, IF or baseband.*
3. *ADC core offset, gain and phase calibration. Noise injection can be performed at either IF or baseband for DC offset and gain calibration. The noise drive level to the ADCs must be similar to the actual optimal drive level during observation. Phase calibration of the ADC cores requires tone injection. This noise and tone source can be performed at W-band, IF or baseband.*

- Regardless of the approach taken, noise injection must not compromise the existing antenna-to-antenna isolation with a preliminary goal of >110 dB.

III. Baseband Noise Source Design

A conceptual design for the baseband noise source is provided in Fig. 3 [2]. Beginning with the I/Q Noise Generator chassis, a common 3.5 to 8.5 GHz noise source is power divided by PD1 and fed to the R-port of mixers, MX1 and MX2. The L-port of both mixers are driven with a 6 GHz tone at 0 degrees for MX1, and 90 degrees for MX2. The baseband noise output of both mixers consist of the folded noise spectra, i.e., 3.5 to 6 GHz is translated to -2.5 to 0 GHz (inverted spectra), and 6 to 8.5 GHz is translated to 0 to 2.5 GHz (non-inverted spectra). This I/Q design approach will permit testing of the sideband separation function within the ROACH-2 F-engines. The X-Pol and Y-Pol Noise Distribution chassis will be located within their respective F-engine racks. Note the use of individual 2-way power dividers (instead of 4 or 8-way) was largely dictated by the requirement to support a large octave bandwidth of 5 to 2500 MHz. The Interface Panel is envisioned to be a 1U unit collocated above or below the associated ROACH-2 chassis. The ADAM controller (not shown) for the Interface Panel will consist of two 8-slot ADAM-5000/TCP base units, one for each F-engine rack. And finally, the variable attenuator (VA_x) will be driven by a loop amplifier to provide closed loop servo control of the power level entering the ADC. The ADAM controller will be used to set the target drive level for the automatic level control (ALC) to achieve a desired ADC drive level.

