Quarterly Technical Summary | *Division* 6

Space Communications | 15 September 1977

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LEXINGTON, MASSACHUSETTS

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FOR THE COMMANDER

Raymond L. Loiselle

Raymond L. Loiselle, Lt. Col., USAF
Chief, ESD Lincoln Laboratory Project Office

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LINCOLN LABORATORY

SPACE COMMUNICATIONS

QUARTERLY TECHNICAL SUMMARY REPORT
TO THE
AIR FORCE SYSTEMS COMMAND

1 JUNE – 31 AUGUST 1977

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INTRODUCTION

This Space Communications — Division 6 Quarterly Technical Summary covers the period 1 June through 31 August 1977. It includes satellite communications work performed within Divisions 6 and 7. Other work in Division 6 is reported separately.

B. Reiffen
Head, Communications Division

C. W. Niessen
Associate Head

15 September 1977

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REPORTS ON SPACE COMMUNICATIONS

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PUBLISHED REPORT

Technical Note

*   *   *   *   *

UNPUBLISHED REPORT

Journal Article

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* Author not at Lincoln Laboratory.

ORGANIZATION

DIVISION OFFICE

B. Reiffen, *Division Head*
C. W. Niessen, *Associate Head*
S. Gould, *Assistant*

R. M. Lerner

GROUP 61

L. J. Ricardi, *Leader*
A. J. Simmons, *Associate Leader*

Burns, R. J.	Lindberg, C. A.
Burrows, M. L.	Mayhan, J. T.
Cummings, W. C.	Niro, L.
Dion, A. R.	Potta, B. M.
Frediani, D. J., Jr.	Turbett, T. M.
Lee, J. C.	Weikle, D. C.
Lim, H. K.	Weiner, H. S.

GROUP 63

L. W. Bowles, *Leader*
R. S. Berg, *Associate Leader*

Babbitt, H. S.	Leeds, K.
Bauer, R. F.	Robbio, T. P.
Berglund, C. D.	Safran, M.
Blomberg, E. L.	Small, C. E.
Collins, C. J.	Solman, F. J., III
Dolbec, R. E.	Staecker, P. W.
Hodsdon, D. M.	Stevens, M. L.

GROUP 64

T. S. Seay, *Leader*
D. R. McElroy, *Assistant Leader*

Bucher, E. A.	Liias, G. G.
Collins, L. D.	Metzger, L. S.
DeRosa, J. K.	O'Leary, G. C.
Eaves, R. E.	Rafuse, R. P.
Harvey, R. L.	Weiner, L. N.
Jones, L. R.	Willim, D. K.
Kalet, I.	Wilson, R. A.

GROUP 66

S. L. Bernstein, *Leader*
R. W. Chick, *Associate Leader*

Capetanakis, J. I.*	Sellers, G. W.
Hazel, D. F.	Siemasko, J. F.
Heggestad, H. M.	Spencer, N. W.
Helfrich, J. H.	Storch, S. B.
Levasseur, A. H.	Swanton, C. R., Jr.
McNeill, D. A.	Taylor, L. E.
Mui, S. Y.	Tiedmann, E.
Perry, K. E.	White, D. P.
Saklad, M. S.	Zeuli, H. E.

GROUP 68

F. W. Floyd, Jr., *Leader*
D. M. Snider, *Associate Leader*
W. W. Ward, *Associate Leader*

Alger, L.	Millner, A. R.
Conrad, P. J., Jr.	Pelletier, R. J.
Curley, C. R.	Petersen, W. A.
Davis, E. S.	Provencher, W. C.
Enxing, D. J.	Sarantos, T.
Flanders, G. T.	Siegel, D. A.
Giordano, J. L.	Sullivan, R. F.
Gjelsvik, A. M.	Trudeau, N. R.
Hart, J. M.	Walther, F. G.
Hoover, H. H., Jr.	White, N. B.
Hutchinson, W. K.	Woods, J. P.
MacPhee, J. V.	Wright, J. N.

GROUP 69

F. W. Sarles, Jr., *Leader*
B. H. Hutchinson, *Associate Leader*
C. M. Rader, *Assistant Leader*

Boroson, D.	Morton, S. G.
Coomber, D. B.	Rhodes, R. R.
Culmone, A. F.	Roberge, J. K.‡
Gagnon, G. P.	Rogers, D. C.
Godfrey, B. W.†	Semprucci, M. D.§
Hale, A. F.	Sitler, D. G.
Johnson, D. H., Jr.	Smith, W. B.
MacInnes, R. D.	Srivastava, S.
McKenzie, P. F.	Tai, C. H.

* Research assistant
† Part time
‡ Summer
§ Leave of absence

CONTRIBUTORS
TO
SPACE COMMUNICATIONS PROGRAM

DIVISION 7

J. F. Hutzenlaub, *Division Head*
P. Waldron, *Associate Head*
A. E. Johnson, *Assistant*

Blaisdell, E. W.	Hendrie, S.
Boisclair, W. F.	Hom, S.
Bouvier, A. J.	Knowles, P. G.
Brawn, M. W.	Leyenaar, A. R.
Caunt, J. W.	MacKay, R.
D'Arcangelo, A. J., Jr.	McLaughlin, J. D.
Farnsworth, L. P.	Murphy, E. B.
Folino, F. A.	Purdy, R. W.
Gordon, L. J.	Staffiere, A. R.
Greaves, A. W.	Sullivan, C. M.
Hagerman, A. H.	Wainwright, E. S.
Harney, W. F.	Weidler, D. E.
Heaslip, D. J.	Young, R. W.

