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The CARNARVON TRACKING STATION

Antenna system for the FPQ-6 radar installation, one of the most accurate radar tracking systems yet developed. Diameter of the dish is 29ft, gain 51dB, beamwidth 0.4 degree and tracking angle precision 0.005 degree. Nominal range in space is 32,000 nautical miles, tracking being controlled automatically by the receiver or manually, if necessary.

Rising from the flat saltbush plains of North-west Australia is the Carnarvon Tracking Station, a multi-million pound complex of electronic equipment. While it is playing a vital part in current space activities, its chief purpose is to assist in the most spectacular achievement of civilisation—the landing of a man on the moon.

WITH the inception of the man-on-the-moon project, tracking stations were planned in strategic positions around the world within the latitude range of 35N to 25S. In the early stages a tracking station was built at Muchea, Western Australia, but this was too far south for subsequent stages of the program and plans were made for its replacement by a new station sited at Carnarvon.

By arrangement between the United States and Commonwealth Governments, the station was established and wholly financed by the National Aeronautics and Space Administration (NASA). The station is under the direction of the Department of Supply and is maintained and operated under contract by Amalgamated Wireless (Australasia) Limited.

The company fully staffs the station from its own resources, augmented by special recruiting campaigns in Australia and overseas.

The major aim of the station is to form a vital link between the spacecraft and the Mission Control Centre in the United States during the manned space-flight programs. With both voice and teletype communication channels, the station can transmit in "real time" ground radar tracking and telemetry control data to the Mission Control Centre. It also provides voice communication and command capability directly to the spacecraft.

In addition, day-to-day support is given to the non-manned scientific missions, such as Eccentric Geophysical Observatory (EGO) and Interplanetary Monitoring Platform (IMP).

Valuable tracking support is also given to special missions such as Ranger, whose object was to relay close-up pictures of the moon to earth, and the now famous Mariner mission which gave the first close-up pictures of Mars. New launch vehicles and experimental satellites are also accorded this support.

The hub of the tracking station is the Telemetry and Control building. In order to obviate interference and transmission hazards, other groups of equipment are dispersed about the one square mile site area, but this building remains the station's nerve centre. Apart from its administrative wing and crew room, it houses most of the telemetry receiving, data handling and communications equipment.

When a satellite comes within range, it is first picked up by the Acquisiton Aids systems. These are two separate systems relying on radio transmission from the spacecraft beacon to fix its position. The antennas consist of an array of 18 small antennas arranged in four quadrants. The phase difference of the signals on arrival at opposing quadrants gives an output dependent on the pointing error. This is used to slew the antenna to reduce the error to zero. The Acquisition Aid can thus acquire targets without difficulty, and track them with an accuracy of about half a degree.

The dual system is particularly important for the Gemini project, which is an exercise in space rendezvous and docking. The separate Acquisition Aids will each be able to track a space vehicle, even when the spacecraft are in similar orbits and in proximity to each other.

Immediately the Acquisition Aid systems have acquired the target, other equipments may be "slaved" to it, i.e., they may use the Acq. Aid to point their antennas, and thus also acquire it.

The FPQ-6 radar system makes particular use of this facility. This is one of the most accurate tracking radars yet developed, and is the major tracking equipment of the station. It has a range of 32,000 nautical miles with, incredibly, an error of only six feet.

When the target is acquired, the radar can be set to track it automatically; at the same time measuring range, azimuth and elevation, displaying these values on indicators, and converting them to teletype for direct transmission to the computers at Control Centre in Houston, U.S.A.

The facility consists of a tracking antenna, transmitter, receiver, display console, range tracking system and data processor. It has three megawatts of RF power, an unambiguous range readout of 32,000 n.m., and a tracking angle precision of 0.005 degree. The antenna, a 29ft parabolic reflector, has a gain of 58dB and a beamwidth of 0.4 degree.

The antenna is positioned by a hydraulic servo-drive system controlled either by the receiver output signal or by manual controls on the operator's console with a choice of either joystick or handwheels.

A secondary radar tracking system is the Verlort. Although it has neither the range nor the accuracy of the FPQ-6, it is useful as a back-up and secondary facility to assist with the rendezvous and docking program.

Once the spacecraft is acquired and tracked, the Command and Telemetry Systems come into operation. Voice communication between the astronauts and the station is controlled from a console, operating on a two-way radio system on duplicated HF and VHF bands.

