BBDev Memo 007

Experiment X1
X-band GGAO(2poln) Wfrd(circ) Plan – 1

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2007/11/13

2008/08/25: This experiment was done 2007 Nov 19. This memo documents many details that apply to both that session and subsequent ones.

Table of Contents

1. Introduction

As the first step in demonstrating the effectiveness of the broadband delay concept, we will use GGAO with the full chain of the new hardware but for only one frequency band, X-band. The two linear polarizations recorded at GGAO will be cross-correlated with right-circular polarization recorded at Westford. Both sites will require one digital back end (DBE) equipped with one iBOB1 and one Mk5b+ recorder to record 2 gigabits per second.

A single strong source will be tracked for approximately six hours to get some measure of phase stability by looking at the difference of phase and group delays and by comparing the phases of the two linear polarizations correlated with the same circular polarization from Westford.

2. Objective and expected results

SNR
Phase stability: differential phase between polarizations
Stability of differential phase delay – group delay

3. Experiment description

Dual linear polarization at GGAO; single circular polarization at Westford (recorded in duplicate to mimic dual polarization).

Each polarization comes down an RF line, is filtered into the second Nyquist zone in the Up-Down Converter (UDC), and enters the Digital Back End (DBE) as a 512 MHz band. The DBE processes each IF as sixteen 32 MHz channels, sampled at two bits. The odd channels from each IF are merged onto one VSI-H output which is recorded on a Mark5B+. See section 4 for the frequency/channel assignment.

Two types of session are planned:

a) **Test session:** Monday Nov ??, when installation and pointing/focus go okay. This will be extended or rescheduled as needed.

   For this session data for the fringe test will be transferred from GGAO to Haystack over the network.

   Disk modules from Westford will be hand carried to the correlator.

b) **Six hours on a strong source:** if possible observe a source that passes between GGAO and Westford to observe phase rotation due to different parallactic angles at the two antennas.

4. Frequencies

Local oscillator: 8080 MHz
Frequency channel width: 32 MHz
Sampling: 2-bit
Record odd channels from each IF.
Total data rate: 2024 Mb/s
Input to DBE: 2nd Nyquist Zone ➔ lower sideband

IF0 = Vertical polarization = L; IF1 = Horizontal polarization = R

X-band 2nd Nyquist zone DOM		freq that goes to zero (MHz)	Correlator	
mag	sign	(LSB)	channel label	channel number
1	0	9088	X1L	1
3	2	9088	X1R	2
5	4	9024	X2L	3
7	6	9024	X2R	4
9	8	8960	X3L	5
11	10	8960	X3R	6
13	12	8896	X4L	7
15	14	8896	X4R	8
17	16	8832	X5L	9
19	18	8832	X5R	10
21	20	8768	X6L	11
23	22	8768	X6R	12
25	24	8704	X7L	13
27	26	8704	X7R	14
29	28	8640	X8L	15
31	30	8640	X8R	16

5. Experiment setup (including diagrams)

a. Optical fiber

Optical fiber on loan from Photonics

October 26: I found out that only one fiber will be provided, and it will not be High Gain as had been promised. (Apparently this was known earlier, but I missed the information somehow, probably because I skipped a telecon.)

Original information from Skip

Fiber: Transmitter is Photonics PSI-1604

!!! Receiver is PSI-1601 so link gain is -5 dB and NF is about 17.2 dB !!!

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Here are the basic specs on the Photonics Systems, Inc. Model PSI-1604
Amplified Link (Demo Model);

Photonic Link Specification Highlights
PSI-1604 Amplified Microwave Photonic Link
Parameter Value *
Operating Bandwidth 0.045 -10 GHz
Gain -5 dB typical
VSWR ' 2:1 across BW
Noise Figure 18 dB typical
Spur-free dynamic range 106 dB typical (in 1 Hz)
1-dB compression dynamic
range
129 dB typical (in 1 Hz)
Input IP3 4.25 dBm typical
Fiber-optic connectors ** FC/APC
DC Power Requirements† Tx ' 7.5 W; Rx ' 25 mW
AC Power Requirements 110 VAC, 60 Hz

The fiber transmitter is amplified, the receiver is NOT amplified.
The spec on the fiber is;
BX-Breakout Cable (8 strand) with FC/APC connectors.
Attenuation through the fibers is 0.5dB per Kilometer @ 1310/1550nm.
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I repeat: !!! Receiver is PSI-1601 so gain is -5 dB and NF is about 17.2 dB !!!

