Figures 3—The three NH₃ spectra observed for G353.4-0.4.

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Conclusions
These results show that more work must be done in order to understand the conditions in the molecular clouds that give rise to the ammonia lines. Further observations will be made to establish how the relations between the ammonia lines change with position in the cloud and to extend the survey to other classes of objects. Observations of other ortho-ammonia lines are also needed to determine how ortho-ammonia differs from para-ammonia. Finally, comparisons of these results will be made with those obtained from other molecules.

Instrumental

The Parkes Radio Telescope—1986

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Abstract: The Parkes radio telescope was commissioned in 1961, with an anticipated operational life of 15 years. Twenty-five years later the telescope has been refurbished with the aim of extending its life yet another decade or two. A major undertaking has been the complete replacement of the drive and
control system. This presentation outlines the main features of the new system and its effect on the observing facilities offered at the observatory.

The completion of the 210 ft paraboloidal aerial at Parkes at the end of 1961 marked the beginning of a new phase in Australian radio astronomy (Pawsey 1963).

Introduction
At the time of the construction of the Parkes radio telescope in 1961 it was expected that it would have an operational life of 15 to 20 years. Now, 25 years later, the instrument has been refurbished so that it can play a key role in the long baseline array of the Australia Telescope, and operate well into the 1990s.

Two features of the original design and construction have largely made this updating possible. The original design study provided for a structure of 100 m in diameter to meet the performance specifications, but the final funding available at the time of construction resulted in the designers recommending that the diameter be limited to 64 m. However, the design of the structure supporting the reflecting surface was such that it has been possible to resurface the inner 44 m diameter portion of the dish, reducing the original overall rms error of about 5 mm to 0.3 mm for the central 17 m and to about 1 mm out to 44 m. The result is that useful operation can now be achieved at wavelengths < 1 cm.

The other factor prolonging the productive life of the telescope follows from the ingenious solution by Dr Barnes Wallis for the control problems associated with accurately pointing such a large instrument (Wallis et al. 1957). His idea was to use a small equatorially mounted guide device, known as the master equatorial (ME), at the intersection of the telescope axes on a central column structurally isolated from the main antenna support. The motion of the antenna dish was locked to that of the ME by a servomechanism driven by an error detector using a light beam to sense the misalignment between the dish and the ME. Not only did this provide, automatically, the conversion between celestial and altazimuth coordinates needed to track celestial radio sources, but it also transferred the precision of the relatively small ME to the much larger main instrument while greatly reducing the effects on pointing of flexure in the main supporting structure caused by gravity and wind. The introduction, many years later, of computers to aid in controlling the antenna has made coordinate conversion easy and has removed the need for the guide device to be equatorially mounted, but the other benefits remain valid. Today's more advanced technology has been used to outfit the ME with improved motion control and more precise position encoding, and the old error detector has been replaced with a completely new unit. A pointing resolution for the ME of < 1 arcsecond and an absolute accuracy of ~5 arcseconds has now been obtained.

By 1983 it had become apparent that the telescope control system was in a critical state. For instance, it was becoming increasingly difficult to maintain the vacuum tube amplifiers and outdated electromechanical components, and variation in these circuits often led to unstable operation. Furthermore, at this time negotiations were under way with the National Aeronautical and Space Administration (NASA) and the European Space Agency (ESA) concerning the use of the telescope to receive spacecraft data. It was planned that the Parkes radio telescope would play key roles in the Voyager II flyby of the planet Uranus and the Giotto encounter with Halley's comet. These missions could not afford the prospect of unreliable operation from the receiving station at Parkes, and it was apparent that a substantial improvement of the control system was necessary.

