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Results of Tests at Goonhilly Using the Experimental Communication Satellites Telstar I and Telstar II*

W. J. BRAY, F. J. D. TAYLOR, and R. W. WHITE

POST OFFICE ENGINEERING DEPARTMENT

The first active communication satellite—Telstar I—was launched from Cape Canaveral by the National Aeronautics and Space Administration (NASA) on 10th July, 1962, and was later followed by Relay and Telstar II. Since the 10th July, 1962, many tests and demonstrations of television, multi-channel telephony and telegraphy, facsimile and data transmission have been made via these experimental satellites. In addition, much data has been accumulated on microwave propagation, earth-station receiving system noise temperatures and satellite tracking accuracy. Such tests and data will be of considerable value for the planning and design of future operational communication-satellite systems.

The aim of this lecture is to review the results obtained from the tests with the Telstar Satellites and to draw some broad conclusions as to their implications. Since it will not be possible to present all the data, a representative selection has been made.

Several communication-satellite earth stations, including those at Andover, Maine, and Pleumeur-Bodou, France, took part in the tests. The results presented, however, are mainly those obtained from measurements made at the British Post Office earth-station at Goonhilly, Cornwall. It is to be noted that much additional data on the performance of the communication satellites themselves, and on the intensities of radiation in space and its effect on the lives of solar cells and other components in satellites, has been obtained by the Bell Telephone Laboratories and NASA via telemetry transmissions from the satellites.

The cooperative programme of tests between the various earth stations has been coordinated by a *Ground Station Committee.* This Committee, which is chaired by NASA, includes representatives of NASA,

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and the administrations concerned with operation of the stations and the satellite designers.

Before discussing the tests it will perhaps be of value to outline briefly the characteristics of the Telstar satellites and their orbits, and the characteristics of the Goonhilly earth-station.

THE TELSTAR AND RELAY SATELLITES AND THEIR ORBITS

The main characteristics of the Telstar and Relay satellites are shown in Table I.

TABLE I — CHARACTERISTICS OF THE TELSTAR SATELLITES

SATELLITE	TELSTAR I	TELSTAR II
DATE OF LAUNCH	10th JULY, 1962	7th MAY, 1963
PRESENT STATUS (NOVEMBER 1963)	FAILED 21st FEBRUARY, 1963	OPERATIONAL
TRANSMISSION CHARACTERISTICS		
Transmit Frequency (Mc/s)	4170	4170
Beacon Frequency (Mc/s)	4080	4080
Receive Frequency (Mc/s)	6390	6390
Radiated Power (Watts)	2	2
Transponder Bandwidth (Mc/s)	50	50
ORBIT		
Perigee (Statute Miles)	590	600
Apogee (Statute Miles)	3500	6700
Inclination (Degrees Relative to Equator)	45	43
Period (Minutes)	158	225

It will be seen that, although Telstar I failed, it is believed finally, on 21st February, 1963, Telstar II is operating effectively at the present time.

Both satellites transmit on the same frequencies in the 4000 Mc/s band with radiated power about two watts; the receive frequencies, i.e. the frequencies of the earth-station transmitters, are in the 6000 Mc/s band.

Both satellites are in highly elliptical orbits with different maximum (apogee) heights, but have approximately the same inclinations of the orbital planes relative to the Equator.

The increased height of the Telstar II orbit compared with the

Telstar I results in slant ranges up to 10,000 miles or more. The longer range without increased transmitted power result in significantly lower received signal levels at the earth stations, and place stringent requirements on the earth-station receiving system in respect of aerial gain and overall noise temperature. However, the greater height also results in a longer orbital period and the mutual visibility between Andover and Goonhilly may extend up to an hour or more on certain passes.

CHARACTERISTICS OF THE GOONHILLY EARTH-STATION

In its present form the Goonhilly earth station has been designed and built primarily to enable tests with experimental communication satellites to be made, but also to be capable of development into an operational station at a later stage if required. For this reason it incorporates extensive testing equipment and other facilities that would not necessarily be part of an operational station.

Steerable Aerial

The steerable aerial at Goonhilly employs an 85-ft. diameter parabolic reflector with a feed in the aperture plane, Fig. 1. Unlike the aerials at Andover and Pleumeur-Bodou, the Goonhilly aerials is designed to operate without a radome. The dish can be rotated in azimuth through ± 250 degrees, and in elevation from 0 to 100 degrees, by servo-controlled motor drives. The aerial is steered on the basis of predicted orbital data, with either manual or automatic fine correction of any residual errors in the data. The predicted data, which corresponds to the X, Y, Z co-ordinates of the satellite position at 1-minute intervals of time, is supplied over a teleprinter link from the Goddard Space Flight Centre, up to a week or so in advance of each satellite pass. From it is derived, via a computer at Goonhilly, azimuth and elevation angle pointing data at 1-second intervals of time. The latter data is recorded on punched tape and used to control the aerial steering system.

Any errors in aerial pointing are determined by causing the aerial beam to scan conically over a very small angle, e.g. 0.03 degree. The resulting amplitude modulation of the microwave beacon signal received from the satellite is detected and used to correct the aerial pointing, by either manual or automatic remote-control of the position of the feed at the focus.

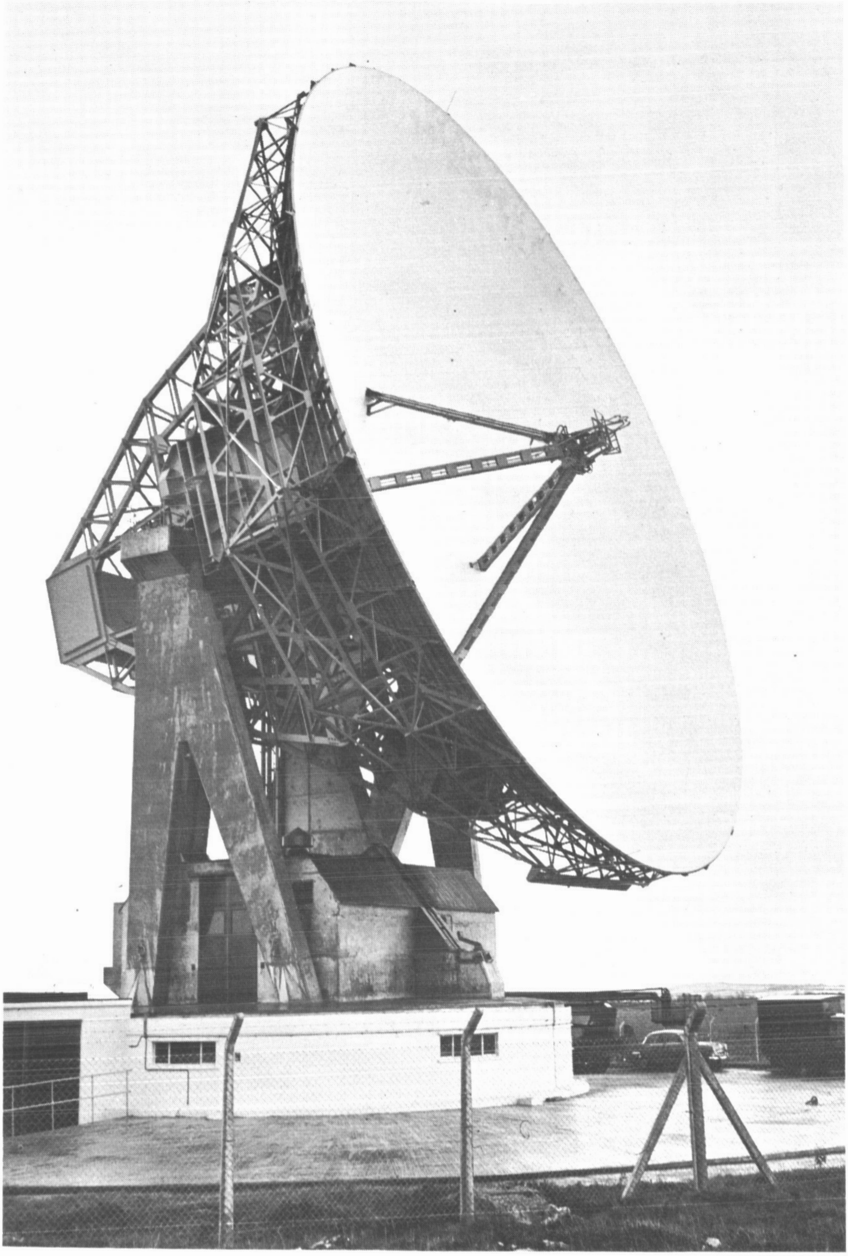


Fig. 1 — General view of Goonhilly aerial.

Aerial Gain and Radiation Diagram

The accurate measurement of the gain of large-aperture microwave aerials is a matter of some difficulty, since the test transmitter or receiver must be located at least several miles away if a sufficiently plane wave is to be achieved. If tower-mounted test aerials are used, undesirable ground reflections are liable to arise thus causing errors. However, the radio star Cassiopeia A provides a source of known and stable amplitude free from such limitations. Measurements of the gain of the Goonhilly aerial at 4170 Mc/s using Cassiopeia A indicate a gain of 55.6 db (excluding waveguide losses) relative to an isotropic aerial, as shown in Table II.

TABLE II — CHARACTERISTICS OF GOONHILLY AERIAL

CHARACTERISTIC	GAIN OR LOSS (db)		
FREQUENCY Mc/s)	1725	4170	6390
GAIN OF IDEAL AERIAL			
Gain with uniform illumination	53.4	61.1	64.8
Loss due to tapering	1.8	2.0	3.0
Gain with tapered illumination	51.6	59.1	61.8
ADDITIONAL LOSSES DUE TO			
Feed support shadowing	1.5	1.5	1.5
Reflector profile inaccuracies	0.4	2.0	4.8
Total	1.9	3.5	6.3
GAIN OF ACTUAL AERIAL	49.7	55.6	55.5

The gain at 4170 Mc/s is some 3.5 db less than that of an ideal aerial with the same feed radiation pattern, the loss being mainly due to dish profile inaccuracies (these being less than 3/16 inch or $\lambda/16$ at 4170 Mc/s over the area of the dish within the 45-ft. diameter); the remaining losses are due to scattering from, and aperture blocking by, the feed supporting structure. It is to be noted that the feed pattern is heavily tapered, the radiation intensity at the rim of the dish being some 18 db below that at the centre, in order to reduce noise pick-up from the ground. The aerial gains at 1725 and 6390 Mc/s are 49.8 and 55.5 db, the losses being 1.8 and 6 db respectively, relative to an ideal aerial. The larger losses at 6390 Mc/s are due to the greater effect of profile inaccuracies as the frequency is increased.

