Results of the *Telstar* System Communications Tests

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The results of the communications tests on the Telstar satellite system which have been conducted at the Andover earth station are presented. These tests have included successful transmissions of telephone, television, and data signals. In addition, measurements of received carrier power, noise, transmission characteristics, linearity, data system errors, absolute delay, and Doppler shift have been made. The results are in good agreement with the expected performance.

AUTHOR

I. INTRODUCTION

Since the launch of the Telstar satellite on July 10, 1962, a large number of communications tests have been conducted at the A.T.&T. earth station at Andover, Maine. These tests have consisted of numerous successful transmissions of monochrome and color television signals, two-way telephone signals, and a variety of data signals. In addition, communications test signals of many types have been transmitted. Most of the television and telephone transmission tests have been conducted between the Andover station and the British Post Office (GPO) and French National Center for Telecommunications Studies (CNET) stations. These stations are respectively located at Goonhilly Downs, England and Pleumeur-Bodou, France. In addition, a number of one-way transmissions were made from the Andover station to the Bell Telephone Laboratories station at Holmdel, New Jersey, described in a companion paper.[1] Communications tests, most of which have been made on a loop basis to the satellite and back to the Andover station, have included measurements of received carrier power, noise, transmission gain and stability, system linearity, data system errors, absolute delay and Doppler shift. A large amount of valuable data has already been obtained; and, as this is written, system tests continue. This paper summarizes the more significant communication test results, most of which have been gathered during the period from July to November, 1962.

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Although the companion papers provide detailed descriptions of the various subsystems which make up the Andover-Telstar communications system, it seems advisable to devote a small portion of this paper to a short over-all description. This has been provided in Section II, which also includes a communications system block diagram that will be useful in understanding and interpreting the test results to which most of this paper is devoted.

Section III provides a brief summary of the modulation methods, baseband signals, and the frequency allocation used for both the one-way and two-way tests.

Section IV is devoted to a description of the experiment plan. This section includes a list of the principal experiments which have been conducted and are herein reported. As such it serves as a table of contents for the remainder of the paper, which is devoted almost completely to documentation of test results.

II. COMMUNICATIONS SYSTEM

An over-all block diagram of the Andover communications system is shown in Fig. 1. The major part of the communications equipment, including the ground transmitter and ground receiver, is located on the horn antenna structure. A video transmission system interconnects this communications equipment and the test area, which is located in the control building 1600 feet away. Most of the communications test equipment is located in the test area. The Andover station is connected to the Bell System network via a microwave radio system from Boston which also terminates at the test area.

The over-all layout permits a large amount of flexibility in the way tests are conducted, as indicated in Fig. 1. Most of the tests described in this paper are RF loop tests. In this case, the communications path is from the test area, through the ground transmitter to the satellite, back through the ground receiver, finally terminating in the test area. Transmission to the satellite and back can also be simulated by transmitting to a boresight repeater located on Black Mountain about 4.5 miles from the ground station. This repeater is a bay-mounted duplicate of the Telstar communications repeater and uses waveguide feeds to small tower-mounted horn antennas. Adjustable attenuators are provided in the feeds so that the received power at both the repeater and ground receiver can be adjusted to simulate those in the actual satellite system.

In addition to these two RF loops, provision is also made for IF and baseband loops as shown. In this paper those test results which were

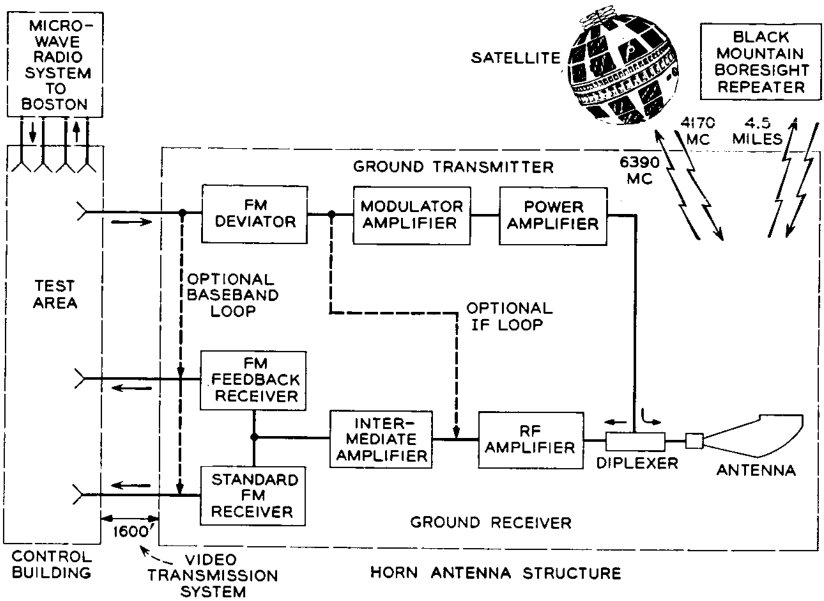


Fig. 1 — Telstar communications system.

taken on loops which do not include the Telstar satellite are identified as boresight, IF, or baseband loop test results.

The baseband transmission characteristic for a loop from the test area to the satellite and back depends on which FM receiver is used. As some of the later data will show, the transmission is essentially flat to well beyond 5 mc with the standard receiver and is flat to about 3 mc with the FM feedback receiver. Additional design and performance information for the individual parts of the communications system are included in the various companion papers.

III. MODULATION METHODS AND BASEBAND SIGNALS

Many of the test signals can be applied directly at baseband in the test area and similarly measured there. Typical examples are baseband transmission measurements such as gain-frequency characteristics and baseband noise spectra. However, other signals such as the combined video and audio signals for television transmission and the frequency-multiplexed telephone signal require additional equipment. In this section the special arrangements used for these signals will be described.

Fig. 2 is a simplified block diagram showing the optional patching arrangements for television and two-way message transmission. For television transmission, the audio signal is applied to the transmitting diplexer, which frequency-modulates the audio signal onto a 4.5-mc subcarrier. The video signal is band-limited by a 2-mc low-pass (roll-off) filter and combined with the 4.5-mc aural subcarrier. The combined signal is then transmitted to the ground transmitter via the video transmission system.

At the receiving end of the system the reverse procedure takes place. The combined signal is received at the ground receiver and transmitted to the control building via the video system, where it is applied to the receiving diplexer. Here, the 4.5-mc aural subcarrier is separated from the video signal and demodulated by a frequency discriminator centered at 4.5 mc. Separate video and audio outputs are provided from the diplexer.

For two-way message operation, standard telephone channel bank equipment replaces the diplexers, as shown in Fig. 2. In this arrangement, 12 individual telephone channels are frequency-multiplexed into the 60 to 108-kc band as shown. However, there is an additional difference between

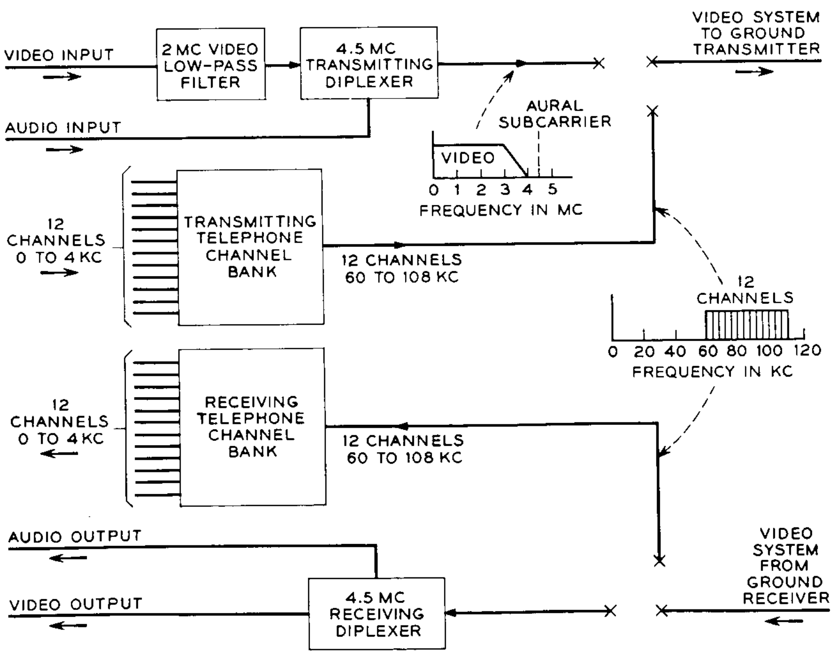


Fig. 2 — Arrangements for television and two-way message transmission.

the television and two-way telephone tests; the television tests are one-way tests which normally use the entire RF bandwidth of the system, whereas the two-way message tests involve simultaneous transmission and reception by two ground stations. This is accomplished by simultaneously using two separate bands for the two directions of transmission. In this case, the individual ground transmitters and receivers are offset by 5 mc from their normal center frequencies, as shown in Fig. 3. Typically, the Andover transmitter and the European receiver are tuned 5 mc above the nominal center band frequency. Similarly, the European transmitter and the Andover receiver are tuned 5 mc below the center of the band. Both signals, separated 10 mc in frequency, are simultaneously received and amplified by the satellite repeater. Since the repeater has only a single wideband channel and a single automatic gain control circuit, the two amplified signals at the satellite output will be unequal in power unless the two input signals are equal. In fact, due to the compression in the traveling-wave tube, any difference in signal power at the input is exaggerated at the output. In order to prevent vastly different signal powers, and hence unequal noise performance for the two directions of transmission, it has been customary for the two participating ground stations to coordinate and control their transmitter power so that approximately equal signals are received at the satellite repeater input.

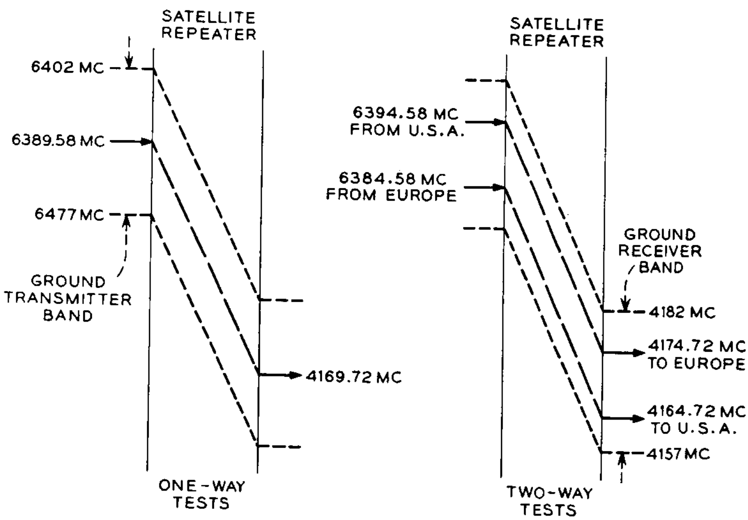


Fig. 3 — Frequency allocation plan.

When two ground stations are conducting two-way tests, both signals are received at a particular ground receiver input. Narrow bandpass filters (3 mc wide at Andover) are inserted at IF to pass the desired signal and reject the unwanted one.

Normal frequency deviations for both television and two-way message transmission are presented in Table I. Television transmission tests have been made both with and without the standard 525-line television pre-emphasis and de-emphasis prescribed by the CCIR.[2] The respective networks, when used, are inserted directly in front of the FM deviator and immediately following the FM receiver. These networks have the effect of increasing the frequency deviation for the high video frequencies by about 3 db and reducing the deviation for the low video frequencies by about 9 db. No pre-emphasis was used for the 12-channel two-way telephone tests.

Table I also shows the nominal frequency deviation used for one-way noise loading tests which simulate 600-channel loading.

TABLE I — NORMAL FREQUENCY DEVIATIONS

Television	
Peak-to-peak deviation by video	14 mc
Peak-to-peak deviation by aural subcarrier	2.8 mc
Nominal peak-to-peak deviation of aural subcarrier by audio signal	100 kc
Two-way message	
Nominal peak-to-peak deviation by 12-channel telephone signal	2 mc
Full load sine wave power at 0 db TL	+16 dbm
One-way message (600-channel noise loading)	
Nominal peak-to-peak deviation by 600-channel telephone signal	20 mc
Full load sine wave power at 0 db TL	+23 dbm

IV. EXPERIMENT PLAN

Prior to the launch of the Telstar satellite it was apparent that special consideration would have to be given to the test procedures because:

(a) the time per day available for tests would be small

(b) significant variations in the system signal-to-noise ratios would occur because the satellite range would change rapidly with time

(c) there would be a time variation in the apparent gain of the satellite antenna due to change in the "spin angle," defined as the angle between spin axis of the satellite* and the line of sight to the satellite from the earth station

(d) Doppler shift might affect some of the tests

* Measured from the south pole (opposite the telemetry antenna) of the satellite.

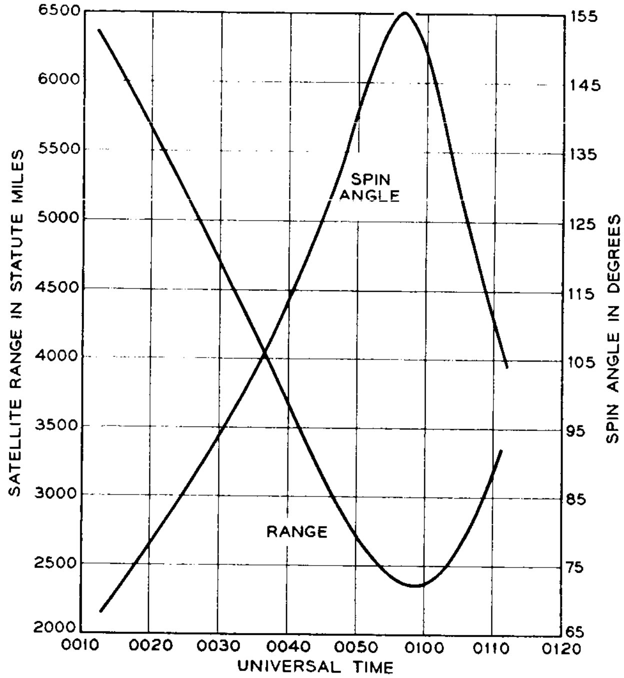


Fig. 4 — Range and spin angle vs time; pass 125, July 24, 1962.

(e) the life of the satellite might be shorter than expected, and it would therefore be essential to gather as much data as possible during the first few weeks.

Of the above considerations, the small amount of available test time has probably been the most important. With a total of about four thirty-minute passes per day and six operating days per week, there is a total of only two hours per day or twelve hours per week to be shared by several earth stations conducting a variety of tests, demonstrations, and special transmissions. This, plus the rapid variation in range and spin angle due to satellite orbital motion (Fig. 4 shows the variation in range and spin angle for a typical pass), made it very important to plan the individual tests to insure rapid and accurate completion. Several steps were taken to make this possible. An experiment plan was developed describing each of the proposed tests in detail, including test equipment requirements, patching arrangements, prepass calibration procedures, data to be recorded, and the recording method. Where possible, several individual tests were combined so that they could be per-formed simultaneously. In addition, the station itself was arranged so that as many tests as possible could be made from a single test area in the control building. Finally, a video switch was provided so that input and output signals to the satellite system could be rapidly switched during a pass without the need for patch cords.* A portion of the test area is shown in Fig. 5.

The principal experiments described in this paper are listed in Table II. The section numbers are included, so that this table also serves as an index to the experimental results reported in the remainder of the paper.

No tests were made of correction techniques for the effect of Doppler shift on transmission, or on the problem of transferring transmission from one satellite to another without interruption.

V. RECEIVED CARRIER POWER

Received carrier power in the communications channel centered at 4170 mc was continuously measured at the ground receiver by monitoring the voltage in the main IF amplifier's automatic gain control circuit. Similarly, the 6390-mc received carrier power at the satellite was measured by monitoring the automatic gain control voltage in the satellite's IF amplifier; in the latter case, the measurements were taken at one-minute intervals and the quantized readings transmitted to the ground via the telemetry system. The over-all accuracies in these measurements are estimated to be approximately ± 0.5 db at the ground receiver and ± 1 db at the satellite receiver. Large amounts of these data have been obtained and analyzed in various ways. In general, the measured values of received carrier power agree with the predicted values when both range and spin angle effects are included.

5.1 *Received Carrier Power as a Function of Time*

A typical pen recording of the 4170-mc received carrier power at the ground receiver is shown in Fig. 6. This trace, taken with a recorder speed of about 50 cm/hour, covers a period of about 20 minutes during pass 125. The relatively broad width (1 to 3 db) of the trace is due to a rapid jitter of the pen following the variations in the antenna pattern due to the spin of the satellite. The slower variations which are more clearly visible are caused primarily by the variation in the spin angle at the satellite and to a lesser extent by range variations.

* Even with these precautions, it has been difficult to obtain completely consistent sets of data; a critical reader can undoubtedly find some evidence of this in the paper.

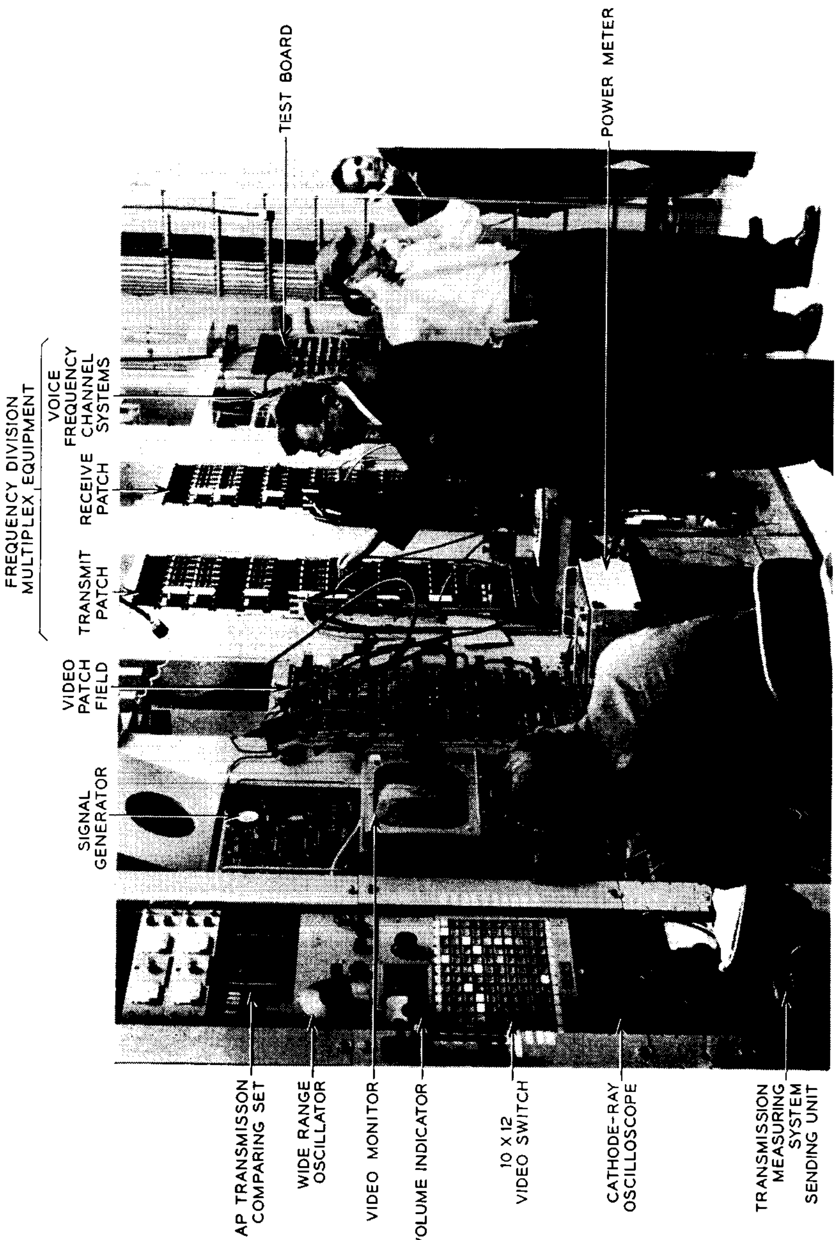


Fig. 5 — Portion of Andover test area.