ANTENNAS
GROUP 61

I. INTRODUCTION

Group 61 is concerned with the development of antennas and associated microwave components. Particular emphasis is placed on satellite, ground, and airborne antenna systems.

II. TECHNOLOGY PROGRAM

A. Introduction

As part of its satellite communications program, Lincoln Laboratory is studying a number of techniques which might permit the realization of more effective military satellite communications (MILSATCOM) systems.

MILSATCOM systems should discriminate between desired signals and interference. Modulation techniques which spread the signal bandwidth beyond that required by the data rate are widely used for this purpose. Additional discrimination can be obtained in principle by designing a receiving antenna which discriminates adaptively between signal and interference on the basis of direction. We have begun to study the feasibility of such a spacecraft antenna system operating at UHF.

B. UHF Antenna Nulling — Scale-Model Measurements

A program has been written to control the automated measurement system (AMS) to form nulls in any desired direction with the scale-model paraboloid multibeam antenna system. The AMS makes "instantaneous" measurements of the output of each antenna port, and then determines the weights required to form the nulls within approximately 10 min. after measuring the signals at each output port. This is to be contrasted to our previous technique where basic beam set data would be taken over a frequency band during a time period of several days. These data were stored on tape and used thereafter for an indefinite period of time to calculate weights and/or predict performance. Results using each method cross-check well; those using the AMS yield nulls in the desired direction and not offset from the desired direction as with the previous method. (This shift was due to the small changes in measuring environment between acquiring the beam set data and measuring the antenna performance.) Using the one-quarter-scale antenna and manually set weights, measured null depths ranging from 25 to 30 dB over a 44-MHz band (centered at 1550 MHz) have been obtained. These results are similar to those reported previously using the beam set data. However, with the AMS we can now examine in detail the channel mismatch encountered between output ports and how its variance, over the nulling band, sets the null depth. Examination of these data indicates that the antenna environment and feed-dish multipath effects account for a 30- to 35-dB limitation on null depth. We are currently pursuing techniques to isolate these multipath effects to determine their precise origin.

The effects of channel mismatches as a function of frequency and weight settings have been studied from the viewpoint of obtaining a desired cancellation over the nulling bandwidth, for an arbitrary number of elements (N) and number of interfering sources (J), where J < N. These results extend the simpler N-channel, single-interference case discussed previously. As N increases, it is found that the achievable interference <u>cancellation</u> equals the rms channel

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mismatch error independent of the number of interfering sources. Hence, since the interference power at the array output increases linearly with increasing number of incoherent jammers (assuming earth-coverage quiescent mode), the channel matching tolerances must decrease correspondingly (i.e., the nulls achieved must become deeper on each interfering source to keep the output below a specified minimum level after adaption).

C. Jammer Test Range

Studies of the feasibility of using one of the bays of the Bedford Antenna Test Range for the quarter-scale adaptive nulling tests were pursued further during the last quarter. A 200-ft range has been chosen for these tests; the principal problem is the level of the images of the sources. Attempts to reduce the image levels by means of fences have resulted in image levels about 20 dB below the level of a 5-ft-diameter source. It is doubtful that this level could be reduced much further because the bays are at ground level and the adaptive antenna diameter is about equal to its height above ground. The principal effect of 20-dB images on the adaptive antenna performance is that it will make the nulling bandwidth substantially smaller than the expected free-space value. In addition, the use of the ground-level bays is inappropriate for the accurate measurement of element gains and radiation patterns. This is due to a taper of about 2.5 dB in the vertical plane over the adaptive antenna aperture. This behavior also results because the adaptive antenna diameter is about equal to its height above ground.

To accurately measure the radiation characteristics of the elements of the adaptive array or to accurately measure its nulling performance, it is desirable to install this antenna at a height several times its diameter. The roof mount turntable is being considered for this purpose. With this mount, the adaptive antenna is about 35-ft above ground, resulting in image levels about 30 dB below the level of 5-ft-diameter sources. By means of fences, this level can be reduced to ~40 dB which is expected to be the level resulting from other effects (principally scattering by the roof edge and by nearby structures).

The principal problem with use of the roof mount is that it is unprotected from the weather. Use of an air-inflated radome for weather protection is being investigated. Such a radome is not expected to have deleterious effect on measurements, provided that it is fabricated of material with good transmission characteristics, that its wall thickness is less than about 0.020 in., and that its means of support does not introduce additional scatterers in the path of transmission.

D. Full-Scale Antenna

Development of a lightweight UHF crossed-dipole radiator for possible use in a satellite array continues. The radiating elements themselves consist of half-inch-wide copper strips encapsulated in Kevlar. A prototype antenna utilizing these elements has been fabricated and mounted on a simple square ground plane. The balun design consists of four parallel strip lines mounted on a Kevlar substrate cylinder and a conducting cylinder. The lines are fed by strip-line hybrids for proper excitation. Initial tests indicate full receive band axial ratios of $\leqslant 2$ dB and uncompensated input VSWRs of less than 3.0:1. Some work on element gain is necessary inasmuch as values recorded at the high end of the receive band were approximately 1-dB lower than expected.