I have used original values of -6 dB and 18 dB for gain and NF, respectively.

b. GGAO (see spreadsheet that follows; begun by Dan Smythe)

Signal paths:

Vertical pol'n → UDC Channel A → IF0

Horizontal pol'n → UDC Channel B → IF1

Power levels for setting attenuation in UDC

Assume 500 MHz bandwidth.

LNA+sky – T_S = 50K

P_S = 1.4e-23*50K*500 MHz = 3.5e-13 W = 3.5e-10mW = -95.4 dBm

G(LNA) = 37 dB

P into fiber = -58 dBm ≈ 1.0e-6 mW

Fiber: Photonics PSI-1604 transmitter; PSI-1601 receiver

G = -6 dB net for fiber link

NF = 18 db

P(300K) = 1.4e-23*300*500MHz = 2.1e-12W = 2.1e-9mW = -87 dBm

P_f = P(300) + NF = -87 dBm + 18 dB = -69 dBm = 1.25e-7 mW = 0.125e-6

So fiber noise is about 1/8th of power into fiber.

See following table for power into UDC in 12 GHz band over fiber path.

Power into DBE needs to be -10 dBm to -15 dBm

BBDev_level.xls	DLS		10/29/2007												
	modified by aen 07/11/05														
RF Levels for X-band GGAO Westford BBDev Experiment										<-------------------Sun ------------------------>					
GGAO						<---------------for 1 MHz Video Resolution on scope ----------------->							!! Take out 24 dB of gain !!		
	fiber	coax	fiber	coax		fiber	coax	fiber	coax	fiber	coax		fiber	coax	
T(K)	50	50	50	50		50	50	300	300	12000	12000		12000	12000	
Bandwidth (GHz)	12.000	12.000	0.500	0.500		0.001	0.001	0.001	0.001	0.001	0.001		12.000	12.000	
LNA In (kTB)	-81	-81	-95	-95	dBm	-122	-122	-114	-114	-98	-98		-57	-57	
LNA Gain	37	37	37	37	dB	37	37	37	37	37	37		37	37	
LNA Out	-43.8	-43.8	-57.6	-57.6	dBm	-85	-85	-77	-77	-61	-61		-20	-20	
Amp Gain	12	26	12	26	dB	12	26	12	26	12	26		12	26	
Amp Out	-31.8	-17.8	-45.6	-31.6	dBm	-73	-59	-65	-51	-49	-35		-8	6	
8ft coax (SF142)	-6	-6	-6	-6	dB	-6	-6	-6	-6	-6	-6		-6	-6	
Short Coax Out	-50	-24	-52	-38	dBm	-79	-65	-71	-57	-55	-41		-14	0	
Fiber/coax Gain	-6	-19	-6	-19	dB	-6	-19	-6	-19	-6	-19		-6	-19	
Fiber Out	-38	-36.8	-51.6	-50.6	dBm	-79	-78	-71	-70	-55	-54		-14	-13	
Amp Gain	0	0	0	0	dB	0	0	0	0	0	0		0	0	
UDC In	-38	-36.8	-51.6	-50.6	dBm	-79	-78	-71	-70	-55	-54		-14	-13	
Maximum	-22				dBm										
UDC gain range			30 to 60 dB			30 to 60 dB		30 to 60 dB		30 to 60 dB			30 to 60 dB		
UDC atten setting			20	21		20	21	20	21	20	21		20	21	
UDC gain (60-atten)			40	39	dB	40	39	40	39	40	39		40	39	
UDC Out			-12	-12	dBm	-39	-39	-31	-31	-15	-15		26	26	
Attenuator			0	0	dB	0	0	0	0	0	0		-14	-14	convert fro
DBE In	(Spec -15 to -10 dBm)		-11.6	-11.6	dBm	-39	-39	-31	-31	-15	-15		12	12	12 to 0.5 (
DBE Input level must be set BEFORE connecting															bandwidt
DBE 'IF in' monitor (-15dB)			-26.6	-26.6	dBm	-54	-54	-46	-46	-30	-30		-3	-3	
UDC IF unfiltered output (has to be connected to external port on back)															
UDC gain for this output:			29	29	dB	29	29	29	29	29	29		29	29	
UDC IF monitor out			-22.6	-21.6	dBm	-50	-49	-42	-41	-26	-25		15	16	

c. Westford

Power levels for setting attenuation in UDC

Assume 500 MHz bandwidth.