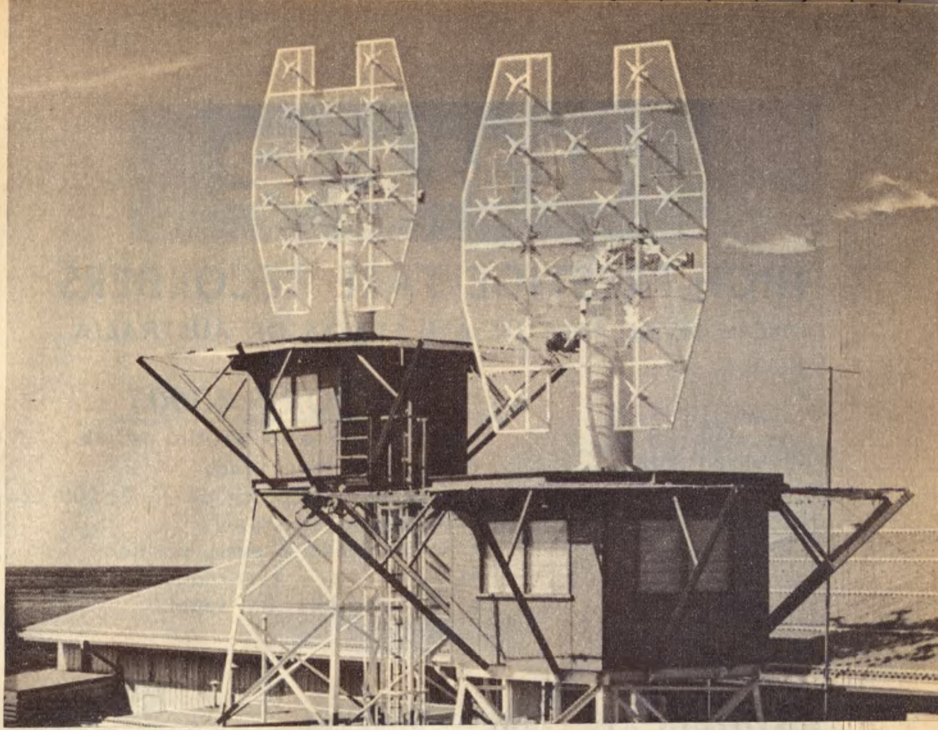
The major command and communication task, however, is performed by the Digital Command System (DCS). In the case of a manned flight, the DCS enables the flight controller at the station to send commands and to load data into the spacecraft's computer. In the case of unmanned flights, the system becomes the only means of communication.

This has particular importance in the Gemini project, where the unmanned Agena vehicle will have to be manoeuvred close enough to the spacecraft to achieve rendezvous. In order to effect such command, the Digital Command System is capable of storing in coded form up to 500 commands.

New commands may be fed into the store by teletype received direct from the Mission Control Centre, locally from paper tape or they can be inserted manually at the DCS console. An intricate checking system is included, so that any errors in storing or transmitting are at once discovered and corrected.

Commands are relayed from either of two duplicate 10 kilowatt transmitters, which, in turn, can be served by either of two steerable antennae.

Radio transmission of data from spacecraft to station is received through the Acquisition Aid antennae. The Telemetry System demodulates the RF signals, producing an output in one of several coded forms.



The Acquisition Aid antenna system which, incidentally, was featured in colour on our cover for August, last year. The two antennas can be used conjointly or separately. They are particularly valuable for their ability to pick up and lock on to satelites, providing data by which higher performance, narrow-beam systems can be directed to "acquire" the target.

Typical information from a manned spacecraft would include measurements such as cabin pressures and temperatures, and astronaut's temperature and cardiogram. Such information is displayed immediately on consoles and recorders in the control room and telemetry rooms.

The PCM/FM/FM or PAM Telemetry System, depending on received code, separates out the hundreds of measurements from the one complex signal. It is equipped to handle many different types of coding, so can receive telemetry from a wide range of spacecraft.

The computer is programmed to select certain measurements, and to transmit them immediately to the Mission Control Centre. It can also check automatically when measurements show unexpected changes or apparent danger levels.

