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Design of the Electronic System to Minimize the Effects of Interference

A. R. Thompson

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1. Introduction

This report is concerned with aspects of the electronic system design intended to eliminate or minize the effects of radiation from man-made sources. The most serious forms of this unwanted radiation are the radar signals (Dolan, 1973) and the various kinds of interference to be expected from electrical devices at the VLA site, including parts of the receiving and computing equipment.

A multiplying interferometer, which is the basic component of the correlator array is, of course, very much less disturbed by low levels of interference than is any type of receiving system which measures the total power collected by an antenna, as was long ago remarked by Ryle (1952). The correlator responds to signals coherent at the two inputs, and is relatively insensitive to interference that occurs only in one antenna. Furthermore the rate of change of the relative phases of the signals at the various antennas, resulting from the motion of a source across the sky, is accurately calculable and enables the wanted signals to be identified. The settings of the delay units which compensate for the different path lengths of the incoming wavefront from the source to the antennas depend upon the direction of the source, and broadband signals from other directions tend to become decorrelated. For example, radar pulses of duration 1 μsec or less when received by antennas at distances from the transmitter that differ by more than a few hundred meters can generally be expected to overlap in time only to a small degree. All of these effects which help to minimize the response to interference depend, however, on the generally large spacings of the antennas, and for the shorter spacings of the array, particularly at the low resolution configurations, interference could be a serious problem. In addition, strong interference can cause saturation and other non-linear effects which affect the desired signals even though it produces no direct response in the output of the correlators.

Starting at the antennas we shall now consider the various points at which interference can enter the system, and the measures which can be taken to keep it out or minimize its effects.

2. R. F. Interference at the Antennas

In continuum operation a signal band of 500 MHz width (370 MHz at L-band) is amplified in the 4.5-5.0 GHz parametric amplifier and then transmitted back to the terminal building. The response of the delay system and the correlators is, however, limited to 100 MHz bandwidth and this determines the bandwidth of the signals observed. Whenever possible this observing-frequency band will be chosen to avoid interfering signals, and to facilitate this the final 100 MHz signal band will be made tunable over the 500 MHz response of the earlier stages. Further frequency selection is possible in the two higher frequency bands in which the 500 MHz IF response can be tuned over 14.0-15.5 and 20-25 GHz. It is also planned to split the 100 MHz observing bandwidth into two 50 MHz intervals using two complete sets of correlators, so that interference in one half will not affect the output from the other. To detect the presence of interference the computer program which determines the amplitude and phase of the correlator output signals will also determine the rms deviation of these values from the expected signal form. In the absence of interference these deviations result from the system noise, the level of which is accurately known. Data containing interference can then be identified and rejected automatically if desired. In the presence of interference it may be also useful to consider rejecting the data for which the natural fringe rate is very low, since it is then difficult to distinguish between wanted and unwanted signals in the correlator outputs.

The most serious interference is believed to be in the 1.35-1.72 GHz band for which the signals that have been detected are described by Dolan, (1973). For continuum observations the low end of the band appears to be the best and only two signals, present less than 1% of the time, have been found between 1.35 & 1.45 GHz. For HI line observations the important band below 1.42 GHz appears to be clear, and we note that the red shifted line has recently been observed as low as 1.38 GHz in absorption. At the high end of the band the three OH line frequencies are the most important ones and here relatively narrow bands should suffice. It appears therefore that we can generally hope to avoid interference falling within the range of frequencies being observed.

The most serious remaining problem is that of signals at nearby frequencies which can be up-converted to fall within the 500 MHz bandwidth of the parametric amplifier and which are strong enough to cause overload problems. The up-converter has 3 dB gain over a 100 MHz tunable band but is expected to convert nearby frequencies outside the band with only a small power loss. The parametric amplifer suffers 1 dB gain compression with -43 dBm at its input, and Napier (1973, Table 2) indicates a maximum tolerable signal level of 10^{-6} Wm^{-2} at the antenna based on -55 dBm at the amplifier input. In the 1.35-1.72 GHz band only one signal, at 1.6 GHz and present less than 1% of the time, has been found which reaches this level.

The effect of pulsed radar signals can be somewhat alleviated by keeping the recovery times after overload to a minimum for all components. The recovery time is less than 100 μs for the parametric amplifier and care will be taken to avoid long time constants in the bias circuits, etc. of all components. A more drastic measure that can be contemplated is blanking of the received signals during the reception of each pulse. This would require generating a train of blanking pulses centered on the received pulses, and a small antenna could be set up to monitor the interfering transmitter since the collecting area of the VLA antennas in directions away from the main beam is only about 0.1 square wavelengths. For CW signals rejection filters may be necessary, and these can be inserted either in the input waveguide between the feed horn and the up-converter or in the coaxial line at the up-converter input within the dewar. In the latter case a higher insertion loss can be tolerated because of the low temperature.

The effects of interference on the action of an alc loop were considered by Napier (1973), who gives a figure of 10^{-13} Wm^{-2} for the level at which significant gain changes occur. It appears preferable therefore to use instead an agc system operating on a modulated noise signal to hold constant the system gain. The noise would be squarewave modulated and injected at the receiver input using either a directional coupler or a horn at the center of the subreflector. To obtain adequate sensitivity the added noise need only increase the overall system noise temperature by a few percent. In choosing the modulation frequency care must be taken to avoid the pulse repetition frequency of any nearby radar.

A strong radar signal, with a level of $\sim 10^{-5}$ Wm^{-2}, has been found near 1.24 GHz. It falls outside the maximum response of the receiving system and should not present a problem any more serious than the 1.6 GHz signal discussed above. The power level required for 1 dB gain change in the parametric amplifier increases by about 10 dB in the first 100 MHz below the lower edge of the passband, and this effect together with appropriate filtering should prevent overloading. A further discussion of the input filter requirements is given in Section 5.