E.   UHF Adaptive Array Configuration

Central to the evaluation of the configuration of an array is the processing gain of the array. This is the increase in received-signal-to-jammer-power ratio as a result of the adaptive response of the array to the presence of the jammer. The deeper the null on the jammer, the better the processing gain. In the present application, both the array width and the signal bandwidth are small enough so that they are not the limiting constraint on null depth. Two likely candidates for this role are channel mismatch and polarization mismatch. Thus, it is necessary to incorporate a consideration of their effects in the evaluation of an array.

During the last quarter, the array-evaluation program has been modified to take both these features into account. The channel mismatch was expressed as a Fourier series representing the perturbation of the channel transfer function from the nominal as a function of frequency. The Fourier coefficients can be generated randomly. The polarization mismatch modification involves the inclusion in the jammers' radiated power of a cross-polarized component which is statistically independent of the like polarized component, and the provision of a cross-polarization sensitivity into the specification of the antenna elements. In the program, the cross-polarization sensitivity factors are generated randomly.

Some results obtained during the quarter bearing on the mismatch question are: (1) that an existing simple formula for the null depth (mentioned in Sec. B above) was shown to be valid, at least as a useful rule-of-thumb, but that significant deviations from the formula's predictions occur as the number of elements or jammers changes; (2) that a method of channel alignment exists (in which each channel is separately aligned with the earth-coverage channel), promising substantially deeper nulls than are obtainable otherwise; (3) that the most serious threat in exploiting polarization mismatch is that for which practically all the jamming power is radiated in the cross-polarized sense; and (4) that the expected quantitative relationship between null depth and polarization mismatch was upheld when the number of jammers was one less than the number of array elements.

Some channel-mismatch results are given in Table I illustrating the variation in null depth as the number of jammers changes, and also the increase in null depth as a result of aligning the remaining channels to the earth-coverage channel, rather than aligning them to an external reference.

Figure 1 shows the effect on null depth of the power division adopted by the jammer in an effort to exploit polarization mismatch. The array used for this example was again the 7-element double-triangle array with all elements having 13-dB gain. The cross-polarized sensitivity of each element was assumed to have a mean value of zero and a variance corresponding to an expected cross-polarized power 25 dB less than the power received in the expected sense, assuming the illuminating power flux was equally divided between the two senses.

Some attention has been given this quarter to the choice from among all the elements of the array of the earth-coverage element. We conclude that the nulling resolution of the array is strongly affected by the choice when there is only one jammer, but that the choice makes no difference when the number of jammers is one less than the number of elements. (For an intermediate number of jammers, the effect is also intermediate.)

This effect results in an increase in the nulling resolution as the choice of earth-coverage element increases its distance from the mean position of the remaining elements. Its cause lies

TABLE I
AVERAGE GAIN ON JAMMERS FOR GIVEN CHANNEL MISMATCH (7-Element Double-Triangle Array,* 13-dB-Gain Elements, rms Channel Mismatch 0.078 dB, 0.51°)

No. of Jammers	Expected Average Gain on Jammers (dB)	
	External Alignment	Earth-Coverage Alignment
1	−28.1	−34.8
2	−26.9	−32.0
3	−25.6	−28.5
4	−25.6	−29.1
5	−25.5	−28.7
6	−25.3	−28.2

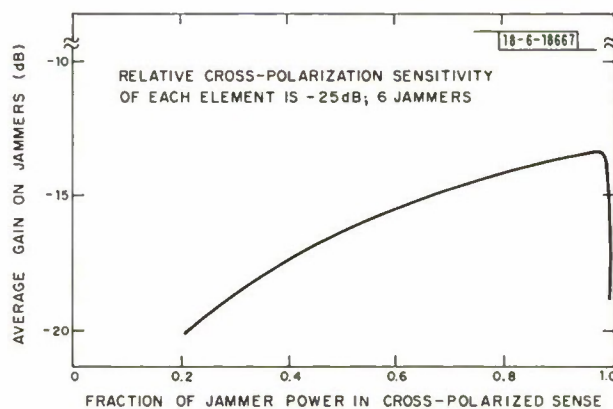*See Quarterly Technical Summary dated 15 June 1977.

Fig. 1. Expected average gain on jammers as a function of jammer power division between two senses of polarization.

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in the mathematical "degree" of the null. If the earth-coverage element is at the same place as the centroid of the remaining elements, the zero in the gain pattern placed on the jammer is of fourth degree. When the two are separated, however, the zero is of second degree, in the plane (A) containing the line between them and perpendicular to the plane of the array. The zero is of fourth degree in the plane perpendicular to this line and the plane of the array. Thus, the null width in the plane A is smaller than in the other plane.