P from receiver after splitter and cable compensation = -35 ± 5 dBm

Splitter and Nyquist Zone filter contribute approx -6 dB

Power into DBE needs to be -10 dBm to -15 dBm

so at least 30 dB of gain is needed beforeDBE.

Figure A. GGAO equipment diagram for X-band test of Broadband Delay System.

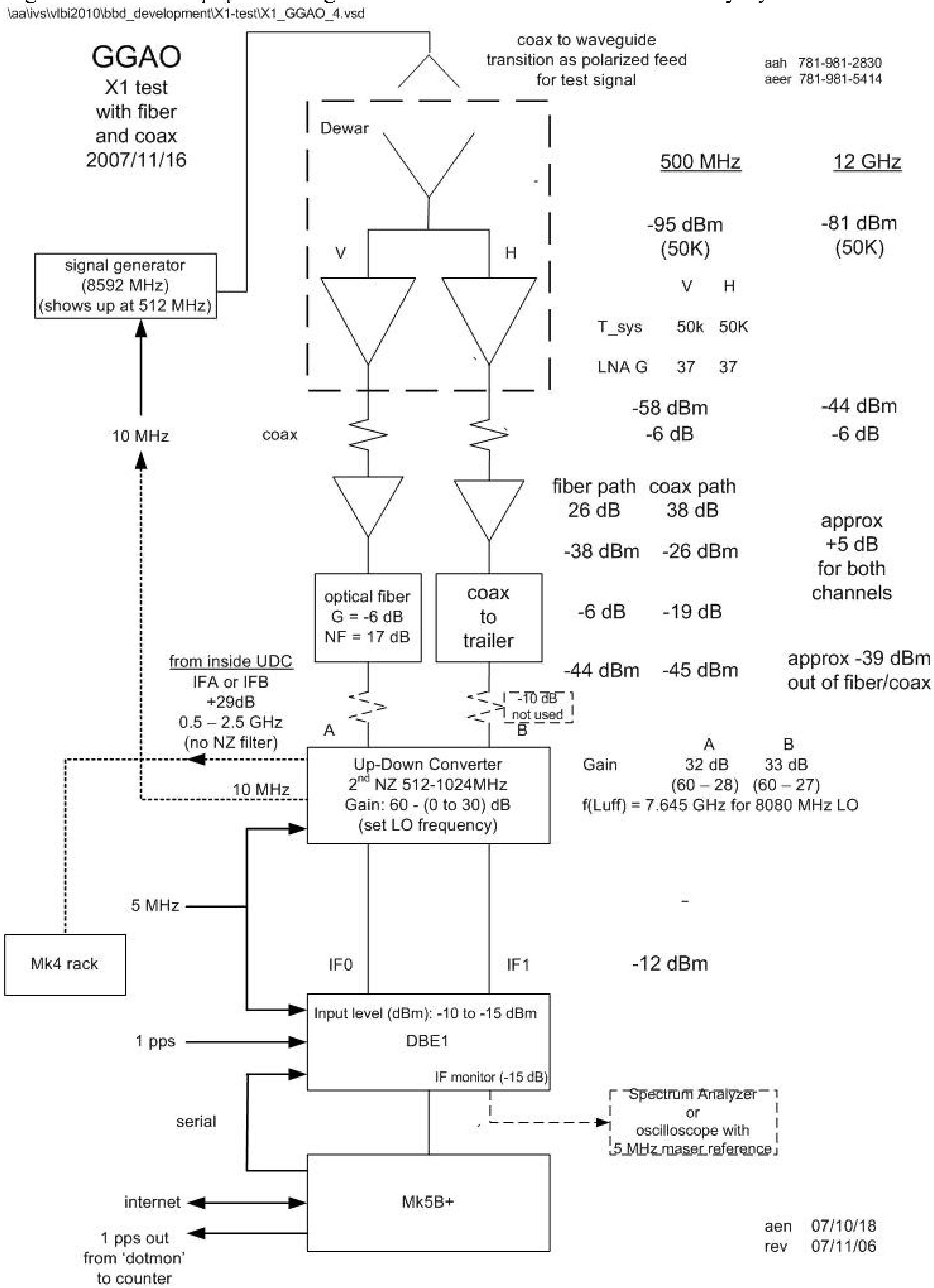
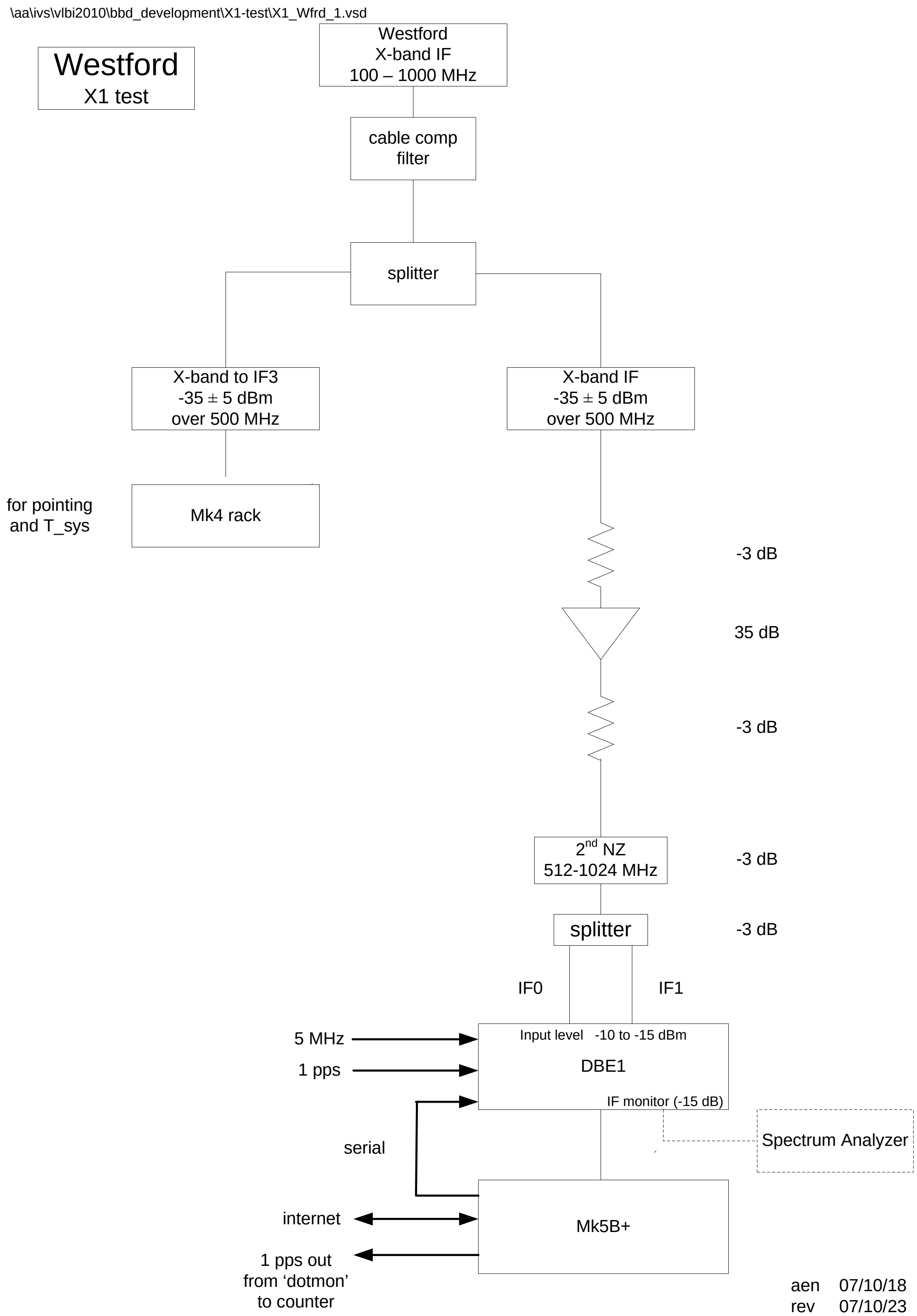


Figure B. Wfrd equipment diagram for X-band test of Broadband Delay System.