The aerial radiation diagram at 4170 Mc/s, for angles up to ±6° from the main lobe, is shown in Fig. 2. For angles between ±10° and ±90° the minor lobes are at least 50 db below the main lobe, and beyond ±90° they are at least 70 db below. The high discrimination provided by such aerials is, of course, a major factor in avoiding interference to and from terrestrial radio-relay systems, and other satellites, using the same frequency bands.

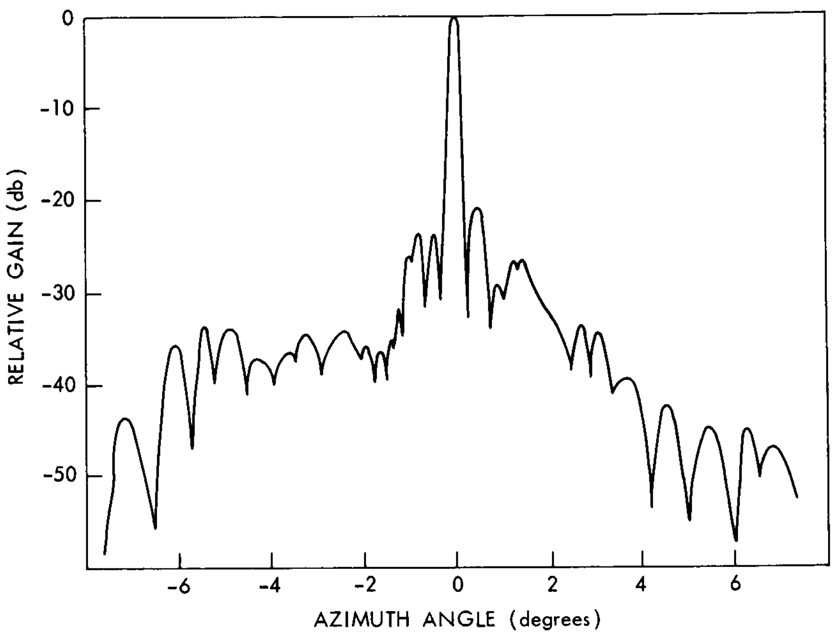


Fig. 2 — Goonhilly aerial horizontal radiation diagram.

The main lobe of the radiation diagram at 4170 Mc/s is shown in greater detail in Fig. 3, which gives a comparison between the measured and computed values. The amplitudes of the first pair of minor lobes are somewhat larger than the computed values, due to scattering from the feed supporting structure. The width of the main lobe at 4170 Mc/s is about 12 minutes of arc at 3 db below the maximum amplitude, and only nine minutes at 6390 Mc/s; thus pointing accuracies of less than a few minutes of arc are essential if significant losses of received signal strength at earth station and satellite are to be avoided.

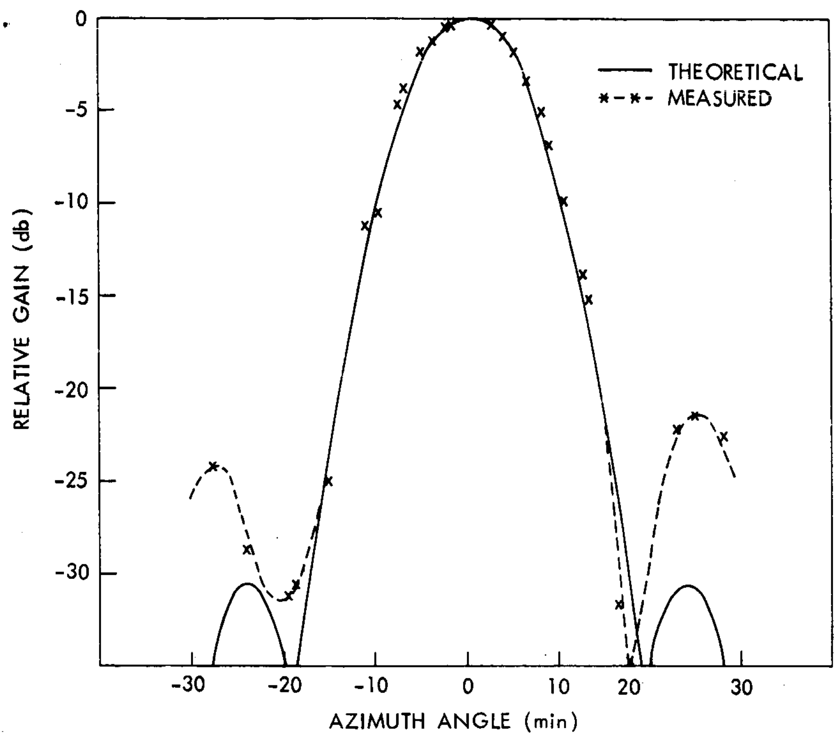


Fig. 3 — Goonhilly aerial main lobe radiation diagram.

Receiving System Overall Noise Temperature

The signals received from Telstar—even allowing for the gain of the 85-ft. aperture aerial—may be only of the order of a micro-microwatt, and a low-noise receiving system is therefore essential. The Goonhilly receiver incorporates a liquid-helium cooled maser operating at about 2°K, the equivalent noise temperature at the maser input being about 12°K. However, the losses in the waveguide feeders, filters and other components between the maser and the aerial feed increase the overall receiving system noise temperature to about 55°K when the aerial is pointing at the zenith, as shown in Fig. 4. As the aerial moves from the zenith towards the horizon, additional noise is picked up from the atmosphere and, for angles of elevation below a few degrees, from the ground via the minor lobes of the radiation diagram. Fig. 4, shows curve (c), the calculated noise contribution from a "standard" atmosphere. The difference between the measured overall noise temperatures shown in curves (a) and (b) represents an improvement of some 15°K

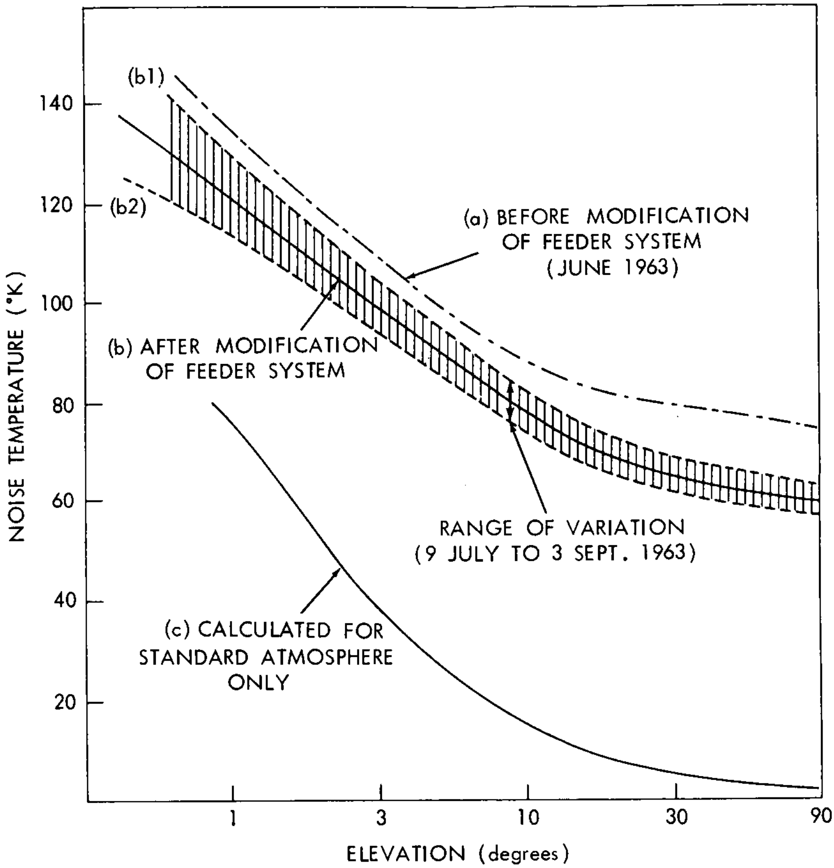


Fig. 4 — Overall noise temperature variation with elevation angle.

due to a reduction of the feeder system losses by 0.2 db. Of particular interest is the limited range of variation of the noise temperature at given angles of elevation over a period of some two months with changing atmospheric conditions, i.e. clear skies interspersed with rain, cloud and occasional ground mist. It is believed that this small range of variation is in part due to the absence of a radome, which when wet could contribute significantly to the overall noise temperature.

Transmitters

The transmitter used at Goonhilly for tests with Telstar produces an output of up to 5 kW at 6390 Mc/s; the maximum effective radiated power, allowing for the aerial gain and the feeder losses, is some 5000 megawatts.

RESULTS OF TESTS AND DEMONSTRATIONS

Characteristics of Received Carrier

The characteristics of the received carrier of primary interest are: the variation of level during a satellite pass, especially at low angles of elevation; and the Doppler frequency shift due to the motion of the satellite relative to the earth stations.