TABLE II — EXPERIMENT RESULTS INCLUDED IN THIS PAPER

Type of Test	Section
Received Carrier Power	5.0
Received Carrier Power as a Function of Time	5.1
Received Carrier Power vs Range	5.2
Antenna Patterns	5.3
Radio Frequency Transmission Stability	5.4
Linear Transmission	6.0
Baseband Transmission	6.1
IF-RF Transmission	6.2
Baseband Stability	6.3
Noise	7.0
Baseband Noise Spectrum	7.1
Noise at 6 mc	7.2
Television Noise	7.3
Telephone Noise	7.4
Impulse Noise	7.5
IF Noise Spectrum	7.6
Nonlinearity and Cross-Modulation	8.0
Envelope Delay Distortion	8.1
Differential Gain and Phase	8.2
Noise Loading	8.3
Intermodulation: Video to Audio	8.4
Television	9.0
Early Transmissions	9.1
Color Television	9.2
Two-Way Television	9.3
Two-Way Telephony	10.0
Early Transmissions	10.1
Channel Noise	10.2
Crosstalk	10.3
Data Transmission	11.0
Digital Data	11.1
Facsimile	11.2
Miscellaneous	12.0
Doppler Shift	12.1
Absolute Delay	12.2
Time Synchronization	12.3
Interference	12.4

The symmetry of the pattern around 00:57:00 Universal Time occurs at the point of maximum spin angle. This point can be quite accurately determined and, therefore, serves as a check against computer-produced spin angle data.

In Fig. 7, similar but higher-speed pen recordings are shown of the 4170-mc received carrier power. Here, the details of the previously mentioned pen jitter become apparent and show the variations in received carrier as the satellite rotates. These variations correspond to the constant-latitude antenna patterns of the satellite for the three values of spin angle shown. The spin rate of 159 rpm was determined from the periodic nature of the patterns.

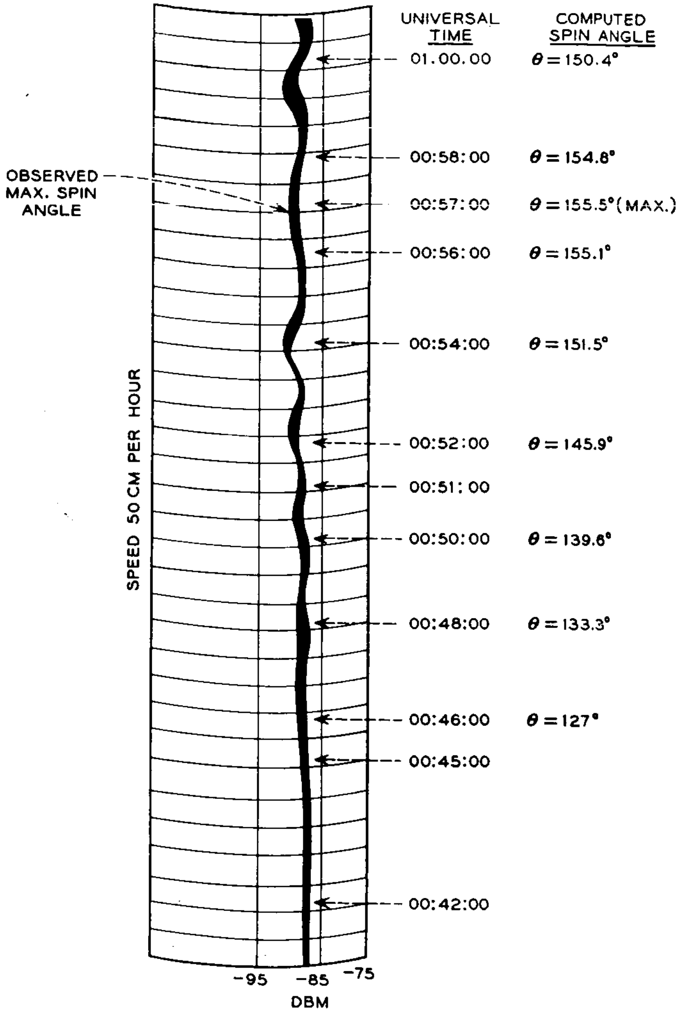


Fig. 6 — Recording of received signal power; pass 125.

Transmission phenomena at low elevation angles are not normally observed at the Andover station because the satellite is commanded on and off well above the horizon. However, on pass 470 the Bell Laboratories command system at Cape Canaveral was instructed to command on the satellite as it rose above the horizon at Andover so that low-elevation effects could be observed. The pen recording shown in Fig. 8 was obtained during this pass. For this test, the horn antenna was slaved

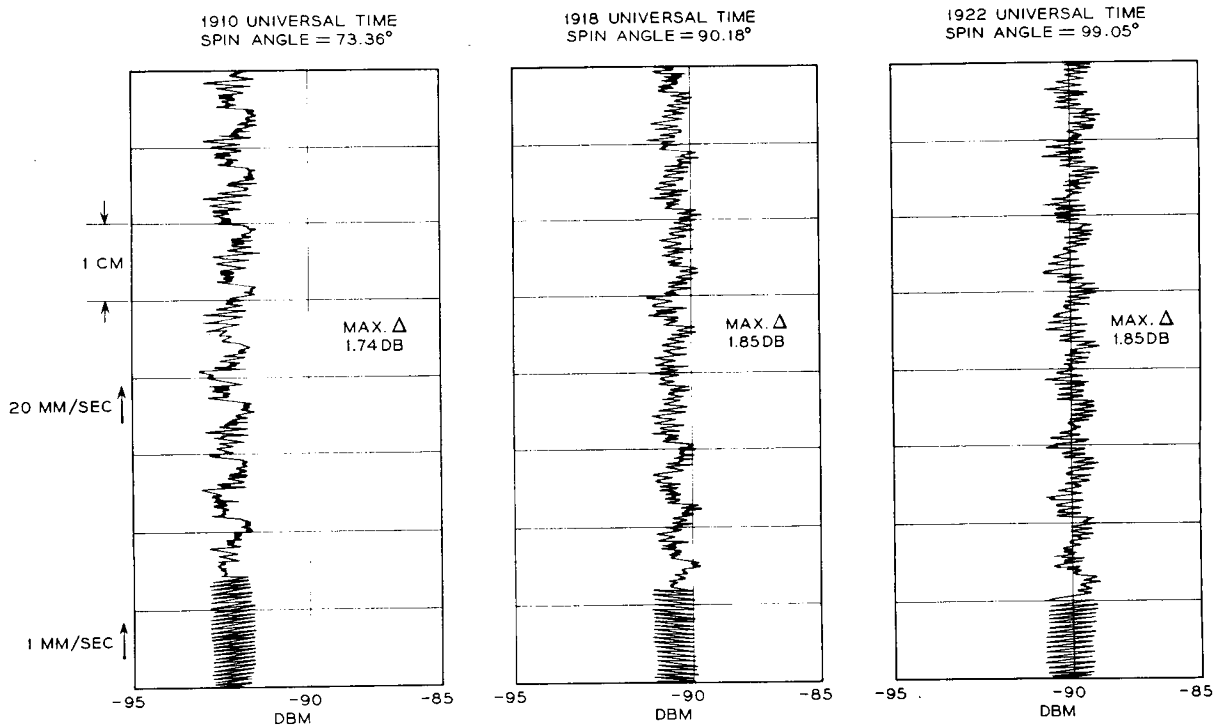


Fig. 7 — Received carrier power recordings showing constant-latitude satellite antenna patterns at 4 kmc; spin rate = 159 rpm; pass 397, Aug. 22, 1962.

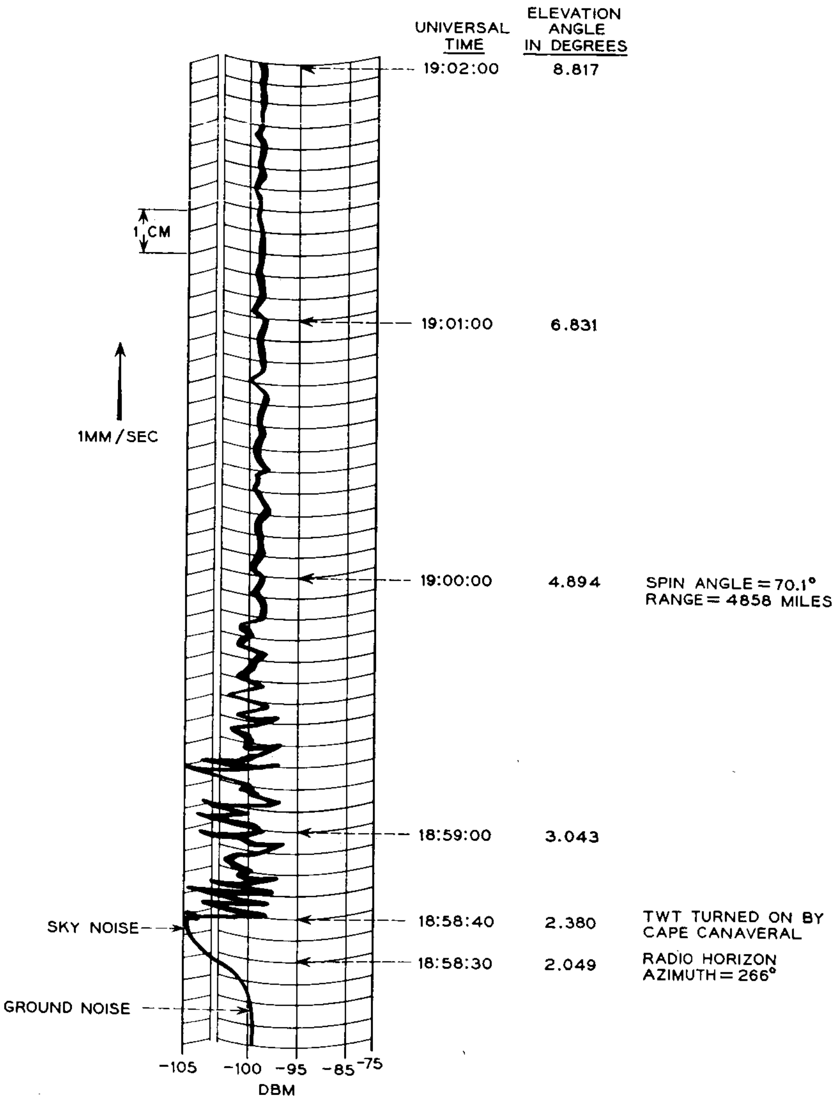


Fig. 8 — Low-angle fading at 4170 mc; pass 470, Aug. 30, 1962.

to a magnetic tape drive with an estimated accuracy of $\pm 0.02°$ (well within the 4-kmc antenna beamwidth). A ground noise level of -99.5 dbm was observed (bottom of Fig. 8) while the horn antenna was pointed below the radio horizon. At 18:58:30 UT the antenna was driven above the radio horizon at 2.04° elevation (optical horizon 1.95°) and the noise dropped to a level of about −104 dbm. A few seconds later, at 18:58:40 UT, the satellite was commanded on from Cape Canaveral. For a period of about one minute large variations in the signal were observed. Some of these appear to be almost complete fades or cancellations of the signal. Reliable transmission was not attained until an elevation angle of about 4° was reached.

5.2 *Received Carrier Power vs Range*

The received carrier power in db plotted against range is shown in Fig. 9 on a logarithmic scale for pass 125. If range were the only variable

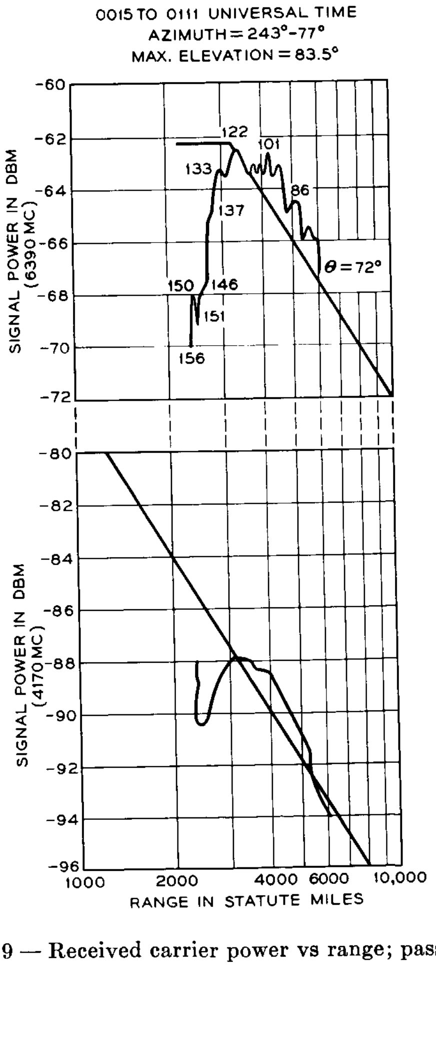


Fig. 9 — Received carrier power vs range; pass 125.

affecting received carrier power, the curves would be straight lines. The straight lines appearing on the graph represent the theoretical results under the assumptions shown in Table III.

5.3 *Antenna Patterns*

At elevation angles well above the horizon, the variation in received carrier power has been found to be primarily a function of range and spin angle. Thus, it is possible to take received carrier power measurements such as those in Fig. 6, compensate them for range variations, and plot them against accurate spin angle data to display the polar patterns of the 4-kmc satellite antenna. Fig. 10 illustrates the received carrier power measurements obtained during pass 125, compensated for range and plotted against spin angle. The resulting curve agrees very well with antenna pattern measurements made in the laboratory prior to launch.[3]

Fig. 11 shows a similar curve for the 6-kmc antenna. In this case, the received carrier power measurements were only obtained once per minute from telemetry, and it is not possible to get the same accuracy and fine detail as is possible for the 4-kmc antenna.

The pointing accuracy of the horn antenna has also been checked by means of the satellite. This has resulted in determination of the 4- and 6-kmc horn reflector antenna patterns shown in Figs. 12 and 13. Known offsets were added to the programmed horn antenna drive tape, and the changes in carrier power were measured and plotted after correction for range and spin angle. In order to obtain the 4-kmc measurements, the French station at Pleumeur-Bodou transmitted a 6-kmc signal to the satellite during pass 132 to insure a constant output as the Andover horn was offset. The 6-kmc pattern was taken during pass 105 and the received carrier measurements were made at the satellite. The measurements confirmed that there was no offset between the 4- and 6-kmc communications patterns or between the patterns and the drive tape. The patterns themselves were comparable to those obtained earlier by means of the boresight tower.

TABLE III — ASSUMED SYSTEM CONSTANTS

	6390 mc	4170 mc
Radiated power	62 dbm	33.5 dbm
Satellite antenna gain at 90° spin angle	1 db	0 db
Earth station antenna gain	60 db	58 db
Loss in satellite antenna cable	2 db	
Radome loss		0.4 db

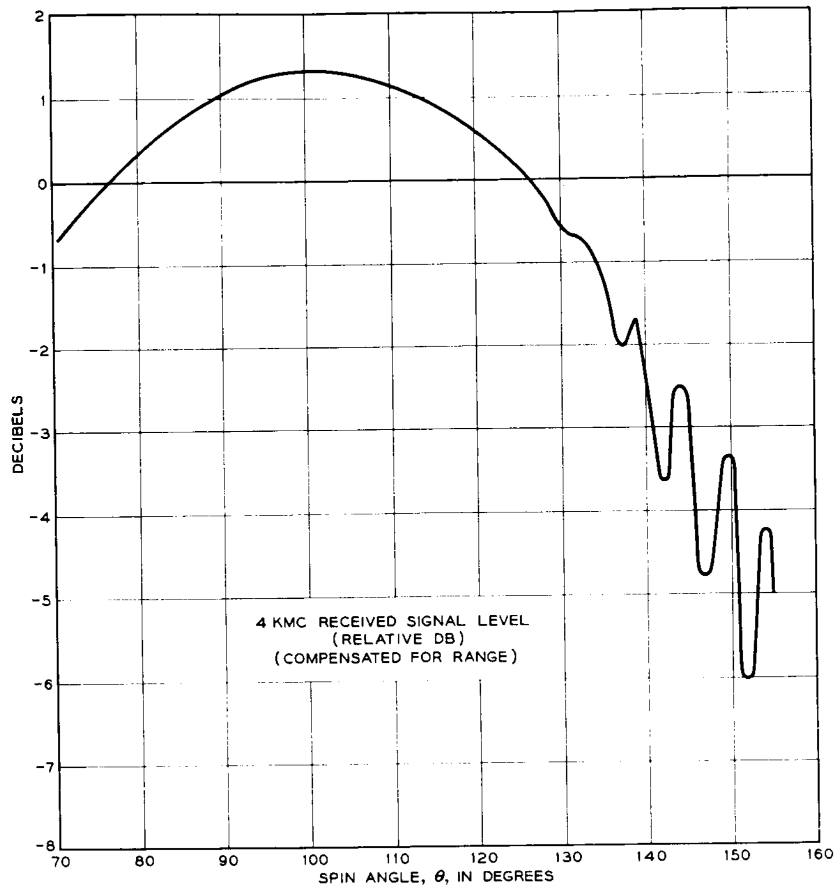


Fig. 10 — 4-kmc satellite antenna pattern; pass 125.

5.4 *Radio Frequency Transmission Stability*

Fading is a common phenomenon in 4- and 6-kmc overland microwave radio systems. In fact, this problem is so severe that in systems where high reliability is required, it is customary to provide spare radio channels and automatic switching equipment to protect the working channels. A fading problem was not anticipated in satellite systems except at very low elevation angles. The performance thus far achieved tends to confirm this expectation.

To study the system stability, received carrier power measurements from a number of passes were compensated for range and plotted against

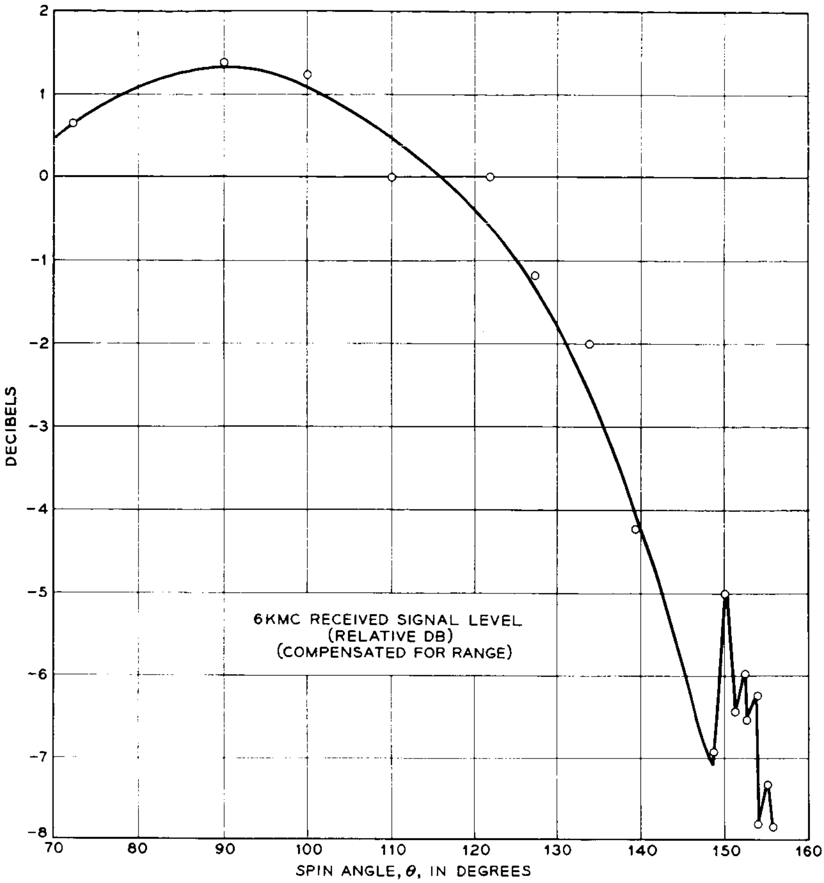


Fig. 11 — 6-kmc satellite antenna pattern; pass 125.

the computed spin angle of the satellite. The scatter diagram which is thus obtained provides a basis for estimating the system stability and the predictability of received carrier power. Two such scatter diagrams are shown here as Figs. 14 and 15.

