methodical testing and analysis of a prototype by Mr. R. A. Batchelor.


Reduction of the Baseline Ripple on Spectra Recorded with the Parkes Radio Telescope

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Introduction

One of the factors determining system sensitivity in radio astronomy measurements of microwave emission and absorption spectra is the flatness of the spectrometer response in the absence of any spectral features. Ripple appears as a quasi-sinusoidal variation of this baseline and occurs whenever two or more components of the same signal reach the receiver by different paths and interfere. This paper is a progress report on an experimental investigation of the spectral baseline ripple on the Parkes 64-m radio telescope at frequencies near 5 GHz.

The mechanisms which cause ripple are by now fairly well understood (Poulton 1974; Morris 1974). They may conveniently be divided into off-source mechanisms, which give rise to ripple even if the telescope is pointing at cold sky, and on-source mechanisms, where the ripple depends on the characteristics of the radio source (strength and angular size). The component of the ripple due to the off-source mechanisms can be removed from a line spectrum by subtracting an off-source reference from the signal spectrum. The reference is obtained by tracking the telescope at the same declination and over the same range of hour angle as the source observation. The off-source ripple terms, which in general are a function of the telescope position, will then be nearly identical in the signal and reference, and will be removed by the subtraction process. The technique is very effective, but in most cases leads to a twofold increase in observing time.

On-source ripple is not so readily removed. Various techniques have been proposed for reducing it, and a number of these have been tried at Parkes, as described in a later section.

Existing ripple levels

On-source ripple at Parkes arises primarily from the failure of the primary feed (usually a horn antenna) and/or the receiver to accept all of the incoming signal. Multiple reflections of the rejected energy then occur in the region between the focal plane and the vertex region of the paraboloid (the focus/vertex cavity), as shown in Figure 1. Both direct and reflected signals enter the receiver, forming an interference pattern. In the frequency domain then the ripple consists of a harmonic series of sinusoids with a fundamental period of $c/2L \approx 5.71 \text{ MHz}$, where $c$ is the velocity of light and $L$ is the distance between the vertex and the focal plane ($\approx 26.3 \text{ m}$).

If $T_A$ denotes the antenna temperature produced by the continuum radiation of the source and $\Delta T$ the peak-to-peak ripple amplitude, then, when no steps are taken to reduce the ripple, values of $\Delta T/T_A$ of 0.85%, 1.3% and 0.35% are observed for the fundamental, second-harmonic and third-harmonic ripple respectively (see Fig. 2; see also Padman (1977)). It can be seen that the second harmonic,

![Figure 1: Schematic diagram of the general on-source ripple mechanism. The energy not accepted by the feed may be energy which strikes the ground-plane rather than the feed (as illustrated), or may be radiation falling on the feed which is reflected because of an impedance mismatch. The apparently non-specular reflection is a result of using ray optics to describe a diffraction phenomenon.](https://www.cambridge.org/core/terms).

![Figure 2: 10 MHz spectrum showing baseline ripple. The spectrum was observed using a 1HE feed and unmodified vertex region. The source continuum antenna temperature was 56 K.](https://www.cambridge.org/core/terms).
corresponding to the ‘two-pass’ reflection, is the dominant feature. This has been discussed by Morris (1973). The seriousness of the ripple for studies of recombination line spectra can be seen from the fact that the line temperatures are, on average, only 6% of the source continuum temperature for H109α recombination lines and one-tenth of this for the He109α lines.

There is some evidence that the ripple has increased significantly since the centre 16.7 m diameter section of the paraboloid was resurfaced (Yabsley 1977). This is probably due to a step in the parabolic profile of approximately 1 cm at a radius of 2.0 m.

Reduction of on-source ripple

In this section a number of techniques for reducing on-source ripple are described. All the observations were made by subtracting an off-source reference spectrum from the on-source spectrum, so that off-source ripple was eliminated. Accordingly, off-source ripple will not be considered in this section.

In most systems reflections from the impedance mismatch at the receiver terminals, and from the feed/focal plane structure will be of the same order of magnitude. Eliminating or reducing one or other of the reflections will not necessarily reduce the ripple, as each reflection produces ripple of a different phase within the passband, the phase depending on the length of the delay path involved.