Fig. 2. Resolution, as measured by size and shape of 0-dB contour for (a) center-element and (b) outer-element earth coverage.
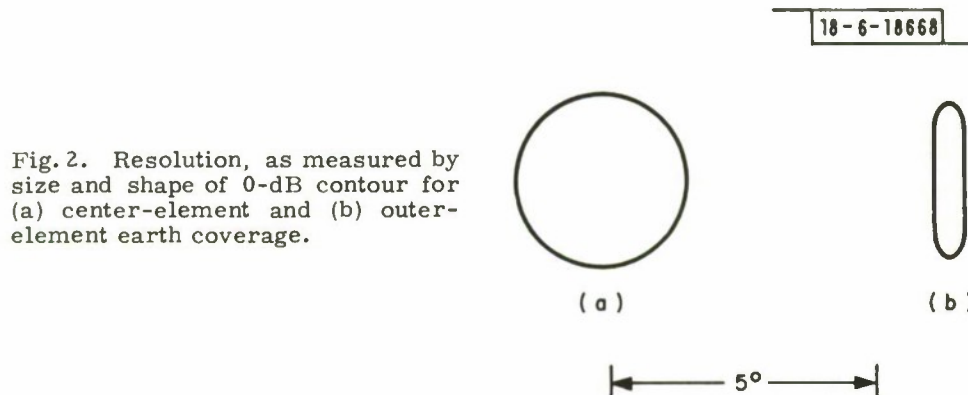
(a)   (b)

|← 5° →|

Figure 2(a-b) was obtained by plotting the 0-dB contour of the gain pattern of the 7-element double-triangle array after the weights had adapted to a single jammer. One of the shapes was generated when the center element was selected as the earth-coverage element, the other when one of the elements of the larger triangle was selected.

F.   Bench Test Simulator

Responses to Requests for Quotation for components for the Bench Test Simulator have been received and are being evaluated. The responses have not been entirely satisfactory, and it may prove necessary to consider fabricating some of these units in-house.

G.   Beam-Forming Networks

A synthesis procedure for beam-forming networks involving an arbitrary number of elements has been developed. The synthesis technique develops circuits which utilize 3-dB couplers and fixed phase shifts to convert an array into a multiple-beam antenna. The circuits synthesized are applicable to planar arrays which utilize antenna elements located on a regular rectangular or triangular lattice. The hexagonal arrays such as the 7- and 19-element arrays are included in this class. When the circuit is used with these arrays, the number of beams formed is equal to the number of array elements, the full gain of the aperture is realized for each beam, and the beams are distributed in a regular triangular lattice as are the elements.

Networks for "unfilled" arrays such as the 7-element double triangle previously described can also be formed. For this array, two beam-forming networks are used. One network uses the three elements forming the outer triangle to form a set of high-resolution beams. The other network uses the three elements which form the inner triangle to form a set of broad (BW ≈ 1/3 earth diameter) beams. The center element is utilized as an earth-coverage element. The nulling processor is then used to combine the appropriate high- and low-resolution beams with the earth-coverage element to place nulls on interference sources.

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A study is nearly complete which will determine the effects of component tolerances and frequency sensitivity on achievable null depths. The study utilizes the 7-element hexagonal array and the 7-element double-triangle array in order to test both the single beam-forming network and the dual beam-forming network approaches.

A theoretical investigation is in process to determine beam-forming networks which are applicable to arrays of arbitrary configuration. In many of these cases, the beams formed will not realize the full aperture gain of the array because the beams will be coupled to some extent. A network for the 5-element pentagon array has been synthesized which demonstrates this property. The gain of each beam is 1.1 dB less than the full aperture gain.

H.   Weighting Network

Investigation of networks which can be used to set the antenna element weights is currently under way. The weighting networks are to be designed to operate over a 10-MHz IF bandwidth (centered at ~120 MHz), to be used with a UHF system. In addition, they must also operate satisfactorily over the larger IF bandwidth (~44.2 MHz) of the scale-model L-band adaptive antenna currently under development.

The development of a single-weight circuit utilizing commercially available stripline quadrature hybrids and PIN diodes is under way. Various driver circuits for controlling the PIN diodes have been fabricated and are undergoing final checkout. The relative merits of voltage-vs current-controlled driver circuits are being evaluated. Techniques for temperature stabilizing the PIN diodes and for linearizing the weight networks are also under investigation.

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RF TECHNOLOGY

GROUP 63

I. INTRODUCTION

During this past quarter, the development of receivers and feedback loops for demonstration-model adaptive nulling systems has continued. In addition, progress is reported in the development of frequency sources and receiver components at X-band, and an investigation of IMPATT diodes for K-band transmitters has been completed. The effort to provide added capabilities for automated RF measurements is producing results.

In addition to the work reported below, other activities have included participation in technical reviews of the NATO III, DSCS II, and FLEETSATCOM satellites.

II. RECEIVER DEVELOPMENT

A. Adaptive Nulling

Loop component development for the L-band scaled nulling project is proceeding in the following areas: low amplitude-to-phase conversion amplifiers, zonal filters, and correlators. Component procurement has progressed to the stage where most evaluation units have either been received or ordered. This includes hybrids and mixers, as well as an electronically controlled attenuator.

Work is continuing on the development of a receiver front end for use with the L-band adaptive nulling system. All components for this unit are in-house, with the exception of some mixers which are on order. Two 121.4-MHz IF filters have been designed and breadboarded. Initial measurements show that component matching is sufficient to produce at least a 35-dB null depth. This represents the limits for the network analyzer presently in use. Considerable effort is planned during the next quarter to improve measurement capability so that component matching equivalent to 50-dB null depths can be evaluated.