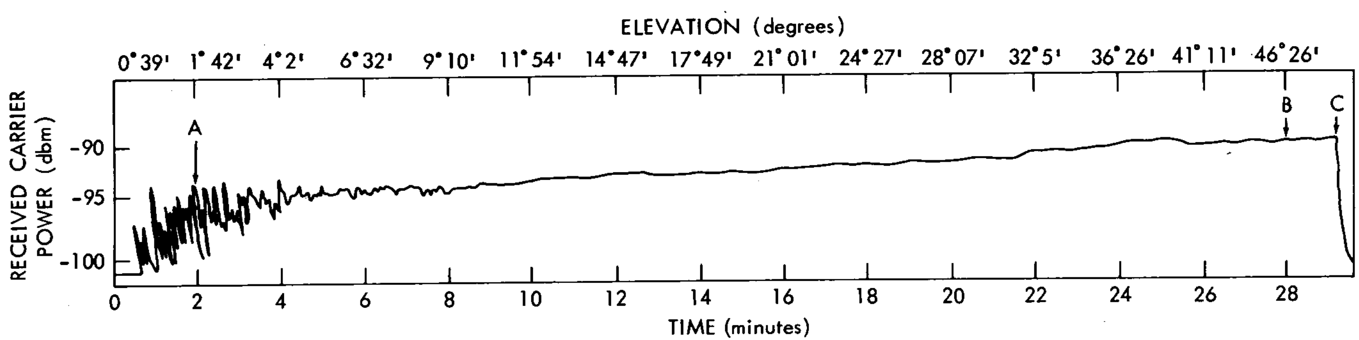
The variation of received carrier level during a typical pass of Telstar I is shown in Fig. 5. It indicates:

1. asquisition of the satellite with the aerial beam only 0.5 degree above the horizontal;
2. fluctuations of level of a few decibels for angles of elevation up to about three degrees, due to the tropospheric layers and irregularities; and
3. a steadily increasing level from about three degrees elevation, to the end of the pass.

Study of the variations of received carrier level for low angles of elevation is of considerable importance for the design of operational communication satellite systems, since the coverage obtainable and therefore the number of satellies required depends on the minimum angle of elevation at which signals can be consistently received. The fact that the horizon at Goonhilly is not more than 0.5 degree above the horizontal has facilitated such studies. Statistical data of the variation of received carrier level at low angles of elevation, obtained during a number of satellite passes, is shown in Fig. 6. It is considered that reliable operation can be achieved for angles of elevation down to about three degrees; however, more data are needed to confirm this provisional result.

For angles of elevation above about three degrees, the received carrier level can be calculated with good accuracy from the free-space transmission equation, allowance being made for the satellite "look angle", i.e., the angle which determines the effective gain (or loss) of the satellite aerial along the direction between the satellite and the earth station.

Fig. 7 shows a comparison between the measured and calculated received carrier powers for a typical pass. It also shows the Doppler frequency shift of the carrier during the pass, due to the rate of change



AT A THE SATELLITE WAS 7000 MILES FROM GOONHILLY
AT B THE SATELLITE WAS 3000 MILES FROM GOONHILLY
AT C THE SATELLITE TRANSMITTER WAS SWITCHED OFF

Fig. 5 — Variation of received carrier power with elevation angle and time during a typical pass.

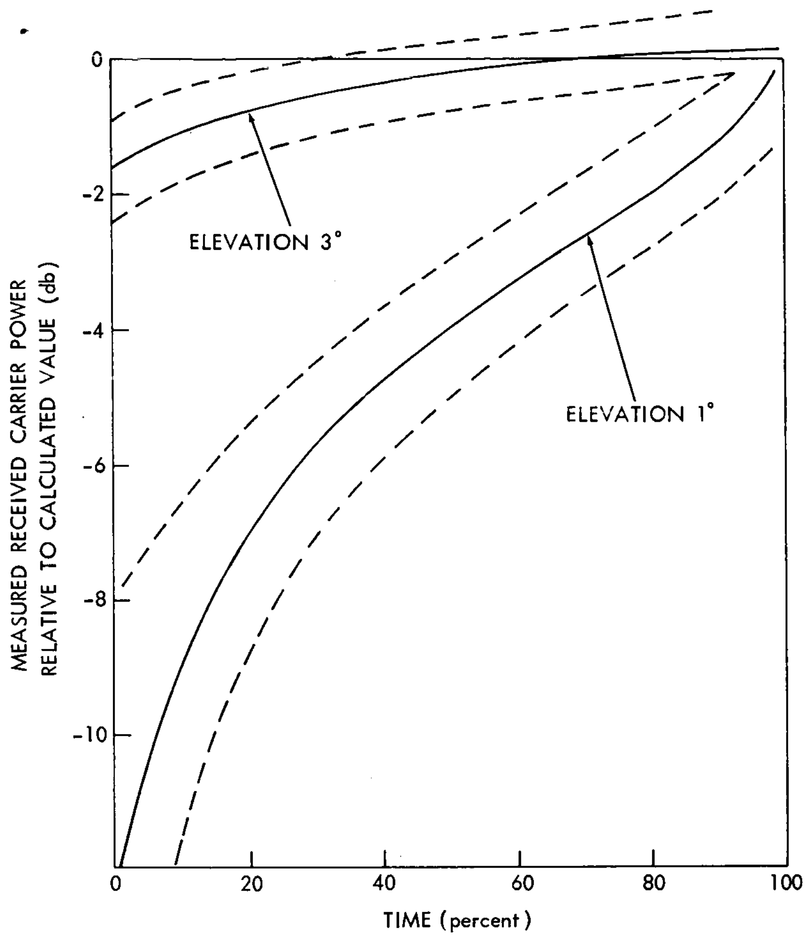


Fig. 6 — Variation of received carrier level at low angle of elevation.

of path length between the earth stations via the satellite. The varying small difference between the measured and calculated values is due to frequency drift of the oscillators in the satellite and earth stations.

The Doppler frequency shift may be up to some 80 kc/s on the 4170 Mc/s received carrier (i.e. up to 2 parts in 10^5) in the case of the Telstar satellites, for a loop connection via the satellites (i.e. from one earth station to the satellite and back to the same earth station). For earth stations on opposite sides of the Atlantic the Doppler shift rarely exceeds 1 part in 10^5, and is generally appreciably less. Such shifts of the carrier frequency are not significant in the wide-band

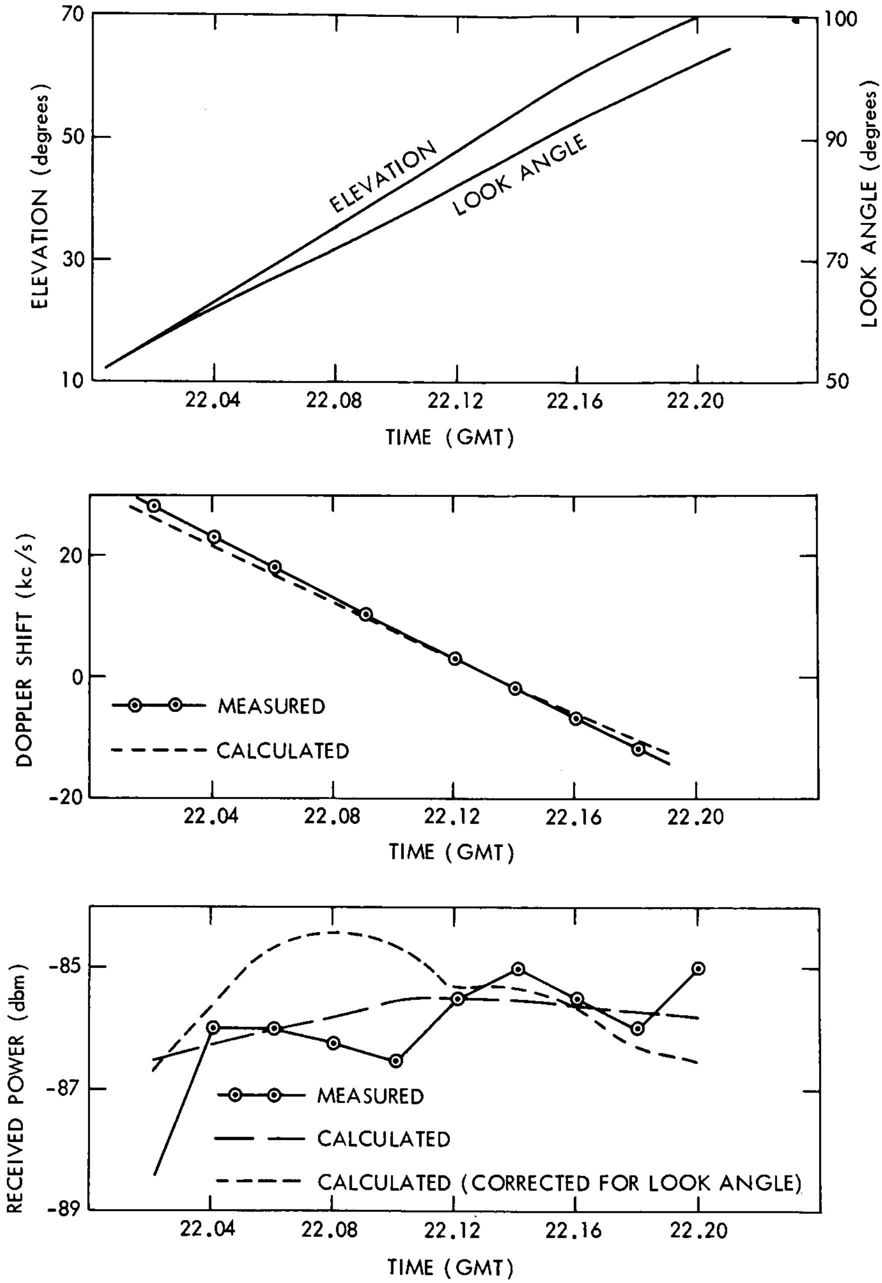


Fig. 7 — Comparison of measured and calculated received carrier power and doppler shift.

RF or IF channels of the FM communication systems; they are important, however, in the narrow-band beacon channel which has to be tuned to allow for the shift. Doppler frequency shifts of up to 1 or 2 parts in 10^5 also occur in the baseband signals; the effects for various types of baseband signal will be discussed later.

