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Hazards and Future Improvements to H I Surveys

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Abstract. Most radio astronomical observations are affected to some degree by man-made and natural interference. There are a few avoidance techniques that can reduce the impact of interference on the survey, but we must make quite significant advances in the understanding of our antennas and receivers and the interference itself before a substantial improvement can be expected. A major increase in the efficiency of future surveys will likely come from phased-array feeds, which have the potential for much closer beam spacings, greater antenna efficiency, and wider fields of view than current independent-feed arrays.

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1 Introduction

This workshop and preparation for this talk have presented a nice opportunity to take a long-range look at the problems of interference, spectral baseline distortions and antenna efficiency, particularly in connection with large sky surveys. My comments may be a bit too long-range to be of very much immediate benefit to the Parkes multibeam surveys.

Improvements in interference immunity and spectral baselines cannot rely heavily on post-observation data analysis. We need a much better understanding of antenna far-sidelobe structure and of the temporal and spatial properties of interference. The next big step in multibeam array efficiency requires a jump from our present one-feed/one-beam arrays to closely spaced arrays of small elements whose signals are combined to form more efficient, overlapping beams on the sky.

2 Interference

In principle, if interference is not coincident in time, frequency, polarisation and direction with a celestial object, we should be able to observe in the presence of the interference. We should not forget that most of time–frequency space is still open to us in the skies above our observatories, even at frequencies that we think of as full of active signals (Gulkis et al. 1991; Swarup & Venkatasubramani 1991). Lest the active users of the radio spectrum conclude that the problem of interference suppression falls solely on the receiving antenna designer, I should point out that this same 'in principle' statement implies that all active users could share a much smaller fraction of the present radio frequency spectrum than is currently allocated. The degree to which we can approach this ideal depends on economics and the state of the electronics and antenna arts.

Isolation of celestial signals in direction means very low response of our antennas to signals well away from the main beam. Even the best antennas have some response in their ubiquitous far sidelobes, so nulls must be steered onto the sources of strongest interference. My guess is that the extremely low signal-to-noise levels of radio astronomy present unique challenges to adaptive nulling that have not been considered in the literature. This implies that we need to add more information to the signal processing, such as *a priori* knowledge of the antenna phase and amplitude response in the direction of interference. The introduction of a cancelling signal to the receiver means added noise and gain instabilities which must be minimised by having considerable reception gain and stability in the auxiliary interference sampling antenna.

Temporal rejection of interference can involve timescales from microseconds, e.g. radar pulses, to many tens of seconds. Most of the integration times that we currently employ in our observations are much too long for effective interference rejection. Strong bursts of interference are easy to recognise and excise, but most intermittent interference has an amplitude distribution that resembles white noise too closely for it to be removed with post-observation data selection. Again, added information in the form of a separate interference monitor and known periodicities and duty cycles must be added to the process.

As the radio spectrum gets more crowded (Thompson, Gergely & Vanden Bout 1991), rejection of interference in the frequency domain will require filters closer to the front ends of our receivers. Satellite down-link signals already pose some severe dynamic range problems for receivers designed for adjacent radio astronomy bands. Our present optimisation of gain distribution for the system temperature and tunability must be tempered by the need for large signal handling capacity.

Every radiated man-made signal is completely polarised, by the very nature of a transmitting antenna, even if it is a random collection of wires in an incidental radiator. Hence, for any given interference signal there should be an orthogonal received elliptical polarisation in which there is no interference power. To test this I have made a series of measurements in the 60 to 80 MHz range with the 140 ft telescope with a polarisation-sensitive spectrometer. Most of the received signals were from broadcast TV stations. In subtracting the polarised component of the measured spectras the expectation was that we would be left with only the unpolarised natural radiation.

Of approximately 400 spectral features measured, a few were suppressed by 20 dB or more, but most were suppressed by an average of about 8 dB and some were reduced very little. The distribution of suppressions is shown in Figure 1. This tells me that we really do not understand the nature of interference signals as propagated to our radio telescopes, and that until we do, our efforts at rejection will have limited results. Nevertheless, a significant suppression of interference can be achieved by recording all polarisation information in our spectra.

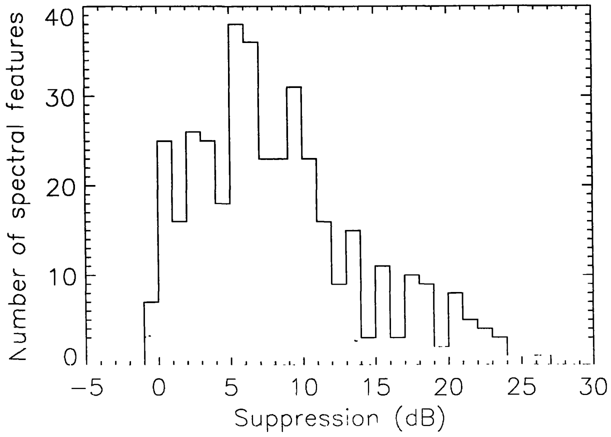

Figure 1—Distribution of suppression achieved on 392 interference features in spectra between 60 and 80 MHz by substracting the polarised flux.

3 Phased Array Feeds

The Parkes thirteen-beam receiver is an impressive implementation of the state of the art of centimetre-wave array receivers. There is not much room for improvement within the constraints of independent feeds and good off-axis efficiency.

The next big advance in array feed efficiency requires that we abandon the use of independent feeds and that we fully sample the focal plane field with small elements. This opens the possibility of arbitrarily close beam spacing, which means about a 16-fold increase in sampling density, greater on-axis aperture and spillover efficiency, and maintenance of this efficiency at large beam offsets. Present signal processing capacity now makes prototypes of these arrays feasible, but it will be a number of years before these arrays approach the sensitivity of the best single-feed receivers.

