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We have discussed general issues of IF transmission and channelization at some length in our meetings. To make further progress in this area I think we need to look at a specific design. The following memo describes my attempt to come up with a practical block diagram. I leave it to you to draw conclusions, which we can perhaps discuss at our next meeting on April 26.

Channelization and IF Transmission in the MMA

(1) Signal Bandwidths

At the present time the preferred bandwidth for SIS front ends made at NRAO is 2 GHz, resulting from the use of an IF response of 4-6 GHz following the mixer. A recent development at Caltech, in which the first IF stage is integrated into the mixer unit, has resulted in good performance over a 4 GHz bandwidth, with the IF covering approximately 0.5-4.5 GHz (Padin et al. 1995). It is believed that with the use of the best InP HEMTs and the integrated design it may be possible to increase the bandwidth to as much as 8 GHz, covering approximately 0.5-8.5 GHz. Thus in considering possible block diagrams it would be good to consider a bandwidth of 8 GHz (in each sideband) for SIS front ends, since even if this is not achieved for the initial design it may well be possible for later front-end upgrades. Thus I will use 1-9 GHz, as round numbers, for the SIS outputs.

The highest bandwidths of the HEMT front ends can be taken to be about 30 GHz, since the two highest frequency bands with these amplifiers are currently planned to be 60-90 and 90-115 GHz.

The limitation on the usable bandwidth will occur at the correlator. The original specification of 2 GHz total input bandwidth for the spectral line correlator will probably not be increased. However, at this stage of planning it is better to overestimate the usable bandwidth than to underestimate it since it is easy to omit unwanted bandwidth at a later stage. The bandwidth of a continuum correlator is likely to be something between 8 and 16 GHz. Thus in this memo I will try to accommodate bandwidths of 4 GHz for spectral line and 16 GHz for continuum.

(2) Intermediate Frequencies

In the IF system it is very desirable to keep all frequencies below about 20 GHz, for several reasons. First, switching of IF signals will be an essential function in selecting between different receiving bands. Coaxial switches, mechanical or solid state, are widely available up to about 20 GHz only. Waveguide switches are almost the only alternative above this frequency and they are relatively clumsy and expensive. (Nevertheless it will be necessary to use some of them for switching LO signals.) Second, the upper frequency limit for most SMA connectors is 18 GHz. Other coaxial connectors are available for higher frequencies but they are much more expensive. Third, mixers and amplifiers generally become more expensive as frequency increases, and any cost increase per front end is multiplied by 80 because there are 40 antennas and each has two polarizations.

(3) Transmission Bandwidth

Consider first the case of analog transmission on the optical fiber. The cost per unit bandwidth of analog systems (optical transmitter plus receiver) decreases a little as one goes to higher bandwidth transmitters and receivers. This points in the direction of using a small number of wide bandwidth systems rather than a larger number of narrower ones. Also, in an instrument in which bandwidth may increase with future upgrades, narrow band transmission components are likely to prove a poor investment. The bandwidths considered in section (1) could be handled by one fiber system per antenna of width 16-20 GHz. However, I prefer to consider two fibers each carrying 8-10 GHz of bandwidth since one does not completely loose an antenna if a fault develops in a fiber link. Also the transmission bandwidths approximately match the SIS output bandwidths which simplifies the electronics.

Figure 1 is a sketch of a possible analog system at the antenna. The typical SIS front end has four outputs, for two sidebands and two polarizations, each covering 1-9 GHz. Any two of these outputs can be connected to the 0-10 GHz input of the two optical transmitters. Each transmitter also has separate inputs for the 0-5 GHz and 5-10 GHz halves of its band. This allows observations to be made using two front ends simultaneously. In this dual band mode the first LOs of the two front ends would be tuned so that the desired lines fall within 0-5 GHz in one front end output and 5-10 GHz in the other.

HEMT front ends have two outputs, one for each polarization. For front ends with bandwidths up to 20 GHz the lower 10 GHz of the band can be converted to an IF of

0-10 GHz using an LO frequency equal to the lower cutoff of the HEMT amplifier band. The image frequency would fall outside the HEMT band (it may be necessary to put a bandpass filter at the HEMT output to define the band edges sufficiently sharply). Similarly the upper end of the HEMT band could be converted to 0-10 GHz using an LO frequency equal to the upper cutoff frequency. For HEMT front ends with bandwidths greater than 20 GHz an IF of 5-15 GHz is used in Fig. 1. This allows the full band to be converted without the image falling within the signal band, again using a low-side LO for the lower part of the band and a high-side LO for the upper half. (Alternatively each output from the front end can be filtered to provide two bands, each with width less than 2 GHz. To switch between these band it would be necessary to use waveguide switches.)