Selective Fading and Multi-path Effects

Observations have been made on many occasions to determine whether frequency selective fading or multi-path effects, e.g., due to partial reflections from tropospheric layers, are present. Such effects might be expected to occur, for example, at low angles of elevation with glancing incidence on the tropospheric layers.

Frequency selective fading can be investigated by transmitting a frequency-modulated carrier with a deviation of several megacycles per second and observing the received signal on an IF spectrum analyser; multi-path echo signals can be investigated by transmitting a narrow pulse (e.g., 0.2 microsecond pulse-width) and observing the received baseband signal.

Although many observations have been made, no evidence of selective fading or multi-path effects within the limits of resolution of the equipment have been detected for angles of elevation above about three degrees. This favourable result is attributable in part to the very high directivity of the earth-station aerial, which discriminates markedly against any tropospheric reflections more than a fifth of a degree off-beam, and partly to the smaller reflection coefficients for angles of incidence of greater than a few degrees relative to the mainly horizontal layers.

Below about three degrees elevation of the earth-station aerial beam, the received carrier level fluctuations indicate reflections from tropospheric discontinuities. However, even in this region, the relative delays of such signals are so small that they do not give rise to significant selective fading or echo effects.

The foregoing observations are confirmed by the excellent transmission quality of the satellite link for television and multi-channel telephony signals, referred to later.

Satellite Tracking Accuracy

For angles of elevation above about three degrees, errors in uncorrected aerial pointing relative to the wave arrival direction rarely exceed 10 minutes of arc, and are generally less than 5 minutes of arc for satellite orbits predicted up to two weeks in advance. The manual or auto-track fine correction systems enable even these small errors to be reduced to one or two minutes of arc.

These results indicate the practicability in operational systems of using aerials with beamwidths of only 10 minutes of arc, i.e. with gains of up to about 60 db, provided that such regular operation does not extend below about three degrees elevation relative to the horizon. Below about three degrees elevation, ray bending due to atmospheric refraction plays an increasingly important role; in the case of a satellite the true direction of which is horizontal, the aerial must be pointed about 0.6 degree above the horizontal, for a "standard" atmosphere. In practice the amount of refraction varies somewhat about the "standard" value and small fluctuations of wave arrival direction occur at low angles of elevation.

Television Transmission

It is to be noted that a sound channel is normally provided with

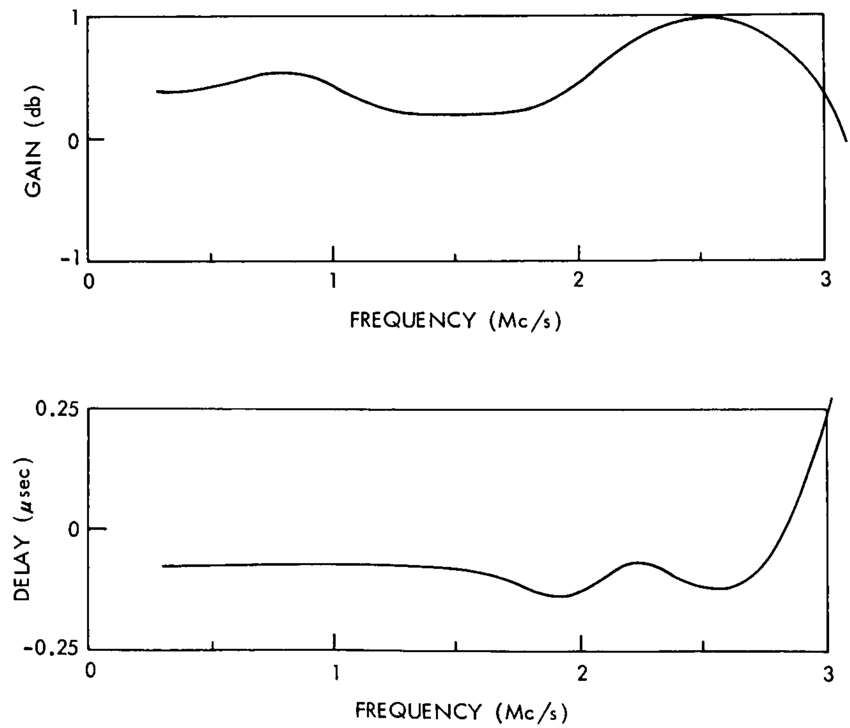


Fig. 8 — Insertion-gain and group-delay frequency characteristics of video channel.

the television channel, using a 4.5 Mc/s frequency-modulated subcarrier in the baseband. This requires that a 3 Mc/s low-pass filter be inserted in the television channel; the results reported are with such a filter in use, except where indicated otherwise.

VIDEO CHANNEL TRANSMISSION CHARACTERISTICS

Typical video channel gain and delay/frequency responses, measured at Goonhilly via the Telstar satellites in loop, are shown in Fig. 8. As would be expected in a frequency-modulation system, the loop-gain stability is good, the variation being generally less than ± 0.2 db.

The video waveform response, measured with a sine-squared pulse ($2T = 0.3$ μsec) and bar signal with the satellite in loop is shown in Fig. 9. The corresponding K-rating factor, which defines the waveform distortion, is less than 2%.

The good quality of the satellite video channel is shown by Fig. 10, a typical test card on the US 525-line television standard transmitted from Andover, Maine, to Goonhilly. Multi-path and echo signals are imperceptible; such imperfections as are apparent on close examination of the received test card are due to the bandwidth restriction imposed by the 3 Mc/s low-pass filter on the nominal 4.5 Mc/s bandwidth video signal.

Doppler frequency shifts have no effect on the quality of the received monochrome video signals, since they correspond to a slow variation of transmission time of a few tens of milliseconds during each pass and this is imperceptible to viewers.

COLOUR TELEVISION TRANSMISSION

During the 60th and 61st passes of Telstar I, on 16th/17th July, 1962, the first transmissions of colour television signals were made from Goonhilly, with the co-operation of the Research and Designs Departments of the BBC who provided a colour-slide scanner and picture-monitor equipment. The signals, which were on 525-line, 60 frames/second National Television System Committee (NTSC) standards, comprised captions, test cards and still pictures used to assess colour quality. The transmissions were made initially from Goonhilly to the Telstar I satellite and back to Goonhilly, and were also monitored by Andover. Fig. 11 shows typical colour test cards before and after transmission.

Similar colour television transmission tests were also carried out on the 88th pass on the night of 19th-20th July, 1962; these included transmissions from Andover to Goonhilly. The success of these tests

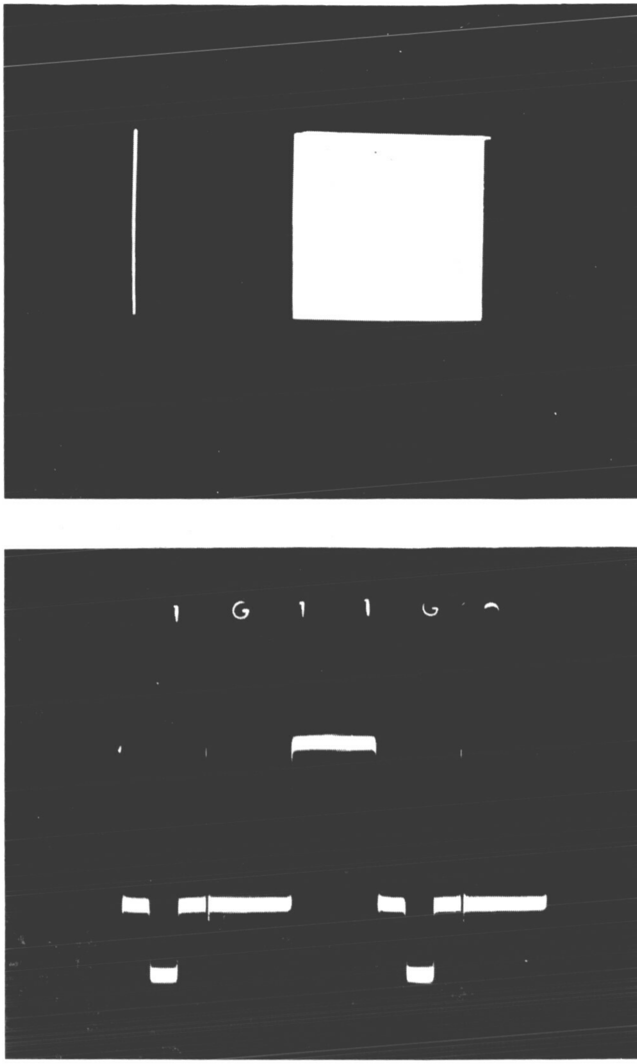


Fig. 9 — Video waveform (sine-squared 2T pulse and bar) response.

is a striking demonstration of the excellent transmission quality of the satellite link; in particular it was observed that there was no perceptible deterioration of colour quality due to Doppler frequency shifts. It also appeared that the Doppler frequency shift of up to some 40 c/s of the 3.58 Mc/s chrominance sub-carrier was within the lock-in range of typical colour receivers.