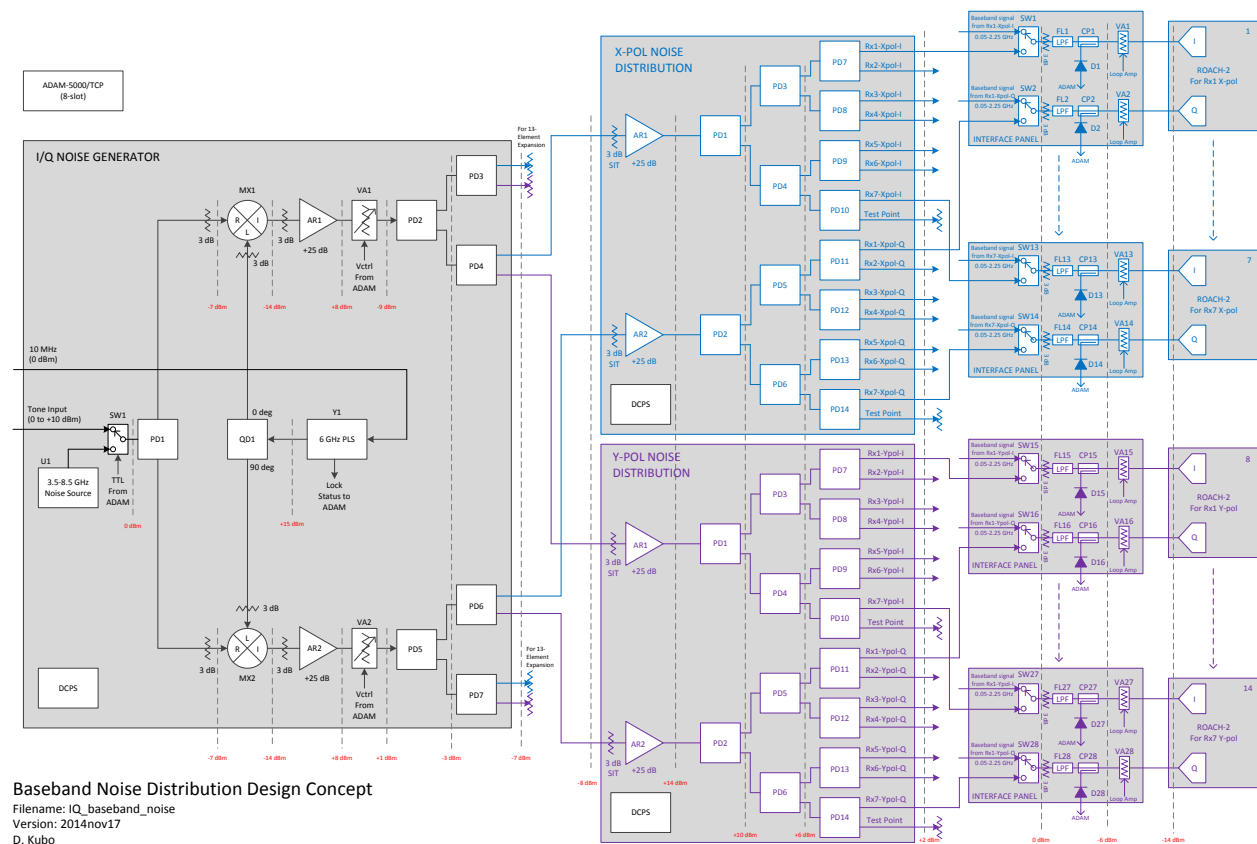


Fig. 3 Baseband Noise Source Design. This design consists of 3 separate 2U height chassis, one to generate I and Q baseband signals, and 2 more to distribute the signals to the X-POL and Y-POL ROACH-2 F-engine racks. The SPDT switches, LPFs, couplers, power detectors, and variable attenuators will be installed behind 1U panels (7 panels for 7 F-engines per rack). The system can be expanded to support 13-elements with the addition of 2 more Noise Distribution chassis.

IV. ROM Cost

The Bill of Materials (BOM) for each sub-assembly shown in *Fig. 3* is provided in *Table I*. The total cost is estimated to be \$14.7k + \$10.6k + \$15.1k + \$9.6k = \$50k and excludes labor.

Table I Bill of Materials

ITEM	REF DES	MAKE	PART NO	DESCRIPTION	RQD QTY	SPARE QTY	\$/EA	TOTAL \$
1	U1	TBD	TBD	Noise source unit, 3.5-8.5 GHz, 0 dBm	1	0	\$2,500	\$2,500
2	SW1	TBD	TBD	SPDT switch, 2-8 GHz, TTL control	1	0	\$1,500	\$1,500
3	PD1	MiniCircuits	ZFSC-2-10G+	2-way power divider, 2-10 GHz	1	1	\$70	\$140
4	QD1	Krytar	TBD	Quadrature hybrid, 4-8 GHz	1	0	\$800	\$800
5	Y1	Luff	TBD	Phase lock source, 6 GHz, +15 dBm	1	0	\$1,500	\$1,500
6	MX1, MX2	Marki	TBD	Mixer, 2-10 GHz	2	1	\$650	\$1,950
7	AR1, AR2	MiniCircuits	ZFL-2500VH+	Amp, 10-2500 MHz, +25 dB, +23 dBm	2	1	\$265	\$795
8	VA1, VA2	MiniCircuits	ZX73-2500-S+	Variable atten, 10-2500 MHz, 25 dB	2	1	\$50	\$150
9	PD2-PD7	MiniCircuits	ZAPD-2-252-S+	2-way power divider, 5-2500 MHz	6	1	\$80	\$560
10	Misc	Inmet	TBD	Fixed attenuator, 3 dB	6	2	\$45	\$360
11	ADAM	Advantech	ADAM-5000/TCP	Controller base, 8-slot	1	1	\$445	\$890
12	-	Advantech	ADAM-5017	Thermocouple module, 7-ch	1	1	\$220	\$440
13	-	Advantech	ADAM-5055S	Digital I/O module, 16-ch	1	1	\$120	\$240
14	-	Advantech	ADAM-5024	Analog output module, 4-ch	1	1	\$285	\$570
15	DCPS	Daitron	TBD	DC power supply, 15 V, 150 W	1	1	\$200	\$400
16	Misc	RFCoax	TBD	Coaxial cable, semi-rigid	26	2	\$35	\$980
17	Misc	MiniCircuits	ANNE-50+	Termination, 50 Ohms, DC-18 GHz	4	2	\$10	\$60
18	Misc	ParMetal	TBD	Chassis, EMI, 2U	1	0	\$175	\$175
19	Misc	Qualtek	880-03/005	AC power inlet, EMI	1	0	\$50	\$50
20	Misc	-	-	Fabrication, custom	1	0	\$500	\$500
21	Misc	Orion	OD6025-24HB02A	Fan, +24 V	2	1	\$15	\$45
22	Misc	Orion	WMG60M	Fan guard, mesh	2	0	\$2	\$4
23	Misc	Orion	G60-4	Fan guard, wire	2	0	\$2	\$4
24	Misc	TDK/Lambda	LS25-24	Power supply, 24 VDC, 1.1 A	1	1	\$18	\$36
25	Misc	MiniCircuits	SF-SF50+	Panel mount feedthroughs, SMA f/f	10	2	\$5	\$60
26								
27				TOTAL FOR I/Q NOISE GENERATOR CHASSIS				\$14,709