Interference entering the antennas from local electrical equipment is not expected to be a serious problem. Requirements in the specification of the antennas include filtering of all power and control leads, bypassing or filtering of relay contacts, shielding of all amplifiers and oscillators in the drive and control system and all lighting is to be of the incandescent type (RFQ-VLA-01, pp 03.13 and 03.19). It is also planned that all power lines associated with the array will be buried.

3. IF Interference at the Antennas

After considering interference entering at the antennas we must now turn to the possibility of strong signals breaking into the system in the intermediate frequency range which covers various parts of the spectrum up to 5.0 GHz. If such interference is picked up at a number of antennas it will appear in the correlator outputs where if could be difficult to distinguish from the wanted signals if phase shifters in the first local oscillator are used to compensate for the natural fringe rate. Two methods of fringe control are presently being considered. The fringes may be merely a slowed down and sinusoidal variations will still appear at the correlator outputs, or they may be entirely removed in which case a squarewave phase-switching sequence will be introduced. In either case there will be some recognizable signal form at the correlator outputs to distinguish the wanted signals from the d.c. or randomly varying levels to be expected from IF interference.

Eliminating IF interference is basically a problem of good construction of the electronics enclosures and adequate filtering of power and control leads. The receiving electronics at each antenna will be located within a single room at the vertex and all IF, local oscillator, and control signals will pass in and out of it on modulated carriers in the waveguide transmission system. Prevention of IF interference at the antennas should therefore be a relatively simple problem.

No interference is expected in any part of the waveguide transmission system since the waveguide is well shielded by the outer steel pipe and, in any case, strong interfering signals in the waveguide frequency range are very unlikely.

4. IF Interference at the Central Terminal

The final part of the system is located at the central terminal building. Here the IF signals are demodulated from the carriers, and this is also the point at which self-generated interference is likely to be strongest. Equipment capable of producing interference in the IF range includes parts of the local oscillator system, the 100 MHz sampling circuits and other parts of the digital delay system, if it is used, and the computers and their associated equipment. To confine such interference it is planned to install as much as possible of the computing and other high-speed digital equipment inside a screened room. The waveguide terminal equipment and the IF amplifiers will be in a separate room which can also be screened if necessary. All of the monitoring and control signals between the computers and the antennas will be filtered in passing from one room to the other. Serial data transmission is to be used which will greatly reduce the number of lines to be filtered. In deciding the layout of equipment within the terminal building attention will be given to avoiding wherever possible long cables carrying IF signals or waveforms likely to give rise to interfering radiation. Estimation of the radiation levels to be expected from coaxial cables with braided outer conductors is a complicated problem, some figures can be found in studies by Ikrath (1958) and Roble and Shatz (1958).

It appears that achieving freedom from interference in the central equipment complex will call for great care in construction and layout, but no problems of extraordinary magnitude are foreseen.

5. Input Filters for the 1.35-1.72 GHz Band

We should like to obtain a rejection of 20 dB at 1.3 GHz and below, and possibly also at some frequencies in the 1.44 to 1.72 GHz range, while not introducing ripples greater than about 0.1 dB or more than 10°K increase in noise temperature in the signal passband.

The waveguide to be used between the feed horn and the up-converter input is about 2 meters of WR650 with a nominal frequency range of 1.12-1.70 GHz and a cutoff frequency of 0.908 GHz. By decreasing the width in the broad dimension by 1.11 inches the cutoff frequency can be raised to 1.095 GHz which is about as high as can be used to retain good matching but this is not sufficient since there are strong radars in the 1.25-1.3 GHz range. An estimate of what can be achieved using a waveguide filter is found by examining curves for pseudo-high-pass filters given by Matthaei Young and Jones (1964, see figures 9.06-1 and 9.06-2). These indicate that a filter with 10 resonators would give a rejection of $\sim$6 dB at 1.3 GHz and 15 dB at 1.25 GHz wilst introducing a ripple with peak loss 0.05 to 0.15 dB in the range above 1.35 GHz. This is probably sufficient rejection, but more data on the interference will be required to be certain on this point. The narrow-band rejection filters in the 1.44-1.72 GHz range could probably best be implemented by tuned cavities coupled to the waveguide.

In coaxial filters we find that a commercially available filter with 1 dB points at 1.35 and 1.72 GHz and 20 dB points at 1.29 and 1.78 GHz requires about 8 sections and would have an insertion loss near the center of the passband of 0.8 to 1.0 dB. Mounted in the dewar at a temperature of ∿5°K such a filter would increase the noise temperature by about 1° only but would produce a signal loss of about 25%.

It would also be possible to put a filter of 100 MHz bandwidth at the up-converter output to cut out signals outside the observing band. The up-converter is much less easily overloaded than the parametric amplifier and the interfering signals are not expected to cause non-linear effects in it. The center frequency of such a filter would be about 4.7 GHz and because of the greater difficulty in obtaining the required Q of the filter elements it is probably better to forgo the slight advantage of the 3 dB gain of the up-converter and perform any filtering at the input.

The convenience of access of the waveguide filter is a strong point in its favor. The waveguide filter would be designed to give the steepest possible slope below 1.35 GHz, and one or more narrow band filters, possibly tunable, would be added. Further design details must await more data on the interference, since the above remarks are based mainly upon the signals detected in the first few months of the survey at the site. The problem of obtaining adequate filtering is not a trivial one, but it appears to be soluble with only a small decrease in sensitivity.

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