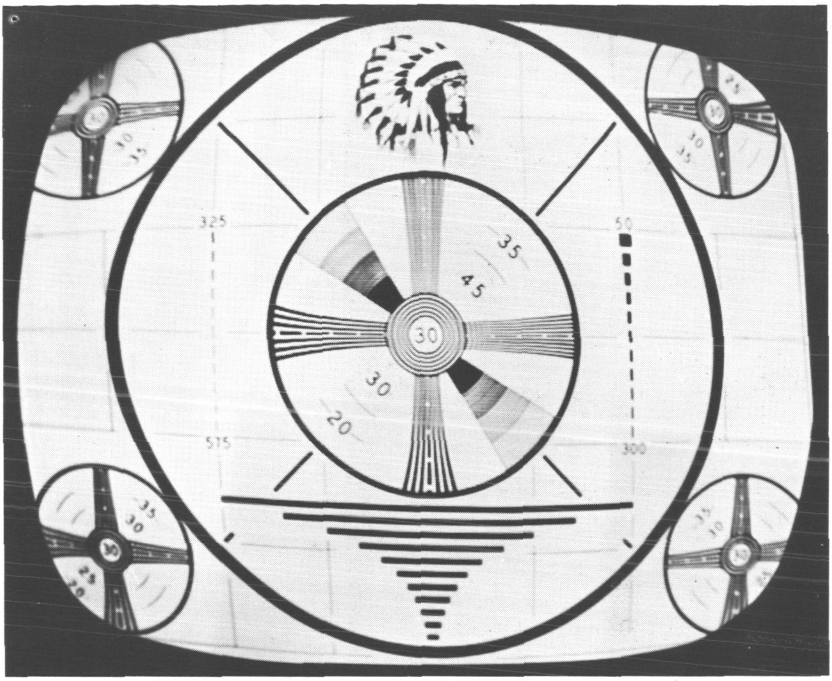
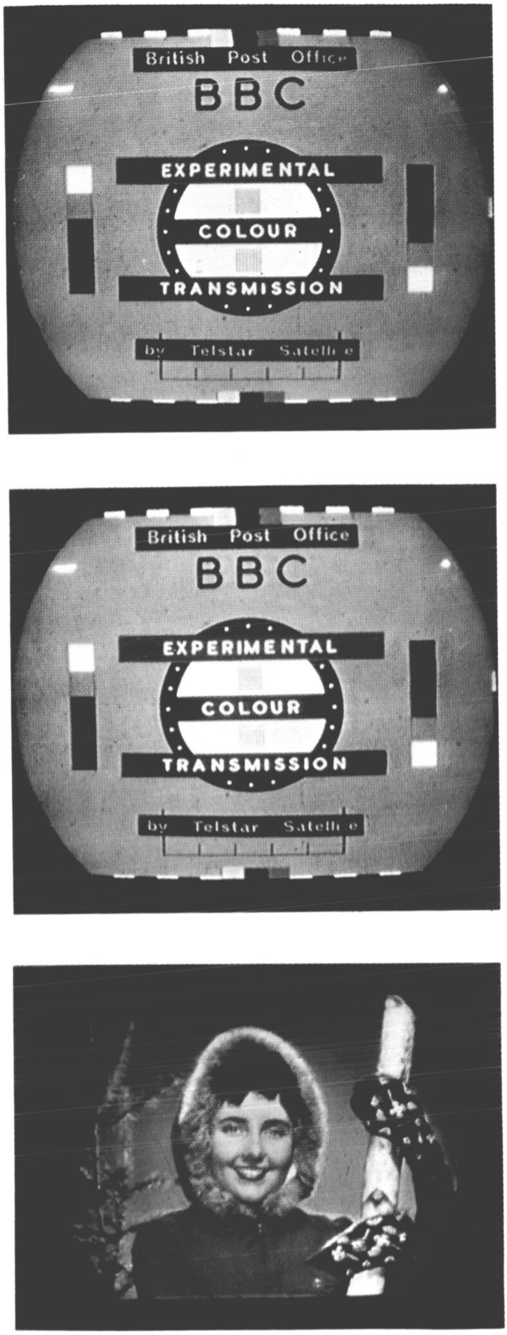


Fig. 10 — Typical test card (US 525-Line) received at Goonhilly.

VIDEO SIGNAL-TO-NOISE RATIO

For most passes of the Telstar satellites, and for angles of elevation above a few degrees, the measured overall weighted video signal (peak-to-peak, black-to-white) to RMS noise ratio has been in the range from about 40 to 50 db, corresponding received carrier-to-noise ratios in a 25 Mc/s IF band exceeding some 10 db. The measured values have agreed, within one or two decibels, with the calculated values allowing for satellite range and look angle, the receiving system noise temperature and other characteristics.

Under the above conditions it is possible to use a normal frequency modulation demodulator to recover the video modulation from the carrier. However, conditions arise occasionally when, due to abnormally long distance of the satellite, unfavourable satellite look angles or low angles of elevation at the earth station, the received carrier-to-noise ratio has been less than 10 db. For example, such conditions have arisen at times with Telstar II, due to the greater apogee height and longer ranges compared with Telstar I. Under these conditions a fre-



Picture as transmitted to Telstar from Goonhilly Downs

Picture returned to Goonhilly Downs by Telstar

Picture transmitted from US to Goonhilly Downs via Telstar

Fig. 11 — Colour television transmission via Telstar.

quency-following negative-feedback (FMFB) demodulator, or variable-bandwidth dynamic-tracking demodulator (DTVB) can be used and have been shown to give satisfactory results for carrier-to-noise ratios, measured in a 25 Mc/s band, of only 6 db and usable results at even smaller ratios. The DTVB demodulator uses a narrowband filter, the centre-frequency of which follows the instantaneous frequency of the FM carrier, the filter bandwidth being adjustable to suit the prevailing noise conditions. Fig 12 shows a comparison of the performance of the FMFB and DTVB demodulators with a normal FM demodulator under conditions of low carrier-to-noise ratio.

USE OF VIDEO PRE-EMPHASIS AND DE-EMPHASIS

It has generally been preferred at Goonhilly to use video pre-emphasis and de-emphasis, since this reduces the mean deviation of the frequency modulated carrier without reducing the overall signal-to-noise ratio. The smaller mean deviation has two advantages:

1. It reduces crosstalk from the video channel into the sub-carrier audio channel due to residual non-linearity of the FM system;
2. It improves the overall performance of the video channel under low carrier-to-noise ratio conditions by minimising effects due to maser bandwidth limitations.

VIDEO-TO-AUDIO CROSSTALK

Without video pre-emphasis the audio noise due to crosstalk from the video channel has varied from about −30 to −40 dbm (weighted), depending on picture content; with video pre-emphasis, values ranging from −44 to −48 dbm have been obtained.

Multi-Channel Telephony Transmission

Multi-channel telephony tests are especially important since the economic viability of communication satellite systems will depend to a considerable degree on their ability to accommodate large numbers of telephone channels, subdivided into both small and large blocks of channels.

The multi-channel telephony tests carried out with the Telstar satellites have been of two types:

1. Two-way tests (e.g. demonstrations between telephone subscribers) using blocks of 12 or 24 channels in the baseband from 12 to 108 kc/s;
2. One-way tests of 300 or 600 simulated telephone channels, using white noise in the baseband from 60 to 2540 kc/s.

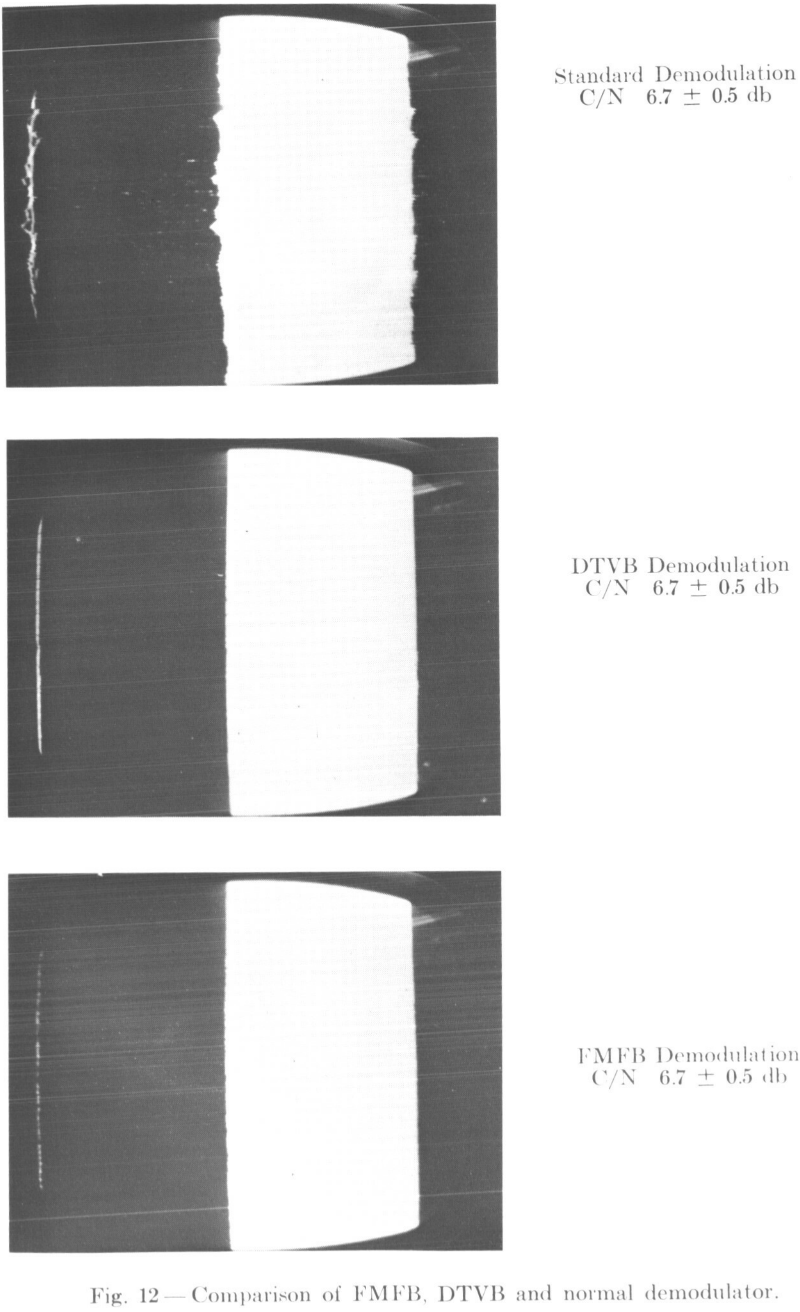


Fig. 12 — Comparison of FMFB, DTVB and normal demodulator.

12/24 CHANNEL TWO-WAY TELEPHONY TESTS

For two-way transmission of 12 or 24 telephone channels the broadband transponder in the Telstar I or II satellite is energised simultaneously by two earth stations, their transmissions being spaced by 10 Mc/s. This represents a somewhat inefficient use of bandwidth, but the arrangement is convenient for experimental purposes in that only one transponder is needed in the satellite for two-way tests.

