MILLIMETER ARRAY
MEMO NO. 109

MMA System Update

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The latest description of the general electronic receiving system of the MMA prior to this update is given in the report "Millimeter Array Design and Development Plan", dated Sept. 1992, which includes a system block diagram. A number of decisions and changes have subsequently been made in the system concept, largely as a result of the discussions at the MMA Advisory Committee meeting of Sept. 16-17, 1993. This memorandum is concerned mainly with the resulting changes in the system block diagram, a revised version of which is shown in Fig. 1.

(1) Front Ends

As a means of simplifying the microwave optics of the receivers, it has been recommended that, (1) it is not necessary to be able to observe in more than one frequency band simultaneously, (2) it is not necessary to terminate of the image frequency bands of SIS mixers with 4K loads, and (3) it is not necessary to provide for reception in circular polarization in all frequency bands. Dispensing with dual-band observing results in a significant simplification of the optics. With regard to dispensing with the cold image termination, the effect on the sensitivity depends upon the type of mixer being used. Successful development of the image-separation type of SIS mixer for the MMA would eliminate the need for a cold load. However, it is not yet clear whether such mixers will be a practicable alternative to conventional SIS mixers with 4K image terminations. For the latter, dispensing with cold image terminations would reduce the sensitivity by approximately 20% to 40%, and it is not clear that it is necessary. The cold termination is retained for the present in Fig. 1.

It has also been decided that simultaneous observation in both sidebands is necessary with the SIS front ends, to increase the spectral bandwidth that can be observed at any instant. To maintain sensitivity the sidebands may be separated using either a Martin-Puplett interferometer, with separate SIS mixers for each polarization in both the upper and lower sidebands, or an image-separation mixer. In either case, each SIS front end has four IF outputs as indicated in Fig. 1. The receiving system must retain the capacity to process four IF signals, even though observations are made in only one frequency band at a time.

(2) IF Transmission

A major change in the block diagram results from the use of analog rather than digital transmission of the IF signals from the antennas to the correlator, which is located at the main electronics building at the site. The use of digital transmission in the earlier block diagram was based on the assumption that the required dynamic range in the images would be comparable to that of the best centimeter wavelength images (i.e. 50 to 60 dB). Experience with the VLA has shown that one of the limiting factors in the dynamic range achieved is the variation of bandpass responses with time, which would be greatly reduced by digital signal transmission. However, there was general agreement at the Advisory Committee meeting that the useful dynamic range at millimeter wavelengths would not exceed 30-40 dB, and that analog transmission on optical fiber would certainly be adequate. With analog transmission all of the filtering and fine tuning required in high spectral resolution observations can be performed at the correlator location, thus reducing the amount of electronics at the antennas. Also the local oscillator system is simplified by the reduction of the number of LO signals that have to be generated independently at each antenna.

In the new block diagram the IF response at the SIS mixer outputs is 4-6 GHz, (previously it was 3-4 GHz) which is now the band of the choice for best overall performance in sensitivity, sideband separation, etc. If each IF signal is accommodated on one optical fiber, the total bandwidth transmitted from each antenna to the correlator location is 8 GHz, which is twice the bandwidth in the earlier block diagram. The proposed bandwidth of the spectral correlator is 2 GHz, so the 8 GHz total IF bandwidth in Fig. 1 allows for an increase in the correlator capacity or for a broadband continuum correlator. The bandwidth that a single fiber can carry depends upon the dynamic range of the signal and the noise level of the optical transmitter and receiver units. A 2 GHz bandwidth per fiber should easily be accommodated, and 4 GHz may be possible. With the HFET front ends the bandwidth transmitted is limited by the optical transmitter and receiver, not the front end, so with the four fibers a total bandwidth of 16 GHz could probably be transmitted to the correlator.