ITEM	REF DES	MAKE	PART NO	DESCRIPTION	RQD QTY	SPARE QTY	\$/EA	TOTAL \$
1	AR1, AR2	MiniCircuits	ZFL-2500VH+	Amp, 10-2500 MHz, +25 dB, +23 dBm	2	1	\$265	\$795
2	PD1-PD14	MiniCircuits	ZAPD-2-252-S+	2-way power divider, 5-2500 MHz	14	1	\$80	\$1,200
3	DCPS	Daitron	TBD	DC power supply, 15 V, 150 W	1	1	\$200	\$400
4	Misc	Inmet	TBD	Fixed attenuator, 3 dB	4	2	\$45	\$270
5	Misc	MiniCircuits	TBD	Coaxial cable, flex	42	2	\$10	\$440
6	Misc	MiniCircuits	ANNE-50+	Termination, 50 Ohms, DC-18 GHz	2	0	\$650	\$1,300
7	Misc	ParMetal	TBD	Chassis, EMI, 2U	1	0	\$175	\$175
8	Misc	Qualtek	880-03/005	AC power inlet, EMI	1	0	\$50	\$50
9	Misc	-	-	Fabrication, custom	1	0	\$500	\$500
10	Misc	Orion	OD6025-24HB02A	Fan, +24 V	2	1	\$15	\$45
11	Misc	Orion	WMG60M	Fan guard, mesh	2	0	\$2	\$4
12	Misc	Orion	G60-4	Fan guard, wire	2	0	\$2	\$4
13	Misc	TDK/Lambda	LS25-24	Power supply, 24 VDC, 1.1 A	1	1	\$18	\$36
14	Misc	MiniCircuits	SF-SF50+	Panel mount feedthroughs, SMA f/f	18	2	\$5	\$100
15								
16				SUB-TOTAL FOR X-POL NOISE DISTRIBUTION CHASSIS				\$5,319
17				SUB-TOTAL FOR Y-POL NOISE DISTRIBUTION CHASSIS				\$5,319
18								\$0
19				TOTAL FOR 2 NOISE DISTRIBUTION CHASSIS				\$10,638

ITEM	REF DES	MAKE	PART NO	DESCRIPTION	RQD QTY	SPARE QTY	\$/EA	TOTAL \$
1	SW1, SW2	MiniCircuits	ZASWA2-50DR-FT+	SPDT switch, DC-5 GHz, 82 dB iso, absorb	2	0	\$94	\$188
2	FL1, FL2	MiniCircuits	VLF-1800+	LPF, DC-2125 MHz,	2	0	\$22	\$44
3	CP1, CP2	MiniCircuits	ZFSC-2-10G+	Z-way power divider, 2-10 GHz	2	0	\$70	\$140
4	VA1, VA2	MiniCircuits	ZX73-2500-S+	Variable atten, 10-2500 MHz, 25 dB	2	0	\$50	\$100
5	D1, D2	MiniCircuits	ZX47-60LN+	Detector, active, 10-8000 MHz	2	0	\$90	\$180
6	Misc	MiniCircuits	SF-SF50+	Panel mount feedthroughs, SMA f/f	6	0	\$5	\$30
7	Misc	TBD	TBD	Blank 1U Panel	1	0	\$25	\$25
8	Misc	-	-	Fabrication, custom	1	0	\$150	\$150
9	Misc	MiniCircuits	VAT-3+	Fixed attenuator, 3 dB	2	0	\$14	\$28
10	Misc	MiniCircuits	TBD	Coaxial cable, flex	12	0	\$10	\$120
11								
12				SUB-TOTAL FOR INTERFACE PANEL				\$1,005
13								
14				TOTAL FOR 14+1 INTERFACE PANELS				\$15,075