The weighted noise in the 3.1 kc/s-wide telephony channels, measured at a point of zero relative level, ranges in general from about −55 dbm to −65 dbm, when working with the larger earth stations.

The two-way telephone channels have been used for many subjective tests and demonstrations between telephone subscribers and the results have been fully comparable with other high-quality long-distance transmission systems.

ONE-WAY TESTS WITH 300/600 SIMULATED TELEPHONE CHANNELS

As mentioned earlier, large numbers of telephone channels carrying speech and other signals may be conveniently simulated by white noise with a uniform spectrum occupying the same frequency range as the telephone channels, e.g. 60 to 1300 kc/s for 300 channels and 60 to 2540 kc/s for 600 channels.

In order to determine the performance of a transmission system, narrow slots are inserted in the spectrum of the white-noise test signal, the slots being centred on 70, 534, 1248 and 2438 kc/s. The slots enable any noise, whether basic, i.e. of thermal origin, or due to intermodulation between the signals in the telephone channels, to be measured at the output of the transmission system under test. The loading of the transmission system, i.e. the RMS frequency deviation produced in a frequency-modulation system, by the multi-channel signal, can be varied by adjusting the level of the white-noise test signal at the input of the system. As the loading is increased the level, at the output of the system, of basic noise in the slot channels decreases and the intermodulation noise increases. Thus, an optimum loading condition giving the best overall signal-to-noise ratio can be determined.

Furthermore, the effect of pre-emphasis of the multi-channel signal before transmission can be readily assessed by means of a white-noise test signal. Pre-emphasis is useful in frequency modulation systems for multi-channel telephony, since in the absence of pre-emphasis the basic noise spectrum tends to be "triangular", the signal-to-basic noise ratio in the high-frequency baseband channels being worse than in the low-frequency channels; with pre-emphasis a more uniform distribution of signal-to-noise ratio in the baseband can be obtained. However, in choosing the amount and shape of the pre-emphasis characteristic a compromise is necessary, since too much pre-emphasis introduces excessive intermodulation noise in low-frequency telephone channels.

White-noise test signals are also useful for comparing the multichannel telephone performance of FMFB and standard demodulators under conditions of low received carrier-to-noise ratio.

The application of these principles to simulated multi-channel telephony tests using the Telstar satellites will now be discussed. Figs. 13 and 14 respectively shows the results of 300 and 600 channel white-noise loading tests with Telstar, the loading being varied about a "normal" value for the simulated multi-channel signal, the deviation produced by a test-tone of 1 mW at zero level point in a telephone channel then being 400 kc/s r.m.s. The results indicate that an optimum deviation is some 5 db higher than the nominal value. However, with a somewhat higher carrier-to-noise ratio, the optimum deviation would tend to move downwards.

The tests have also shown that with a standard FM demodulator system threshold occurs for a carrier-to-noise ratio, in a 25 Mc/s band, of about 10.5 db; with the FMFB demodulator the corresponding ratio is about 6.5 db, an improvement of 4 db.

In an operational system meeting international circuit standards, the test tone-to-weighted noise ratio would be expected to exceed 50 db, compared with the values of 46 to 56 db shown in the 300-channel tests and 37 to 45 db in the 600-channel tests. However, it should be borne in mind that the experimental Telstar satellites do not employ significant aerial gain at the satellites; in an operational system using attitude-stabilized satellites aerial gains of up to 15 db would be possible and would yield a corresponding improvement in signal-to-noise ratio. Furthermore, the linearity of the experimental system is by no means optimum; improved RF/IF delay equalization and more linear modulators and demodulators should be possible with further development. Given such improvements it is expected that at least 1000 telephone channels to international circuit standards should be achievable on each radio carrier, using satellite transmitter powers of no more than a few watts. With large blocks of telephone channels correction of Doppler frequency shifts would be necessary, as discussed later.

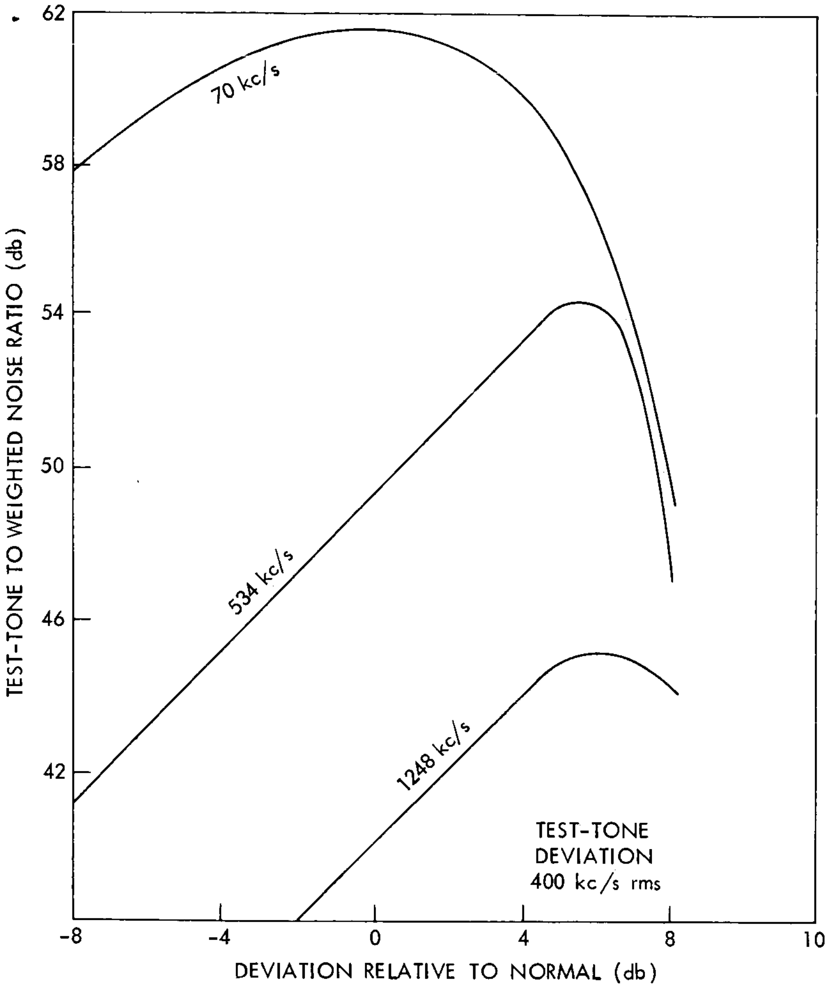


Fig. 13 — 300-Channel white-noise loading test.

FACSIMILE TRANSMISSION

A number of tests of facsimile transmission have been made via the Telstar satellites, using individual audio channels in the 12/24 channel groups and standard facsimile transmitters and receivers.

The facsimile transmissions were of two types: a double-sideband amplitude modulated audio tone, e.g. 1300 cps; and a frequency-modulated audio tone, e.g. with 1500 cps for white and 2300 cps for black.

In general, the amplitude-modulated transmissions are more sus-

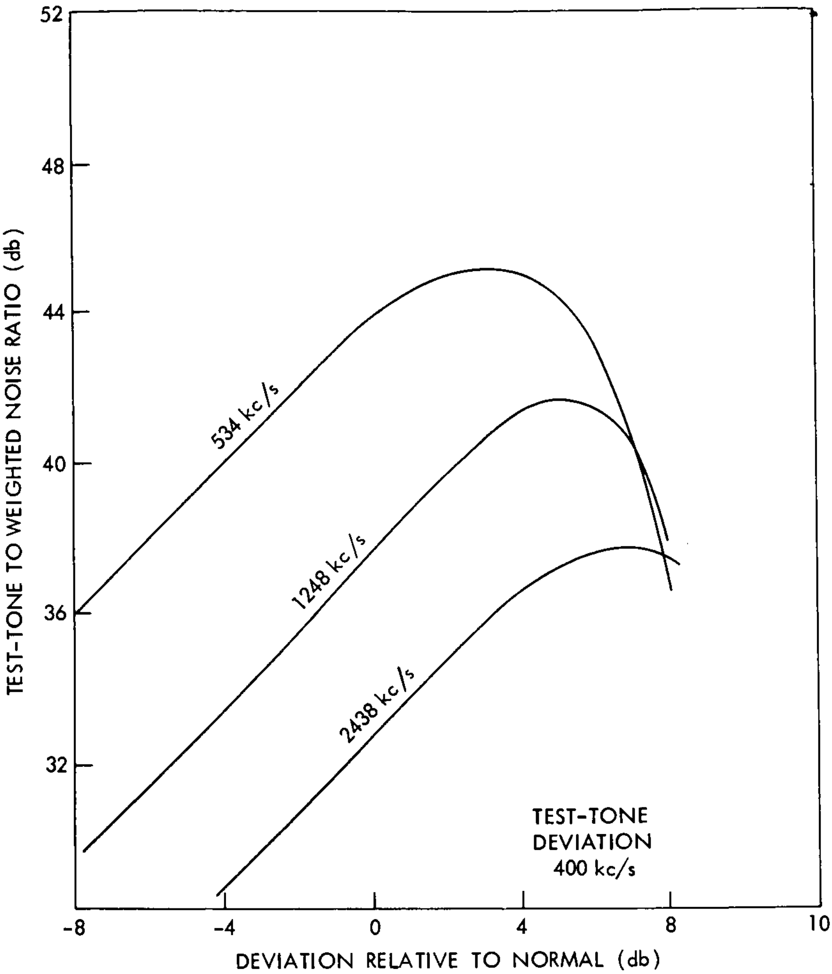


Fig. 14 — 600-Channel white-noise loading test.

ceptible to impairment due to noise or variations of loss in the transmission path, than are the frequency-modulated transmissions, and are thus a more searching form of test.

Fig. 15 shows the CCITT test charts transmitted via Satellite—the upper chart with frequency modulation and the lower chart with amplitude modulation.