(3) Bandwidth Selection of the IF Signals

After the IF signals are received at the correlator location, further filtering is necessary to select a bandwidth appropriate for the spectral resolution required from the correlator. For a given spectral resolution, the total IF bandwidth that the correlator can process will depend upon the design of the correlator, which is not likely to be finally specified until some time close to the start of construction. The frequency conversion and filtering of the IF signals in the upper right-hand part of Fig. 1 is therefore a current best guess of what may be needed. It has been assumed that the correlator will process 2 GHz of bandwidth from each antenna and handle 1000 spectral channels at that bandwidth. Clark (1992) has suggested that it would be possible to eliminate the pre-sampler filtering and do all of the filtering digitally, using FX correlator techniques. At this point we cannot assume that FX technology will be the final choice: on the contrary, there is some evidence of a return to favor of the lag correlator for large array systems. The lag scheme seems better adapted for implementation in very large sized ICs, since the operations are inherently simpler than those of the FX scheme and the numbers of bits required to represent the data does not increase so rapidly as the processing proceeds. If we take 1000 lags and a clock rate of 125 MHz as representative of current goals in lag correlator ICs, then 16 such ICs in parallel would handle a 1 GHz bandwidth and produce 1000 output channels. With 500 MHz bandwidth the ICs could be rearranged as eight pairs in parallel, each pair providing 2000 lags. Similarly, further reductions in bandwidth would allow corresponding increases in the number of lags. With 62.5 MHz bandwidth all 16 ICs could be operated in series to provide 16,000 lags, i.e. an output resolution of 3.9 kHz which is slightly better than the maximum required resolution of 6 kHz generally assumed for the MMA. Thus in the IF Filter Unit in Fig. 1, the output bandwidths go from 1 GHz to 62.5 MHz, being reduced in steps of two[1]. Sampling with a 2 GHz clock rate, as required for a 1 GHz bandwidth is currently feasible. An output with 2 GHz bandwidth is also shown in Fig. 1 as sampling with 4 GHz clock rate may soon be possible. Although a final system may use different bandwidths, those shown in Fig. 1 should adequately represent the complexity of the final system in terms of the number of mixers and filters likely to be required.

In the IF Filter and Sampler blocks of Fig. 1, bandpass sampling is used with filters to reject the image responses at the mixers. The previous version of the block diagram showed lowpass sampling with sideband-separating mixers to eliminate the image responses. That would be the simplest scheme in terms of minimizing the number of filters and LO frequencies required, but experience with sideband separating mixers in the VLA and VLBA indicates that the best maintainable rejection of the unwanted sideband is approximately 24-28 dB. With the VLA the probability of a strong unwanted line falling within an image response is relatively small because the IF bandwidths involved are about and order of magnitude smaller than those being considered for the MMA, and also because the numbers of lines are very much smaller at cm than at mm wavlengths. For the MMA, a spectral dynamic range at least comperable to the dynamic range of image brightness, i.e. 30-40 dB would seem to be desirable: advice from astronomers on this point would be useful. With the bandpass sampling and filtering shown the rejection is limited mainly by the filters, and 40 dB is a reasonable goal. Also with scheme shown in Fig. 1 the time-consuming adjustment of the mixers to achieve adequate separation of sidebands avoided.

Since there are three LO signals used within the IF Filter Unit some attention must be given to the possibility of an LO contaminating an IF signal, for example the 1.5 GHz LO falls within the passband of the 1-2 GHz and 1-1.5 GHz IF filters. A simple solution is to switch off the 1.5 GHz LO when the 1 GHz or 500 MHz bandwidths is being used, since it is then not required. However, there remains the possibility that these bandwidths would be required in one filter unit while the 1.5 GHz LO is required in another. Phase switching would reduce the response to unwanted pickup of an LO by 20-30 dB, but good shielding etc. to confine LO signals would still be important.

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[1]This increase in the number of channels as the bandwidth is reduced is similar to the effect of recirculation that is used, for example, in the VLA correlator. However, in this case the increase in the number of channels can only be obtained so long as the sample rate is greater than the operating clock rate of the correlator ICs.