A direct conversion receiver is proposed for the digital adaptive nulling system. A computer model of this receiver has yielded preliminary requirements for noise figure, gain, and intermodulation performance for each stage. On this basis, prototypes have been designed and are now in fabrication. A bus-controlled test set for measurements of baseband noise, intermodulation, differential gain, and differential phase has been designed and the major components ordered.

B. Test Sources

During the last quarter, most components for the antenna nulling jammer source were requisitioned and mechanical design is in process. Test instrumentation and purchased components are in verification tests, and minor integration is in progress.

C. X-Band Receiver

Work was begun this quarter on the evaluation of GaAs FET transistors for construction of low-noise X-band receiver front ends. Dexcel and Hewlett-Packard devices were obtained, and S-parameter measurements were started on sample devices.

In order to make a characterization of the source impedance required for optimum noise figure, it was necessary to build a pair of slide screw tuners using two slab line slotted sections. These units use a sliding capacitive tuning probe. This design tends to present source and load impedances at low frequencies which approach matched loads, which helps to insure that the device under test is stable during measurements.

III. TRANSMITTER DEVELOPMENT

A. UHF Transmitter

Work is continuing on the dynamic load-pull characterization of high-power UHF transistors. New transistor holders have been built which have made possible the characterization of devices in the 50- to 100-W RF output range. Several high-power devices have been characterized, and amplifiers have been designed making use of the load-pull measurements. One amplifier, using a single device, produced 106 W output with a gain of 7.2 dB and a collector efficiency of 87.2 percent at 230 MHz.

The slotted-section tuner has been modified for greater mechanical and electrical stability, and modifications are now being made to the existing tuner.

The design of a "flight-like" engineering-model UHF transmitter has begun. The transmitter will be used to demonstrate and evaluate new design and construction techniques.

B. K-Band Transmitters

All fabrication and testing of K-band gallium arsenide IMPATT diodes have been completed. The best test results for diodes delivered in this program include added powers of 1.0 W at 20 GHz with 11-percent efficiency, and 0.87 W at 22 GHz with 9.1-percent efficiency. Diode performance achieved using special packaging techniques did not exceed that obtained with conventional diode packages containing discrete subharmonic terminations. This development program was concluded with a five-stage amplifier demonstration which delivered 2.60 W power output at 20 GHz with 33 dB gain, a 1-dB bandwidth of 1 GHz, and an overall DC-to-RF conversion efficiency of 7.1 percent.

IV. FREQUENCY SOURCES

An FET voltage-controlled oscillator, designed for operation at X-band, is being developed. Work to date has concentrated on microstrip realization of circuit elements required for this design. Directional couplers and phase shifters have been successfully fabricated and tested. Devices have been characterized at X-band to allow design and fabrication of an FET amplifier, the main part of the oscillator.

Two planar Gunn triode devices have been obtained from TRW for evaluation as microwave-frequency dividers. Negative terminal resistance has been observed, and frequency division from X-band to 1 GHz has been achieved.

A test system under calculator control allowing step tuning response of VCOs has been set up and is operating. Efforts to improve the system resolution (currently 10 μsec) are continuing.

V. AUTOMATED MEASUREMENTS

The Automatic Network Analyzer was shipped to a contractor on 5 August for modification, and will be out of the laboratory for approximately three months. The modifications will

include upgrading the analyzer and detector, and the addition of a new test set, a new computer with 32K words of memory, a graphics console, a disk memory, and a printer/plotter.

The effort to provide a laboratory automated measurement system for Group 63 is continuing. Three graphic computer systems have been in use for a number of months, and a variety of application programs has been written to allow instrument control and data acquisition. This system has adequate capability in this area for our current needs. However, the input/output data transfer rate is limited and may prove to be inadequate for some future applications.

In addition to collecting data, a laboratory measurement system must provide data-processing capability to extract information from the raw data. The graphic computer system has provided adequate capability in this data-processing step, the strong points being a good high-level programming language and graphic output. However, it is a relatively slow computer and in some applications does not provide an answer in a reasonable time. A study is currently under way to determine the relative efficiency of performing data processing on this system vs transmitting the data to the IBM 370/168 for processing.

The possibility of using a dedicated central computer to provide additional data-processing capability for the local laboratory computers is being studied. Preliminary results indicate that a dedicated central computer would allow higher data-transfer rates than can be achieved with the IBM 370/168, but that this advantage is offset by the relatively long processing times of the candidate central computers as compared with the IBM 370/168.

A controller, programmable in BASIC, has been ordered for evaluation as the next-generation local laboratory computer. This computer has greater input/output data-transfer rates than the present graphics terminal and is a faster data processor.

SATCOM SYSTEM ENGINEERING
GROUP 64

I. INTRODUCTION

Group 64 is responsible for a variety of architectural, system engineering, analysis, and simulation tasks for future MILSATCOM systems and on-going technology programs, as well as transferring the LES-8/9 and associated technologies to potential operational systems. During this quarter, responsibility for planning and execution of the LES-8/9 experiments was transferred to Group 68.

The Group provides support to internal Division projects as well as to SAMSO/SKA and DCA/MSO. In addition, during the last quarter we provided support through:

(a) Participation in the Preliminary Design Reviews and monthly technical reviews for the Single-Channel Transponders (SCT) on DSCS-III and GPS for SAMSO/SKA.

(b) Reviewing and commenting on Statements of Work for the SCT Injection System and the Command-Post Modem/Processor for SAMSO/SKA.

