VLB ARRAY MEMO No. 184

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To: VLBA Design Group
From: Martin Ewing
Subject: Correlator "176" vs. an "ideal" system

The purpose of memo #176 was largely to outline a technical "existence proof" of a correlator that would meet the requirements of the new IF channelization specification, spectroscopic frequency resolution, and suitability for a VLSI correlator implementation. This memo summarizes the capabilities provided by that system (hereinafter called Correlator 176) and compares these with the capabilities of an "ideal" correlator, in which signal switching (recirculation and/or "packet switching") is so arranged to keep all correlation elements fully occupied at all times.

1.0 TWO CORRELATORS.

Correlator 176 apparently meets the requirements of Reid's memo #127 (Spectral Line Experiment Example) in IF mode 2. In this case 2,048 lags (1,024 frequency channels) are provided for each baseline. (Up to 8 input streams at up to 16 MHz bandwidth each can be accepted, but for the proposed spectral line experiment, only a single 16 MHz stream is required.) To provide this capability for a 10-antenna array, 184,320 lags (operating at 16 Mb/s) are required.

An "ideal" correlator architecture, using the same 16 Mb/s correlator chips, would be so arranged that all correlator sections were kept busy, no matter how many antennas, IF streams, etc., were involved in a particular experiment. In practice, such a general capability is not achievable because of the very complicated switching and the odd numbers (in the FFT sense) of lags that would result. The ideal system still requires 184,320 complex lags to support the hypothetical spectral line experiment. The number of lags provided by such an ideal correlator used in a 1-stream non-polarization mode is shown in the following table.

IF MODE	No. of Antennas 10	11	12	13	14	15	16	17	18	19	
1	1024	837	698	590	506	438	384	338	301	269	unrounded
	1024	512	512	512	256	256	256	256	256	256	rounded
2	2048	1675	1396	1181	1012	877	768	677	602	538	
	2048	1024	1024	1024	512	512	512	512	512	512	
3	4096	3351	2792	2363	2025	1755	1536	1355	1204	1077	
	4096	2048	2048	2048	1024	1024	1024	1024	1024	1024	
4	8192	6702	5585	4726	4050	3510	3072	2710	2409	2155	
	8192	4096	4096	4096	2048	2048	2048	2048	2048	2048	
5	16384	13405	11170	9452	8101	7021	6144	5421	4818	4311	
	16384	8192	8192	8192	4096	4096	4096	4096	4096	4096	
6	32768	26810	22341	18904	16203	14043	12288	10842	9637	8623	
	32768	16384	16384	16384	8192	8192	8192	8192	8192	8192	
7	65536	53620	44683	37809	32407	28086	24576	21684	19275	17246	
	65536	32768	32768	32768	16384	16384	16384	16384	16384	16384	
8	*****	*****	89367	75618	64815	56173	49152	43369	38550	34492	
	*****	65536	65536	65536	32768	32768	32768	32768	32768	32768	
9	*****	*****	*****	*****	*****	*****	98304	86738	77101	68985	
	*****	*****	*****	*****	65536	65536	65536	65536	65536	65536	

IDEAL CORRELATOR, LAGS/BASELINE

184320 total lags.
1 stream, Non-polarization

In the following section, the two correlator systems are compared for the various operating modes.

2.0 SUMMARY OF SUPPORTED MODES

A large number of operating modes is required to support the various channelization parameters (numbers of streams vs. bit rate per stream), polarization vs. non-polarization processing, number of antennas, etc. The following tables present the number of lags achieved by Correlator 176 in each mode. This correlator is compared with an ideal correlator according to two statistics, F(r) and F(u).

F(u) is the ratio of the number of lags provided by Correlator 176 to the number of lags in the ideal correlator, for a particular number of antennas processed simultaneously. It is "un-rounded," meaning that the ideal number of lags has no particular relationship to a power of two.

F(r) is a somewhat more realistic estimate of the efficiency of Correlator 176. It is the ratio of the number of lags provided by Correlator 176 to the "rounded" ideal number, i.e., rounded downward to the nearest power of two. (An alternative rounding would be down to the nearest "highly composite" number.)

2.1 2-10 Antennas, Polarization.

IF mode	No. poln pairs	Bandwidth per Stream	Lags per Baseline	--10 Ant-- F(r)	F(u)
1	2	32 MHz	256*	1.0	1.0
2	4	16	512	1.0	1.0
3	8	8	1024	1.0	1.0
4	16	4	1024	0.5	0.5
5	16	2	1024	0.25	0.25
6	16	1	1024	0.13	0.13
7	16	0.5	1024	0.06	0.06
8	16	0.25	1024	0.03	0.03
9	16	0.125	1024	0.02	0.02

* Corrects error in Memo #176.

The column indicated "No. poln pairs" refers to the number of independent frequency bands. There are two streams (right and left) recorded for each frequency band.

Correlator 176 is very efficient for 10-station polarization; it is equal to the ideal system in IF modes 1-3. These would most likely be the standard VLBA continuum modes. Modes 3-9 are adequate for 512 frequency channel spectral line polarization work.

2.2 11-13 Antennas, Polarization.