The bandpass filters in the IF Filter blocks in Fig. 1 have ratios of the upper and lower cutoff frequencies of 1:2, 2:3, and 4:5, i.e. bandwidths of 66.7%, 40%, and 22.2%. As the percentage bandwidth of the filter is decreased the amount of aliasing at the band edges increases. For example, with a 4:5 ratio filter with 8 sections the ratio of the -20 dB bandwidth to the -3 dB bandwidth is about 1.3. Thus if the filter is 20 dB down at the nominal band edges, aliased components should be reduced by 40 dB or more for the central 77% of the band . Some channels at the band edges would need to be discarded as is commonly the case in digital spectrometers.

(4) Local Oscillator Signals

The high frequency LO units at the antennas need only to be tunable in increments of approximately 250 MHz, since the bands transmitted to the correlator location are at least 2 GHz wide. One fiber should be provided to transmit the LO reference frequencies to the antenna, and the 1 GHz reference frequency is transmitted back from the antenna to allow a round-trip phase measurement to be made. Figure 1 shows the same fibers being used for the transmission of the LO reference signals and the monitor and control signals. It may be possible to save a fiber by returning the monitor and the 1 GHz round-trip phase signals on the fibers carrying the IFs.

Since the IF signals all undergo frequency conversion and filtering together at the correlator location, the number of LO synthesizer units needed to generate the LO signals required for the IF Filter Units is reduced by a factor of 40 from that required if the filtering is performed at the antennas. Phase noise in these oscillators, which might be significant in the finely-tuned one, cancels out in the correlation because the same oscillators are used for the signals from all antennas.

(5) Phase Switching and Fringe Rotation

Since sideband separation in the front end optics may not provide sufficient isolation of the two signals over a 2 GHz bandwidth, phase switching of the first local oscillator in $\pi/4$ increments, as well as the usual $\pi/2$ phase switching, should be provided to allow further separation at the correlator. This was incorporated in the earlier block diagram, and remains. Fringe rotation can in principle be performed on any local oscillator either at the antenna or the correlator location. Since a different fringe rate must be generated for each antenna, there is no great advantage in doing it all in one place, i.e. at the correlator location. There are, however, arguments for performing fringe rotation as early in the system as possible (see, e.g., Thompson et al., 1986). In Fig. 1 it is therefore inserted at the phase lock loop reference of the 30-45 GHz stage of the first local oscillator, along with the phase switching. Note that the frequency of this oscillator is multiplied by factors of 2, 3, 4, 6, or 8 for the higher frequency receiving bands, so the resulting multiplication of phase shifts and frequency offsets must be taken into account. Phase noise in the synthesized fringe frequency is increased in power spectral density in proportion to the square of the multiplying factor. This increase should not be a serious problem, but if it is the multiplication can be avoided by applying the fringe frequency offset to a lower frequency LO later in the signal path.

(6) Continuum Correlator

Provision of a broadband system for high sensitivity continuum measurements, possibly using an analog correlator, is another recommendation of the MMA Advisory Committee. Such a broadband system may be less costly to make in analog than in digital form, but it is more difficult to achieve high precision with an analog system. Note that such an analog system would require an analog compensation delay. Following the design criterion used in the VLA, the minimum increment for delay adjustment should be 1/32 of the reciprocal bandwidth, or 31 ps for 1 GHz bandwidth. The corresponding air-path length is 4.7 mm. With a 2 km baseline the rate of delay adjustment could be as high as every 32 msec. An analog delay line would require 18 elements with lengths from 4.7 mm to 1.2 km, and keeping the longer pieces calibrated to an accuracy small compared with 4.7 mm would require some kind of continuous calibration scheme. In addition, keeping the delay line well matched with such a number of elements in series would require numerous buffer amplifier stages and even then might result in unacceptable variations of the bandpass with delay setting. The conclusion seems to be that a special broadband continuum system should use digital delays and correlator, with parallel processing of IF bands to achieve a large total bandwidth.