The main problems were:
- The large dc machines (Metadyynes and motors) were approaching the end of their useful life.
- The electromechanical drive of the ME unit contributed about 10 arcseconds to the system backlash, and mechanical wear in this drive system was increasing the problem.
- The error inherent in the encoding system of the ME was so large that the benefits of any improvement in the ME drive system could not be realized.
- It was possible to track and scan the antenna in only the equatorial coordinate system of the current epoch.
- The altazimuth servosystem was only conditionally stable and a slight change in loop gain would often send it into an unstable state. The vacuum tube servo controllers, preamplifiers and the photomultiplier tube in the error detector all contributed to stability problems.
- There was only limited interlock logic in the control system, and status sensing was almost completely absent.

A VAX-11/750 computer had been acquired to replace the PDP-9 as the main computer at the observatory, and although this provided the tools to develop new observing facilities, the limitations of the control system were marked. The decision was made to replace the entire control system.

A new computer-based control system was designed by Radiophysics staff at Parkes and was installed in 1985, the European Space Agency providing most of the required funds. The rest of this paper gives a brief outline of the main features of this new control system.

Computer Network
The new system distributes the computing tasks among a loosely coupled network of minicomputers in such a way that interprocessor communication links can be simple, and relatively slow, while still providing real-time response and recording with 1 µs resolution and accuracy (Figure 1).

The design utilizes the VAX/VMS environment for multiuser program development, on-line and off-line data reduction, and the interface between observer and telescope; the real-time requirement of computations for the position control of the ME, 64 m antenna, feed rotation and antenna focus are satisfied by dedicated minicomputers more suitable to the task than the VAX. Each computer is normally controlled by commands that originate from the VAX, but commands for each computer can also be entered from a keyboard connected to that individual computer or to the DESK computer. In addition, in the event
of a failure of the computer system, the 64 m antenna can be controlled directly from a manual control panel, although no observing is possible in this mode. Reliable power for the system is provided by a 55 kVA uninterruptable power supply.

The computers communicate via full duplex serial lines operating at a transfer rate of 960 characters per second. Each processor has its self-contained task requiring little (if any) interaction with the other processors. Control commands originate from the observing programs in the VAX and are passed via the DESK computer to the appropriate stand-alone processor. On each ‘one second tick’ (generated by the CLOCK computer) new commands are passed between the various computers. In most instances this is simply the default command, which is a request for a status report. Each second the DESK computer collates all the status messages and sends the information to the VAX, where it is made available to all VAX processes. Monitoring of the system can thus be carried out in the individual processors, the DESK computer, and the VAX. Continually updated displays of selected parts of the status information are available for the telescope operator.

The command structure has been formulated so that those commands being sent on the interprocessor communication network are of sufficiently high level that the time between successive commands need be no less than 1 s. The commands consist of command keywords followed by command parameters. Typical command keywords are: GOTO, SCAN, STOP and STOW. The command parameters may specify the coordinate system to be used, the scan rate, the coordinate positions, etc. The individual processors then break down the high-level commands into lower-level tasks which are synchronized by the CLOCK system. Because the 1 s response time to the high-level commands is adequate, no more sophistication than the simple serial lines is required for the interprocessor communication. Real-time response at the microsecond level is made possible by the CLOCK system.

Clock System

Central to the control system is the CLOCK system (Figure 2), which relates all positioning of the telescope to absolute time and synchronizes the logging of astronomical data. The CLOCK is the sole arbiter of time in the system, and it has been designed to achieve an accuracy and resolution of 1 μs for the recording and generation of events. This is more than adequate to give a position resolution of 1 arcsecond.

The CLOCK computer generates data ‘frames’, each containing 1000 bits of information. These frames are carried via a self-clocking code along a single serial ‘clock bus’ which is connected to a variety of special purpose interfaces installed in the computers. A frame consists of 1000 bit cells, each cell being of 1 μs duration; new frames are transmitted each millisecond. Each frame carries various coded arrangements of the time resolved to 1 ms. These are binary atomic time (BAT), universal time (UTC and its offsets DUTC, DUT1), Australian eastern standard time (AEST), Local Mean Sidereal Time.
Figure 2—CLOCK System. The clock information is generated by special-purpose hardware in the CLOCK computer. The event generator and event recorder are modules that can be installed in any of the computers. The clock frames are transmitted on a serial clock bus.