6. Equipment needed each site

Mk5B+s:

GGAO: machine:mk5_691 hostname: test6.maxigigapop.net

Control IP: 206.196.178.55

Data IP: 140.173.125.2

Westford: machine:mk5_689 hostname: wfmark5_09.haystack.mit.edu

Control IP: 192.52.63.109

Data IP: ~~140.173.125.2~~

GGAO

Dewar/feed/LNA

LNAs: Vertical: #128D Horizontal: #127D (!!CHECK)

12 dB amplifiers: type MiniCircuits ZX60-14012L

fiber

coax – LMR-400 on a reel

UDC (2nd NZ filters incorporated)

2nd NZ filter LarkEng: XMC768-480-7AA

S/N 27118-05 and -06 in UDC

S/N 27118-03 (or -08) as IF filter to Mk4 rack

DBE1: serial number ???

Mk5B+: mk5_691

1pps

5 and 10 MHz reference

Coax-to-waveguide transition for test signal

Westford

NZ filters: 2nd NZ filter LarkEng: XMC768-480-7AA

S/N 27118-08 (or -03)

DBE1: serial number ???

Mk5B+: mk5_689 (wfmark5_09)

1pps

5 MHz reference

7. Operating instructions

A. Up-Down Converter (UDC) (See diagram at the end of this section)

i. Inputs to the UDC are:

a. Two inputs in the range 1.0 to 13 GHz. Total input power in 12 GHz should be about -30 dBm. Maximum input power in 12 GHz is -20 dBm.

b. Reference frequency from the maser of 5 MHz or 10 MHz. For 5 MHz a doubler is used inside. For 10 MHz the doubler is bypassed. Power level should be

ii. Outputs from the UDC are:

a. Two IF outputs are available on the front panel with signal in the range selected by the internal Nyquist zone filters. For this experiment the 2nd NZ is used, covering approximately 0.512 – 1.024 GHz. The filter has a center frequency of 768 MHz and a bandwidth of 480 MHz.

b. As configured for this experiment a second output is available internally for each IF. The output is before the 30 dB attenuator and Nyquist zone filter, so covers the range 0.5 – 2.5 GHz. The gain is +29 dB relative to the input. It can be routed to the connector on the rear panel for external access, perhaps as input to the Mk4 rack if a filter is included in the path, e.g. a 2nd NZ filter corresponding to that used internally.

c. There is a 10 MHz output available internally that is coherent with the 5 MHz or 10 MHz input reference frequency. It can be routed to the connector on the rear panel for external access if this connector is not being used to output the IF that is available for an additional Nyquist zone. See the UDC block diagram below (from Mark 5 memo #056).

iii. Frequency

The frequency set for the Luff synthesizer is shown in the LED display on the front panel and alternates with the attenuator settings.

The frequency is calculated as (see Mark 5 memo #056 by A.E.E.Rogers):

$$f_{\text{Luff}} = (22.5 + (f_{input} - f_{output}))/4 \tag{7.1}$$

where f_{input} is an input frequency and f_{output} is the resulting output frequency. Frequencies are in GHz. For example, to correspond to the X-band setup at Westford, using the second Nyquist zone, the input frequency is the lower edge of the 2nd NZ at 8.080 + 0.512 GHz = 8.592 GHz. The required output frequency is 0.512 GHz. For these values f_{Luff} = 7.645 GHz. (f_{input} - f_{output} is just the LO frequency in all cases. -aen)

iv. Gain

The gain through the UDC is 60 dB minus the reduction in a programmable attenuator, which can take on values between 0 dB and 30 dB. So the net gain is 30 to 60 dB

The attenuation for each IF is shown on the front panel, alternating with the set value for the Luff synthesizer.