ITEM	REF DES	MAKE	PART NO	DESCRIPTION	RQD QTY	SPARE QTY	\$/EA	TOTAL \$
1	ADAM	Advantech	ADAM-5000/TCP	Controller base, 8-slot	2	0	\$445	\$890
2	-	Advantech	ADAM-5017H	Analog input module, 8-ch	4	1	\$275	\$1,375
3	-	Advantech	ADAM-5055S	Digital I/O module, 16-ch	4	1	\$120	\$600
4	-	Advantech	ADAM-5024	Analog output module, 4-ch	7	1	\$285	\$2,280
5	Misc	TBD	TBD	D-connector, 15-pin D-sub	28	4	\$20	\$640
6	Misc	-	-	Fabrication, custom	2	0	\$275	\$550
7	Misc	MiniCircuits	CBL-15FT-SMSM+	Interconnect cable, 15 foot	4	1	\$165	\$825
8	Misc	MiniCircuits	QBL3SMQ-SM+	Interconnect cable, 3 foot	30	2	\$76	\$2,432
13								
14				TOTAL FOR INTERCONNECT & M&C HARDWARE				\$9,592

V. Requirements Compliance

The requirements listed in section II are repeated below with the baseband noise source capabilities list below each item.

1. *Magnitude and phase vs. frequency calibration for each of the 42 baseline products (21 X-pol, 21 Y-pol). Similar to the above, the artificial noise must be flat, preferably with a Gaussian distribution, and be injected as early as possible at the antenna feed or equivalent at W-band (86-102 GHz). The calibration for the present analog correlator is being performed by periodically looking at astronomical sources during the track and takes into account Z-direction antenna movement caused by platform deformation. This astronomical calibration is still viable for the digital correlator upgrade.*

Cross correlation magnitude and phase vs. frequency can be performed for all 42 baseline products using the baseband noise source described in this memo, however, the information obtained will not represent the actual products produced by the receivers. No Walsh modulation is provided on the noise and thus demodulation in the ROACH-2 X-engine must be disabled. In addition, the baseband noise source, as presented in this memo, will be 100% correlated and will necessitate the reduction of the digital gain within the ROACH-2 X-engine to prevent overflow of the cross correlation products. This exercise of using the baseband noise source still could be useful for testing out the digital backend system functionality.

2. *Delay calibration for the ROACH-2 correlator. The ROACH-2 correlator chassis currently power up with arbitrary delays between the ADCs and causes a large number of phase wraps in the phase vs. frequency cross correlation product. A strong artificial correlated noise source is required to provide initial phase unwrapping. This noise source can be performed at W-band, IF or baseband.*

The baseband noise source is particularly suited to meet this requirement. Though the delays from the baseband noise source may not exactly match the delays of the receivers looking at an astronomical source, a table representing the fixed delay offsets can be generated to accommodate the differences. As noted above, the Walsh demodulation must be disabled and the gain within the ROACH-2 X-engine must be reduced.

3. *ADC core offset, gain and phase calibration. Noise injection can be performed at either IF or baseband for DC offset and gain calibration. The noise drive level to the ADCs must be similar to the actual optimal drive level during observation. Phase calibration of the ADC cores requires tone injection. This noise and tone source can be performed at W-band, IF or baseband.*

The baseband noise source is particularly suited to meet the requirement of DC offset and gain calibration of the ADCs. Tone injection (3.5-8.5 GHz at IF) will result in a single tone at baseband tunable from approximately 10 MHz to 2.5 GHz and can be used to calibrate the phase offsets of the ADC cores.

4. *Regardless of the approach taken, noise injection must not compromise the existing antenna-to-antenna isolation with a preliminary goal of >110 dB.*

The signal leakage from one receiver to another can occur through the common baseband noise source paths. Referring to [Fig. 3](#) with the switch located in Interface Panel configured for astronomical observing (up position), the isolation specification for a single switch is 60 dB. The isolation specification of the output power divider is 14 dB, and due to the configuration of the power dividers, the worst case leakage will occur for adjacent receiver numbers, e.g., Rx1 to Rx2, Rx3 to Rx4, etc. Thus the worst case isolation can be calculated as $60 + 14 + 60 = 134$ dB and is significantly better than the 110 dB specification.

V. Summary

The baseband noise source design is complicated by the I/Q down converter implementation currently proposed for the upgrade and requires the addition of the I/Q Noise Generator chassis. The implementation, nevertheless, is considered fairly straight forward and is expected to require approximately 1 week of labor for the identification and ordering of components, and another 3 weeks of fabrication and assembly labor. One desirable aspect of the baseband noise source is that all of the components will reside at the ground level and will simplify the integration effort. The material cost for this effort is estimated to be approximately \$50k USD. Expansion to support 13-elements to support phase II of the AMiBA Intensity Mapping Project (30 GHz receivers) is designed in and will entail a cost upper of approximately \$33.3k USD.