While investigating the ripple it was discovered that the effects of the receiver mismatch could be reduced with the aid of the already existing noise balance facility. It is common practice when observing line radiation from strong continuum sources to maintain the receiver output at approximately the same level during signal and reference observations. To this end, during off-source observations, noise is injected into the system by means of a directional coupler at a point between the feed horn and the receiver input terminals. If the intensity of the injected signal is adjusted to be exactly equal to that of the signal from the source, then any reflection from the receiver input during a signal run will be exactly matched by the reflection of the noise signal during the off-source reference run. When the reference is subtracted from the signal any ripple due to receiver mismatch is eliminated. Noise injection was therefore used in all the experiments described below. The observed ripple is then almost entirely due to reflections from the feed horn and surrounding ground-plane.

Vertex scattering cone. A wire mesh scattering cone 4 m in diameter with a semi-vertical angle of about 85° was designed and installed at the vertex of the paraboloid by J.D. Murray. It was hoped that this would reduce the reflection from the paraboloid of energy radiated from the feed (such as receiver-generated noise, or energy reflected at the receiver input). Alternatively, it may be viewed as an attempt to break up the focus/vertex cavity by increasing the loss at each transit of the reflected signals and should then lead to a reduction in the ripple level, especially the harmonic ripple. This was found to be so. Almost total elimination of the second and higher harmonic ripple was achieved, and the fundamental 5.71 MHz ripple was reduced by about 40% to give a \( \Delta T/T_A \) of 0.45%.

Furthermore, the amplitude of this residual ripple remained almost constant over the full range of zenith angle (0-60°). If it can be shown that the phase also behaves in a predictable fashion it might be possible to use this a priori knowledge of the ripple behaviour to remove the residual ripple from the data.

Focal plane absorber. Earlier efforts to reduce ripple included the use of absorbing material in the focal plane. A six-foot-square region surrounding the feed, but excluding the central two-foot-square region, was covered with microwave absorber having a return loss of better than 20 dB. This was intended to absorb the energy spilling past the feed, rather than allowing it to be scattered as an interfering signal. Unfortunately, most of the energy not accepted by the feed falls on the central region of the focal plane reflector, which until recently could not be covered with absorber because of structural constraints. The absorber was expected to strongly damp harmonic ripple by introducing a further loss into each reflection from the focal region.

Observations made with the vertex region unmodified showed that the absorber by itself was ineffective in reducing the fundamental and second-harmonic ripple, although the third harmonic was reduced by 50%. It is hoped at a later date to determine the effect of fitting absorber closely around the feed.

Shaped vertex plates. Poulton and Almoayyed (1973) have described the design of an optimum vertex plate for a prime-focus paraboloid antenna. This device is similar to the vertex cone, but whereas the cone was designed using simple geometrical optics, the vertex plate was designed using a physical optics procedure to minimize the reflection coefficient over a wide (e.g. 3:1) bandwidth. Poulton (1974) has shown that it also reduces the energy entering the feed after scattering from the focal plane structures. He has described a vertex plate for use on the Parkes telescope in the 3-9 GHz band. This vertex plate was built and installed at Parkes on a trial basis in September 1976. It was found that the fundamental ripple could be reduced to about half of the value observed when using the scattering cone, or about 0.25% of the continuum temperature. However, the harmonic content was much higher, the amplitude of the second and third harmonic being comparable with the fundamental amplitude. It is thought that the amplitude of the harmonic components observed when using the vertex plate could be significantly reduced by the addition of more absorber in the area immediately surrounding the feed.

Use of a two-hybrid-mode feed horn. The standard single-hybrid-mode feed horns (1HE feed) used for \( \lambda \leq 21 \text{cm} \) accept only the energy in the central bright spot of the Airy pattern formed by the reflected fields in the focal region. For the Parkes telescope, with an \( f/D \) of 0.41, only \( \sim 72\% \) of the incident energy falls in the central spot (Thomas 1971). The two-hybrid-mode feed horn (2HE feed) accepts in addition the energy in the first bright ring of the Airy pattern. This increases the theoretical efficiency to \( \sim 83\% \). The energy available for scattering is therefore reduced by 40%. The 2HE
feed also has a lower gain on axis than the 1HE feed, and the amount of energy returned to the feed following a reflection from the feed/focal plane structure should then also be reduced. Thus the 2HE feed can be expected to yield substantially lower values of on-source baseline ripple.