(c) Reviewing and commenting on the Strategic Satellite System (SSS) satellite configuration work under way at Rockwell International for SAMSO/SKA.

(d) Participation on the communications system, spacecraft, terminals, and support teams involved in the System Engineering Design/Trade-off Group efforts supporting the GPSCS/SSS DSARC for SAMSO/SKA and DCA/MSO.

(e) Participation in the Requirements Team activities supporting the planned GPSCS/SSS DSARC for DCA/MSO.

(f) Reviewing and commenting on modifications to the LES-8/9 modulation proposed for improved performance against nuclear propagation efforts, and participating in an informal review of a contractor study task of nuclear propagation effects relative to GPSCS and/or SSS, for SAMSO/SKA.

II. LES-8/9 COMMUNICATIONS LINK TESTING

During this quarter, the Lincoln terminals have been primarily engaged in Phase IV cooperative demonstrations and measurements with the Service terminals. These activities have been directed toward completion of the LES-8/9 test program. The following subsections summarize the activities of the Lincoln K-band command-post (ABNCP) and the three Lincoln-built UHF force-element terminals in communications link testing. Activities associated with the Lincoln K-band Navy terminal are reported separately.

A. K-Band Command-Post Terminal

The Lincoln K-band command-post terminal has provisions for computing the range to the satellite based on measurement of the elevation angle by the autotrack antenna. The range

computation is performed by suitably programmed read-only memories (ROMs). This feature is quite useful when the NOVA computer is not available for range prediction. This backup range prediction was successfully demonstrated for both forward and 10-kbps conferencing-link communication. The algorithm does not provide the accuracy required for 100-kbps conferencing operation, however.

Ephemeris data (9th-order polynomial coefficients) were transmitted via the conferencing link from the NOVA computer at Lincoln to AFAL. These data have been used subsequently in the operation of the AFAL terminals, and on one occasion the transfer took place while the aircraft carrying the airborne terminal was in flight. The ephemeris data transfer takes place at 1200 bps, coded rate $1/3 \times 1/2$. Transmission over the link is synchronous ASCII. The data transmission originates in either of the Lincoln NOVA computers as asynchronous ASCII, with the reformatting being performed in the Lincoln ABNCP. When the NOVA (an integral part of the Lincoln terminal) is used as the source of the ephemeris data, it is not available for antenna-pointing, time-delay, and Doppler predictions. Backup means of providing this information must be used. When the NOVA in the Lincoln Experimental Satellite Operations Center (LESOC) is used to generate the ephemeris data, the ABNCP's NOVA is available for use by the terminal. Both configurations were demonstrated.

Cooperative conferencing-link tests were conducted with AFAL in which all the TDMA and multiplex modes and addresses were successfully exercised with Lincoln transmitting to both AFAL terminals. A timing problem in the AFAL terminals prevented their transmitting messages to Lincoln; this demonstration will be done at a later date.

B.   Lincoln UHF Force-Element Terminal (FET)

The final flight-testing of FET 3 on-board AFAL aircraft No. 12662 based at Wright-Patterson AFB, Ohio, was conducted during this quarter. The first flight provided for in-flight report-back to LES-8 and then via the crosslink to LES-9. The report-back messages were received via the LES-9 K-horn downlink by the K-band ABNCP terminal on-board the aircraft. With LES-8 at the most northerly part of its orbit, the aircraft flew 15-min. racetrack patterns over southern Maine, while maintaining UHF line-of-sight communication with Lincoln Laboratory for test coordination. During the eight passes, narrow-band UHF report-back messages were transmitted in the HELP and HOP uplink modes using the forward blade, the Lincoln Laboratory crossed-slot, and the Dorne-Margolin crossed-dipole antennas. Further details of these tests will be contained in a forthcoming report.

A successful forward-link handoff from LES-9 to LES-8 was accomplished during the second flight northwest of Wright-Patterson AFB. In order to minimize the westward flying time required to accomplish the handoff, the flight occurred with LES-9 near the most southerly part of its orbit. The Lincoln Laboratory K-band Navy terminal transmitted continuous forward messages through LES-9, while the Lincoln K-band ABNCP terminal transmitted continuous forward messages through LES-8. As the aircraft flew into cloud cover and turbulence with LES-9 at approximately $-2.5°$ elevation angle, the Lincoln UHF FET lost lock on two occasions, but it reacquired the LES-9 hopped UHF downlink each time. Finally, with LES-9 at approximately $-2.8°$ elevation angle, the terminal stopped printing the LES-9 forward messages (i.e., the signal was below the communication threshold), but it continued to track the UHF downlink. Handoff occurred 1 min. later, with subsequent receipt of forward messages from LES-8.

FET 3 (the flight unit) was returned to Lincoln Laboratory during the week of 20 June.

A series of UHF downlink multitone-jamming performance tests were conducted with FET 2 and the laboratory prototype satellite, following completion of corrections in the terminal (the corrections were needed to optimize jam resistance). The tests demonstrated anti-jam performance which agrees well with the predicted performance. The results will be reported elsewhere.

As a part of correcting FET 2 for jam resistance, the acquisition and tracking thresholds were changed. The performance of the equipment was then tested in Gaussian noise. The terminal will auto-track at 29 dB-Hz, and the probability of acquisition is greater than 90 percent at 29 dB-Hz. Communications threshold (90 percent probability of message receipt) is 30 dB-Hz.