VI. LINEAR TRANSMISSION

The linear transmission tests define the baseband and IF gain vs frequency characteristics. Due to the many varying parameters, e.g., range, spin angle, and satellite antenna patterns, the stability of these characteristics is of prime concern and is included as part of these tests. The accuracy of the baseband transmission tests is estimated at ±0.1 db and

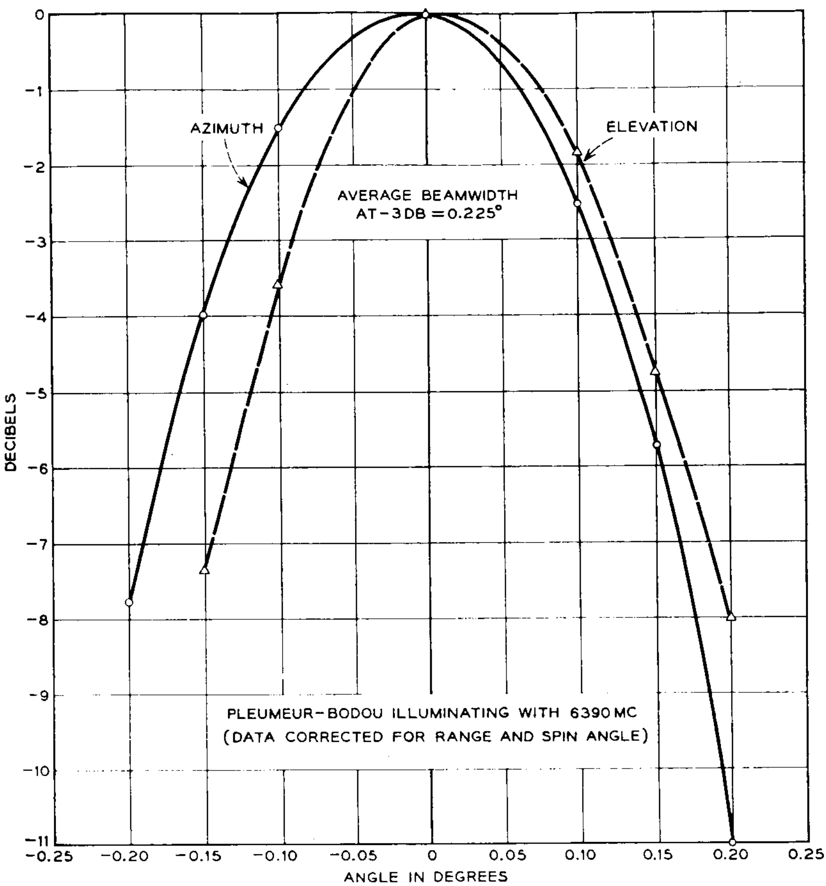


Fig. 12 — 4-kmc horn antenna pattern; pass 132, July 24, 1962.

that of the stability measurements at ± 0.05 db. In general, the results of these tests with the Telstar satellite show that the transmission shapes are primarily due to the ground equipment, as expected, and that the baseband transmission is not a function of the varying satellite parameters.

5.1 *Baseband Transmission*

The baseband gain vs frequency characteristic for various transmission loops is shown on Figs. 16 and 17. Fig. 16 shows the baseband frequency response for the baseband loop (A), the IF loop (B), and the

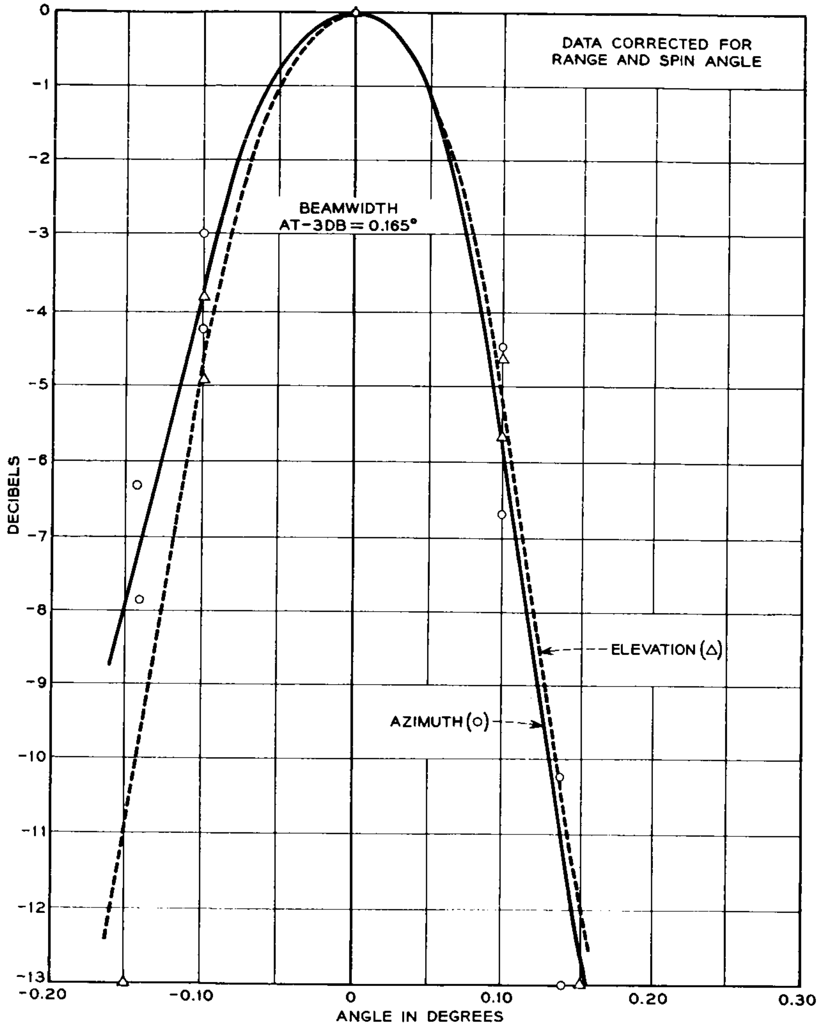


Fig. 13 — 6-kmc horn antenna pattern; pass 105, July 21, 1962.

satellite loop (C). The standard FM receiver was used in determining (B) and (C); no diplexers or roll-off filters were used for any of the three curves.

The gain of the baseband loop appears to be about 0.5 db higher than that of the other loops. However, the baseband loop was measured on a different day than the others, and the difference is probably due to a

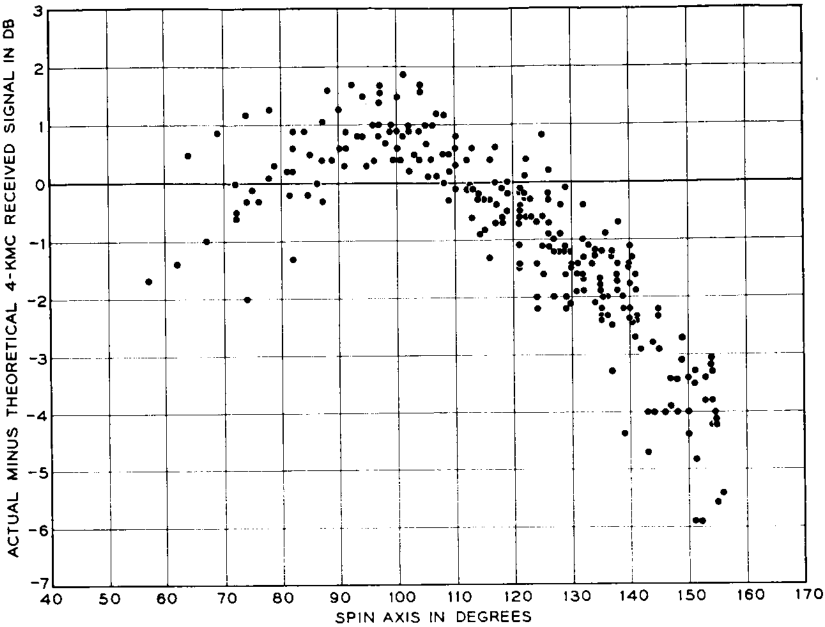


Fig. 14 — 4-kmc received carrier: difference between actual and theoretical power vs spin angle.

slightly different gain adjustment for the various video amplifiers in the transmission path.

The principal difference between the IF and the satellite loops, (B) and (C) of Fig. 16, is the peak of about 0.5 db at 1.7 mc. This is a characteristic of this particular satellite, and was first discovered during pre-launch tests. No noticeable degradation of transmission is caused by this irregularity. It is clear from Fig. 16 that the transmission is essentially flat, up to at least 5 mc, when the standard FM receiver is used. Color television signals were transmitted across the Atlantic, as described in Section 9.2, using such an arrangement.

The effect of the FM feedback receiver (FMFB) on the baseband transmission characteristic is shown on Fig. 17. Curves (A) and (B) show that there is little difference in baseband frequency response between the IF and the satellite loops;* the response is essentially flat to within ± 0.5 db to about 3 mc and approximately 3 db down at 4 mc. Adding the 2-mc roll-off filter and diplexers for video transmissions results in the characteristic shown by curve (C). This transmission shape

* The peak at 1.7 mc is not shown due to the coarseness of this measurement.

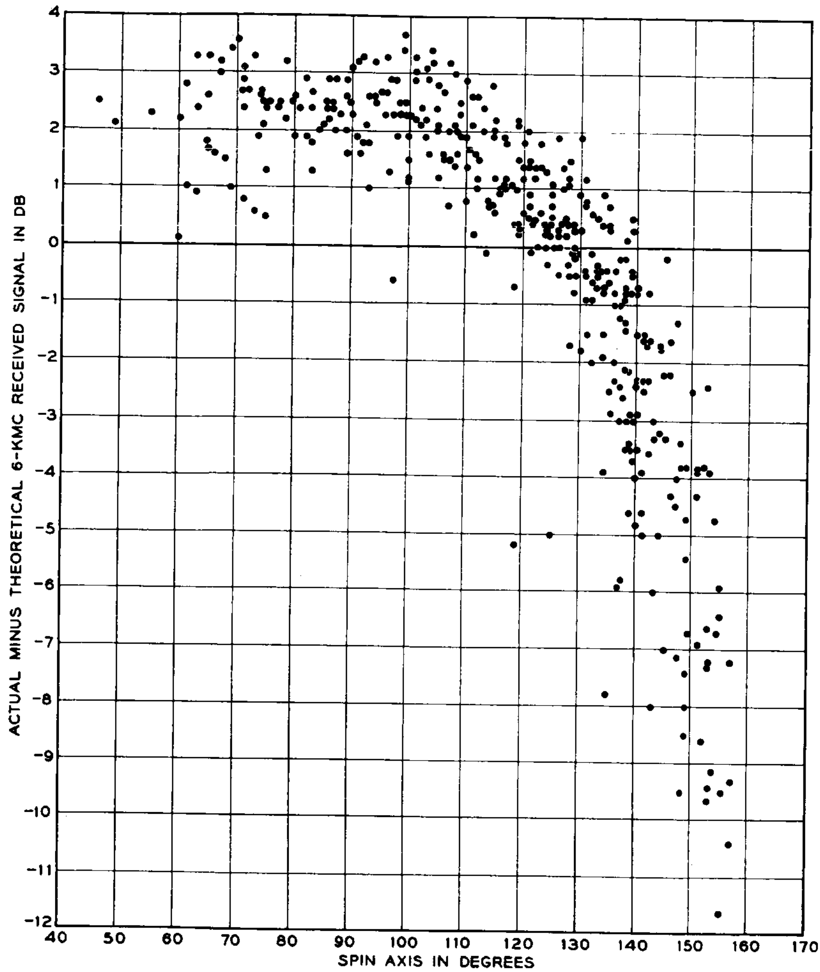


Fig. 15 — 6-kmc received carrier: difference between actual and theoretical power vs spin angle.

is the product of a preliminary design and has been used with satisfactory results for many of the television demonstrations. A substantial improvement is possible by a redesign of the diplexers and the roll-off filter.*

The baseband transmission characteristics, shown in Figs. 16 and 17,

* A roll-off filter is desirable to limit the video spectrum at the aural subcarrier frequency and also to restrict the amount of high-frequency energy entering the FMFB receiver.

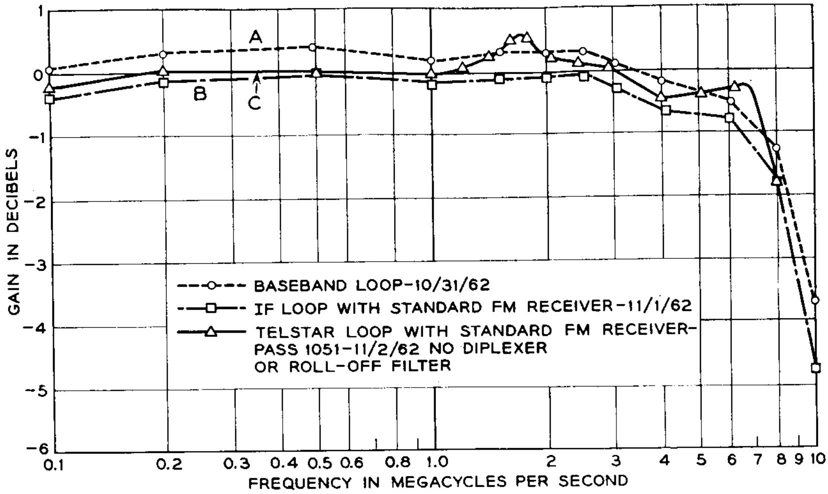


Fig. 16 — Baseband frequency response (standard FM receiver).

determine to a large extent the quality with which black-and-white television pictures are transmitted over the system. The effect of the system with a characteristic as shown on (C) of Fig. 17 on various patterns and signals is illustrated in Fig. 18. The reduction in the high-frequency content is obvious from the "after" pictures.

6.2 *IF-RF Transmission*

A gain-frequency characteristic of the IF and RF equipment, including the satellite repeater, determined during pass 188, is shown in Fig. 19. Before each pass the maser is adjusted to produce a transmission curve similar to the center curve of Fig. 19. When the satellite first appeared on pass 188, the transmission characteristic was that shown at the left of the figure; it then changed gradually over to the middle curve and finally to that shown on the right. The phenomenon can be explained by the interaction of the earth's magnetic field with the field of the maser. The earth's field either adds to or subtracts from the maser field, and thereby shifts the maser frequency at the rate of 2.4 mc per gauss. This shift, superimposed on the maser equalizer characteristic, then introduces the transmission slopes shown. The tilt in the transmission characteristic has not caused any detrimental effects to the system performance. However, this characteristic must be taken into account when analyzing the IF noise measurements of Section 7.6.

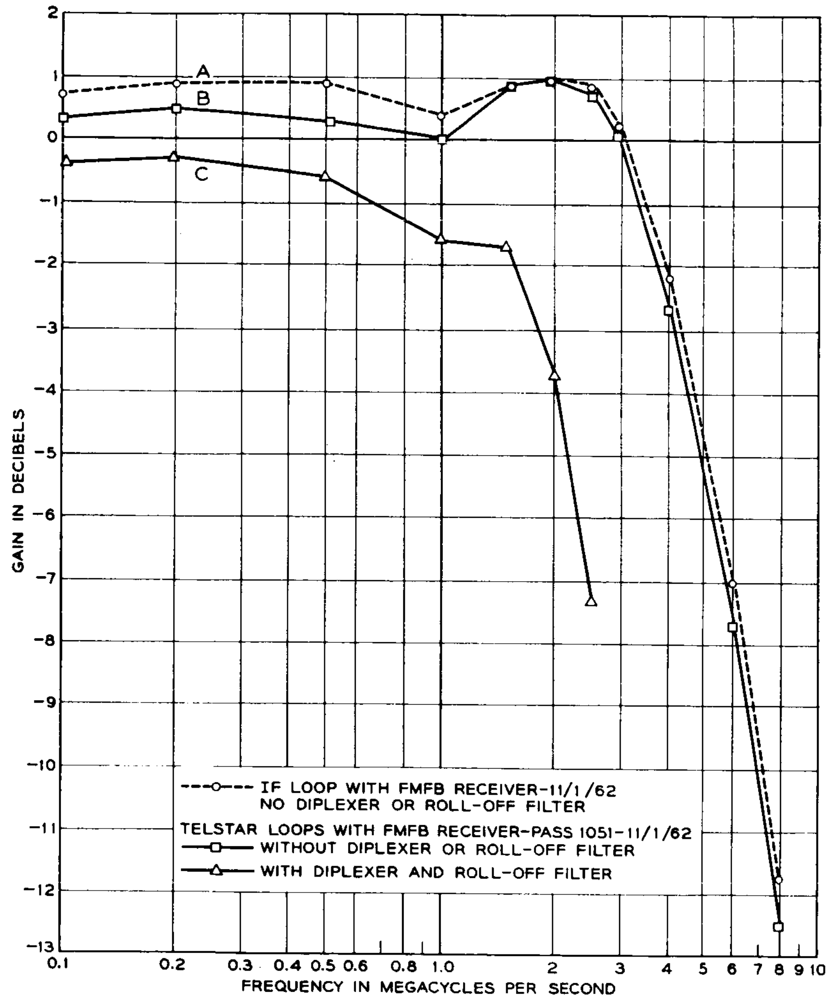


Fig. 17 — Baseband frequency response (FMFB receiver).

6.3 *Baseband Stability*

Stability measurements of the baseband gain-vs-frequency characteristic were made on several passes under conditions of varying slant range (or received carrier powers) and spin angle. The test was made by applying a 450-kc tone to the input of each of the five type "L" supergroups Nos. 2, 4, 6, 8, and 10.[4] The 450-kc tone was then translated to the frequencies 415, 915, 1411, 1907 and 2651 kc, respectively, and trans-

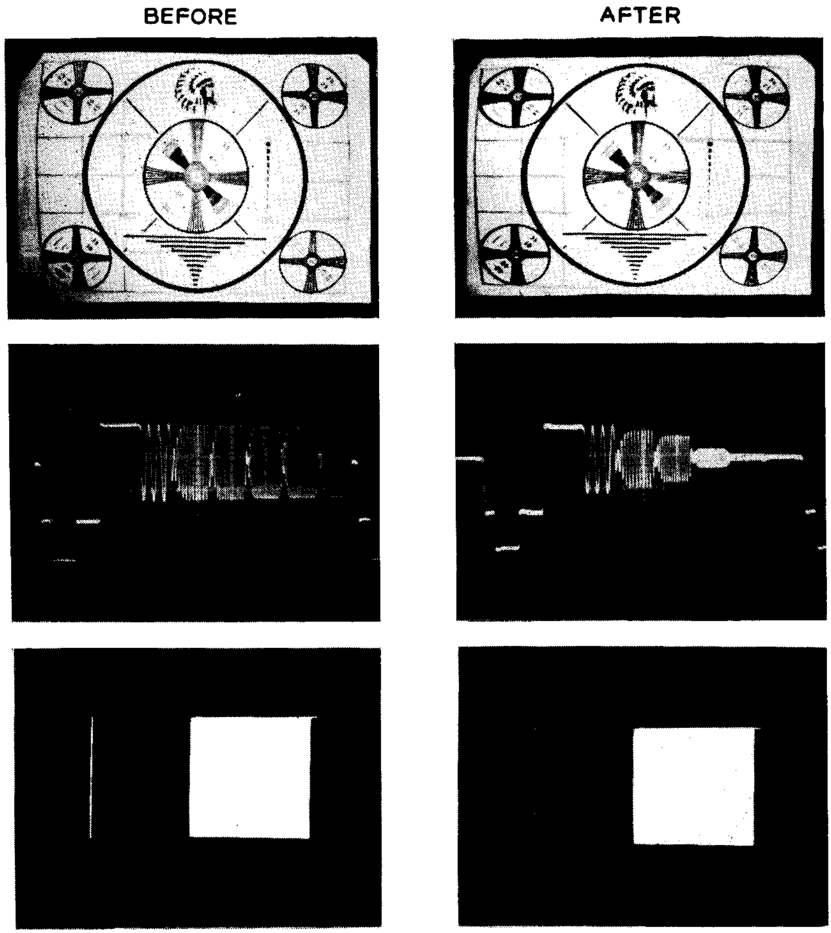


Fig. 18 — Effect of transmission on various test signals.

mitted over the satellite communications repeater. The five received signals were shifted back to 450 kc by means of the receiving supergroup equipment, detected and recorded on a strip chart. An expanded db scale capable of discerning changes of 0.05 db was used. In all cases the stability was better than ± 0.1 db, most of which is attributable to drift in the measuring equipment.

VII. NOISE

Various measurements of baseband and IF noise are described in this section. In view of the many varying parameters affecting the system's

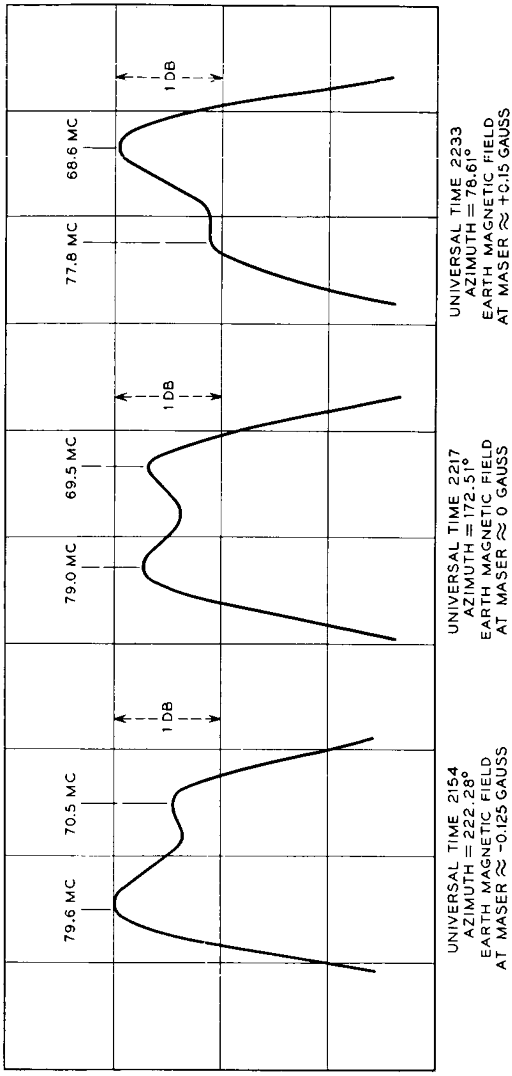


Fig. 19 — **IF-RF** transmission characteristics; pass 188, July 30, 1962.