At NRAO, Richard Bradley, Kamaljeet Saini and I are constructing a 19-element prototype feed array using broadband sinuous antennas designed for the 1 to 2 GHz range (Du Hamel & Scherer 1993; Saini & Bradley 1996). Our intention is to try the array on the 140 foot telescope later this year. The preamplifiers are uncooled, and we will use a switching matrix to sample the 171 element pairs, 4 at a time, with an existing FFT spectrometer. Hence the first prototype will be relatively insensitive.

The array bandwidth, limited by a minimum element spacing of half a wavelength and the appearance of a grating lobe at the high frequency limit, is expected to be about 1·4 : 1. An optimised element is now in hand, and linear array tests show that mutual coupling is manageable with the element separation required. The first objective for the prototype array is to verify our array theory from measurements of aperture efficiency, reflector beam shape and spillover, using different array correlation weights.

The next planned developments are a balanced HEMT amplifier for each element and experiments with cooling the amplifiers with a distributed cooling system or a small inexpensive cooler on each amplifier. Ohmic losses in the sinuous antennas may be significant so we need to develop a method for measuring very low antenna losses. Ray Escoffier has investigated both direct and correlation-based digital signal combining networks, and as money becomes available we will construct a correlator to measure all antenna pairs simultaneously.

The long-range goal is to be able to build arrays of up to 100 elements that can form more than 50 simultaneous beams with aperture efficiencies and system temperatures as good as present dual hybrid mode waveguide feed receivers. This is 5 to 10 years away.

4 Spectral Baselines

By far the greatest loss of centimetre-wave telescope observing efficiency due to poor spectrum quality comes from solar interference. Measurements of weak extragalactic H I is nearly impossible during the daytime without spending a large fraction of the time calibrating off-source baselines in connection with clever techniques such as those described by Frank Briggs elsewhere in these proceedings (Briggs *et al*. 1997, present issue p. 37). The main instrumental problem is that we do not know the frequency response of our telescope to strong sources in far sidelobes. This is the same problem that we have in creating nulls in the directions of man-made interference.

The instrumental model that we most commonly use to calibrate spectral observations is close to the one shown in Figure 2. We assume that the only difference between signal and reference spectra is the desired signal and that all of the spectrometer filters follow the single source of white noise.

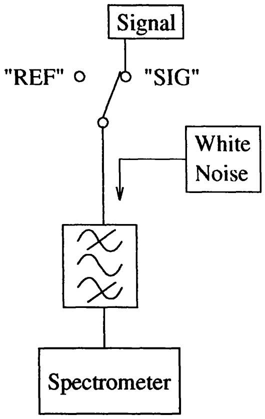

Figure 2—Simple receiver model used in most spectrometer calibrations.

Figure 3 is closer to reality. There are many sources of white noise, each of which is injected through its own combination of filter paths. The filters represented in Figure 3 are a combination of antenna multi-path and receiver transfer functions. To the extent that the sources and filter functions common to the signal and reference paths can be assumed to be identical, a lot of complexity can be hidden in the guise of the simpler model.

However, the only three noise sources shown in Figure 3 which can be made to be the same between signal and reference phases are the ground, atmosphere, and receiver noise. The other sources will inevitably be different in the reference because, when the antenna is moved off the signal source, the response of our antenna to the other noise sources changes. A more subtle effect is that when the fraction of total system noise ahead of each receiver filter in the lower part of the diagram changes, the relative contribution of each filter in the chain to the total system spectral shape will change.

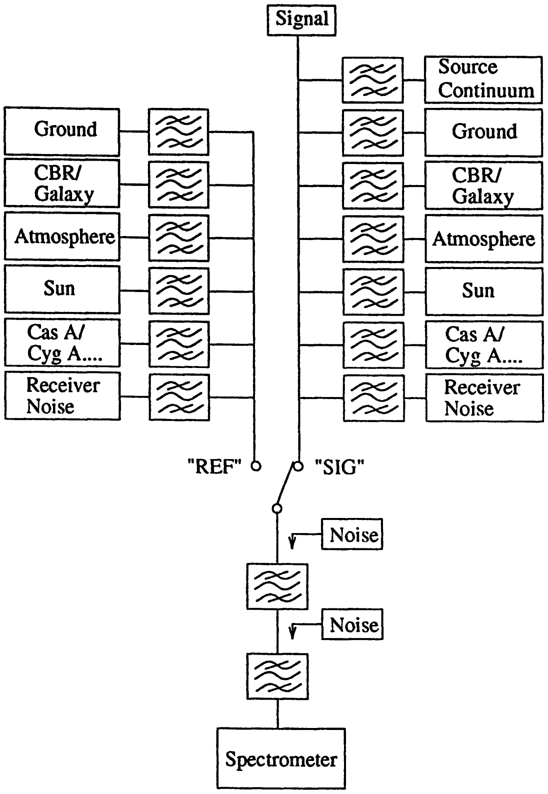

Figure 3—Receiver model that is closer to an actual spectrometer noise and filter distribution.

Before we can make major improvements to spectral baselines we must understand our telescope systems to at least the level of complexity shown in Figure 3. Which components shown in this diagram are stable enough to be measured once and made part of a routine correction? Can our antenna theory be strengthened to the point of being able to interpolate a sparsely sampled far sidelobe pattern where solar radiation is expected to enter? What calibration procedures are needed to determine the time-variable components? Are there useful areas of the antenna sidelobes where the response is low enough to observe with small modifications to current techniques?

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