(LMST), and modified Julian day number (MJD). Each frame also carries fixed bit patterns for generation and synchronization of the 1 s ticks and error checking code to ensure validity of the frame. The start of each frame can be synchronized with an external time reference to an accuracy of 500 ns. This is done by presetting the time in the various CLOCK registers and initiating operation with an externally derived pulse. Software in the CLOCK computer then allows this time to be finely adjusted to achieve synchronization with an absolute time reference. Once set, the accuracy is maintained by a rubidium atomic frequency standard. This accuracy is checked daily against other atomic clocks in Australia.

Interfaces in the various computers receive the clock frames from which they extract the time. This time is updated each millisecond, with the update instant accurate to better than 1 μs. An internal 10-bit counter in each interface is cleared at the beginning of each frame and incremented for each 1 μs bit cell from the self-clocking code (rubidium stabilized) in the frame. This 10-bit extension of the time extracted from the frame gives the time to an accuracy and resolution of 1 μs. The hardware in each computer interface automatically performs the entire frame decoding without any intervention from the host computer.

The various CLOCK interfaces include:

- Event Generator. This interface allows registers to be set up under software control so that ‘events’ (pulses or level transitions) can be produced at specific times. It should be noted that the computer does not have to read the time and then decide whether an event should be generated; rather the special-purpose hardware simply looks for coincidence between the time that was set up beforehand by the computer and the current time extracted from the clock bus. The scheme allows events to be generated at times that are accurate to 1 μs and selected to occur at any one particular microsecond until the year 2034.

- Event Recorder. This interface allows the time of occurrence of events to be recorded in a first-in first-out (FIFO) memory with 1 μs resolution. The computer may be set to be interrupted upon receipt of these events, but can read the FIFO registers at any later time to obtain the time the event occurred. The system completely eliminates any effect due to delays within the computer itself.

The CLOCK system enables the COORD computer to synchronize the positioning of the ME with the generation of trigger pulses to the A/D converters in the VAX computer so that the sampling of the radiometer outputs by the VAX is accurately associated with the desired points in the sky. This has solved previous synchronization problems between computers that were required to continually read the ME position encoders while sampling the radiometer outputs as the telescope was being scanned across the sky.

**Telescope Position Servo**

There are two completely independent servo loops that provide the telescope positioning. One servo loop controls the ME guidance system, while the other loop locks the 64 m antenna motion to that of the ME.

(1) Control of Master Equatorial

The COORD computer performs all the coordinate transformations and pointing corrections necessary to provide the ME computer with the required hour angle and declination positions. It provides transformations from any one of eight standard coordinate systems and the facility to use a user-defined coordinate system (McConnell 1986).

After performing the appropriate transformations the COORD computer approximates the desired hour angle and declination tracks for the following 1 s by a parabolic track in hour angle and declination. This parabolic approximation can be parameterized with three constants for each axis, that is

$$\theta = At^2 + Bt + C$$

where, the time origin is taken as the start of the 1 s interval and

- \(A = \text{acceleration}/2\)
- \(B = \text{velocity at } t = 0,\)
- \(C = \text{position at } t = 0,\)
- \(\theta = \text{position at time } t.\)
The maximum error involved with the second-order approximation to a desired track which is consistent with the acceleration constraints of the telescope is < 1 arcsecond over the one second interval.

The ME computer receives the three parameters for each of the two axes once per second; then 16 times per second it uses the above expression to first compute the required position, and from that position compute the velocity to be applied to a rate control system driving the motors in the ME. The ME computer thus forms the computing element for a digital position controller which encloses a rate control loop. Figure 3 shows this scheme (for one axis).

![Diagram](image1)

**Figure 3**—ME position control. The ME computer is a PDP-11/21 single-board computer. This computer forms the computing element for a digital position controller which encloses a rate loop.