C. Satellite-Commanding from an Airborne K-Band Terminal

In conjunction with the flight-testing of the UHF FET 3, a demonstration of the capability of commanding the LES-8/9 satellites from an in-flight ABNCP was conducted. Using the Lincoln Laboratory command/telemetry status panel and the AFAL K-band command-post terminal on-board aircraft No. 12662, commands were sent via the alternate (MFSK) command channel. The test command (No. 511, execute only) and command of the downlink synthesizer from HOP to HELP and back to HOP (both data and execute commands) were exercised several times. A LES-9 change of downlink modulation (from T to F^u) and a partial change of the LES-9 satellite from the forward (Mode 34G) to the report-back (Mode 2B) configuration were also accomplished.

D. Documentation

The latter portions of the Laboratory's post-launch LES-8/9 communications test program have concentrated on the coded performance, the message throughput rates, and the general utility of the links which the satellites can support. Most of these tests have now been completed, and their results, which are generally grouped according to the particular links involved, will be contained in the Project Reports which are shown in Table II. During this quarter, the forward-link, conferencing-link, and K-band jamming reports were completed.

III. APPLICABILITY OF NUCLEAR-POWER SOURCES TO GPSCS

A preliminary study was done comparing the use of a nuclear-power source and a conventional solar-power source on a possible General-Purpose Satellite Communications System (GPSCS) spacecraft. To assess the impact of a nuclear GPSCS, a list of technical issues was identified. Three types of nuclear-power sources were considered: Selenide RTG and Brayton and Rankine dynamic systems.

Table III summarizes the advantages and disadvantages of nuclear-power sources in reference to GPSCS. Use of a nuclear-power source would eliminate the problem of solar-array stowage and deployment. The design and testing of the solar-array mechanism would require significant engineering effort. One dominant trade-off is providing cooling of the nuclear heat source in the shuttle bay during ascent to the parking orbit (and during re-entry for an aborted launch). While studies of such a cooling system have already been made, the actual design and testing efforts would be comparable to those associated with the solar-array deployment mechanism of the solar GPSCS.

TABLE II
DOCUMENTATION OF THE LES-8/9 POST LAUNCH COMMUNICATIONS LINK TESTS

Phase III ond IV Test Results	Appropriate Report	Report Clossificotion
Forward Link	SC-41-1	Unclassified
Satellite Monitoring and Command		
Conferencing Link	SC-41-2	Unclossified
UHF Report-Back Link	SC-41-3	Unclossified
Supplement 1		Secret
Navy Report-Back Link	SC-41-4	Unclassified
K-Band Jamming Results	SC-41-5	Secret
UHF Jamming Results	SC-41-6	Secret

TABLE III
NUCLEAR-POWER APPLICABILITY TO GPSCS

Feature	Advantage	Disodvontoge
Shuttle stowage and deployment	Eliminates solar panel stowage and deployment	Cooling in Shuttle payload boy
Power conditioning ond distribution	AC source may simplify conditioning/distribution	–
Weight	Specific power (W/lb) comporoble to solar system ot GPSCS power levels	
Antenna design	Little or no effect	–
Satellite design	Simplify thermol control Slower degradation Orientotion independent	Not spoce-tested Reliability unknown Radiator and shape must change from present designs
Handling and safety	–	Extra constraints
Costs	–	More expensive

The output of a dynamic nuclear-power system is AC with a frequency of about 2 kHz. AC may be preferable to DC for conditioning, since it eliminates a power oscillator and gives smaller distribution losses. However, since most communication circuits require DC, rectification and filtering would be needed. There appears to be no net conditioning benefit from an AC power source.

For a 1-kW EOL system, a solar-power system would weigh about 470 lb compared with 525 lb for a Selenide/Modular system or 600 lb for a Brayton/MHW system. These weights include conditioning, distribution, batteries, and 7-year geosynchronous degradation, and are sufficiently close that no decision can be made solely on the basis of weight savings. Above 2 kW or 7-year missions, nuclear systems become significantly lighter than solar systems.

A satellite powered by solar cells will require careful design and testing efforts to produce a reliable system. Thermal control of battery temperature is critical to long life, particularly if the NiH type is used because of the low operating temperatures. The solar-system output is dependent on orientation, and the drive assembly alone can be expected to cost about $0.5M per spacecraft if prudent ground testing is done. In addition, a solar system is vulnerable to circuit breaks between individual panels and the resulting significant loss of output. On-orbit degradation will be larger than nuclear systems. While the solar system presents many problems, the solar technology at the 1-kW power level has been space-tested and the problems and their solutions are known. In contrast, a nuclear system has not been space-tested at this power level and would represent a large, nontrivial increase in capacity from the largest (300-W) static system yet used (in the LES-8/9 program).

For a nuclear-power system, the use of radioactive material will require significant handling and safety constraints. ERDA has developed many computer programs to use in assessing the safety aspects of nuclear payloads. In addition, there is a strong, effective review cycle for all nuclear missions which a nuclear GPSCS would have to pass. Based on the LES-8/9 and other programs, indications are that a nuclear GPSCS could meet the safety criteria.