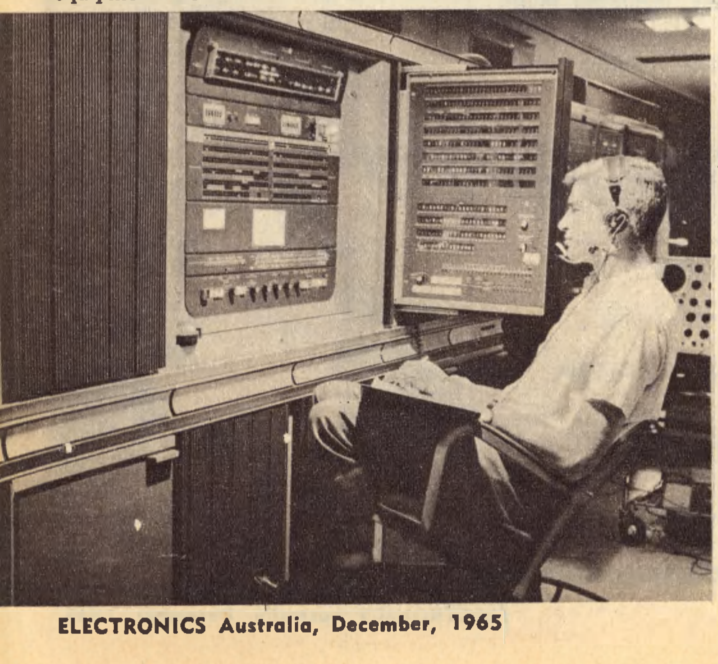
Still under construction is the newest equipment for the station. This is the Unified S-Band System, which is designed for the extremely long distance tracking of the moonshot. Technicians employed in this system have just returned from the NASA briefing course in the U.S.A.

The equipment consists of a single 30ft parabolic antenna, through which commands, telemetry, tracking data, etc., may be transmitted and received. Information obtained from the spacecraft is fed into receiver racks, which demodulate and channel information to the appropriate sections within the system.

Although the Carnarvon Tracking Station is specifically designed to assist in the manned flight programs, it has one important facility which has no commitment whatever to this project. This is the Range and Range Rate system, which is allied to STADAN (The Scientific Tracking And Data Acquisition Network). Its function is to provide range, range-rate (velocity) and angular data measurements from scientific satellites.

It consists of a receiver-transmitter, parabolic S-band transmitting and receiving antenna, and a cavity-backed slot VHF transmitting and receiving antenna. This system is intended to supplement existing satellite tracking systems and to improve upon present tracking accuracies, particularly for highly elliptical orbiting spacecraft.

It acquires and tracks by transponding with the spacecraft to measure its range, range rate and bearing as a function of time. The bearing is obtained from the X-Y mounted S-band antenna, which provides accurate angular data. The spacecraft's range is determined from the use of ranging side-tones, where the phase delay of these side-tones is directly proportional to the two-way distance between the tracking stations and the spacecraft.



Trevor Housley at the control centre of the Digital Command system. Through this system, data can be fed into a spacecraft's computer, or coded commands issued relative to maneouvres. The information is transmitted to the spacecraft through duplicate 10KW transmitters and antennas.

Although a low-frequency tone (e.g., 8cps for 1900KM) is required for unambiguous range readout, present techniques of determining phase delay accurately are only about 1 per cent accurate. Using 8cps only, an error of about 120 miles would therefore result. The error decreases proportionally as the frequency is raised, i.e., using 100KC the error would be only 1,500/100 = 15 metres. The system therefore transmits a range of tones, using the lower frequencies to detect ambiguity and the highest frequency for accuracy.

The range rate is determined by measuring the received doppler cycles, per unit of time to obtain the average velocity over that time interval.

At the ranges expected, the signal would be very weak and noise would prevent demodulation. Individual filters are therefore used for each frequency component of the received spectrum. The bandwidths required to eliminate noise (0.1cps) are so narrow that they necessitate the use of active filters utilising dynamic compensation from the independently measured doppler. They are second order phase lock loops, optimised for minimum total dynamic plus random error.

Two separate RF channels are available between the station and the spacecraft. One channel is provided at S-Band (about 2500MC) for precision tracking the Range and Range Rate transponder in the spacecraft; the other channel, having a broad beamwidth is at VHF (about 150MC) to provide fast acquisition and tracking of either the Minitrack or VHF transponder.

The equipment is designed to track satellites orbiting either at very short ranges or at distances increasing to the lunar orbit, with a range of 400,000KM. Range may be measured with a typical accuracy of plus or minus 25 yards, while range rate accuracy may be measured at plus or minus one third of a mile per hour. The system is scheduled to track continuously 24 hours a day. It has provided information on such vehicles as the IMP and EGO series, and the launch phase of the Early Bird satellite.