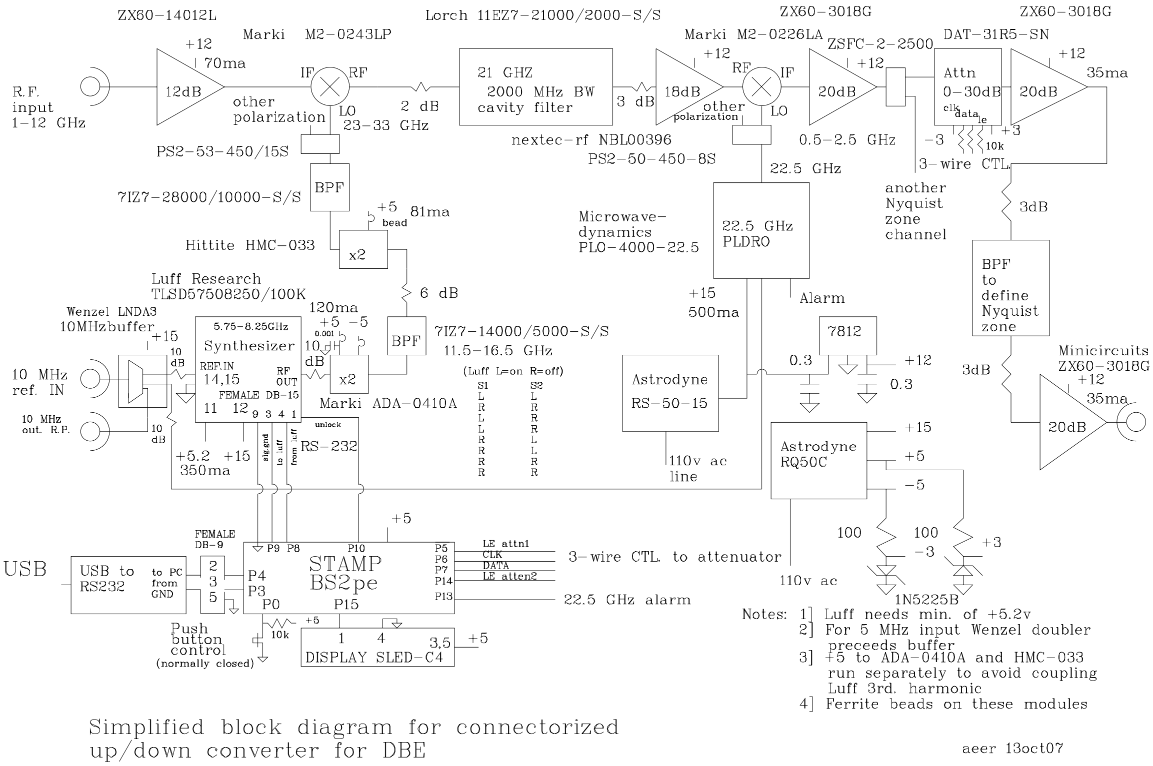
v. Setting the frequency and attenuations

The frequency and attenuations alternate. To change the frequency, when it appears on the display, push the button until the least significant digit flashes. Then push the button one time for each increment of one. When the desired value for that digit is reached, push the button in and hold it until the next digit flashes. Then increment it as for the first digit. After the fourth digit is set, push and hold the button until the four digits are on continuously.

To change the attenuations, follow the same procedure, except the attenuations cycle from 0 through 30 then start over again.

Remember that the attenuation is the amount subtracted from a maximum gain of 60 dB.

Figure C. Up-Down Converter (A.E.E.Rogers).



B. DBE (connection; input levels, setting gains)

i. Inputs to the DBE are:

a. Two IF inputs, each of bandwidth 0.512 GHz in the range 0.5 to 2.5 GHz. Input power in the range -15 dBm to -10 dBm.

b. Reference frequency from the maser of 5 MHz or 10 MHz.
For 10 MHz reference frequency, J1 must be jumpered.
5 MHz level: 0 to 5 dBm.

c. 1 pps (on the back)

max high input: 5V
min high input: 2.3V

max low input: 2V
min low input: -0.5V

d. Serial input from the Mk5B

Level: RS-232

ii. Outputs from the DBE are:

a. Eight channels from each input IF are spliced on to one VSI-H output connector.

b. A monitor port for each IF input is available on the front panel at -15 dB relative to the input. This can be used as input to the spectrum analyzer or to the Mk4 rack.

c. Four ports that output the 1.024 GHz used in the sampler are output on the front panel.