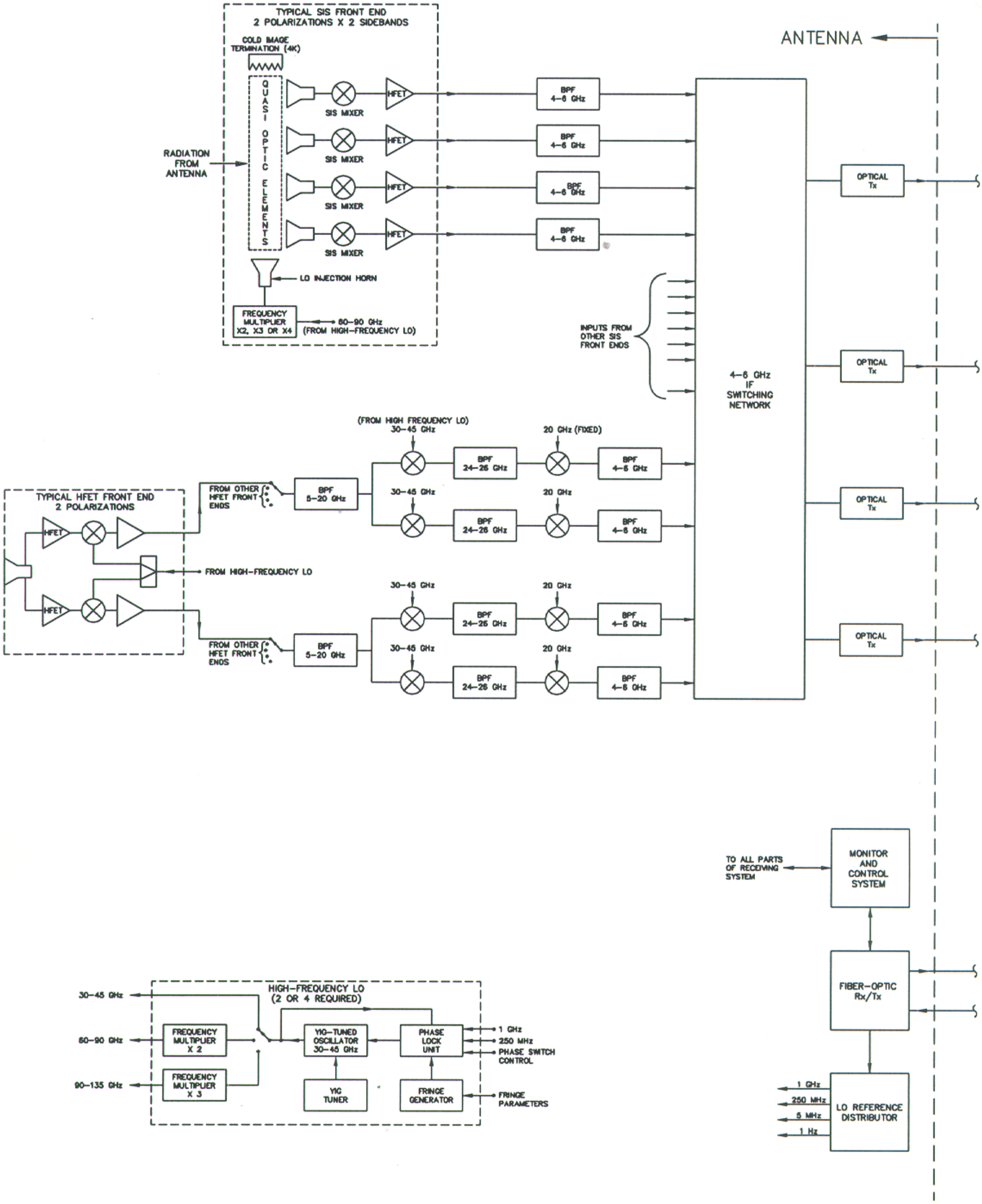
Since the emphasis on bandwidth in the continuum system results from the requirement for maximum sensitivity, cold-load image termination of SIS mixers remains desirable. In terms of sensitivity such termination is equivalent to a bandwidth increase of 1.4 to 2. Double sideband operation allows the image to be terminated on the cold sky, but the sensitivity is less than the that of the single sideband case by a factor of $\sqrt{2}$. Also, with double sideband operation the delay setting accuracy would be increased by a factor of more than 6.