New buildings scheduled for completion by the end of the year will house the Jupiter Monitor and SPAN programs. These are both concerned with research into radio activity within the solar system.

Other than the sun, Jupiter is the strongest source of radio emission within the solar system. This process is not yet understood but, by monitoring the Jupiter emission, it is hoped to gain information on this process and its effects, and on the effects of Jupiter's moon, 10.

The synoptic monitoring system consists of two Yagi antennas in tandem at each end of a 2,000ft baseline. Output from these is fed into a pair of lobe-sweeping radiometers operating on 16.7 and 22.2MC. This in turn is fed into a phase-detector, giving an output proportional to the cosine of the angle between Jupiter and the baseline. The output and amplitude of signals are recorded, and the information forwarded to Yale University, the research body responsible for the monitoring system.

The purpose of the Solar Particle

Acquisition Aid consoles. In the foreground is Clive Cross at the Agena console. Centre is Ed Goldsmith, while Alec Stevenson, at rear, is at the Gemini console.

Alert Network (SPAN) is to advance knowledge of the action and occurrence of high energy "particle" radiation, emitted at irregular intervals by the sun. This will have particular application in the Apollo moonshot, when the astronauts may be in danger from bombardment by these particles.

This system consists of an optical and a radio telescope. The optical telescope uses a 6-inch quartz objective to collect light. This is passed through a Lyot filter which eliminates all but the red light of hydrogen alpha. This is then split to permit direct viewing, continuous monitoring by closed circuit TV, and photographic recording. The film is processed on site before forwarding to Spacecraft control centre.

The radio telescope consists of a 9ft parabolic reflector using a log-period feed at the focus. It receives simultaneously on 5000, 3000 and 1500MC. These signals are recorded on chart and in digital form on magnetic tape for computer readout. Once operations are commenced, both telescopes function semi-automatically.

It is hoped that, from the information so received, prediction of solar flares and several hours warning of radiation burst may be obtained.

In order to maintain contact between the site facilities and the Station Control Centre, the station maintains an extensive communications system. An elaborate intercom system provides conference facilities between key operating personnel.

Communications between the station and the Mission Control Centre in the U.S. are through either teletype or voice channels, thus maintaining an immediate and effective dual link. At mission times, telemetry information may be fed from the computer into the teletype circuit. Similarly, the voice circuit becomes an essential link during countdown and spaceflight. At other times, it is used for briefing and discussion between the station and control centre.

To supplement the vulnerable single landline link to Geraldton, a tropospheric scatter radio link has been established. This consists of two horn-fed parabolic reflectors operating at 1000MC. By pointing the antennae at the horizon, facing in a direct line antennas 300 miles distant below the horizon, a small percentage of the total output can be received at Geraldton. It is picked up by the antennae after being refracted and scattered by the turbulent atmosphere at about 35,000ft.

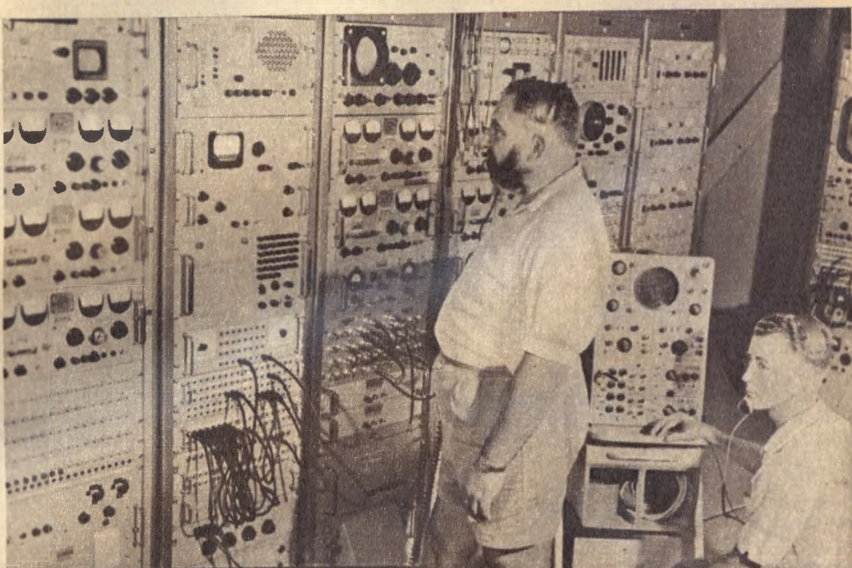
Being dependent on tropospheric (lower atmospheric) conditions, propogation is not always possible. However, 98 per cent reliability has been achieved through the 72 information channels available in similar systems throughout the world.