The principal defect likely to occur in facsimile transmission via a satellite link, unless special means are taken to prevent it, is 'skew' of the received picture due to the gradually changing transmission delay as the path length via the satellite changes. For typical Telstar orbits, which are highly elliptical, this might be up to 10 milliseconds in a picture transmission time of 7.5 minutes, i.e. up to 2 parts in 10^5 compared with the CCITT recommended limit for skew of 1 part in 10^5.

In an operational satellite system using a medium-altitude circular equatorial orbit the rate of change of transmission delay would be less than for the Telstar orbits, and would be within the CCITT limit for skew.

VF TELEGRAPHY AND DATA TRANSMISSION

Many tests of V.F. telegraphy transmission have been made via the Telstar satellites, using individual audio channels in the 12/24 channel groups. Standard frequency-modulation VF telegraph terminal equipments were used with the following characteristics:

120 cps channel spacing and a frequency deviation of ±30 cps (CCITT standard); and

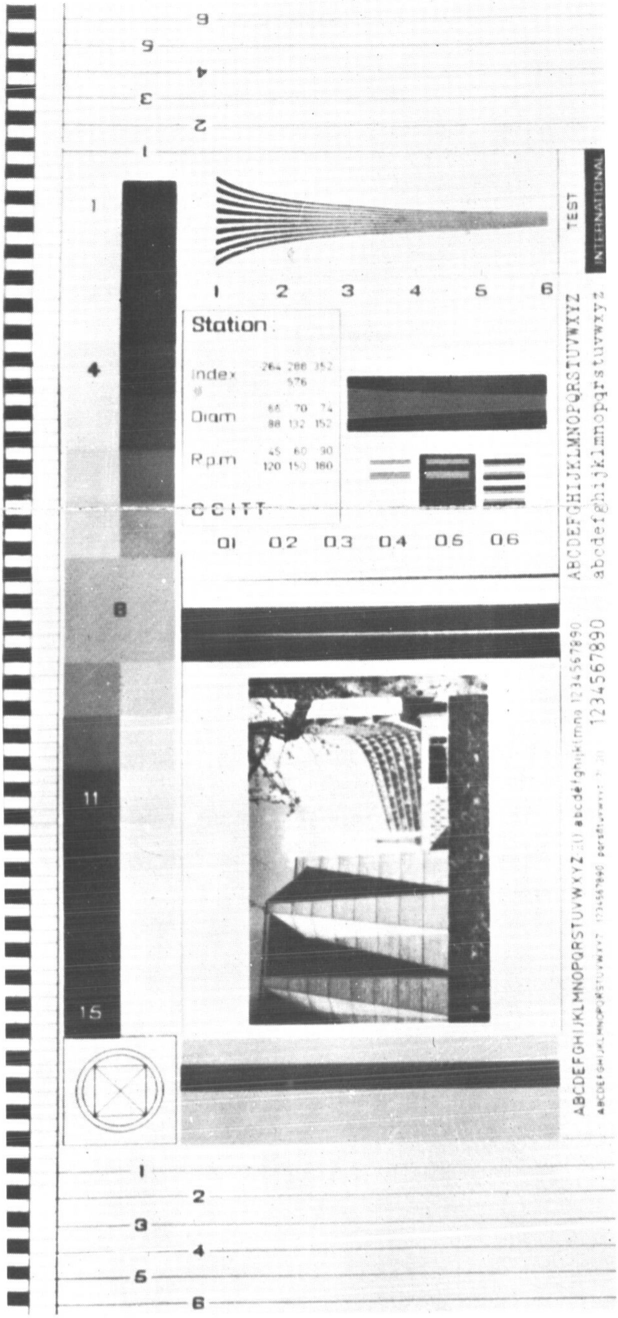
170 cps channel spacing and a frequency deviation of ±35 cps (US standard).

The tests were in three main classes:

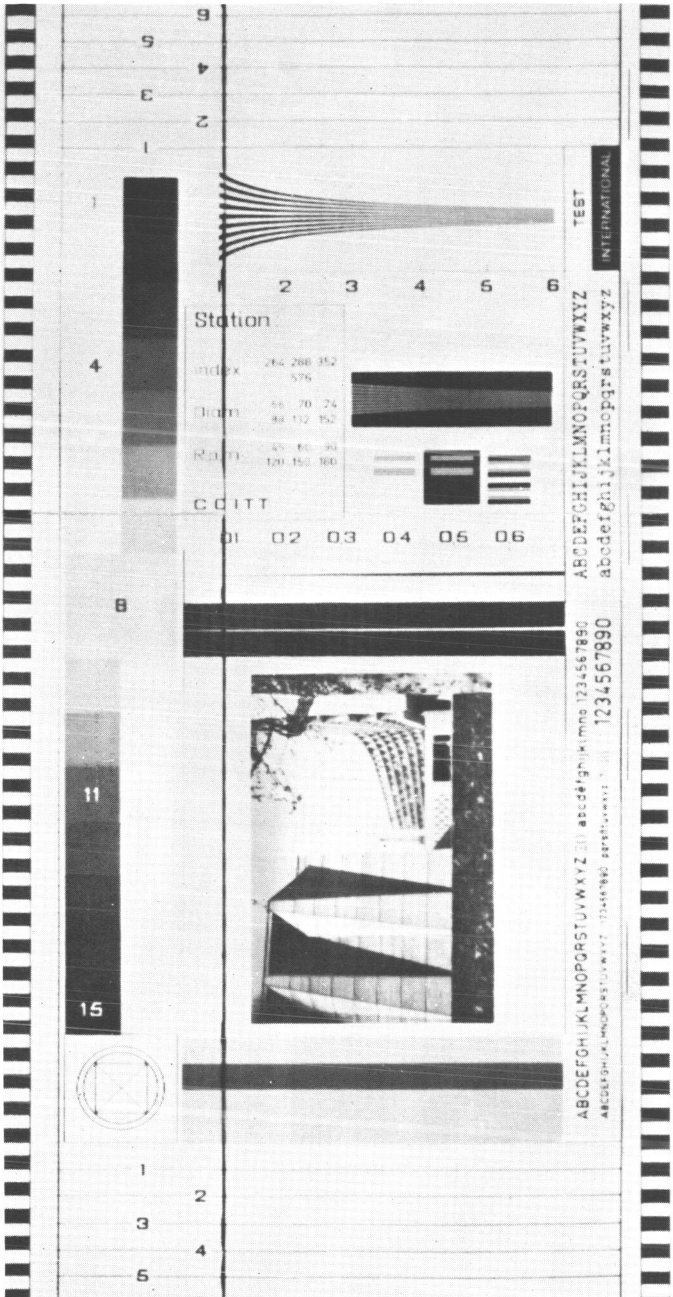
1. *Demonstrations, in co-operation with American telegraph common carriers, between Telex subscribers in London and New York.* Although some difficulites were encountered initially, apparently due to differences between British and American VF telegraph equipments, most of the demonstrations were successful and it was concluded that the satellite link did not contribute any significant adverse factor.

2. *Tests over the loop London-Andover-London, using 50-baud signals and CCITT standard terminal equipment.* The start-stop distortion round the loop was not higher than 16% for a normal pass, and even when the signal-to-noise ratio was lower than would normally be expected, the distortion did not exceed 25%. On a number of passes a synchronous telegraph test set was used to determine the error rate. In a total of 150,000 signal elements transmitted, only one error was counted. A detailed analysis of the distortion during a representative pass (Telstar I Pass No. 787, 4th October, 1962) indicated a mean value varying during the pass from 2.5 to 4%, with a standard deviation of from 3 to 3.7%, as shown in Fig. 16.

The gradual increase in the mean value of the distortion is attributed


Station:
Index
Diam
Rpm
CCITT
TEST
INTERNATIONAL
ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz
1234567890

(upper chart)



(lower chart)

Fig. 15 — Facsimile transmission.

to a Doppler shift in the order of 1 cps in the mean carrier frequency of the telegraph channel.

It was concluded that the basic error-rate of the satellite link was about the same as that of a long-distance circuit provided by conventional means.

3. *One-way tests between New York and London using US standard terminal equipment.* Up to 18,000 characters (126,000 signal elements) were transmitted without error on typical passes.

For the channels in the 12/24 channel groups used for the various telegraph tests, Doppler frequency shifts were less than 1 or 2 cps, and thus did not present a major source of distortion. However, it was noted, that while the gradually changing transmission time caused no difficulty for start-stop teleprinter systems, an adequate range of automatic speed correction is necessary for isochronous systems. In future operational satellite communication systems using larger blocks of channels with higher baseband frequencies than the 12/24 channel groups used in the tests it will be necessary to correct for Doppler frequency shifts, e.g., by the use of pilot reference frequency carriers, path-delay correction or by other means. Consideration will also need to be given to compensation for the change of transmission delay in switching from satellite-to-satellite, which may be up to 10 or 20 milliseconds, equivalent to one element of a 50-baud teleprinter signal, in some types of satellite system.

In addition to the VF telegraphy tests, a number of low, medium and high-speed data transmission tests have been made via the Telstar satellites by the American Telephone and Telegraph Co. with, it is understood, satisfactory results. Some of the high-speed data transmissions were made from Goonhilly at 875 kilobauds, using quadruple-phase modulation of a 2.6 Mc/s carrier in the baseband of the satellite link. The ability of the link satisfactorily to transmit such high-speed data is due in large measure to the absence of multi-path and echo effects.

During medium-speed data transmissions (1200 bauds), made from London over an audio channel looped at Andover, a total of two million signal elements were transmitted during two Telstar passes with only one error.