IF mode	No. poln pairs	Bandwidth per Stream	Lags per Baseline	--11 Ant-- F(r)	F(u)	--13 Ant-- F(r)	F(u)
1	2	32 MHz	128*	1.0	0.61	1.0	0.87
2	4	16	256	1.0	0.61	1.0	0.87
3	8	8	512	1.0	0.61	1.0	0.87
4	16	4	512	0.5	0.31	0.5	0.43
5	16	2	512	0.25	0.15	0.25	0.22
6	16	1	512	0.13	0.08	0.13	0.11
7	16	0.5	512	0.06	0.04	0.06	0.05
8	16	0.25	512	0.03	0.02	0.03	0.03
9	16	0.125	512	0.02	0.01	0.02	0.01

* Corrects error in Memo #176.

For continuum work, Correlator 176 supports 13 antennas virtually as well as 10. In spectroscopic mode, 256-frequency work is still possible for 13 antennas in one processing pass.

2.3 14-19 Antennas, Polarization.

IF mode	No. poln pairs	Bandwidth per Stream	Lags per Baseline	--14 Ant-- F(r)	F(u)	--19 Ant-- F(r)	F(u)
1	2	32 MHz	*				
2	4	16	128	1.0	0.51	1.0	0.96
3	8	8	*				
4	16	4	*				
5	16	2	*				
6	16	1	*				
7	16	0.5	*				
8	16	0.25	*				
9	16	0.125	*				

* Mode not available.

For 19 antennas, only IF mode 2 is permitted to process full polarization. However, the full RF bandwidth is available in this mode. (Mode 1 is prohibited by the need for the second step of bandwidth doubling, and modes 3-9 are prohibited because of the excessive numbers of polarization pairs.)

Spectral-line processing would be very slow for 14-19 antennas in full polarization mode.

2.4 2-10 Antennas, No Polarization.

IF mode	No. data Streams	Bandwidth per Stream	Lags per Baseline	--10 Ant-- F(r)	F(n)
1	4	32 MHz	1024*	1.0	1.0
2	8	16	2048	1.0	1.0
3	16	8	4096	1.0	1.0
4	32	4	4096	0.5	0.5
5	32	2	4096	0.25	0.25
6	32	1	4096	0.13	0.13
7	32	0.5	4096	0.06	0.06
8	32	0.25	4096	0.03	0.03
9	32	0.125	4096	0.02	0.02

* Corrects error in Memo #176.

Mode 2 supports a large spectral line experiment, such as outlined in Memo 127. Up to 2,048 frequency channels are available in modes 4-9.

2.5 11-13 Antennas, No Polarization.

IF mode	No. data Streams	Bandwidth per Stream	Lags per Baseline	--11 Ant-- F(r)	F(u)	--13 Ant-- F(r)	F(u)
1	4	32 MHz	512*	1.0	0.61	1.0	0.87
2	8	16	1024	1.0	0.61	1.0	0.87
3	16	8	2048	1.0	0.61	1.0	0.87
4	32	4	2048	0.5	0.31	0.5	0.43
5	32	2	2048	0.25	0.15	0.25	0.22
6	32	1	2048	0.13	0.08	0.13	0.11
7	32	0.5	2048	0.06	0.04	0.06	0.05
8	32	0.25	2048	0.03	0.02	0.03	0.03
9	32	0.125	2048	0.02	0.01	0.02	0.01

* Corrects error in Memo #176.

Again, except for a factor of 2 in frequency/lag channels, 13 antennas are supported as well as 10. Large spectral line experiments are still feasible.

2.6 14-19 Antennas, No Polarization.

IF mode	No. data Streams	Bandwidth per Stream	Lags per Baseline	--14 Ant-- F(r)	--14 Ant-- F(u)	--19 Ant-- F(r)	--19 Ant-- F(u)
1	4	32 MHz	256*	1.0	0.51	1.0	0.95
2	8	16	512	1.0	0.51	1.0	0.95
3	16	8	1024	1.0	0.51	1.0	0.95
4	32	4	**				
5	32	2	**				
6	32	1	**				
7	32	0.5	**				
8	32	0.25	**				
9	32	0.125	**				

* Corrects error in Memo #176.
** Mode not available.

In the non-polarization case, 19 antennas are supported in modes 1-3. "Conventional" (512-frequency) spectroscopy is still available. (Note that "bandwidth per stream" is a maximum; it can be reduced to any value supported by the IF system.)

3.0 IS CORRELATOR 176 GOOD ENOUGH?

In the tables above, the reader will notice some values of F(u) are nearly as low as 0.5. This is a result of permitting only divisions by two in the correlator structure. In some modes only about half of the unit correlators are active.

A second "shortcoming" of Correlator 176 is that only certain modes are supported for 14-19 antennas, again because of halving and quartering.

The correlator does, however, support full-bandwidth continuum observations even for 19-antenna experiments. Indeed, 512-frequency spectral line work is available for 19 antennas.

The chief variation of Correlator 176 from the ideal occurs at low bandwidths. It is unlikely that the very large numbers of channels ideally available would ever be used: the post-correlation computing burden is enormous, and the astronomical need is unclear.

Correlator 176 has a number of technical advantages over a "packet-switching" or recirculating system. All signal switching is local to the unit correlator or quad correlator; there is no "global" buffer memory required; and there are only well-defined and restricted interconnections between system components.

Given a particular IC technology, running at 32 Mb/s or less, the same number of correlation ICs is required for Correlator 176 as for any more efficient system. The number is determined by the need to support the "large" spectral line experiment.