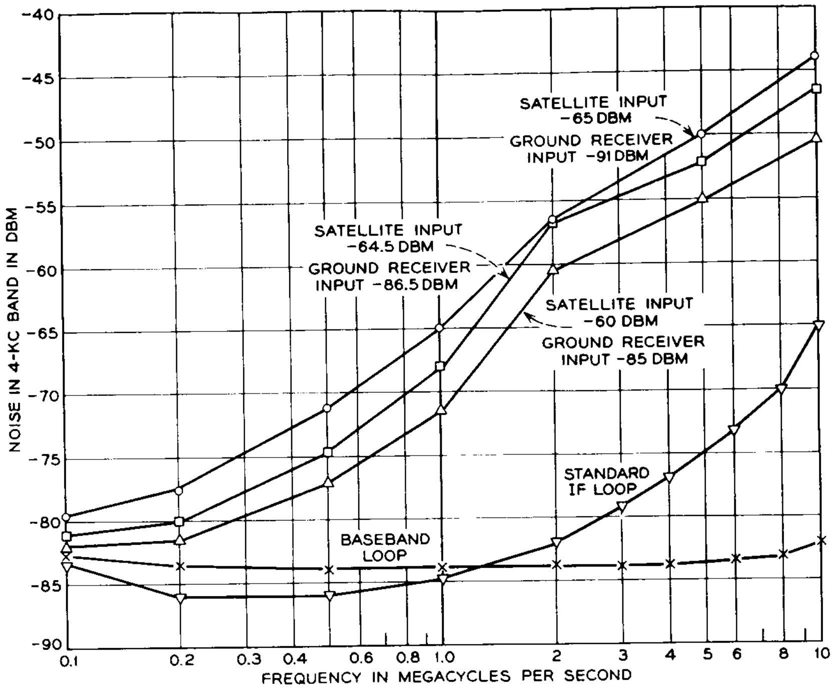


Fig. 20 — Baseband noise spectra: standard FM receiver; no diplexer or clamper; measured at test area; pass 62, July 17, 1962.

baseband noise, i.e., satellite elevation above the horizon, slant range, spin angle, power transmitted to the satellite, and ground receiver used, most noise measurements have been repeated often in order to obtain sufficient data for statistical analysis.

7.1 *Baseband Noise Spectrum*

Typical measurements of the baseband noise spectrum made from the test area* during pass 62 are shown in Fig. 20. These noise measurements, made in a 4-kc band, have been corrected for the transmission characteristic of Fig. 16. The figure clearly exhibits the effect of changing slant range on received carrier power and on the system's noise performance. In addition, noise measurements for the standard IF loop and the baseband loop are also shown. The latter show that significant noise is contributed by the video circuits and FM terminals below 200 kc.

* Fig. 1 shows the system block diagram.

Baseband noise spectrum measurements were repeated often during the first four months after the launch of the Telstar satellite. The results are consistently similar to those of Fig. 20.

To relate baseband noise measurements made at various points in the system to RF signal-to-noise performance, the following constants of the Telstar system must be defined:

(a) A tone (or a one-cycle band of noise) X dbm at the test area is $X - 5$ dbm at the deviator input (or at the FM receiver output).

(b) Zero dbm of a sine wave at the deviator input corresponds to an rms frequency deviation of 7.07 mc.

If the RF noise spectrum is white, the expected baseband noise spectrum is triangular. In practice, the baseband noise is decreased at the high-frequency end due to the IF-RF transmission characteristic (see Fig. 19) and increased at low frequencies due to noise in the terminal and baseband equipment, as well as FM noise from the satellite carrier supplies.

To obtain data under carefully controlled conditions of range and satellite attitude, eleven complete noise spectrum measurements were made at one-minute intervals at the test area during pass 297. The total system noise at each frequency was plotted against time, and smooth curves drawn. The smoothed values obtained at 20:32 UT for a satellite slant range of 4000 miles are shown in Fig. 21, curve A.

To isolate the satellite or up-path contribution to the total noise for comparison with pre-launch measurements, the down-path baseband noise is computed. Assuming a receiving system noise temperature of 35°K and a 4-kmc received carrier of -88.6 dbm, the down-path noise at 10 mc in a 4-kc band is -50.4 dbm at the test area and decreases at 20 db/decade. The calculated down-path noise is shown by the dotted line on Fig. 21. At low frequencies, the noise contribution of the baseband trunks and FM terminals is added in to get the total down-path noise. Subtraction (on a power basis) of the down-path noise from the total system noise gives the up-path noise, shown as curve B of Fig. 21.

Fig. 21, curve C, shows the up-path noise measured in the laboratory prior to launch. The two curves, B and C, agree within the measurement error. It is therefore concluded that the satellite's noise performance has not been changed by the launch or by space environment. This is further substantiated by the IF noise measurements of Section 7.6. Fig. 21 shows that the contribution of the up-path to the total system noise is somewhat greater than the down-path for this pass. The data consistently show that two paths contribute about equally to total noise, with a tendency for the up-path to be the larger contributor.

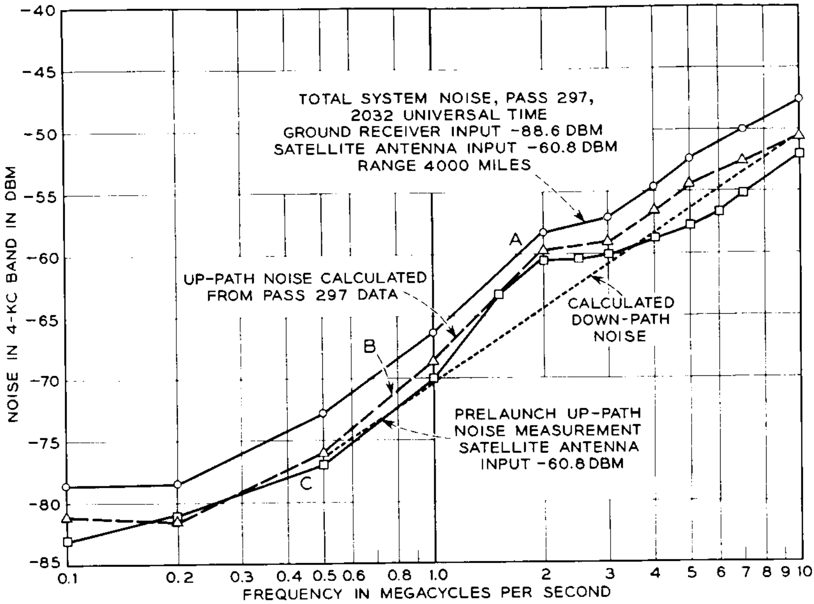


Fig. 21 — Comparison of pre-launch and post-launch baseband noise spectra: post-launch data from pass 297, Aug. 11, 1962.

7.2 *Noise at 6 mc*

Since typical monochrome television signals have negligible energy at 6 mc, the system noise at this frequency serves as a monitor of the system performance during video transmissions and noise tests and is therefore recorded continuously at the test area. Such a recording, made during pass 988, is shown at the top of Fig. 22. This figure clearly exhibits the dependence of the baseband noise on the range and received carrier powers tabulated thereon. Further, it shows that after appropriate adjustments are made for transmission losses (see Figs. 16 and 17), the two FM receivers detect the same noise at 6 mc, everything else being equal.* The 6-mc noise is measured at the same point as the baseband noise spectra of Section 7.1, but in a 6.3-kc band.

Of the several parameters affecting the noise at 6 mc, the slant range and spin angle are both reflected in the 4170-mc carrier power received at the ground receiver. Therefore, Fig. 23, which is the scatter diagram

* At the time of switching between FM receivers, the sensitivity of the measuring equipment was decreased 10 db. This accounts for the apparent decrease in 6-mc noise on Fig. 22.

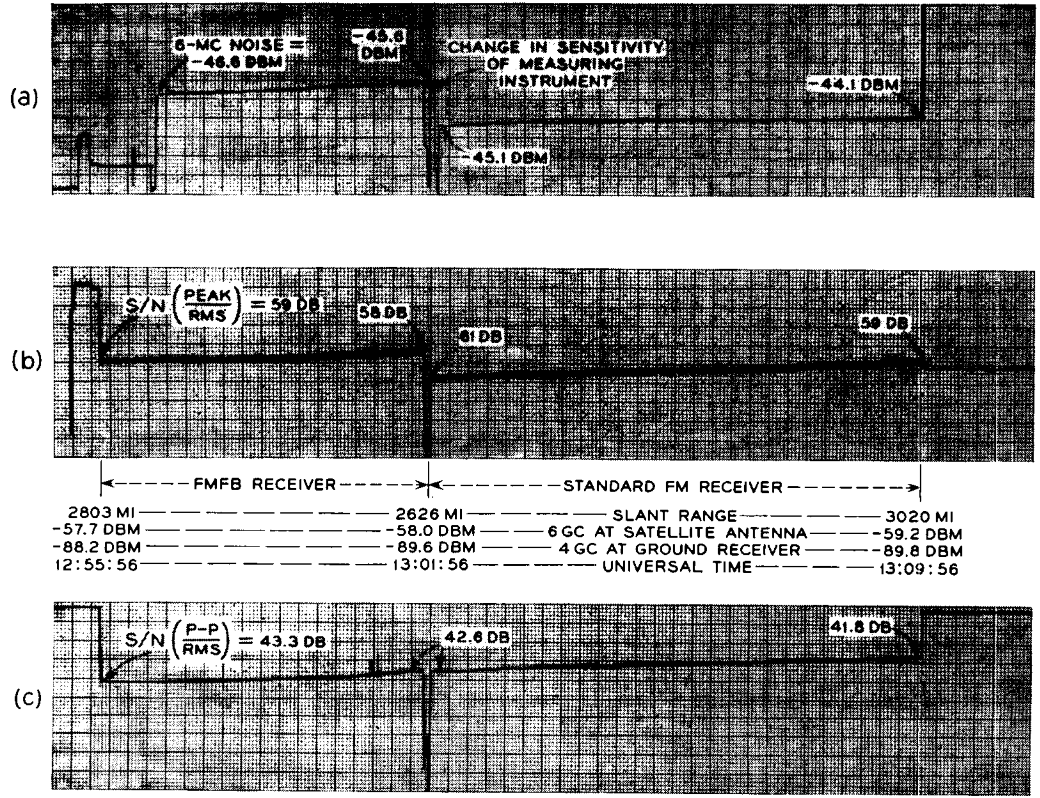


Fig. 22 — Baseband noise recordings; pass 988, Oct. 26, 1962. (a) Noise at 6 mc in 6.3-kc band; (b) weighted audio noise; (c) weighted video noise.

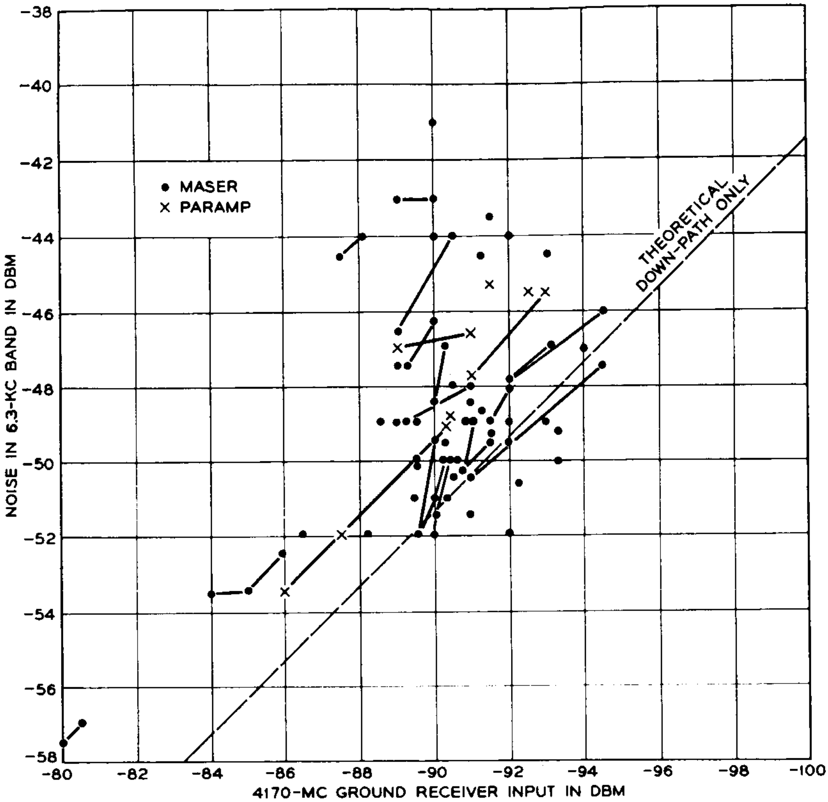


Fig. 23 — 6-mc noise vs received carrier power.

of 6-mc noise vs received carrier power,* shows the effect on the noise of the remaining parameters and of the measurement errors. The principal known parameter is the carrier power transmitted to the satellite. This affects the up-path contribution to the total noise. Since the maximum available power of 2 kw was not always transmitted to the satellite, only noise measurements corresponding to received carrier powers within the satellite's 20-db AGC range were used for this figure. The satellite's elevation angle, which determines the ground receiver's effective noise temperature, is of secondary importance in Fig. 23 since all values used correspond to elevations of 15° or more. The effect of using the parametric amplifier instead of the maser at the ground receiver is also shown explicitly on the figure.

* The straight lines on the figure represent continuous measurements during a pass.

There are two principal sources of measurement error in the data of Fig. 23: human errors and the different system configurations. The human errors are particularly acute, because of the relatively short time available for both measurements and calibrations, and because of inability to reproduce exactly any given set of testing conditions. The use of different system configurations for various tests has resulted in variations of the baseband transmission characteristics which were not always observed and recorded, thus leading to errors.

The large variance of the data on Fig. 23 thus reflects the measurement uncertainties and the increases in noise due to decreases in transmitted power to the satellite. The theoretical line shown on the figure gives the down-path noise alone, based on a 35°K system noise temperature and on the assumption of a triangular noise spectrum. The fact that the mean value of the figure is above the theoretical down-path line substantiates the assertion of the previous section, namely, that the up-path contributes about as much noise to the total as does the down-path.

The contribution of the baseband and IF loops to the 6-mc noise is negligible in every measurement: about −70 dbm for the IF loops and −80 dbm for the baseband loop.

7.3 *Television Noise*

7.3.1 *Video Noise*

The noise in the video channel is weighted using the latest Bell System video noise weighting network ahead of the measuring instrument. The detected video noise is recorded continuously during a pass simultaneously with the 6-mc noise and often with the audio channel noise. A typical recording of these noises is shown on Fig. 22, with the video noise at the bottom.

As expected, the video signal-to-noise ratio (SNR) is the same for both FM receivers, since their transmission characteristics are both essentially flat in the band of interest for video noise, i.e., below 2 mc. This is also evidenced by the scatter diagram of video noise vs received carrier power, Fig. 24, which shows the scattering to be the same for both receivers. The comments on the variance of the 6-mc noise data apply here equally well.

To account for the clampers used in the video circuit between the FM receiver and the test area in the computation of SNR, 1.0 db has been added to noise measured without clampers. Thus, the signal-to-noise ratios shown represent the practical situation for television receptions.

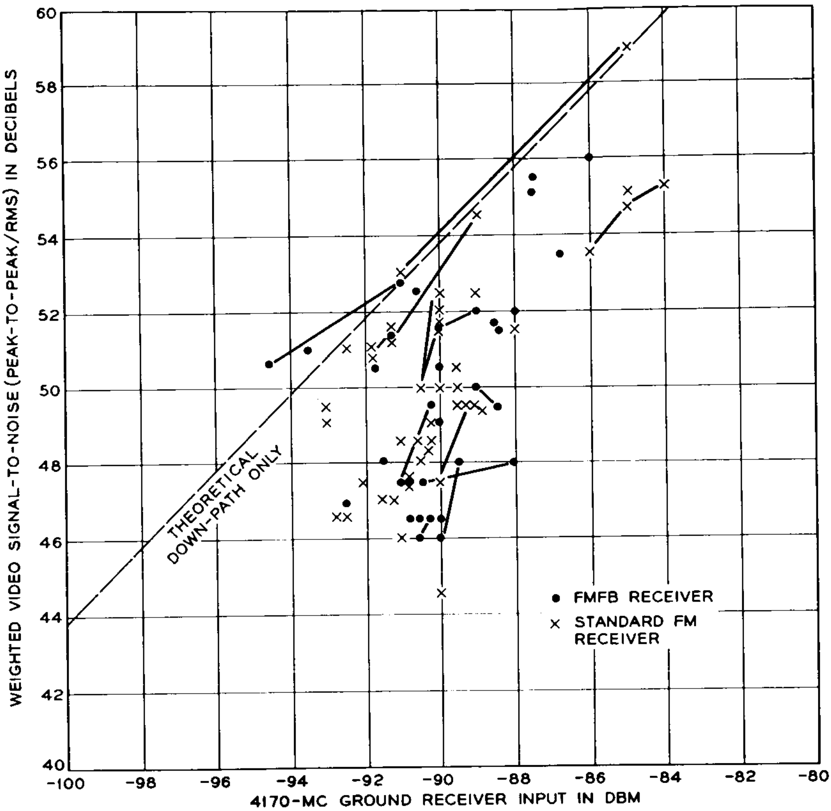


Fig. 24 — Video noise vs received carrier power.

The calculation of the theoretical value of the SNR for the down-path of Fig. 24 again assumes a triangular noise spectrum, plus the effect of the clamper and of the noise weighting. In this case, however, a triangular noise spectrum is too optimistic an assumption, as can be seen from the baseband noise spectra, Figs. 20 and 21. Because the up- and down-path noise contributions are about equal at 1 mc and because of the excess noise in the 1- to 3-mc band, it is not surprising that the average total video noise is about 5 db higher than the theoretical down-path noise.

As can be predicted from the baseband noise spectra measurements of Section 7.1, the IF loop video noise is at least 12 db lower than the satellite loop noise and the baseband loop noise is 2 to 3 db lower than the IF loop noise. The IF loop SNR is about 72 db.

TABLE IV — AUDIO SIGNAL/NOISE RATIO

	Audio SNR
Baseband loop	80 db
IF loop with FMFB receiver	75 db
IF loop with standard FM receiver	77 db
Satellite loop	55-65 db

7.3.2 *Audio Noise*

The Bell System 8-kc program noise-weighting network is used for the measurement of noise in the sound channel of the television signal. A continuous recording of the audio noise using the two FM receivers is also shown on Fig. 22, curve B.

This figure shows that under identical conditions the audio noise measured with the FMFB receiver is about 3 db higher than with the standard FM receiver. For the purpose of computing SNR, the signal is taken to be the peak power of a 1000-cps sine wave, resulting in a peak frequency deviation of the aural subcarrier of ± 50 kc.*

The audio SNR measurements range from about 55 db to 65 db for 4-kmc received carrier powers of -95 dbm to -85 dbm. These measurements are not extensive enough to warrant presenting them in the form of a scatter diagram. The audio signal-to-noise ratios for the baseband. IF and RF loops are shown in Table IV.

7.4 *Telephone Noise*

The noise in five telephone channels located across a 3-mc band has been measured using the Telstar repeater. In addition to the circuits of Fig. 1, supergroups 2, 4, 6, 8 and 10 of the type L multiplex system were used for these measurements. The measuring equipment connected at the output of each supergroup consisted of a selective voltmeter† and a six-channel pen recorder. The noise was thus monitored continuously for several complete passes in order to observe the variation in noise with range, spin angle and satellite elevation.

The pen recordings for these measurements are very similar to those made for 6-mc and video noise shown on Fig. 22 and therefore are not reproduced here. However, typical values of noise in dbrn at 0 db TL (transmission level), measured during pass 1088, are shown in Table V.

* The so-called "program level" signal sometimes used for the calculation of SNR is 10 db lower than the signal assumed for the above computations.

† The voltmeters have a noise bandwidth of 6.3 kc and were each tuned to 450 kc. The values of Table V are corrected to a 3-kc bandwidth and for "C" message weighting.