The scheme in Fig. 1 is about the simplest collection of components that I can devise to fulfill the necessary IF functions at an antenna. It provides at least as much bandwidth as the most optimistic correlator design will be able to handle. It provides for dual frequency observation and, except for the front ends with greater than 20 GHz bandwidth, it requires only one frequency conversion per band. There are no switches at frequencies greater than 10 GHz. The practical realization of such a system will need to take into account that the finite slopes of filter edges, and a goal for rejection of unwanted signals should be 40 dB minimum.

(4) Channelization and Sampling

The signals received at the electronics building of the array need to be filtered and converted to digital samples before going to the correlator. It will be assumed that digitizers with a sample rate of 4 GHz will be available for the MMA, and thus it is necessary to break down the IF bands into 2-GHz wide sections for the individual digitizers. For continuum observations it is assumed that almost all of the IF band would be used. Figure 2 shows a system in which the 1-9 GHz band from an SIS front end is divided into four sections and digitized. Four fixed-frequency LOs are required but since the equipment is all in one location (the electronics building) these frequencies would each be generated once and distributed by a network of power splitters and amplifiers. Either one or two of the systems shown in Fig. 2 would be required per antenna, depending on the capacity of the correlator in continuum mode.

For spectral line observations it is necessary to be able to select a band of frequencies centered at any desired point within the 0-10 GHz IF band, and to filter it to a bandwidth that is variable in factor-of-two steps from a maximum of 2 GHz. A possible scheme for accomplishing this is shown in Fig. 3. Note that I do not consider the use of sideband separating mixers to be satisfactory here since they do not provide sufficient isolation to prevent image responses to strong lines. The required frequency is first converted to a band from 6 to 8 GHz using an LO that is finely from 8 to 16 GHz. As the LO is tuned over this range the lower sideband tunes across the 0-10 GHz input band. A 6 GHz fixed LO then converts the band to 0-2 GHz. The 6-8 GHz filter response must have steep enough edges that there is very little fold-over of the signal at the lower edge of the band, and the 0-2 GHz filter must be steep enough at the edges that very little aliasing results from the sampling. The signal is also passed through other filters with bandwidths progressively decreasing by factors of two. The center frequencies of these filters are also reduced to keep the percentage bandwidth 40% and greater. Two further frequency conversions are introduced to prevent the center frequencies from moving close to parts of the band where there may be some residual fold-over from previous frequency conversions. A bandwidth of 2 GHz, 1 GHz, ... or 31.25 MHz can be selected and sampled. With the lower bandwidths the 4 GHz sample rate provides redundant samples that can be discarded. If narrower bandwidths are required they can be obtained by digital filtering after sampling. Digital filter ICs are available for frequencies up to about 50 MHz.

The filtering and sampling system in Fig. 1 provides for observation of one line or group of lines with one polarization. The minimum number of such units required for good astronomical flexibility is probably four per antenna. Their inputs can be assigned to the two optical receiver outputs in any way desired by the astronomer. For example, a different filter/sampler could be used for each polarization of two different bands, or they could all be assigned to one optical receiver to observe four different parts of one band with one polarization. A continuum system, as in Fig. 1, could also be fed from the same optical receiver to provide simultaneous line and continuum observations, limited only by the capacity of the correlator.

(5) Digital IF Transmission

Now consider what changes would be required to the system described above to implement transmission of the IF signals in digital rather than analog form. In section II(6) of the notes on the March 2, 1995 Systems WG meeting it is pointed out that to transmit an IF signal of bandwidth B takes a transmission bandwidth of 2B for 2-level samples or 4B for 4-level samples. (It is assumed that the light level in the fiber takes only two values, thus representing only one bit per clock cycle, as is the present practice for digital transmission). In the MMA correlator, the increase in sensitivity in going from 2 to 4 levels is almost root-2, and is especially important for line observations where sensitivity cannot be increased by increasing the bandwidth. Thus in a digital transmission system the full 4B bandwidth is required if performance is not to be sacrificed.