Observations of the ripple were made using the 2HE feed in combination with each of the other measures described above. It was found that with either a vertex plate or scatterer the fundamental ripple was reduced by between 40% and 50% relative to its value when the 1HE feed was used with the same vertex treatment. The reduction in amplitude of the harmonic ripple was generally about 30%. Thus when the 2HE feed was used in conjunction with the scattering cone the total ripple was reduced to ~0.25% of the continuum temperature, with no noticeable harmonic content (see Fig. 3). With the shaped vertex plate the fundamental ripple approached 0.15% of $T_A$, although in this case harmonic ripple was significant. The amplitude of the second harmonic was about equal to that of the fundamental ripple, so that the maximum possible amplitude was ~0.3% of the continuum temperature.

Conclusions

Recent improvements to the Parkes radio telescope have enabled the total on-source baseline ripple to be reduced from approximately 1.3% of the continuum antenna temperature to ~0.25% of $T_A$ with negligible harmonic content, or alternatively to <0.2% for the fundamental but with higher values of harmonic content (>0.1%). These values are obtained by using respectively a conical scatterer or shaped vertex plate in place of the vertex. The antenna temperature was 66 K.

Figure 3: 10 MHz spectrum observed with the 2HE feed and conical scattering cone in place of the vertex. The antenna temperature was 66 K.

Millimetre Wavelength performance of the new 16.7m surface of the Parkes Radio Telescope

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A new surface installed recently over the central 16.7-m-diameter zone of the 64-m radio telescope at Parkes has extended the operating range of this instrument to millimetre wavelengths.

The overall efficiency of this 16.7-m zone now exceeds 40% at 7-mm wavelength and is ~16% at 3.3 mm. Operation at millimetre wavelengths appears to be unaffected by exposure of the new surface to the direct rays of the Sun.

Introduction

The 64-m-diameter radio telescope at Parkes was originally designed for use at 10-cm and longer wavelengths. A semi-automatic survey instrument was installed at the centre of the paraboloidal surface in 1964 (Puttock and Minnett 1966). This produced data which showed that operation at much shorter wavelengths could be achieved if suitable modifications could be made to the telescope surface (Minnett et al. 1969).

The first stage of a surface improvement program, involving the replacement of the original mesh panels between diameters 16.7m and 37m, was completed in 1972 (Yabsley 1975). This doubled the aperture efficiency at 3.4cm, and provided a 37-m zone which gave useful performance down to 1.35cm (Johnston et al. 1972).

The possibility of extending the performance of the central 16.7-m zone to millimetre wavelengths was then examined. A new surface consisting of aluminium alloy plates fixed a few millimetres above the original welded steel plating was designed by a collaborative effort between the CSIRO Division of Radiophysics and the CSIRO National Measurement Laboratory. The 330 plates, arranged in seven rings of closely-spaced panels, were installed in October 1975. The resulting step in the parabolic profile was removed by resetting the screw adjusters to raise the remainder of the surface. A more detailed description of the new surface is being published elsewhere (Yabsley et al. 1977).

The receiver used for performance evaluation covers two waveguide bands 33-50 GHz and 75-110 GHz, with separate feed horns and cryogenically cooled mixers for each band (McCulloch et al. 1977). The mixer is followed by a frequency-changeover switch and a two-stage 4.5-5.0 GHz parametric amplifier, also cooled. Since the perforated surface beyond the central 16.7-m zone of the telescope is virtually transparent at 7mm and shorter wavelengths, the wideband HE$_{11}$ corrugated conical feed horns (Thomas 1975) used for each of the two bands were designed to produce illumination with 10 dB taper at the rim of the 16.7-m surface. To calibrate the receiver, batts of microwave absorber, one at ambient temperature and one immersed in a bath of liquid nitrogen, were placed in turn in front of the feed horn.

Performance tests were carried out in June 1976 in...