C. Mk5B+
Use *drudg* option 11 to select:
rack=none
Rec1=Mark5B
In /usr2/conrol/equip.ctl file
none   type of rack
mk5b_bs   type of recorder 1

8. Interferometer sensitivity

From memo v2c_bbd_estimation_1 (aen, 2006/06/01)

The expected amplitude of the correlation coefficient at each frequency, f_i, in terms of the system equivalent flux density at that frequency, $SEFD(f_i)$ (assumed the same for all antennas), and source correlated flux density at that frequency, $S_c(f_i)$, is

$$A(f_i) = \eta \frac{S_c(f_i)}{SEFD(f_i)} \quad (8.1)$$

The loss factor, η, is approximately 1/(1.13*0.850) ≈ 1.04, where the terms are for four-level quantization (1.13) and three-level one-path fringe rotation (0.850) (TMS p. 366 Table 9.7).

From a note by RJC the noise for two-bit samples, with a correction for the effects of the digital correlation, is

$$\begin{aligned} \sigma &= 1/(0.985*0.790*\sqrt{\text{number of samples per AP}}) \\ &= 1.285/\sqrt{2BT_{AP}} \end{aligned} \quad (8.2)$$

where B is the video bandwidth and T_{AP} is the length of the accumulation period. This is the noise for each frequency channel, assuming sixteen lags are used (accounted for by the factor 0.985). If eight lags are used, the factor 0.985 becomes approximately 0.96 (AEER VLBI Geodetic technical memo #008 1992 Oct 8).

The noise calculated this way applies to the amplitude and phase for each frequency channel. In estimating these values from the correlation coefficients in a least squares sense, the number of bits can be treated as distributed among both cos and sin correlation coefficients and across all lags.

As an example, for S_c = 1 Jy, SEFD = 2500 Jy, B = 16 Mhz, T = 3 seconds, the amplitude is $42*10^{-5}$, and the SNR should be A/σ = 1.04*1/2500*sqrt(2*16e6*3)/1.285 ≈ 3.17 for one frequency channel. For a 30 second scan, with no coherence loss, the SNR should be ≈ 10.0. An SEFD of 2500 is close to the value of 2430 that would be obtained for a 12 m antenna with T_{sys} = 50K and an efficiency of 50%.

Combining the equations for amplitude and noise, the SNR for a scan of length T (seconds) and bandwidth B (Hertz) is given by

$$SNR = 0.8 * \sqrt{2BT} * \frac{S_c(f_i)}{\sqrt{SEFD_1(f_i) SEFD_2(f_i)}} \tag{8.3}$$

In the first radical term B is the total bandwidth recorded, which is 8*32 MHz = 256 MHz in each IF. However, at Westford the RF filter cuts off at approximately 8.9 GHz, so two channels will not have significant signal, and the bandwidth is more likely to be 192 MHz. Furthermore, for this test Westford is observing in circular polarization, so the SNR will be reduced by approximately 30% due to the crossed linear and polarization.

For Westford the SEFD is about 1300 Jy (from the 2007 Session Station performance figure). The SEFD for a 5m antenna with T_{sys} = 50K and efficiency of 40% is approximately 17500 Jy. If we calculate for a 60 second scan and account for the polarization loss, the expected SNR is

$$SNR(60\sec) = 18 * S_c(f_i) * \sqrt{\frac{17500}{SEFD_{MV3}(f_i)}} \tag{8.4}$$

If the SEFD for MV-3 is five times worse than hoped for, as measured by WEH on Nov 11 on the Moon, the SNR for a 1 Jy source will be about 8. The expected calibrators (see next section) for the test session all have correlated flux density on the Wfrd-GGAO baseline greater than 5 Jy, so an SNR of greater than 40 in one minute seems easily achievable.

9. Schedule

Sources are needed both for pointing/T_{sys} measurements and for VLBI fringes.

a. Local sideral time:
(EDT changes to EST on Nov 4)

At 1704 UT and longitude 74.5° LST = 1840
➔ LST = UT+1:36
EDT = UT – 4 = LST – 2:30
so LST = EDT + 2:30

EDT	RA of transiting source
0900	1130
1200	1430

(check: Oct 26 is 1 month after autumnal equinox. On Sept 21 noon+1hr was about 1200 LST (3C273 near sun for Octoberfest VLBI), so 1 month later noon+1 hr should be ~1400 LST; okay)

So what are approximate rise/set times:

3C273 visible approx 10 hours, so transits at 1000 EDT, rises at 0500 EDT, and sets at 1500 EDT.