STANDARD CLOCK COMPARISON

About six weeks after launch, Telstar I was used to compare the precision clocks at Goonhilly and Andover, and since these could be checked against their respective national standards it was possible to

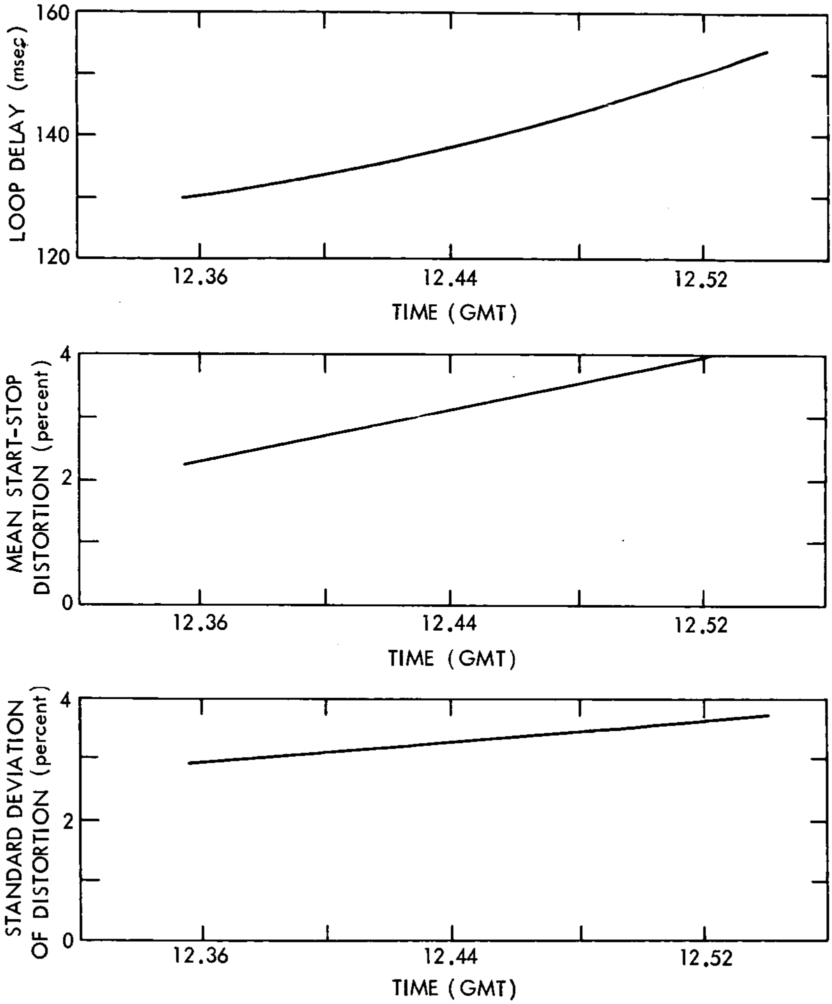


Fig. 16 — VF telegraphy test variation of loop delay and distortion during pass.

assess the difference between UK and USA standards of time. The Royal Observatory and US Naval Observatory collaborated in these tests, in which the national standards were compared with an accuracy some two orders better than had been achieved by any other means.

A simple diagram of the arrangement is shown in the upper part of Fig. 17, while the lower part indicates the basic principle involved.

The earth station transmitter frequencies were spaced approximately 10 Mc/s, as for a two-way telephony test, and IF bandwidths of about 5 Mc/s were used in the receivers. Each earth-station transmitted timing signals from its own clock as short pulses producing a carrier deviation of some 2 Mc/s, each station also retransmitted incoming pulses from the other station. The retransmitted pulses were attenuated by 6 db, i.e. were transmitted with a deviation of 1 Mc/s, to enable transmitted and re-transmitted pulses to be identified.

If the clocks are in synchronism, the local pulses are applied simultaneously at Stations A and B. After a short interval of time 't', of the order of 40 milliseconds, each pulse arrives at the other station, and after an almost identical interval each pulse arrives, but with half amplitude, back at the originating station. Apart from very small corrections which may have to be applied for differences in transmission time through equipment, cables, etc. in the two directions, each station should then receive the other's pulses precisely midway between its own sent and looped-back pulses. If, however, the clock at B is ahead of that at A by an amount Δt, then A will receive B's pulses Δt before the mid-position.

During these tests the Controller of Experiments at Goonhilly devised a very simple but effective display and measuring arrangement using a television monitor. By synchronising the line and frame time bases to 10 kc/s and 50 cps local clock pulses, the raster was converted into an open and accurate time scale, the transmitted and received pulses being applied as brightness modulation. This display allowed the difference between the clocks to be read readily and directly from a scale calibrated in microseconds. By using photographich recording of the raster display, an overall accuracy of about a microsecond is achievable in clock comparisons via satellites.

CONCLUSIONS

In this broad survey is has only been possible to present representative results from the considerable volume of experimental data that has been accumulated since the launch of Telstar I.

Nevertheless, the results obtained from the tests and demonstrations to date have confirmed the expectation that active communication satellites could provide high-quality stable circuits for television, multichannel telephony, VF telegraphy, facsimile and data transmission. The very good results obtained with colour television signals a stringent test of any transmission system—and in the tests with 600 simulated telephone channels, are particularly note-worthy. With further development it is considered that it will be possible to transmit at least a thousand telephone channels, of international circuit perform-

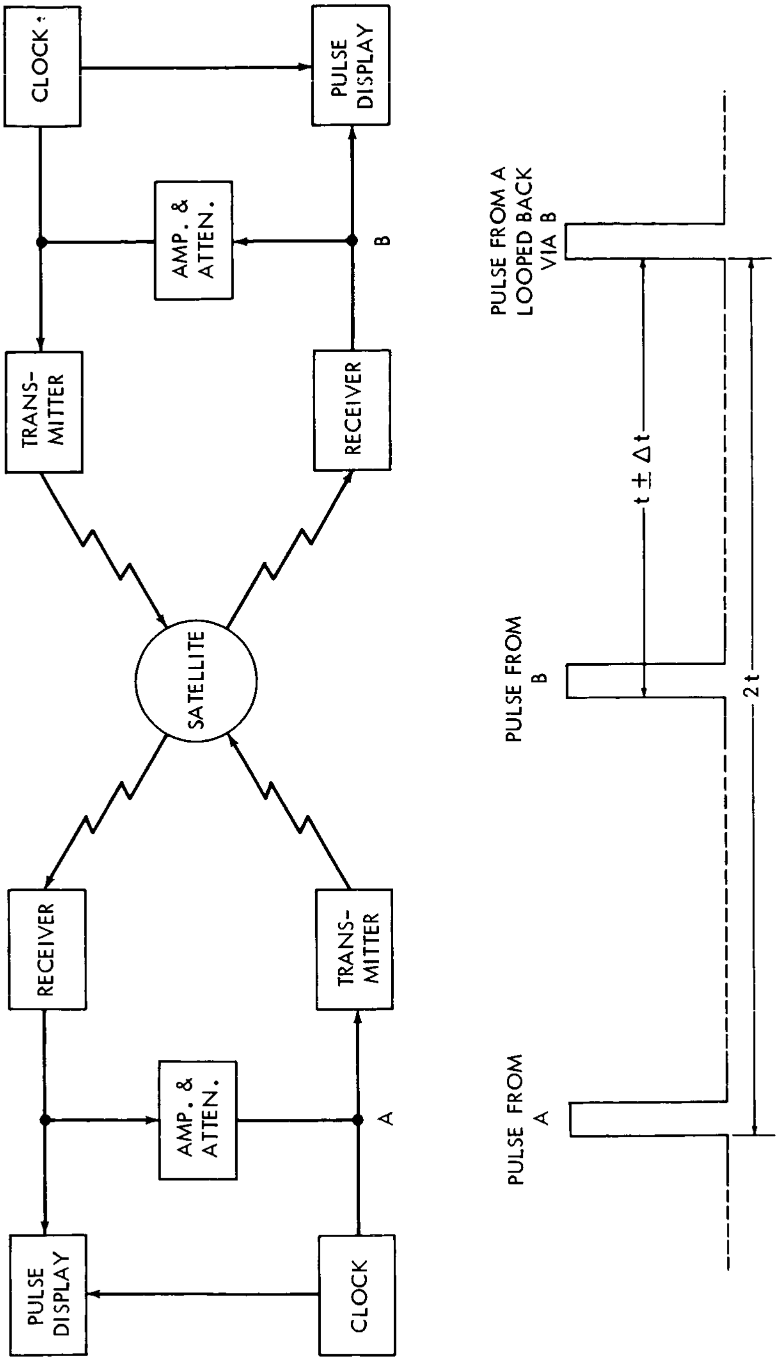


Fig. 17 — Precision clock comparison.

ance standards, on each radio carrier; communication satellites with twice or three times this capacity can be envisaged.

The propagation results obtained at Goonhilly have been particularly interesting since they have revealed the possibility of reliable operation down to elevation angles of only a few degrees. This conclusion has a marked bearing on the coverage provided by a communication satellite and the numbers of satellites required to provide world-wide coverage. It is also of interest that at no time has interference (e.g. from radio-relay systems sharing the same frequency band or from other man-made sources) been detected on the satellite link.

The practicability of tracking satellites, to within some ten minutes of arc, from orbital data predicted up to a fortnight in advance, with automatic fine correction to within a minute or two of arc, has been established.

Standard clock comparisons across the Atlantic have been made with an accuracy of about a microsecond, some two orders better than with other means of comparison.

Finally, it is believed that the results obtained at Goonhilly and the other earth stations participating in the NASA co-operative programme of communication satellite tests will be of considerable value for the design of future operational systems.

ACKNOWLEDGMENTS

The authors would like to thank their colleagues in the Post Office Engineering Department who contributed to the tests and demonstrations described in this lecture, and in particular the staff of the Telegraph Branch who provided information on the VF telegraphy and facsimile tests. Their thanks are due to the BBC and ITA for their help in the television demonstrations, the staff of the cooperating earth stations at Andover and Nutley, and to NASA and members of the Ground Station Committee for their help in planning many of the tests. They also wish to acknowledge the co-operation of the Royal Observatory and the US Naval Observatory in the clock comparison tests, and that of the American Telephone & Telegraph Co. and other US common-carriers in telephony, VF telegraphy and television transmission tests.

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