TABLE V — TELEPHONE NOISE — PASS 1088

		11:52:00 UT	12:03:00 UT	12:07:30 UT	12:11:00 UT
Satellite antenna input (dbm)		−58.5	−60	−61	−62
Ground receiver input (dbm)		−88.5*	−92	−93	−94.3
Spin angle (degrees)		63	50	49	50
Range (miles)		2800	3115	3550	3960
Elevation (degrees)		20	27	22	18
Supergroup 2 (450 kc)	dbrn at 0 db TL	27	30	31.5	31.5
Supergroup 4 (915 kc)		34.5	36	37.5	38
Supergroup 6 (1411 kc)		40.5	42	42.5	43
Supergroup 8 (1907 kc)		42	45.5	47	47.5
Supergroup 10 (2651 kc)		44	46	47.5	48

* This value, although inconsistent with other entries in the table, has been carefully rechecked against the original pen recording.

This table also shows the location of the measured channel in the baseband frequency spectrum.

7.5 *Impulse Noise*

Impulse noise measurements were made on the Telstar system during passes 208, 217, and 226 (August 1–3, 1962). These measurements were made primarily on voice circuits using an impulse counter and an experimental peak noise distribution measuring set. A standard noise measuring set was used to monitor the rms value of the noise.

The distribution of the noise peaks was recorded by the peak noise distribution set on voice circuits at levels of 6 to 10 db above rms value. These data indicate that only random thermal noise was present. The results of counting the noise peaks with the impulse counter also support the conclusion that very little impulse noise is present in the Telstar system.

7.6 *IF Noise Spectrum*

The IF noise spectrum is measured directly in the IF band using a selective analyzer covering the range of 55 to 95 mc. The analyzer used has nominal bandwidths of either 100 or 10 kc, a sensitivity of −100 dbm, and an accuracy and stability in the order of 0.2 db. The analyzer is connected at an intermediate point of the IF amplifier of Fig. 1. This IF amplifier consists of two separate amplifiers in tandem, the first being fixed-gain and the second having AGC. The analyzer is connected at the output of the first amplifier, where the nominal power is −22.5 dbm for a −80-dbm, 4-kmc input carrier to the maser.

Fig. 25 shows the results obtained during pass 1664, January 8, 1963. After the pass, the Andover antenna was pointed at the zenith and the

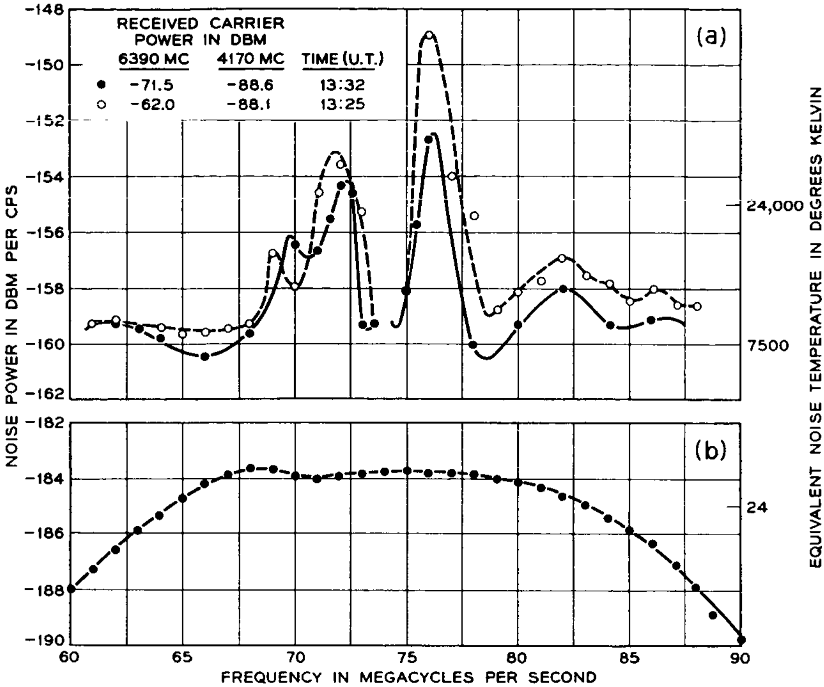


Fig. 25 — IF noise spectra: (a) Telstar satellite noise referred to satellite down-converter input; pass 1664, Jan. 8, 1963; (b) Andover zenith noise referred to maser input.

IF noise was measured. This measurement is referred to the output of the horn-reflector antenna (maser input) by correcting for the gain from this point to the point of measurement.* The bottom curve of Fig. 25 shows this result. The shape of this curve is consistent with the maser's transmission characteristic (see Section 6.2) with a bandwidth of 25 mc at 3-db points. The apparent ground station noise temperature is 30°K, which agrees closely with other observations.

To enhance the accuracy for the noise measurements with the satellite, a technique similar to that described in Section 7.1 was used. Four complete spectrum measurements were first made at about 2-minute intervals with maximum 6-kmc power transmitted to the satellite. The transmitted power was subsequently reduced, in order to increase the satellite's contribution to the total noise, and a detailed spectrum meas-

* This gain was measured only once, at the center frequency, and is therefore taken as fixed and uniform. In addition, the measured gain is increased by 1 db to account for the difference in maser gain when the input is broadband noise as opposed to carrier plus noise.

urement was made. The total noise was plotted as a function of time and smoothed values obtained corresponding to 13:25 UT (for full power transmitted) and 13:32 UT (reduced power). These smoothed values for the total IF noise were corrected on a power basis, for the ground station noise already discussed, to obtain the satellite's noise. Since the 6-kmc input to the satellite is known from telemetry and the 4-kmc input to the ground receiver is known from direct measurement with the selective analyzer,* it is possible to refer the satellite noise to the satellite down-converter input by making the appropriate corrections. The results are shown at the top of Fig. 25.

Several features of these curves are of interest. The humps at 72 and 76 mc, 6 to 10 db above the general noise level, clearly correspond to the hump at about 2 mc in the baseband noise, Figs. 20 and 21, and to the peak at 1.7 mc in the baseband frequency response, Fig. 16. The presence of the two humps suggests that the noise is leaving the satellite as modulation of the carrier.

The general noise level, excluding the humps, is -159 dbm/cps ± 2 db, corresponding to a noise figure of 15 db ± 2 db. The inclusion of the noise humps results in an integrated noise figure of 16.5 db ± 2 db (integrated over a 20-mc band), referred to the satellite's down-converter input. A separate measurement made prior to launch[6] using a noise lamp resulted in a satellite noise figure of 13.5 db ± 1 db, for the region where the noise spectrum is flat.

It was stated in Section 7.1 that the baseband noise attributable to the satellite has not been affected by launch or space environment. The same conclusion is reached from a comparison of Fig. 25, for pass 1664, with Fig. 26, the calculated† pre-launch IF noise spectrum. The exact symmetry of Fig. 26 is due to the fact that these curves were calculated from measurements of baseband noise such as shown on Fig. 21, curve C. As expected, the peaks of the calculated noise of Fig. 26 lie between the levels of the measured, unequal peaks of Fig. 25.

VIII. NONLINEARITY AND CROSS-MODULATION

8.1 *Envelope Delay Distortion*

The envelope delay distortion (EDD) discussed here is that found in in the IF and RF circuitry of the system. It is to be distinguished from

* For this test, the 6-kmc carrier transmitted to the satellite is derived from a crystal-controlled oscillator. The stability of this source is sufficient to enable accurate measurement of the received 4-kmc carrier within the 100-kc band of the selective analyzer used.

† The measurement of noise at IF was not made prior to the launch of the Telstar satellite.

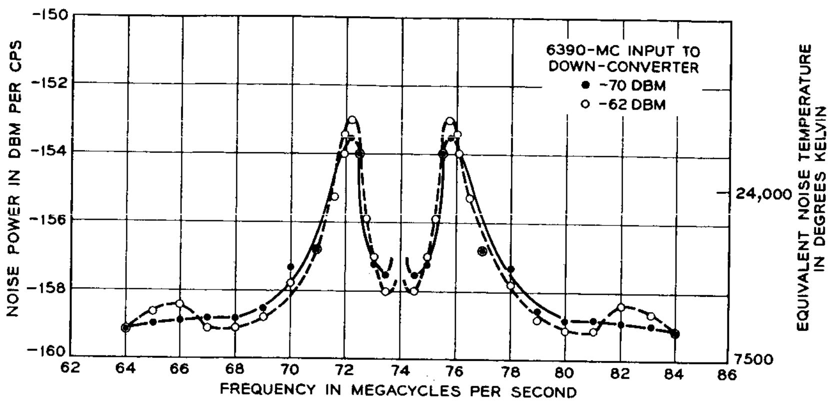


Fig. 26 — Pre-launch IF noise spectra of Telstar satellite referred to satellite down-converter input; calculated from baseband noise measurements.

the over-all baseband delay distortion of the system. This latter, which causes baseband waveform distortion, is of importance in the total baseband when transmitting TV and in individual segments of baseband when data-type signals are transmitted. Measurements of baseband distortion are not presented here for the Telstar satellite because available test equipment does not have adequate resolution in the presence of signal-to-noise ratios typical of those encountered in this experiment. It is inferred that it is satisfactory from examination of television test signal transmissions.

EDD, which causes cross-modulation in FM systems, is measured by the two-frequency sweep method, using the standard test set used on TD-2 and TH radio systems. The test set is located adjacent to the FM terminals, to which it is connected directly.

Briefly, this set operates as follows. A 100-cps sine wave is applied to the BO klystron of the FM deviator[5] so that the output IF sweeps from 62 to 86 mc. Simultaneously, a 278-kc sine wave from a crystal oscillator is applied to the video (baseband) input of the deviator to give a peak deviation of about 200 kc. At the FM receiver video output, the 100-cps and 278-kc signals are recovered and separated. The 100-cps tone is used for horizontal scope deflection. The 278-kc tone is phase-modulated by the transmission delay distortion of the system (at 278 kc, 1° = 10 ns). Its phase is compared with that of a 278-kc crystal oscillator located in the delay receiver. The latter oscillator is phase locked to the long-term average phase of the received 278-mc tone by suitable circuitry. The phase variations are used for vertical scope deflection, with a customary EDD sensitivity of 5 ns per small division (0.2 inch). As may be seen from the photos presented, the signal-to-noise ratio of this set is really not satisfactory for the Telstar system, but is not so poor as to obscure essential results.

Each of the elements shown in the block diagram of Fig. 1 contributes to the total EDD of the system. The EDD is mostly parabolic and is inherent in the bandpass characteristic of the system. Delay equalization provides the inverse characteristic and improves the cross-modulation performance of the system for telephone operation and the differential phase for TV operation. It is desirable to equalize each element individually, but this is frequently impractical.

On pass 925 (October 19, 1962) the over-all system was equalized. The equalization was in four parts, as shown in Table VI.

In the feedback FM receiver, the IF swing is reduced by the feedback to less than 1 mc, and therefore, its EDD is negligible.

Fig. 27 shows the measured EDD of the IF loop, which includes the equipment and equalizers of the first three items of Table VI. Fig. 28 shows the EDD measured through the boresight repeater and Fig. 29 shows the EDD measured through the satellite on pass 925.

8.2 *Differential Gain and Phase*

The differential gain and phase measurements are similar to the EDD test, but are specifically designed to measure the ability of a video system to transmit color TV. The details are therefore different. The low frequency is 15.75 kc and is adjusted to sweep the IF ±7 mc (67 mc to 81 mc). The high frequency is 3.58 mc and is applied at a power level 14 db below that of the 15.75 kc. The test set is located in the test area where it is connected to the video lines. For this test, the low-pass filter and the diplexers of Fig. 2 are removed from the video lines, and

Table VI — EDD Equalization

Equalization for	Location	Amount of Eqn* (ns)
FM deviator	Output of deviator	†
Intermediate IF amplifier	Input of IF amp.	$-0.25(\Delta F) - 0.07(\Delta F)^2$
Standard FM receiver	Input of FM receiver	$+0.44(\Delta F) - 0.10(\Delta F)^2$
RF circuits, including modulator-amplifier, power amplifier, satellite repeater, and RF amplifier	Output of RF amp.	$+0.95(\Delta F) - 0.13(\Delta F)^2$

* This is expressed as a power series, in which ΔF is the difference in mc from 74 mc.

† This is a gain equalizer for the delay equalizer of the standard FM receiver and has negligible EDD.

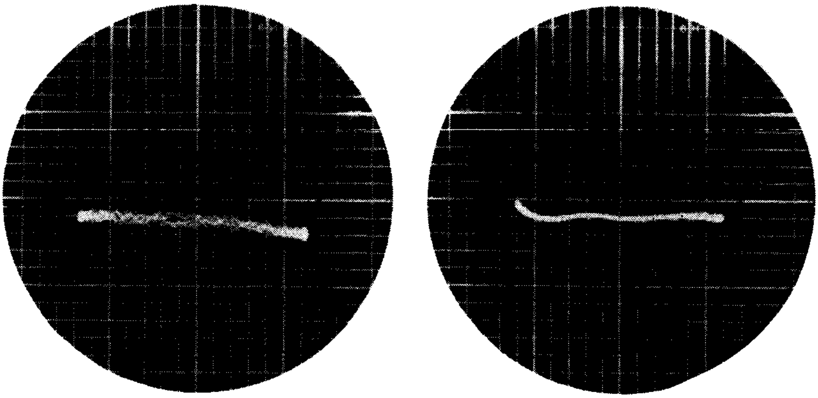


Fig. 27 — Envelope delay distortion of IF loop, Oct. 19, 1962. Left: FMFB receiver. Right: standard FM receiver. Horizontal scale: 1 division = 2 mc (sweep = 62–86 mc). Vertical scale: 1 division = 5 ns.

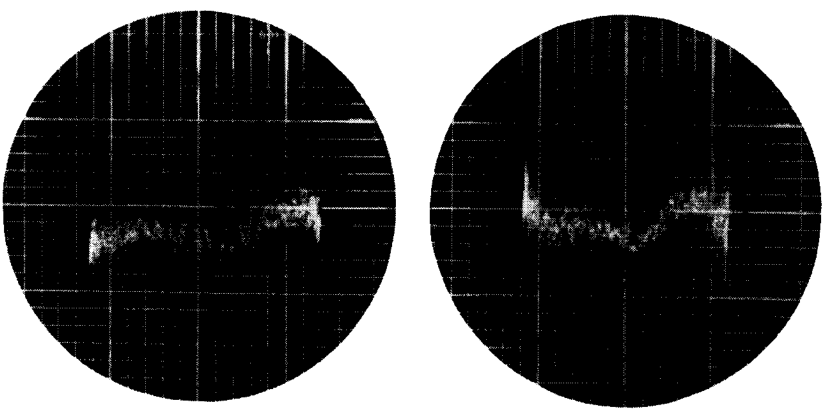


Fig. 28 — Envelope delay distortion of equalized loop through boresight repeater, Oct. 19, 1962. Left: FMFB receiver. Right: standard FM receiver. Scales same as Fig. 27.

only the standard FM receiver is used. At the receiving end, the recovered 15.75-kc tone drives the scope horizontally. Either the gain or phase variations of the 3.58-mc tone can be shown as the vertical deflection. Typically the sensitivity is 0.2 db and 1° per small scope division. The SNR of this test set when used with the satellite system is poor.

On pass 1113 (November 9, 1962) photos were made of the equalized system. Fig. 30 shows the results. The baseband loop has no discernible distortion on this test, and therefore no photo is presented here.

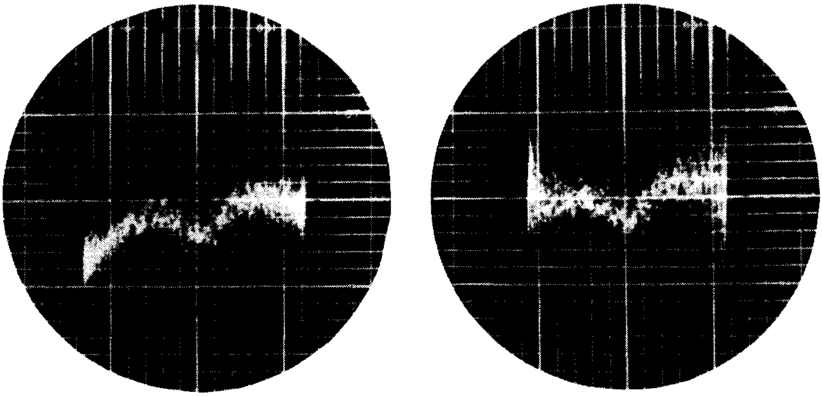


Fig. 29 — Envelope delay distortion of equalized loop through Telstar satellite; pass 925, Oct. 19, 1962. Left: FMFB receiver. Right: standard FM receiver. Scales same as Fig. 27.

8.3 *Noise Loading*

Noise loading simulates the operation of the system with 600 channels of multiplex telephony. The test set used for the noise loading measurements generates white noise in the band of 60 to 2660 kc and has slots cleared of noise at 70, 1248, and 2438 kc. With flat loading, the calculated normal TL at the test point is −18 db TL. The total noise power corresponding to the 600 telephone channels is −7 dbm. The system has an over-all net loss of 0 db, and therefore the receiving TL is the same as the transmitting TL. The noise loading equipment measures the total received noise power (sum of thermal noise and cross-modulation noise) in the noise slots. This is converted, for plotting purposes, into dbrn at the zero db TL point.

There is 5 db loss from the test area to the FM deviator input; hence, at nominal TL, the noise power at the FM deviator is −12 dbm. The deviator sensitivity is set so that 0 dbm of a sine wave gives 20-mc peak-to-peak, or 7.07-mc rms, deviation. Therefore, the rms deviation for nominal TL is 1.77 mc. By varying the applied noise power (the drive on the system) the rms deviation can be changed; this corresponds to changing the assigned TL.

Fig. 31 shows the results obtained on pass 1015.* When circuit noise is controlling, the SNR improves db for db as the drive (rms deviation) is increased. This accounts for the 45° down-sloping line at the left.

* At this time, one of the components of the equalizer for the RF circuit was defective and was removed, so that +0.5 ns/mc of EDD slope equalization was missing from the satellite loop. The measured EDD for this condition (taken on pass 1042, November 1, 1962) is shown in Fig. 32.

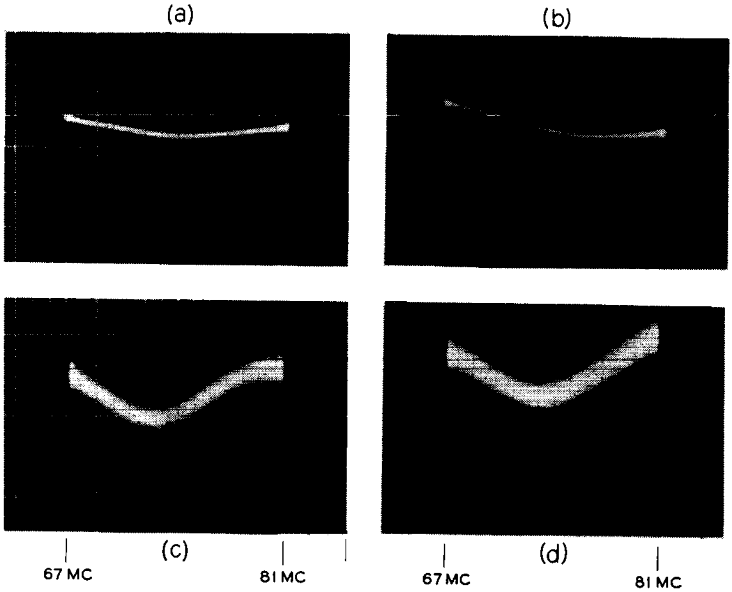


Fig. 30 — Differential gain and phase of equalized loops; standard FM receiver. Sweep: 67–81 mc. (a) Differential gain of IF loop. Vertical scale: 1 division = 0.2 db. (b) Differential phase of IF loop. Vertical scale: 1 division = 1°. (c) Differential gain of Telstar satellite loop; pass 1113, Nov. 9, 1962. Vertical scale: 1 division = 0.4 db. (d) Differential phase of Telstar satellite loop; pass 1113, Nov. 9, 1962. Vertical scale: 1 division = 2°.

However, as the drive is raised, the cross-modulation products increase 2 db per db for second order, 3 db per db for third order, and eventually become controlling. The very sharp upward break at the right shows that very high order modulation products are involved, indicative of severe overload or clipping.

Overloading (or overdrive) occurs when the peaks of the noise substantially exceed the design peak deviation. The peak deviation due to noise is 6 db higher than rms 5 per cent of the time, 9 db higher 0.4 per cent of the time, and 12 db higher 0.01 per cent of the time. For example, with a drive corresponding to an assigned −12 db TL at the test point, or 6 db above normal, the rms deviation is 3.54 mc and the peak deviation exceeds 10 mc 0.4 per cent of the time. At −9 db TL drive, the peak deviation exceeds 10 mc 5 per cent of the time and 20 mc 0.01 per cent of the time. The system bandwidths cannot accomodate such overdrives.