The rate control electronics converts the demanded rate, supplied in digital form, into a sequence of pulses suitable for driving the stepper motor controllers. The use of microstep controllers, together with low-backlash toothed-belt mechanical drives turning precision worm gears on each ME axis gives a resolution of 0.2 arcsecond of motion on the sky, with a backlash of less than 0.5 arcsecond. An encoding system using absolute optical encoders on the worm drive gives an encoding resolution of 0.88 arcsecond.

### (2) 64 m Antenna Servo

The original antenna drive used technology (Metadynes, mechanical choppers, vacuum tube amplifiers) and servo techniques that were state-of-the-art in 1960 (Minnett 1957; Rothwell 1961; Bowen and Minnett 1963; Wilson 1965). In 1983 this hardware was reaching the end of its useful life, and operation of the telescope at wavelengths much shorter than originally planned meant that better pointing and tracking were needed. The dynamic behaviour of the antenna required improvement. The low values of the dominant resonant frequencies (1.2 Hz in azimuth and 1.6 Hz in elevation), a ‘walking mode’ of vibration (Macinante 1967), long time constants associated with the dc machines, limited loop gain, and the narrow closed loop bandwidth afforded by the simple passive compensation, all contributed to less than ideal performance. Attempts to provide a tighter loop with the existing servo resulted in instabilities in the system. In particular, the inherent extreme sensitivity of the gain of the photomultiplier tube used in the error detector (Minnett 1957; Rothwell 1961) to environmental parameters that were difficult to control made ‘fine tuning’ impossible.

It was realized that to make significant improvements it would be impossible to use the existing system configuration (single controller driving two motors in series) and impossible to continue to use the existing time-worn hardware. The desired servo performance would be difficult to achieve even with all new analogue hardware, but relatively straightforward if a digital controller was used. Figure 4 outlines one axis of the redesigned 64 m servo position control loop.

![Diagram](image2)

**Figure 4**—Position servo for one axis of 64 m telescope. The SERVO computer performs the computation required for the digital position control of the 64 m antenna. Note that there is a separate rate controller for each motor.

By using a system with separate electronic silicon rectifier (SCR) rate controllers for each motor (two motors per telescope axis), and adding circuitry to control the difference in the torque produced by the two motors, it has been possible to ensure that the total torque is equally shared and that each motor attempts to move the load at an identical rate. This has completely eliminated the ‘walking mode’ problem. Figure 5 shows the servo loops in more detail.

![Diagram](image3)

**Figure 5**—Torque and rate loops for one axis. The torque share network eliminates the previous ‘walking mode’ problem. Torque bias is used in the azimuth axis to eliminate the effects of backlash in the azimuth gearboxes.
A Novel Noise-Adding Radiometer

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Abstract: Very sensitive low-noise amplifiers designed to receive transmissions from spacecraft are not necessarily suitable receivers for radio astronomy. In the former case a good signal-to-noise ratio is required so that high data rates can be achieved. In the latter the ratio of signal to noise power may be as low as $10^{-4}$ and the stability of receiver gain and that of all sources of noise during long integration times becomes of equal importance.

This paper describes a novel solution to the problem, which allowed important astronomy to be performed while the ruby maser receivers belonging to the European Space Agency were installed on the Parkes radio telescope for an extended period of time.

Conclusion

The control system described in this paper has been in operation since mid 1985. Its performance will not only meet the needs of the Australia Telescope but will allow the Parkes antenna to serve as a stand-alone instrument for some time to come. The Parkes instrument remains the largest fully steerable radio telescope devoted to radio astronomy in the Southern Hemisphere. Its operating wavelengths range from 100 cm to less than 1 cm. Its collecting area of 3217 m² will contribute 55% of the collecting area of the eight antennas in the Australia Telescope. The effort involved in the upgrade of its reflecting surface, control system and computing facilities will be of great benefit.

Rothwell, J., 1961, Control, 4, 84.