The cost of an optical transmitter and receiver pair for analog transmission with 10 GHz bandwidth is about $15k. Prices quoted by Ortel (which makes a number of systems designed specifically for analog transmission) show the cost per unit bandwidth decreasing a little for the wider-band units; i.e. it is not cheaper to use a lot of narrow band units. For digital transmission a number of makers offer units for frequencies above 1 Gb/s, but only a few for frequencies greater than 2 Gb/s. BCP (Broadband Communications Products) offers a transmitter and receiver pair for digital signals with frequencies up to 2 Gb/s for $2.8k. Based on these two examples of available systems it appears that costs for digital and analog systems are comperable for the a given transmission bandwidth (and thus different for a given IF signal bandwidth).

For continuum observations, transmission of 16 GHz of signal bandwidth in the form of four-level samples would require 4x16=64 GHz of transmission bandwidth per antenna. This would be expensive. Probably we could drop back to 8 GHz of signal bandwidth, but the increase in cost is still large. Digital transmission of broad bands for continuum observation seems only marginally feasible.

It is possible to envisage a scheme in which 16 GHz of transmission bandwidth could be used in analog mode for continuum observations or in 4-level digital mode to transmit up to 4 GHz of IF bandwidth for spectral line observations. The transmission bandwidth would be the same as for the analog system considered in section (3) above. To accommodate the analog continuum transmission one would have to use a transmission system designed for analog signals. For spectral line observations four bit streams at 4 Gb/s from the samplers would have to be combined into two 8 Gb/s streams. This would not be easy and multiplexing chips at such frequencies are extremely expensive. The advantage of the scheme is that spectral line observations would be unaffected by the spectral response of the transmission system. A disadvantage is that it would not be possible to make broadband continuum observations at the same time as spectral line observations.

For digital transmission of the spectral line signals the filtering and sampling components shown in Fig. 2 would remain at the electronics building but those of Fig. 3 would have to be moved to the antennas. The four LOs in Fig. 3 would be required at each antenna and the simplest thing to do would probably be to send them out on a fiber. Reference frequencies for the first LOs for simultaneous operation of two front ends are required in any case, but it would probably not be good to put more frequencies on the fiber carrying them. Thus one more fiber link would be required to each antenna. The received LO signals would need filters and amplifiers, or phase-locked oscillators, for amplification and cleanup.

References

S. Padin, D.P.Woody, J.A.Stern, H.C.LeDuc, R.Blundell, C.-Y.E.Tong, and M.W.Pospieszalski, An Integrated SIS Mixer and HEMT IF Amplifier, Sixth Internat. Symp. on Space Terahertz Tech., Pasadena, CA, March 1995.