Fig. 33 shows noise loading curves for the IF loop. This shows the modulation break to be generated, to a considerable extent, in the

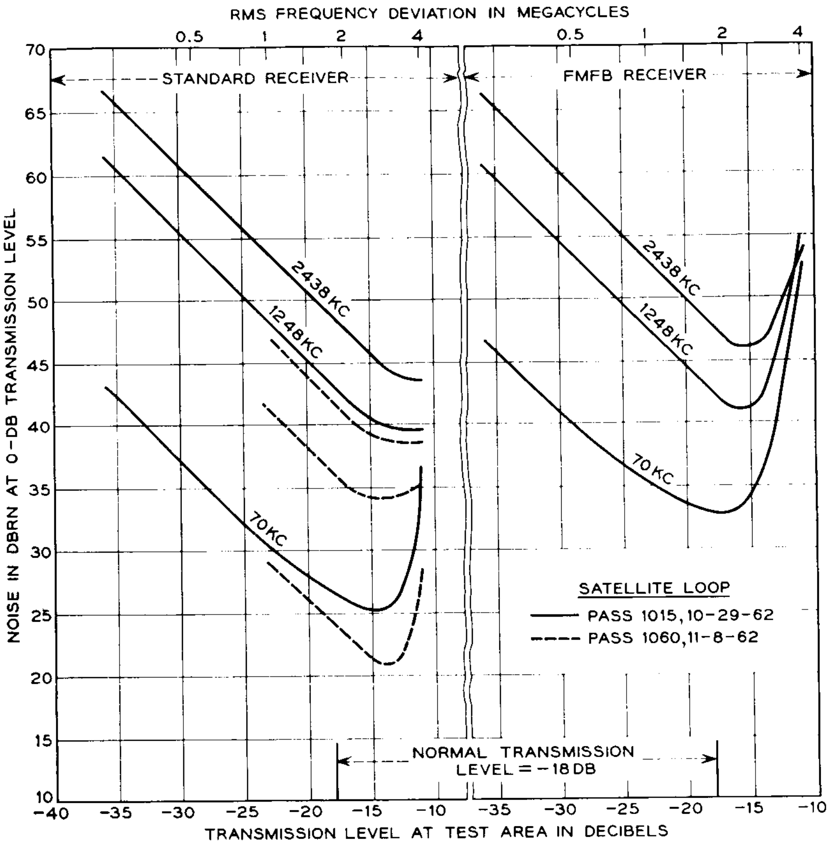


Fig. 31 — Telstar satellite loop noise loading measurement; passes 1015 and 1060.

terminal equipment. The FMFB receiver overloads sooner than the standard FM receiver since its noise performance at normal TL is nearly 10 db poorer than the standard receiver.

Since the video transmission system (Fig. 1) is also included in these tests, Fig. 34 shows noise loading performance of the baseband loop. This graph indicates that the baseband has third-order cross-modulation.

It appears from the noise loading data that for the EDD equalized system carrying 600 telephone channels and using the standard FM receiver, the contribution of cross-modulation to total system noise is small at the normal operating TL. Operation would probably be satisfactory at 3 db higher TL, giving 3 db less noise. The modulation break

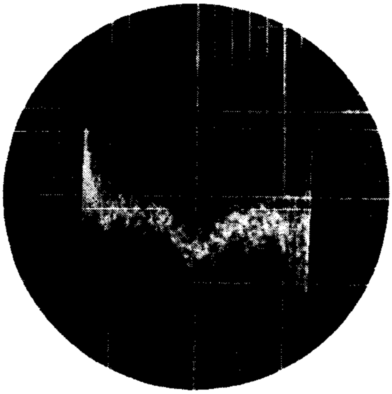


Fig. 32 — Envelope delay distortion of Telstar satellite loop with 0.5 ns/mc EDD equalization missing; pass 1042, Nov. 1, 1962; standard FM receiver. Scales: same as Fig. 27. Compare with Fig. 29, right.

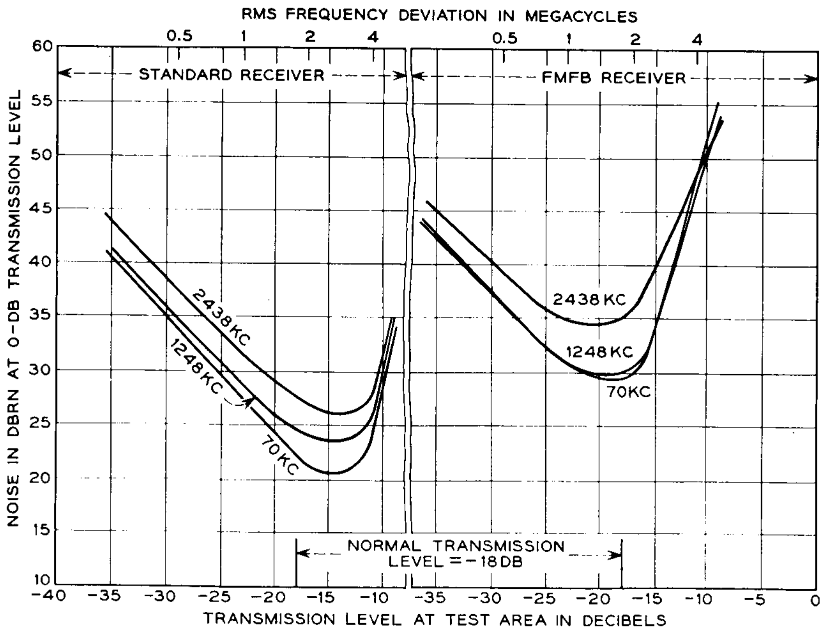


Fig. 33 — IF loop noise loading measurements, Nov. 1, 1962 (no pre-emphasis).

appears to be controlled by the video and IF equipment. However, the tests and calculations are based on telephone loading and take advantage of talker volume distribution and idle time. If a substantial part of baseband is carrying data service, the allowable TL will be reduced.

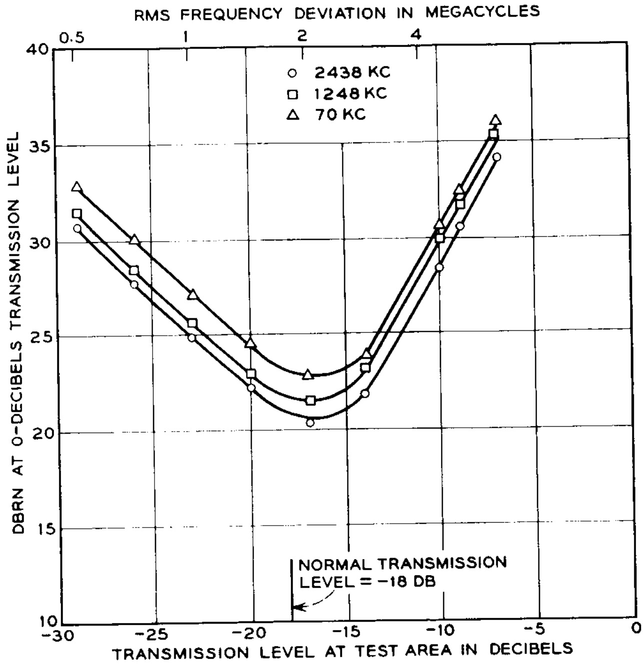


Fig. 34 — Baseband loop noise loading measurements, Sept. 27, 1962.

An acceptable value for channel noise at zero TL is 45 dbrn. Fig. 31 shows this to be exceeded by 3 db at 2438 kc. However, high-frequency noise is determined by the radio path. The dotted lines on Fig. 31 illustrate a noise loading test made during pass 1060 (November 3, 1962) when the range was about 1500 miles instead of the approximately 4000 miles for pass 1015. The channel noise performance therefore is a statistical process, and the data at hand are not sufficient to plot a noise probability distribution curve.

It is clear from Fig. 31 that the noise performance could be equalized across the band by the use of pre-emphasis. Tests have been made using the standard TD-2 pre-emphasis, shown in Fig. 35. The pre-emphasis and de-emphasis networks are patched in ahead of the FM deviator and after the FM receiver (see Fig. 1). Their total loss is a flat 14 db. This was compensated for by removing a 3-db pad in the transmitting line and 11 db of loss in the receiving line. Over the range of 60-2660 kc, the pre-emphasis network reduces the total noise power by 6.5 db with a resulting net power loss of 3.5 db in the transmitting path. Therefore, the normal TL at the test area is −14.5 db TL.

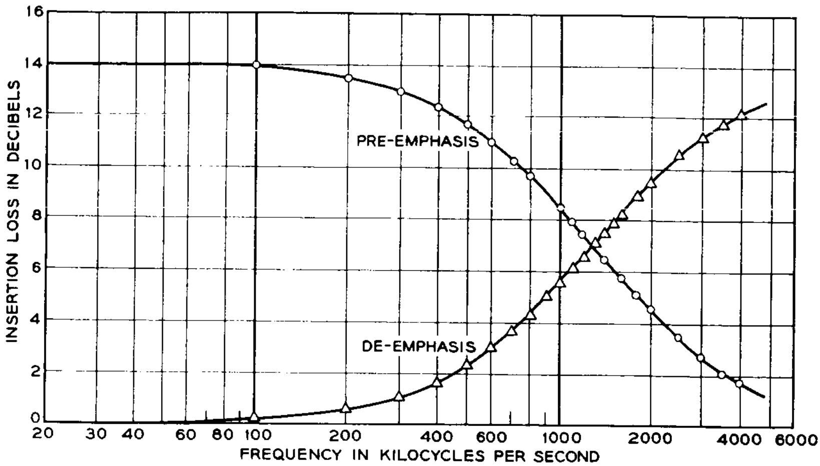


Fig. 35 — Insertion loss for telephony pre- and de-emphasis networks.

Fig. 36 shows noise loading measurements with pre-emphasis. These results show that TD-2 pre-emphasis is not the optimum for this system.

8.4 *Intermodulation: Video to Audio*

The audio noise measurements discussed in Section VII and shown in Fig. 22 are for the condition of no video signal being transmitted. When video material is transmitted, the audio noise increases. Presumably, the additional noise is due to cross-modulation (video-to-audio) due to nonlinearity of the over-all system. Tests of diplexers back-to-back show that direct interference due to power in the video signal at 4.5 mc is not significant, except possibly for the multiburst test signal.

Audio noise was measured repeatedly with no video present and also with a monoscope (Indian Head) signal. The 2-mc roll-off filter was omitted. No EDD equalization or video pre-emphasis was used in the system for this test. Examination of the data shows no clear correlation between audio noise and 6- or 4-kmc received carrier. Accordingly, the data for each pass have been averaged with the results shown in Table VII.

These data show the monoscope signal to give a weighted audio SNR of about 56 db. Tests made on early passes with other types of video test signals (multiburst, stairstep, window) showed the monoscope to have about as much effect as any. No audio to video cross-modulation interference has ever been observed, even under exaggerated laboratory tests.

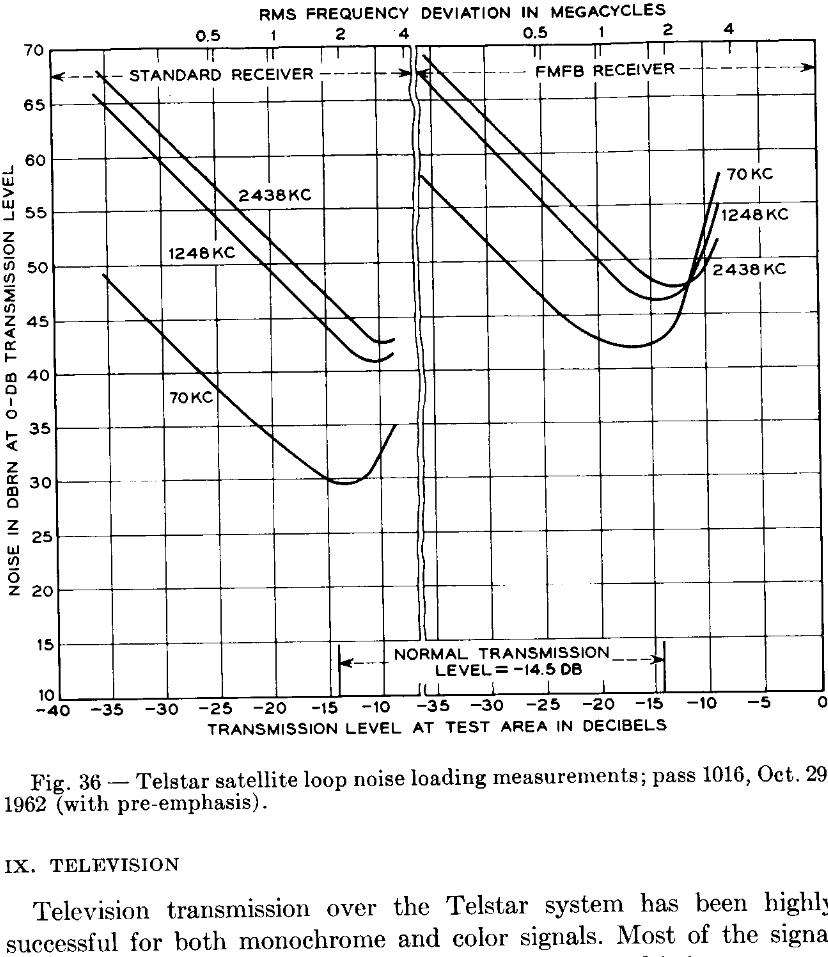


Fig. 36 — Telstar satellite loop noise loading measurements; pass 1016, Oct. 29, 1962 (with pre-emphasis).

IX. TELEVISION

Television transmission over the Telstar system has been highly successful for both monochrome and color signals. Most of the signal impairment which has been observed was expected and is in agreement with calculated performance. One type of impairment which was not anticipated is also reported here.

Probably the most noticeable signal impairment is some loss in picture definition. This is almost entirely attributable to the low-pass characteristics of the ground station equipment. The principal contributors are the 2-mc low-pass filter, the transmission characteristics of the 4.5-mc diplexers, and the roll-off in the FMFB receiver. This impairment was intentionally accepted in order to make possible the transmission of the audio signal as well as the video signal. As indicated by the baseband transmission characteristics presented in Section 6.1, the

TABLE VII — VIDEO-TO-AUDIO INTERMODULATION

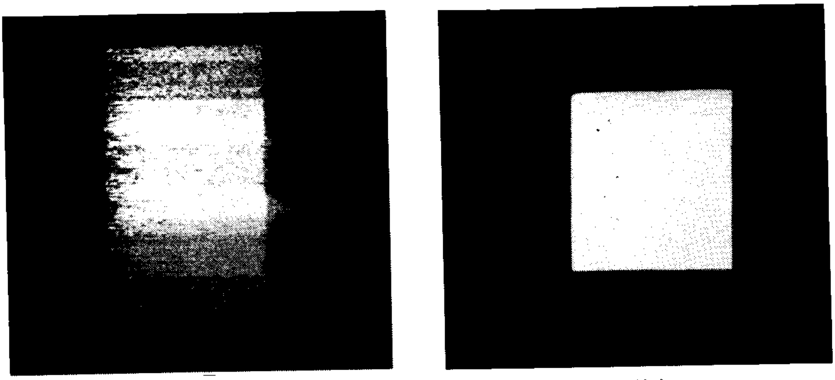
Pass	FM Recvr.	Avg. Recd. Carr. (dbm)		Weighted Audio SNR*	
		6 kmc	4 kmc	No Video	Monoscope
316	Std	−61.5	−90	63	56
326	FB	−61	−89	61.5	55
341	FB	−61.5	−88	61.5	56.5
350	FB	−61	−92.5	60.5	56
350	Std	−62.5	−93	62	58
570	Std	−63	−91	60.5	57 (Monoscope) 55 (Multiburst)

* SNR is defined in Section 7.3.2.

removal of the filter and diplexers and the use of the standard FM receiver eliminate this impairment.

A second impairment, also anticipated, was somewhat noticeable noise at maximum range. Under this condition the predicted (and measured) weighted signal-to-noise performance of the system is somewhat less than the normal Bell System objectives for commercial service. Typical values for the weighted signal-to-noise ratio have already been discussed in Section 7.3.

A third impairment, not anticipated, occurred during several of the demonstration transmissions from Andover to Europe. In these demonstrations, the transmitted signal originated in other parts of the country and was transmitted to Andover via the microwave radio system between Boston and Andover. Coincident with switches at the originating studio from one camera pickup to another, there were very annoying bursts of noise occurring in both the video and audio channels received over the satellite system. These noise bursts were not present in the signal applied to the ground transmitter. The difficulty was apparently caused by the transients which accompanied the switch from one signal to the other. In the signal as received for transmission at Andover, these appeared as relatively long (100 milliseconds or greater) negative pulses which were large compared to the normal peak-to-peak value of the video signal. Since the system itself uses a high-index deviation (14 mc peak-to-peak) in a 25-mc system bandwidth, these pulses were apparently large enough to cause the FM deviator to shift momentarily out of the 25-mc band. This resulted in momentary loss of signal at the various ground receivers, and the automatic gain control circuit increased the receiver gains long enough to cause substantial noise bursts in both the video and audio outputs.



(a) (b)

Fig. 37 — First video signals from Telstar satellite; pass 6, July 10, 1962. (a) Noisy pulse and window; (b) clear pulse and window.

9.1 *Early Transmissions*

This section includes samples of some of the early picture material transmitted over the Telstar satellite. In all cases the television signal was a standard 525-line signal. The photographs were all taken at Andover using a standard picture monitor and oscilloscope and a Polaroid camera. A substantial amount of picture degradation has occurred in the reproduction processes, but the results are believed to be of sufficient historical interest to warrant their inclusion here.

Pass 6—July 10, 1962

During this pass the satellite repeater was turned on for the first time following the successful launch earlier in the day. Some of the significant events of this pass are recorded in Table VIII; the table explains the signals shown in Figs. 37 and 38.

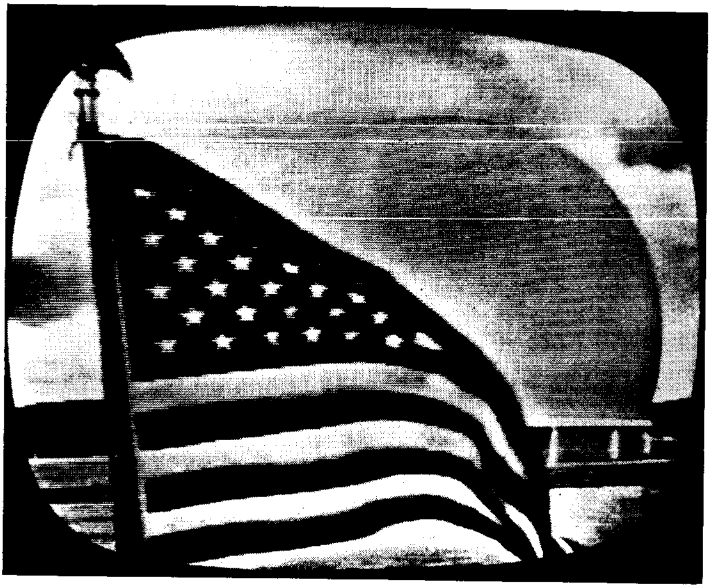
Pass 15—July 11, 1962

On the following day the first television pictures were received from Europe. Fig. 39(a) shows the first signal received from France during pass 15 and Figure 39(b) shows a subsequent picture received during the same pass. The French material had been prerecorded on video tape.

Pass 16—July 11, 1962

A little less than three hours later the first transmissions from England took place. The first signal and a subsequent picture received from the

(a)



(b)

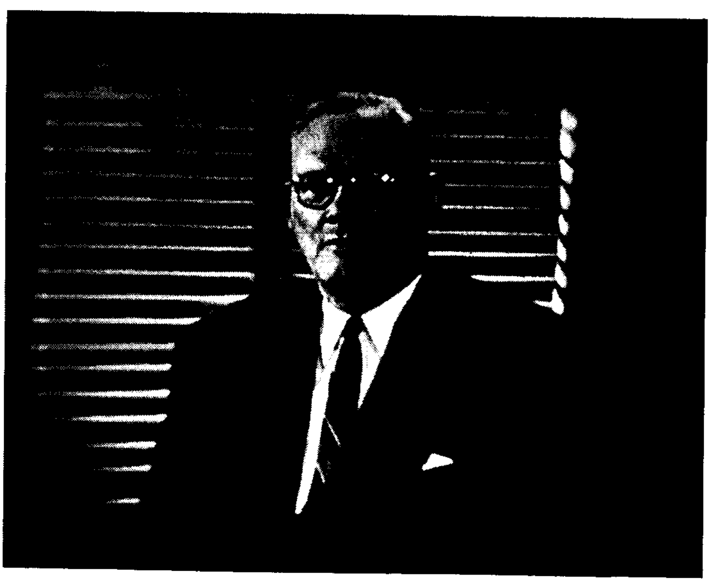


Fig. 38 — First public demonstration of television via Telstar satellite; pass 6, July 10, 1962. (a) American flag in front of radome; (b) Mr. Frederick R. Kappel.