A. R. Kerr, R. P. Escoffier and R. Norrod are thanked for useful discussions.

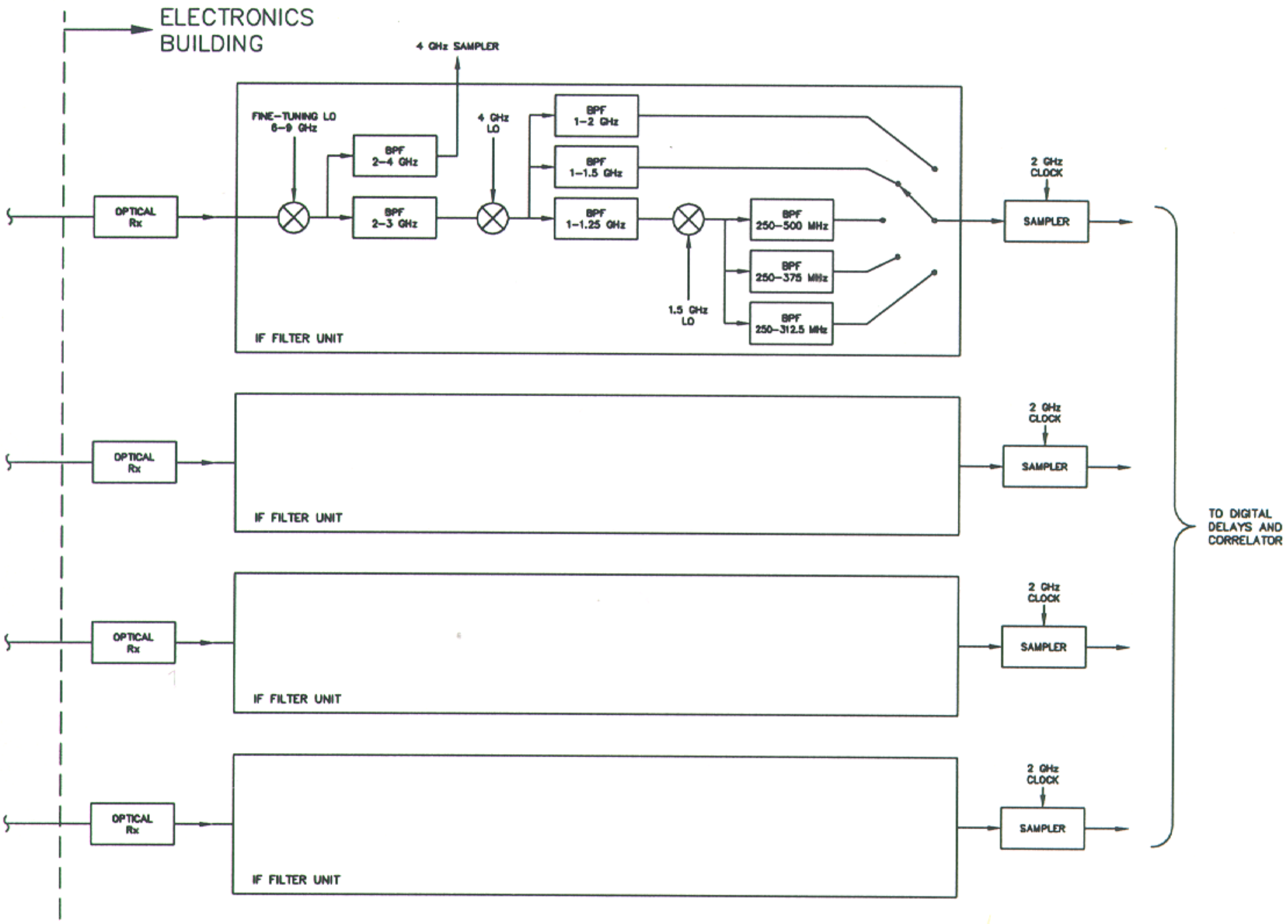
References

Clark, B. G., MMA Memo 85, June 1992.