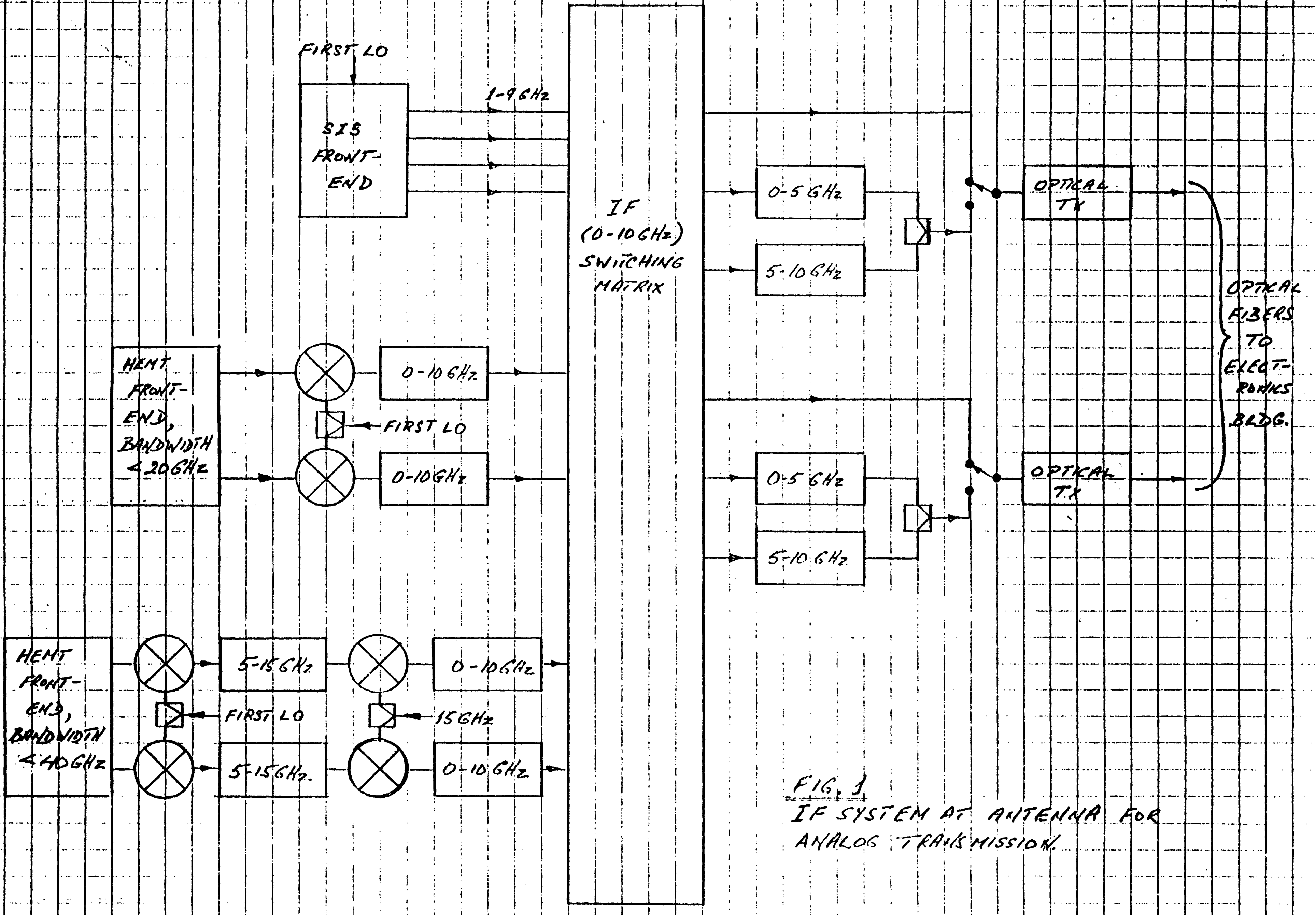

FIG. 1
IF SYSTEM AT ANTENNA FOR ANALOG TRANSMISSION.

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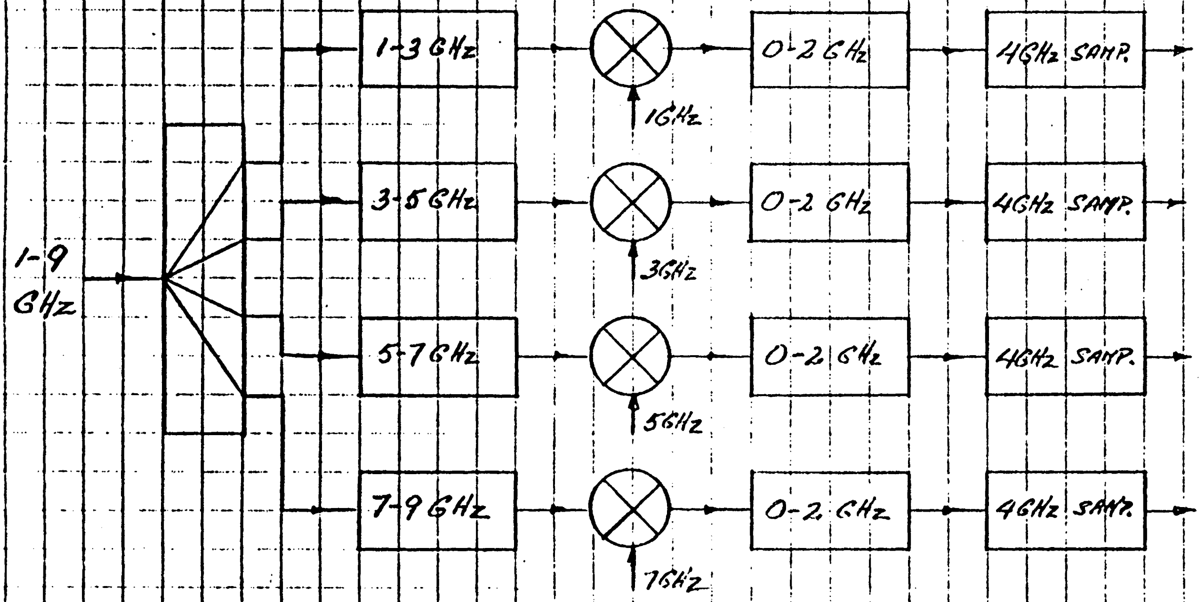