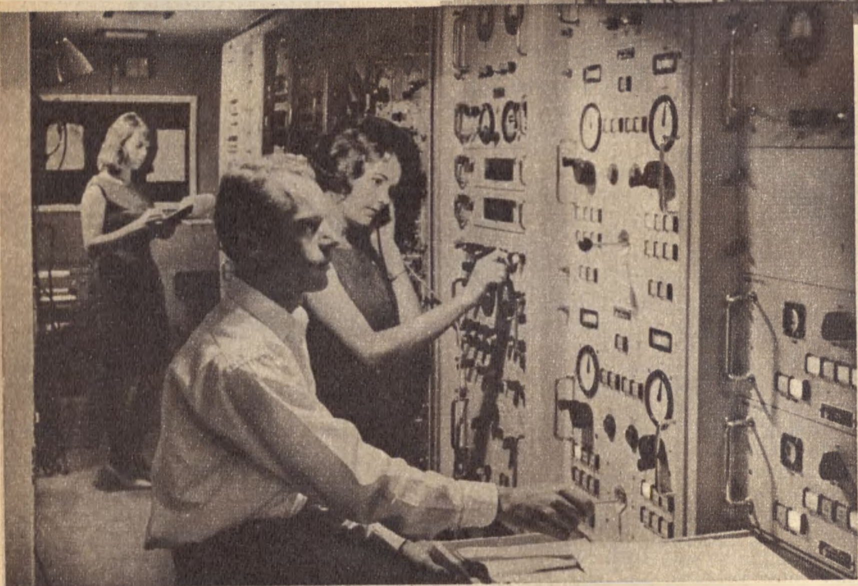
A further interesting communications link is with Woodleigh Station, 120 miles south and using unmanned radio relay equipment located at Gladstone. There, an experimental series of patterns to test visual acuity from spacecraft have been laid out on Woodleigh Station. The communications engineer at the tracking station has evolved a VHF communications link for this purpose, using standard AWA FM car phones. Further research into the network is proceeding.

A service basic to the efficient running of the station is the timing system. The usefulness of all tracking and telemetry information depends on an exact time tagging of the information acquired. A master electronic clock is synchronised with standard time signals transmitted from WWVH, Hawaii. These signals are then used to operate other clocks throughout the building, include time indication marks on chart recorders and provide synchronising pulses for equipment.

The clock is designed around an oscillator vibrating at precisely 1 megacycle per second. It controls the clock to within five thousandths of a second in the 24-hour period and this in turn controls all other timing mechanisms at the station.

The final facility is the powerhouse. Six 60-cycle generators provide power through two entirely separate distribution systems. One generates power for all the sensitive electronic equipment; the other is the service system generating power for normal station needs, e.g., air-conditioning and lighting.





(Above): The radio frequency receivers . . . Dave Ricketts centre and Ben Ryan right. Signals from these receivers are de-modulated, distributed and processed, as necessary, at various points on the station.

(Left): The monitoring equipment for scientific satellites. In the foreground is Kon Tsiaprakas, with trial assistants Joyce King (centre) and Helen Smith (left).

To operate and maintain at the station all these systems, Amalgamated Wireless (Australasia) Limited has assembled a staff of more than 100. The station director, a senior Public Servant with the Department of Supply, retains overall supervision on behalf of the Government interests. He is responsible for ensuring that the station is run in accordance with the specifications of NASA.

The AWA senior company representative is responsible to him for the operations and maintenance of the station. He is assisted by the operations and maintenance supervisors and the engineers in charge of systems. The principal administrative officer heads the administrative and logistics section.