Thompson, A. R., Moran, J. M. and Swenson, G. W., Interferometry..., Wiley, 1986, p. 205.



ANTENNA
TYPICAL SIS FRONT END
2 POLARIZATIONS X 2 SIDEBANDS
COLD IMAGE TERMINATION (4K)
QUASI OPTIC ELEMENTS
RADIATION FROM ANTENNA
HFET
SIS MIXER
LO INJECTION HORN
FREQUENCY MULTIPLIER X2, X3 OR X4
60-90 GHz (FROM HIGH-FREQUENCY LO)
BPF 4-6 GHz
INPUTS FROM OTHER SIS FRONT ENDS
4-6 GHz IF SWITCHING NETWORK
OPTICAL Tx
(FROM HIGH FREQUENCY LO) 30-45 GHz
20 GHz (FIXED)
30-45 GHz
20 GHz
BPF 24-26 GHz
BPF 5-20 GHz
FROM OTHER HFET FRONT ENDS
TYPICAL HFET FRONT END
2 POLARIZATIONS
FROM HIGH-FREQUENCY LO
TO ALL PARTS OF RECEIVING SYSTEM
MONITOR AND CONTROL SYSTEM
FIBER-OPTIC Rx/Tx
LO REFERENCE DISTRIBUTOR
1 GHz
250 MHz
5 MHz
1 Hz
HIGH-FREQUENCY LO
(2 OR 4 REQUIRED)
30-45 GHz
60-90 GHz
90-135 GHz
FREQUENCY MULTIPLIER X 2
FREQUENCY MULTIPLIER X 3
YIG-TUNED OSCILLATOR 30-45 GHz
PHASE LOCK UNIT
YIG TUNER
FRINGE GENERATOR
1 GHz
250 MHz
PHASE SWITCH CONTROL
FRINGE PARAMETERS



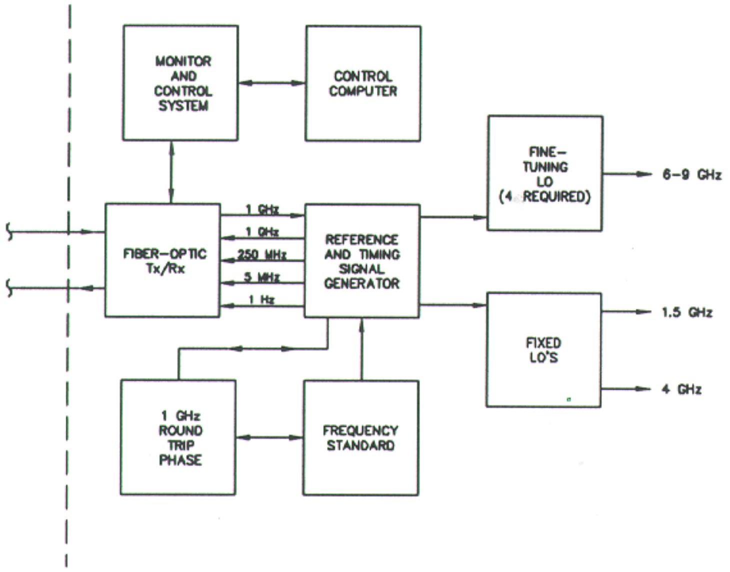


Fig. 1. Block diagram of the MMA receiving system showing signal paths from the antennas to the correlator. The left-hand page shows the system at the antennas and the right-hand that at the correlator location. The two halves are joined by six optical fibers.