FIG. 2 FILTERING AND SAMPLING OF 8GHz BANDWIDTH FOR CONTINUUM OBSERVATION.

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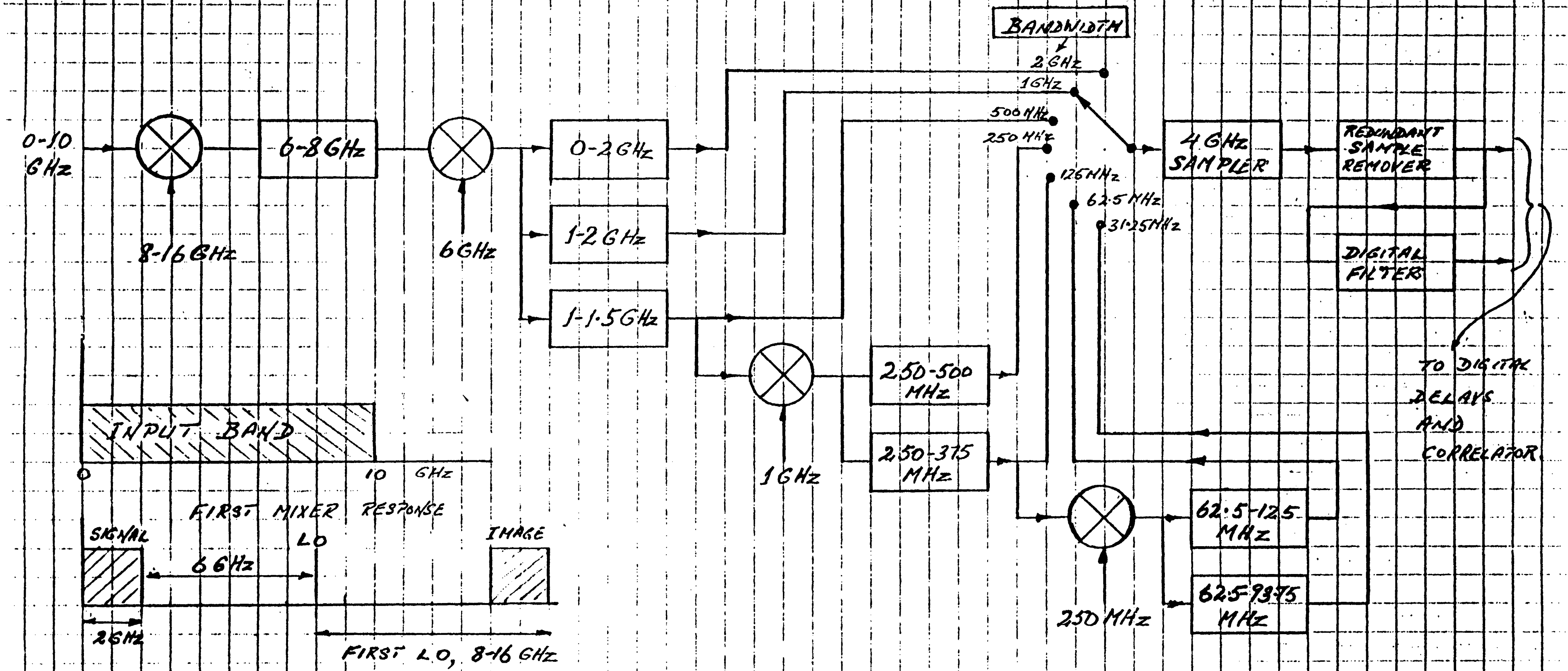

FIG. 3 ANALOG FILTERING AND SAMPLING FOR ONE SPECTRAL CHANNEL.

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