TABLE VIII — SIGNIFICANT EVENTS — JULY 10, 1962

Time (UT)	Event
23:18	Andover command tracker acquires Telstar satellite.
23:20	Andover telemetry in synchronism. First command sent to turn on traveling-wave tube.
23:21	Second command sent to turn on traveling-wave tube.
23:23:36	Third and final command completed turn on of traveling-wave tube.
23:23:56	Precision tracker in autotrack.
23:24:34	Autotrack system for horn antenna in lock.
23:25:00	First video signal from Telstar satellite, a noisy pulse and window, received at Andover. Transmitter not yet at full power. [Fig. 37 (a)].
23:25:30	A clear pulse and window being received [Fig. 37(b)].
23:30	Start telephone conversation from Mr. Frederick R. Kappel, AT&T Board Chairman, to the Vice President of the United States, Mr. Lyndon Johnson.
23:33	Taped television transmission sent to Telstar satellite. The first received picture is shown in Fig. 38(a). The picture shown in Fig. 38(b) was taken about 2 minutes later.
23:47:30	Television pictures were received in France.

Goonhilly Downs station are shown respectively in Figs. 40(a) and 40(b). The picture material is from a live pickup at the Goonhilly station.

9.2 *Color Television*

Color television signals have been transmitted via the Telstar satellite on several occasions. The first such transmission took place during pass 60 on July 16, 1962, when several color slides were transmitted from the Goonhilly Downs station to the Andover station. A similar transmission took place during pass 88 on July 19. Photographs taken at the Andover station of the Goonhilly signals are shown in Fig. 41 (color plates, opposite p. 1614). In addition, several color slides were originated at the Murray Hill location of Bell Telephone Laboratories and were transmitted from Andover to Goonhilly Downs on this pass. Additional test transmissions in both directions took place during pass 178 on July 29, 1962. For all of these tests the 4.5-mc aural diplexers and low-pass filter were removed from the circuit and the standard FM receiver was used.

9.3 *Two-Way Television*

The first two-way transatlantic television tests were conducted during pass 142 on July 25, 1962, between the Andover station and the Pleumeur-Bodou ground station. Separate FM carriers were used for the two directions. The signal from Andover to Pleumeur-Bodou was trans-

(a)

(b)

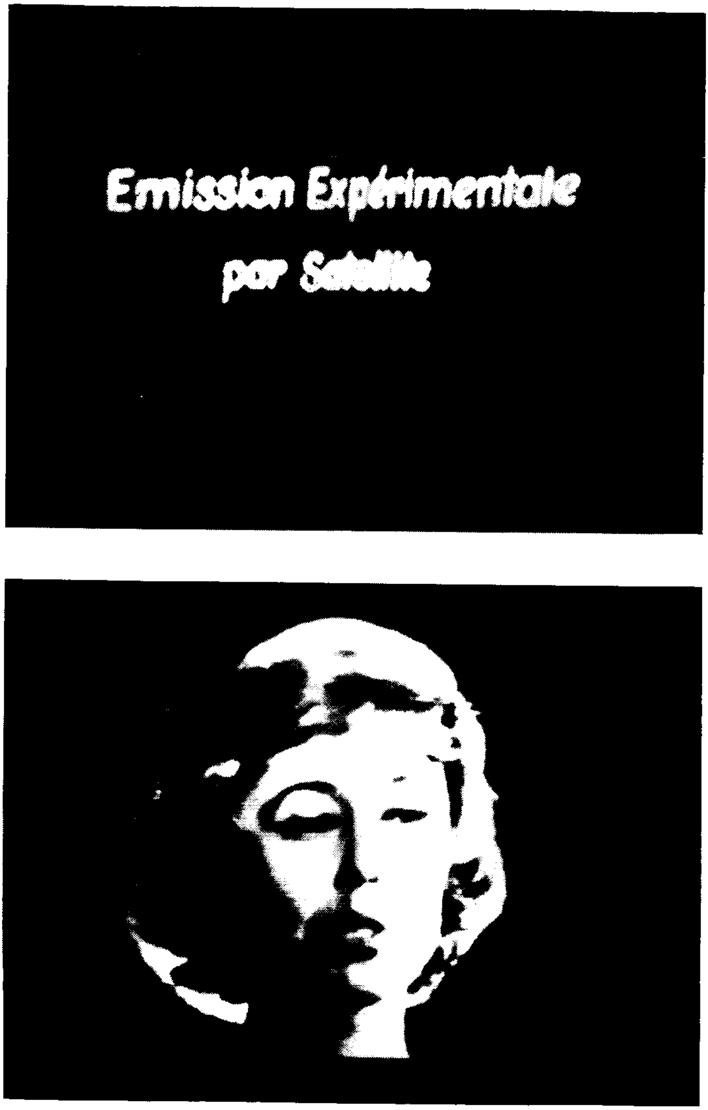


Fig. 39 — First television signals received from France; pass 15, July 11, 1962. (a) First signal received; (b) video tape transmission.

mitted at 6394.58 mc, or 5 mc above the nominal center frequency. The signal in the other direction was transmitted 5 mc below the nominal center frequency, or at 6384.58 mc. Fig. 42 shows a test pattern received from France during this test.

(a)

(b)

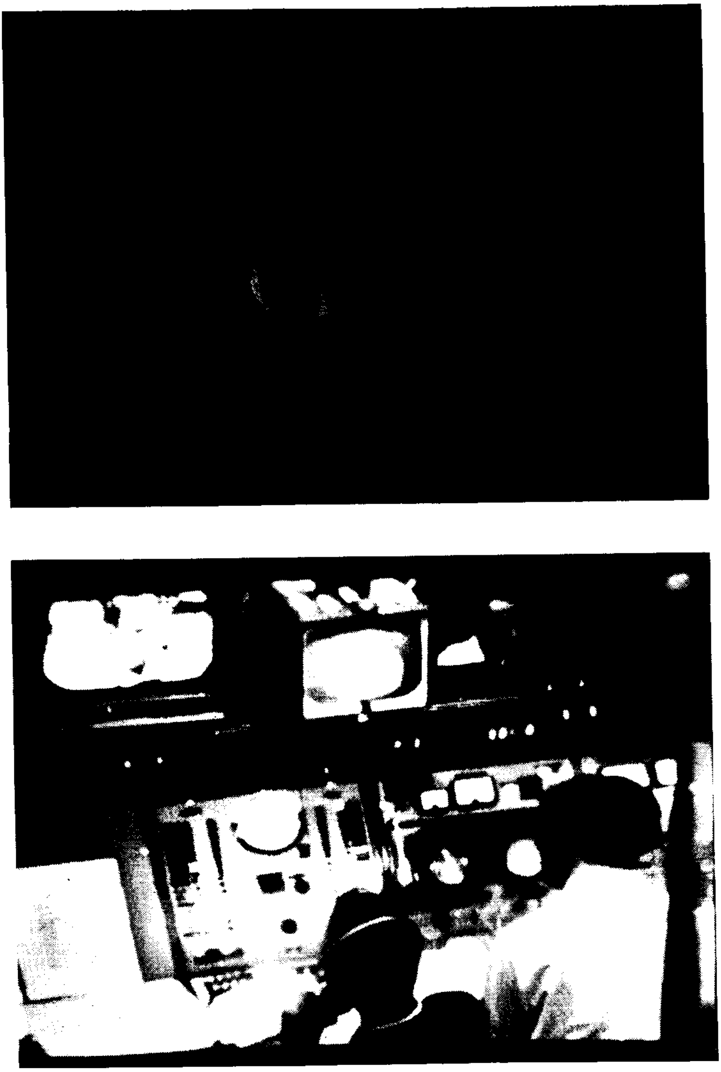


Fig. 40 — First television signals received from England; pass 15, July 11, 1962. (a) First signal received; (b) live video from Goonhilly Downs.

In addition to the simultaneous transmission in two directions, some two-way loop tests were made. Fig. 43 shows a photograph of video tape material after transmission to Pleumeur-Bodou, where the signal was looped and returned to Andover after traveling twice through the satellite repeater.

For these tests, IF bandpass filters 6 mc wide were used in both stations. The frequency deviation was adjusted to be approximately 2 mc peak-to-peak. Audio signals were transmitted in both directions by means of the 4.5-mc diplexers, but with definite degradation in audio quality.

A stabilizing amplifier was used to insert new sync pulses in the received signal. This resulted in definite improvement in the synchronization of the monitors.

In an attempt to optimize signal-to-noise ratios at the ground receivers, the ground transmitter power was programmed at both stations to provide −63 dbm at the satellite converter (assuming an isotropic antenna at the satellite).

The principal degradation to picture quality was noise, which was probably about 20 db poorer than in normal one-way transmissions. About 16 db was due to the reduction in frequency deviations from 14 mc to 2 mc peak-to-peak. The additional degradation was due to the reduced transmitter power per carrier at the satellite output. The ratio of peak-to-peak signal to rms noise was probably between 25 and 30 db. Crosstalk between channels was not noticeable.

X. TWO-WAY TELEPHONY

10.1 *Early Transmissions*

The Andover and Goonhilly Downs stations were arranged for two-way telephone tests for pass 24 on July 12, 1962. Transmission and noise were checked on each of the two-way channels. One of the channels was used as an order wire by technicians in the two stations to coordinate the test procedure. These tests indicated that a successful demonstration of two-way telephony could be expected on the following day.

During pass 33 on July 13, 1962, the first demonstration of two-way telephony took place between Kingston, New York, and Paris, France. The first call was placed by Mr. E. J. McNeely, President of the A.T.&T. Co., to M. Jacques Marette, Minister of Communications, and other French government officials. This was followed by other calls.

10.2 *Channel Noise*

Noise measurements in at least a portion of the telephone channels have been made on nearly all of the many two-way message transmissions. Typically, the channel noise has been in the range between 40 and 48 dbrn at 0 db TL, depending on the satellite range and the relative power in the two signals at the satellite input. Although range information is available for all of the passes, the determination of the relative input power of the two signals is not possible during a normal transmission test. This is because the AGC circuit in the satellite responds only to the total signal. On pass 706 more complete data were obtained in an Andover and Pleumeur-Bodou test. By alternately turning off the two ground transmitters, their individual contributions to the input power at the satellite was measured and adjusted. In this way, it was possible to determine the noise in telephone channels of both carriers being transmitted by the satellite under known conditions. On pass 1014 a similar test was made, at which time the satellite range was substantially less. The results are shown in Table IX and are in good agreement with expected performance. Just as one would expect, when the power of one of the carriers is reduced at the input to the satellite, the noise increases for the channels on that carrier. At the same time, the other carrier gets an increased portion of the total power at the satellite output and the noise decreases in the telephone channels on the stronger carrier.

10.3 *Crosstalk*

The simultaneous amplification of the FM signals in the single satellite repeater gives rise to some crosstalk from one carrier to the other. No problems have been encountered in actual two-way telephone transmissions. However, the mechanism is such that with reduced circuit noise, intelligible cross-talk would occur from a particular telephone channel on one carrier to the corresponding channel on the other carrier. With sufficient noise, the crosstalk falls below the noise level and is not objectionable.

To evaluate quantitatively the crosstalk loss, specific tests were made such that the crosstalk could be measured above the background noise. The results of one such test made during pass 697 are included in Table X. The 6395-mc carrier transmitted at Andover was modulated with either a 100- or 200-kc sine wave. Peak frequency deviations of 1.0, 0.5 and 0.25 mc were used. A 6385-mc unmodulated carrier was transmitted by the Goonhilly station. At Andover the 100- or 200-kc modulation of the carrier received from Goonhilly was measured and compared with the modulation applied to the Andover carrier. The difference was recorded as the crosstalk loss.

Fig. 41 (Opposite page) — Color test signals from Goonhilly Downs to Andover; pass 88, July 19, 1962. ⟶


British Post Office
BBC
EXPERIMENTAL
COLOUR
TRANSMISSION

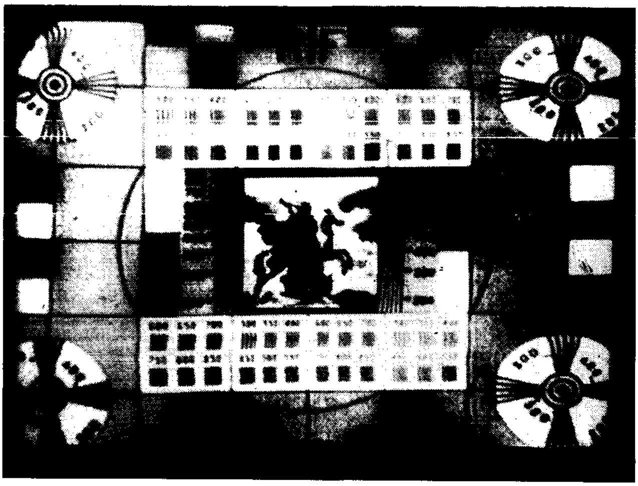


Fig. 42 — Signal received from France during two-way television transmission; pass 142, July 25, 1962. Top: test pattern. Bottom: oscilloscope presentation of individual lines.

XI. DATA TRANSMISSION

The suitability of the Telstar system for handling various types of data signals has been verified by means of tests ranging from the transmission of ordinary 60-wpm teletypewriter signals to 875,000 bit per second serial data, as well as various types of facsimile signals. Bell System data terminals were used for most of these tests. In order to

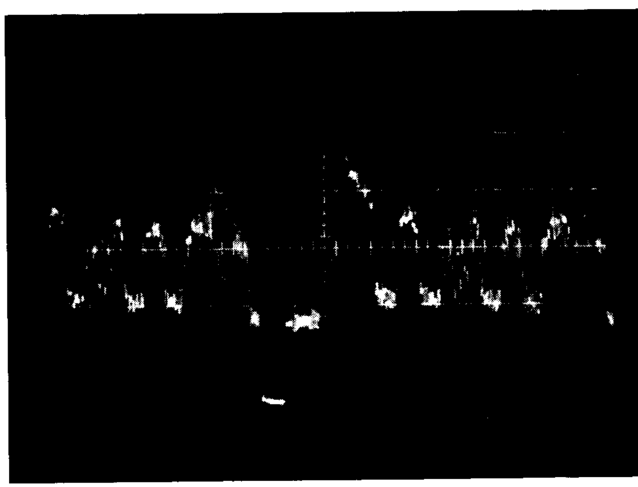


Fig. 43 — Television signal transmitted to France and returned to Andover; pass 142, July 25, 1962. Top: monitor presentation. Bottom: oscilloscope presentation of individual lines.

predict the performance of other signals and data terminals, basic transmission parameters in the voice-frequency band were also measured.

The transmission path for these tests included approximately 800 miles of land telephone circuits* in addition to that shown in Fig. 1,

* Most of the U. S.-based terminal equipment was located at 32 Avenue of the Americas, New York City. The tests described herein were principally conducted by personnel of the Long Lines Dept., A.T.&T. Co., from August 6 to October 18, 1962.

TABLE IX — TWO-WAY TELEPHONE NOISE

Pass No.	Time (UT)	Andover to Satellite Range (SM)	Signal Power at Satellite (dbm)		Telephone Noise (dbrn at 0 db TL)*				Received Carrier Power at Andover (dbm)	
			And-over Carrier	Pleu-meur-Bodou Carrier	Andover Carrier		Pleumeur-Bodou Carrier		And. Car.	P-B Car.
					Chan-nel 1	Chan-nel 11	Chan-nel 1	Chan-nel 11		
706	15:54:30	3390	−65	−65	—	—	43.5	43.5†	—	−95
	15:56:30	3490	−65	−65	40.0	42.0†	—	—	−95	—
	15:59:30	3760	−68	−65	47.0	45.2†	—	—	<−95	—
	16:01:30	3850	−68	−65	—	—	43.0	43.0†	—	−94
	16:04:30	4030	−71	−65	—	—	42.0	42.0†	—	<−95
	16:08:30	4420	−71	−65	51.0	52.0†	—	—	<−95	—
	16:09:30	4470	−71	−65	43.0	44.0†	—	—	<−95	—
	16:10:30	4580	−65	−65	—	—	44.0	46.0†	—	<−95
1014	09:17:30	1800	−61	−61	—	—	36.5	36.0	—	−90.0
	09:18:30	1930	−61	−61	35.0	34.0	—	—	−85.8	—
	09:19:30	2070	−64	−61	37.5	36.0	—	—	−89.6	—
	09:21:00	2300	−64	−61	—	—	37.0	36.0	—	−88.4
	09:22:00	2460	−67	−61	—	—	36.0	35.0	—	−88.5
	09:24:00	2790	−67	−61	41.0	39.0	—	—	−96.0	—
	09:26:00	3120	−58	−61	35.0	34.5	—	—	−91.0	—
	09:27:00	3280	−58	−61	—	—	41.0	39.0	—	−101.0

* All measurements are with "C" message weighting except those denoted †, which are with 3-kc flat weighting.

TABLE X — TELEPHONE CHANNEL CROSSTALK LOSS
(Pass 697 — September 24, 1962)

Andover Carrier Power at Satellite (dbm)	Goonhilly Carrier Power at Satellite (dbm)	Frequency Deviation at Andover (mc)	Crosstalk* on Goonhilly Carrier	
			100 kc	200 kc
−70	−70	1.0	51.6	52.8
−70	−70	0.5	52.6	51.6
−70	−70	0.25	49.0†	50.5†
−64	−70	1.0	48.9	51.2
−64	−70	0.5	48.8	47.0
−64	−70	0.25	46.2†	47.2†
−73	−70	1.0	58.0	
−73	−70	0.5	55.4	
−73	−70	0.25	51.0†	

* Defined as the ratio of modulating signal on the modulated carrier to the received signal plus noise on the unmodulated carrier.
† The crosstalk was below the background noise level.

thereby simulating a typical service offering. Analysis of all the results of these extensive tests has not been completed to date. However, the analyses made indicate that the system performance is as predicted — in fact, very similar to a 4000-mile microwave radio relay system except

TABLE XI — SUMMARY OF DATA TESTS

Type of Test	Equipment	Signal or Modulation	Transmission Rate	Results
Low-speed digital	(a) 43A1 VF carrier terminals (b) 101B DATA-PHONE Data Set	Standard teletypewriter FSK	(a) 60 wpm, 5 level (b) 100 wpm, 8 level	Highly satisfactory. See Fig. 44 for per cent distortion on pass 914.
Medium-speed digital	63-bit word generator with either: (a) 202B DATA-PHONE Data Set (b) 201A DATA-PHONE Data Set	(a) FSK (b) Four-phase	(a) 1200 bauds (b) 2000 bauds	(a) See Fig. 45 for eye patterns, pass 542. (b) See Fig. 46 for eye patterns, pass 578. Eye patterns* indicate sufficient margin against errors. Error rates averaged better than generally accepted standards.
High-speed digital	(a) Bell System high-speed data terminal with IBM 729 magnetic tape units, a 1945 data transmission terminal and a 1401 computer (b) 301A-X1 data set† using as terminal equipment: (1) 63-bit word generator (2) IBM 729 mag. tape units, 7287 data trans. term., and a 1401 computer (c) Experimental high-speed data system‡	(a) Seven parallel double-sideband AM channels, each using a bandwidth of 480 kc and keyed at 62,500 bauds. (b) Four-phase (c) Four-phase	(a) 62,500 characters per second (b) 42,000 bauds (c) 875,000 bauds	(a) Some timing problems experienced due to changing absolute delay. Error-free transmission achieved for several minutes on pass 353. (b1) 69.5 million bits received error-free on pass 270. (b2) 2.8 million characters received error-free on pass 270. See Fig. 47 for eye patterns. (c) On pass 833, 970 million bits transmitted in 18.5 minutes with only one bit in error. Slight signal deterioration observed, probably due to change in slant range.¶ See Fig. 48.

* Eye patterns are formed by overlaying successive demodulated mark and space pulses before reshaping or retiming.
† The signals for these tests originated from Murray Hill, N. J. and were received at Holmdel, N. J.
‡ This test was conducted from Pleumeur-Bodou to New York City.
¶ The slant range to Andover varied from 2996 to 4809 miles during the test.

for the expected frequency shift due to Doppler effect and for the change in absolute time delay due to changing slant range. The test results were satisfactory to excellent. Doppler shift caused some distortion in low-speed data signals; however, transmission results were satisfactory. Changes in absolute time delay caused some degradation in high-speed data and facsimile transmission which can be compensated for in equipment design.

11.1 *Digital Data*

Table XI outlines the digital data tests made and summarizes the results obtained. Some further results are presented in Figs. 44 to 48. The results indicate that digital data can be successfully transmitted over the Telstar system.

11.2 *Facsimile*

Facsimile copy using both voice-band and broadband circuits were transmitted over the satellite repeater via landline facilities between New York and Andover.