The station provides employment for three classes of technicians, ranging from men with basic trade qualifications to

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the transformer should be 40-60% higher than Vz. For example, for a 12V DC voltage source, it is necessary to use Zener diodes with a Vz of 12V and a transformer with secondary voltage 16-19V. The short-circuit current

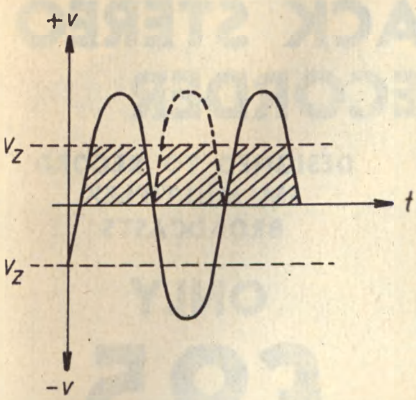

Figure 8: The transformer secondary voltage, the voltage clipping by Zener diodes and the rectifier output voltage (broken lines).

(Idc) should be approx. 20-30% higher than the max. current for which the source is rated.

The choice of the transformer and the capacitor C (see formula (1), is the same as mentioned above.

It is only necessary to determine a suitable type of Zener diode. If no output-current is drawn out of the source (open-circuit condition) the four Zener diodes must dissipate the electric energy which is given by their Zener voltage Vz and short-circuit current Idc. Each diode must therefore dissipate one quarter of the energy, i.e.

$$Nd = \frac{1}{4} K\ Vz\ Idc \quad (2)$$

The co-efficient K is dependent on the relation between Vz and the secondary voltage of the transformer. For the above recommended values K can be conservatively estimated as 0.5.

For example each Zener diode with a voltage Vz = 12V in a circuit with short-circuit current Idc = 6A must be able to dissipate approx. 0.125 x 12 x 6 or 9W.

An example of such a constant voltage device is the circuit in figure 9. This

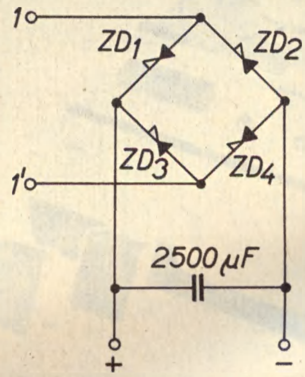

Figure 9: Circuit diagram of a rectifier with Zener diodes ZD1 to ZD4, which is connected to terminals 1-1 of the circuit in figure 5.

circuit has been connected to the secondary (terminals 1 — 1) of the transformer in figure 5. 10W Zener diodes equivalent to 1N1605 have been used in this circuit and the filter capacitor was 2500 uF/12V.

The current-voltage characteristic of this set-up is given in figure 2 (broken-lines, capacitor C = 6 uF). This is a result which can be compared favourably with many current types of simple transistor stabilised DC voltage sources.

CARNARVON TRACKING STATION

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those with considerable experience in the field of advanced electronics.

Broadly, there are five main systems or groups. These are:

(1) The Gemini system, including radar and telemetry sub-systems.

(2) The Service and Ancillary group, comprising communications, computer and test groups, the SPAN and Jupiter monitoring system.

(3) The Apollo system. This is the unified S-band system, divided into groups working in digital, RF telemetry and ancillary sub-systems.

(4) The Range and Range Rate system, whose staff includes a number of female trials assistants who operate the equipment.

(5) The Support Facilities group, comprising engineering, electrical and miscellaneous sections.

During a mission, all positions at the tracking station are manned continuously. The control room becomes the operating heart of the station. In manned missions, overall authority is the capsule communicator (Cap Com), who is seated at a control console and flanked by engineers monitoring the Agena and Gemini vehicles.

These three are generally engineers provided by the spaceflight control centre in Houston. Their consoles receive and display all the relevant telemetry information. Other positions with air to ground voice talk capability are Comtec, Gemini and Agena systems, and the Aeromed.

The maintenance and operations console is manned by the operations supervisor, who is responsible for ensuring the operational status of the station. In manned missions, he acts as liaison between the flight controllers and the station, and in unmanned missions between the station and the mission control centre. Controlling station countdown is also his responsibility.

For the first pass, countdown is usually begun some eight hours before lift-off, thus giving time for all systems to be checked out. For subsequent passes, countdown is reduced to 30 minutes (H = horizon time −30).

An acquisition message, giving predictions of time and position, is usually received before the pass, thus enabling prior pointing of radar and acquisition aid antennas. Once lock-on is achieved, the various systems track automatically, provided signal strengths, etc., remain reasonably constant.

During the pass, it is the function of the station to track the spacecraft, to uplink commands to the spacecraft through the digital command systems and to receive, record and display all telemetry data. This station, working in conjunction with others in the network and with the Goddard spaceflight centre, will play a vital role in man's first exploration of the moon.