3C279 visible approx 9 hours, so transits at 1030 EDT, rises at 0600 EDT, and sets at 1500 EDT.

b. Pointing/SEFD sources (WEH has list from doing previous checks for MV-3)

c. VLBI sources (rise and set are for interferometer pair)
Times are for Oct 29 (or 30) and get earlier by approximately 4 minutes per day.

	name	B1950	J2000	S_0 (Jy)	rise(UT)	set(UT)
	3C84	0316+413		13	2218	1337
	0552+398		0555+398	5	0105	1602
	4C39.25	0923+392	0927+390	12	0440	1928
	3C273	1226+023	1229+020	30	0953	1958
➔	3C279	1253-05	1256-057	13	1046	1955
	1921-293		1924-292	11	1908	0017
	2134+004		2136+006	8	1903	0503
	3C454.3	2251+15	2253+161	7	1931	0717

d. Schedule (DSM)

Start UT	Stop UT	Source name (common or B1950)
1100	1850	3C279
1900	2000	3C273
2010	0450	2134+004
00500	1100	4C39.25

Scan lengths
10 minutes between start times.
Start each scan on even ten minutes.

10.Media needed

1. per hour data volume for Mk5B+ at 2 gbps
   2e9 bit/sec * 3.6e3 sec/hour /8 bits/Byte= 0.9 TBytes per station per hour
2. **Total data volume:**
   Mk5B+ (each station):
   6 hour session: 6 times 0.9 TB for each stations = 5.4 TB
   Note sent to DRS and DLS (who will condition modules) 07/10/17.

11.Correlation

Correlation will be at Haystack.

Westford data will be duplicated so the full polarization correlation can be simulated by doing XW_1, YW_2, XW_2, YW_1, where X and Y are the two linear polarizations at GGAO and W_1 and W_2 are the single Westford right circular polarization output, duplicated to match the X and Y track assignments.

12.Analysis

How to process dual polarization data
Performance – antenna and recording equipment
GGAO
Westford
Differential phase

13.Spreadsheet for testing power levels

Test other values of amp/atten

BBDev_level.xls	DLS	10/29/2007						
	modified by aen 07/11/05							
RF Levels for X-band GGAO Westford BBDev Experiment								
GGAO					<---for 1 MHz Video Resolution on scope --->			
	fiber	fiber	coax		fiber	coax	fiber	coax
T(K)	50	50	50		50	50	300	300
Bandwidth (GHz)	12.000	0.500	0.500		0.001	0.001	0.001	0.001
LNA In (kTB)	-81	-95	-95	dBm	-122	-122	-114	-114
LNA Gain	37	37	37	dB	37	37	37	37
LNA Out	-44	-58	-58	dBm	-85	-85	-77	-77
Amp Gain	12	12	38	dB	12	38	12	38
Amp Out	-32	-46	-20	dBm	-73	-47	-65	-39
8ft coax (SF142)	-6	-6	-6	dB	-6	-6	-6	-6
Short Coax Out	-50	-52	-26	dBm	-79	-53	-71	-45
Fiber/coax Gain	-6	-6	-19	dB	-6	-19	-6	-19
Fiber Out	-38	-52	-39	dBm	-79	-66	-71	-58
Amp Gain	0	0	0	dB	0	0	0	0
UDC In	-38	-52	-39	dBm	-79	-66	-71	-58
Maximum	-22			dBm				
UDC gain range		30 to 60 dB			30 to 60 dB		30 to 60 dB	
UDC atten setting		20	21		20	21	20	21
UDC gain (60-atten)		40	39	dB	40	39	40	39
UDC Out		-12	0	dBm	-39	-27	-31	-19
Attenuator		0	0	dB	0	0	0	0
DBE In (Spec -15 to -10 dBm)		-12	0	dBm	-39	-27	-31	-19
DBE Input level must be set BEFORE connecting								
DBE 'IF in' monitor (-15dB)		-27	-15	dBm	-54	-42	-46	-34
UDC IF unfiltered output (has to be connected to external port on back)								
UDC gain for this output:		29	29	dB	29	29	29	29
UDC IF monitor out		-23	-10	dBm	-50	-37	-42	-29