Voice-band facsimile* was transmitted on pass 461 at keying frequency rates of 555 cps (60 rpm) and 1110 cps (120 rpm) over ordinary equalized L-type multiplex voice-band channels (nominal 4 kc). Envelope delay distortion was equalized to within 460 microseconds, while amplitude distortion was held to ± 1 db over the band 1000 to 3000 cycles for the system. Fig. 49 shows a typical voice-band reception of an IRE test chart copied at 60 rpm. With the exception of a slight increase in noise evident in mid-gray tones, receptions copied at 60 and 120 rpm are subjectively equivalent to those copied over the facilities looped at Andover.

High-speed, two-tone facsimile,† utilizing a keying frequency rate of 675 kilocycles, was transmitted on pass 352 over the Telstar repeater via unclamped video facilities between New York and Andover. Figs. 50 and 51 are copies of portions of two consecutive transmissions conducted during a single satellite pass. Fig. 50 illustrates the result of employing an out-of-band transmitted synchronizing signal to drive the receiving drum motor. Some jitter is noticeable due to unfiltered low-frequency transients located in the landline facilities. Fig. 51 shows the results obtained when local (separate, stable) synchronization is employed. Here, frame skew due to the change of slant range (absolute

* Muirhead D-628-F, D-700-AM, DSB-AM, 1300-cps carrier.
† Westrex modified CTRT-5, DSB-AM, 2-mc carrier.

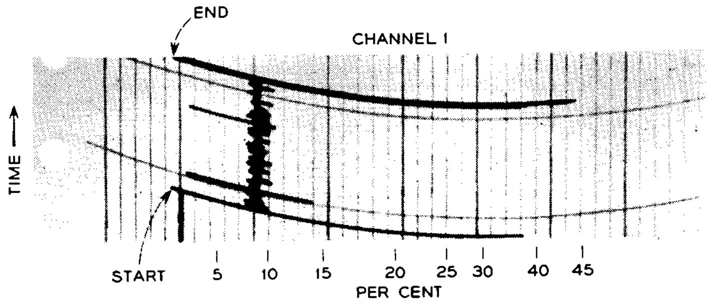


Fig. 44 — Per cent distortion vs time, using 43A1 VF terminals at 60 wpm from London to New York; pass 914, Oct. 18, 1962.

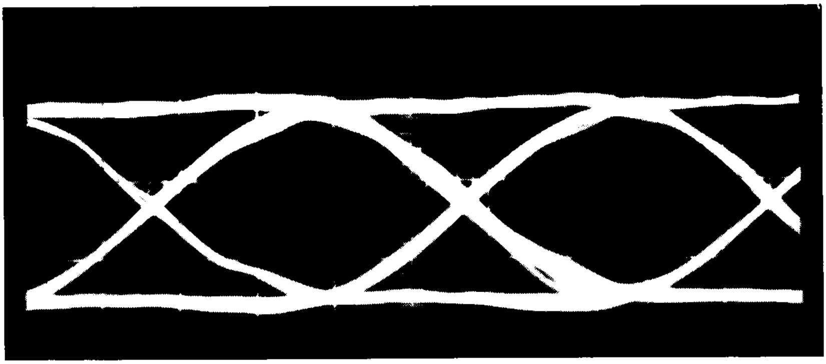


Fig. 45 — Eye pattern; 202B DATA-PHONE Data Set. Satellite loop, pass 542, Sept. 7, 1962.

delay change), is pronounced. This is to be expected at the 3000-rpm scanning rate of 675 linear inches per second.

It is concluded that transmission of facsimile signals via the Telstar satellite repeater, at both voice and video bandwidth rates, is entirely feasible. For wideband, high-speed systems, it will be necessary to utilize a transmitted synchronizing signal to eliminate frame skew in the recorded copy. Voice bandwidth systems require no change in operation.

XII. MISCELLANEOUS

This section includes a few tests not otherwise classified and one test in which the first measurements have been made only very recently and on which testing is still in progress.

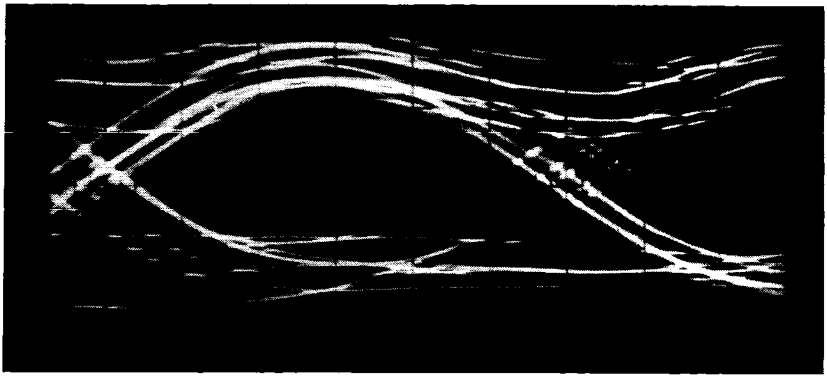


Fig. 46 — Eye pattern; 201A DATA-PHONE Data Set. Satellite loop, pass 578, Sept. 11, 1962.

Fig. 47 — Eye pattern; 301A-XI Wideband Data Set. Satellite loop, pass 270, Aug. 8, 1962.

12.1 *Doppler Shift*

Fig. 52 shows measured and calculated Doppler shifts of the communications carrier in Andover and Goonhilly. Andover transmitted a crystal-controlled carrier at 74.13 mc, received it and measured the frequency in a counter connected to the 74-mc output of the IF amplifier. Goonhilly likewise measured the frequency at the output of the 70-mc IF amplifier. The measured frequency values were set to be zero at the same point where the calculated ones cross zero. This was necessary because zero-doppler is not known with this method. The measured and calculated curves agree to within 1 kc, and this occurs over a period of about 45 minutes.

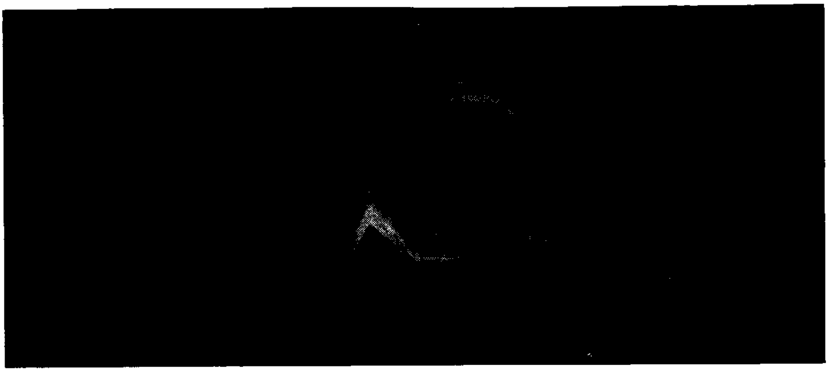


Fig. 48 — Eye pattern; experimental four-phase, high-speed data system. Pleumeur-Bodou to NewYork, pass 833, Oct. 9, 1962.

12.2 *Absolute Delay*

During most of pass 463, the signal delay in an Andover loop was measured. Fig. 53 shows the measured as well as calculated delays based on range information. A maximum error of about 20 microseconds or 2 miles was found.

12.3 *Time Synchronization*

On pass 424, the precision clocks at Andover and Goonhilly were compared by transmitting time pulses simultaneously in both directions. The accuracy of the method was believed to be about 20 microseconds, and a difference in clock time of 2 milliseconds was found. A more detailed description of the experiment is given in Ref. 7.

12.4 *Interference*

Measurements of propagation from potentially interfering TD-2 transmitters were made during October and November, 1962. Special crystal-controlled 4170-mc transmitters were located at the two nearest existing TD-2 stations and were equipped with antennas aimed directly at Andover. Study of the profile between Andover and West Paris, Me., 23.5 miles away, indicated that the controlling mode of propagation would be diffraction over a single obstacle about three miles from Andover. Study of the profile to Cornish, Me., 55 miles away, indicated that the controlling mode of propagation would be tropospheric forward scatter. These expectations were verified by the characteristics of the signal received at Andover. The signal from West Paris was very steady,

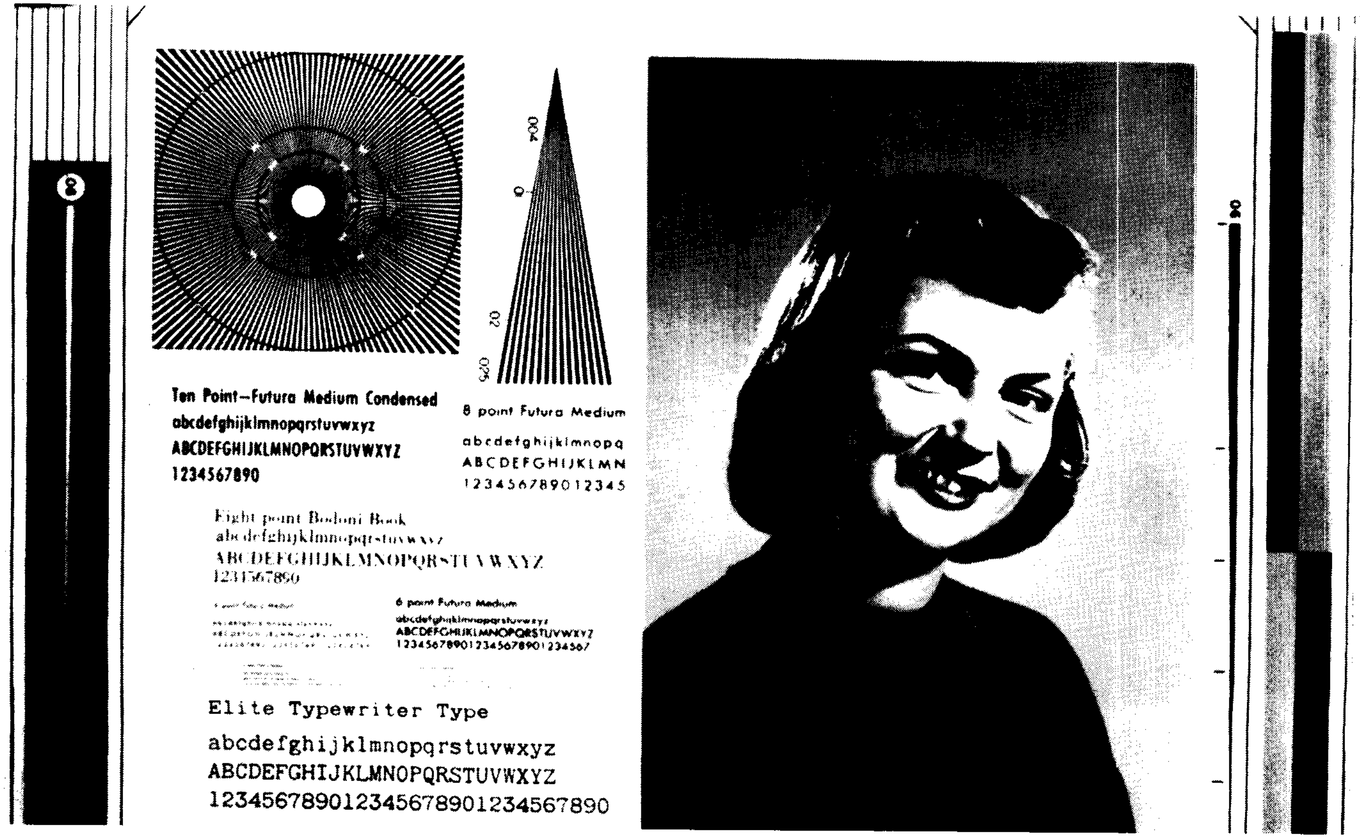


Fig. 49 — Voice-band facsimile transmission; satellite loop, pass 461, Aug. 29, 1962.


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Fig. 50 — High-speed, two-tone facsimile; satellite loop, pass 352, Aug. 17, 1962. (Keying rate is 675 kc. Jitter is due to unfiltered transients in the landline facilities.)

with negligible long-term and short-term variations. The signal from Cornish, on the other hand, showed the very rapid fading characteristic of tropospheric forward scatter. The median signal from Cornish was within about 5 db of what had been predicted, taking into account the "gain loss" of the transmitting and receiving antennas. The signal from West Paris, however, was about 30 db less than had been computed on the basis of knife-edge diffraction. The actual diffracting obstruction was a mountain covered with pine trees.

About 100 hours of measurements of the signal from Cornish were made with the Andover antenna elevated a few degrees above optical horizon. Several short periods of enhancement were noted, usually during the early evening hours, in which the received signal rose as much as 30 db for a few seconds. Several one-hour recordings were made on antenna lobe peaks near elevations of 2, 4, 6, 8 and 10 degrees. No anomalous effects were observed.

During reception from West Paris, elevation sweeps from horizon to zenith were made during moderately heavy rainfall and during dry weather. The rain appeared to augment the received signal when the Andover antenna was elevated more than about 40 degrees, but the augmentation was only about 3–4 db. Several slow-speed azimuth scans

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Fig. 51 — High-speed, two-tone facsimile; satellite loop, pass 352. (Frame skew is due to changing absolute time delay for the synchronizing signal.)

were made at several low elevations to define the "hot spot" at the true bearing of the interfering transmitter. At very low elevations the signal was increased in some directions, apparently by reflections from hills surrounding the Andover station.

Analysis of these data is continuing.

XIII. CONCLUSIONS

With economic, administrative, and hardware design considerations set aside and attention confined to technical transmission aspects, the Telstar satellite communication system is closely related to the FM microwave radio relay systems operating in the same frequency bands, i.e., the TD-2 and TH systems. The design parameters are somewhat different and subject perhaps to different state-of-the-art limitations, but the performance is just as predictable.

The communications tests show that the transmission performance of the Telstar satellite system is as good as or better than an equivalent length of the related land lines, when the satellite is visible to the terminal stations. Certain problems of great design importance in the land

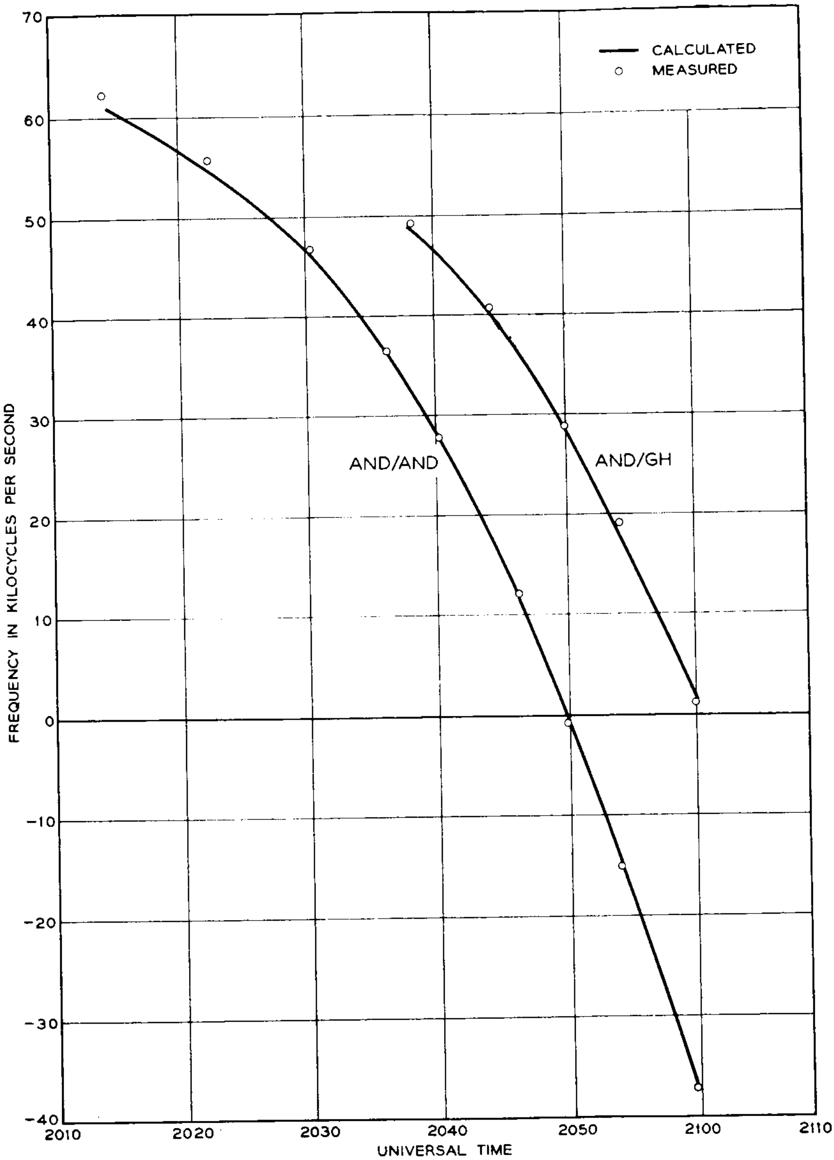

Fig. 52 — Doppler shift of communications carrier; pass 443, Aug. 27, 1962.

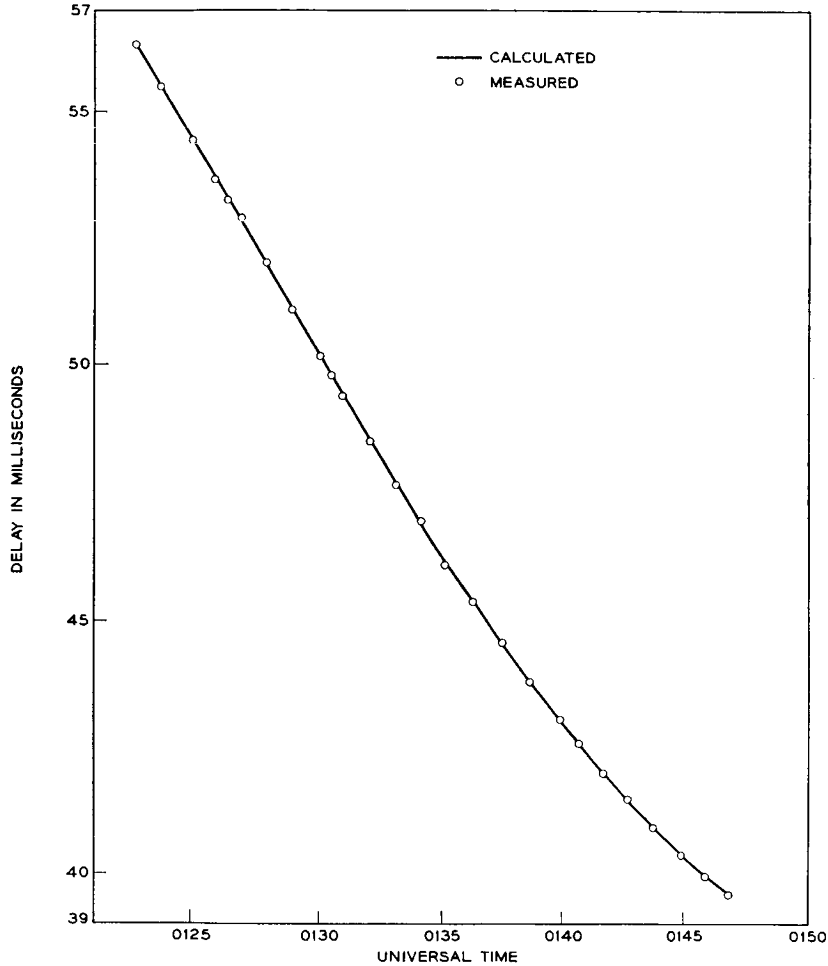

Fig. 53 — Absolute time delay of 5-μs pulse over satellite loop; pass 463, Aug. 30, 1962.

systems mentioned above are not present in the satellite system. These are (a) fading, (b) the need for highly accurate transmission equalization, and (c) the need for extraordinarily good frequency accuracy. The latter two arise from the large number of tandem relay sections in the landline systems.

On the other hand, some problems peculiar to a low-orbit satellite system are a direct result of its orbital nature, and are due to the varying range and spin angle. Although these variable parameters do not affect the transmission gain or delay distortion shapes, so far as is known, the variations in path loss do affect the noise performance. Although satellite spin (about its axis) is clearly seen on some of the recordings, there is no evidence to date of any effects on signal transmission. In addition, there are the Doppler and variable absolute delay effects to consider, particularly when transmission is transferred from a setting to a rising satellite; no tests were made on these effects.

XIV. ACKNOWLEDGMENTS

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Finally, none of this would be possible without the tremendous development effort of hundreds of people who created the Telstar satellite and the Andover earth satellite station. Nor could these data have been obtained without the assistance of the many people of both Bell Telephone Laboratories and Long Lines who have devoted many months of long days to operating and maintaining the Andover station. We also acknowledge the invaluable assistance of our foreign partners at Goonhilly Downs, England and Pleumeur-Bodou, France.

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