Table IV shows a comparison of recurring and nonrecurring costs for the four GPSCS candidate power systems. The solar-system costs are from the SAMSO cost model, and the nuclear-system costs are from a recent DoD/AEC Space Power Study (1976). The table assumes a 1-kW output at the end of a 7-year mission, and an 8-percent inflation rate for projecting costs from the base years to 1980. These costs indicate that a solar system is less expensive than the nearest nuclear system in development costs ($6.9M vs $20.7M) and recurring costs ($1.6M vs $4.2M). Recent studies show that the recurring costs of nuclear systems become less than solar systems only above about 10 kW. For comparison, by agreement with the DoD, the LES-8/9 MHW generator cost was $6.0M for 250 W (EOL), or roughly $24K per W(e) EOL. That price includes the raw 238_{Pu} fuel estimated at slightly over $3.0M.

The principal conclusion is that at the planned GPSCS power level (~1 kW), single-spacecraft mission duration (7 years), and orbit altitude (synchronous), a nuclear-power source is not particularly attractive for a deployment in the mid-1980s. Although such a nuclear system would be roughly comparable to a solar-power system on a specific power (W/lb) basis, the former would be considerably more expensive to develop and procure, would impose extra handling and safety constraints, and would require Shuttle payload bay-cooling procedures. Since solar-power systems which meet requirements similar to those of the GPSCS concepts have already been developed and space-qualified, there do not appear to be any strong reasons for using a nuclear system on the GPSCS spacecraft.

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TABLE IV		
GPSCS POWER-SYSTEM COSTS (1980)*		
System	Nanrecurring (Development) ($M)	Recurring (per Satellite) ($M)
Solor	6.9	1.6
Nuclear		
Selenide	28.8	11.0
Broyton	31.3	4.0
Rankine	20.7	5.3

*Assumes:

(1) 1-kW (EOL), 7-yeor mission.

(2) 8-percent inflation rote, 1980 casts.

(3) Botteries, canditioning, distributian, etc.

(4) 238_{Pu} fuel at $630 per thermol W unencopsulated.

Sources:

1. R. Dominques et al., "Spoce and Missile Systems Organization Unmonned Spacecroft Cost Model," 2nd Editian, SAMSO TR Na. 73-247 (July 1973). (SOLAR)

2. DoD/AEC Ad Hoc Study Group on Space Pawer, "DoD/AEC Power Study," DDR&E and AEC Repart (April 1976). (NUCLEAR)

IV. MODULATION DESIGN FOR MINIMUM CROSSTALK

The optimization of quadrature-carrier modulation systems for close packing of users was continued during this quarter. For many practical operating conditions, the optimum windows which were generated can significantly reduce crosstalk below that for MSK or SFSK and can permit closer frequency spacing of users.

Initially, a one-parameter class of windows was considered which contains MSK and SFSK as subcases. Optimization was accomplished by finding the parameter values which minimize mean-square crosstalk at various spacings. The class of windows was then completely generalized to include all constant envelope windows. The phase of the window function was expressed as a truncated form of a complete expansion which can be made arbitrarily accurate. Fastest convergence was achieved with a composite trigonometric-polynomial expansion, and ten terms were adequate to guarantee good accuracy relative to the error inherent in 8-bit quantization. Optimization was accomplished by finding the expansion coefficients which minimize a performance index based on the integrated mean-square crosstalk. All optimization results were obtained through a quasi-Newton computer algorithm which locates minima in N-space through iterative search. A typical window is shown in Fig. 3, and the resulting optimized crosstalk performance is shown in Fig. 4.

The improvement over MSK or SFSK depends upon the spacing at which the window is optimized. At spacings less than $\Delta_f/R \sim 1.5$, the reduction in crosstalk is noticeable but not large. At spacings $\Delta_f/R \sim 3.0$ or larger, reduction in crosstalk is not relevant since quantization noise and other factors dominate crosstalk. However, for $\Delta_f/R \sim 1.5$ to 3.0, which is likely to be the practical design range, substantial reduction in crosstalk can be achieved. For example, if a maximum crosstalk level of 48 dB is identified, the optimum window permits a spacing of $\Delta_f/R = 1.8$, as compared with $\Delta_f/R = 2.6$ for SFSK and $\Delta_f/R = 2.8$ for MSK.

V. PACKET SWITCHING IN A PROCESSING SATELLITE

Some recent Lincoln Laboratory work concerned with the technology development of digital processing satellites has resulted in significant new results in the area of packet switching.[*] It is demonstrated that in a processing satellite there is no fundamental limitation to the efficiency and throughput of packet-switching systems. With a minimal impact on spacecraft weight and power, throughput is increased by providing more capacity on the uplink than on the downlink. Efficiency is increased because the power-intensive downlink is more fully utilized.

A slotted ALOHA example showed that the throughput per packet time slot is given by

$$S = 1 - (1 - \frac{G}{n} e^{-G/n})^n$$

where

$\quad\quad\quad$ G = mean of the total traffic in packets/time slot

$\quad\quad\quad$ n = number of separate (FDMA) uplinks available.

When n = 1, the slotted ALOHA throughput is Ge^{-G} and the processing satellite acts identically to a repeater satellite. When there is a large number of uplinks (i.e., $n \to \infty$), the throughput

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[*] J. K. DeRosa and L. H. Ozarow, "Packet Switching in a Processing Satellite," private communication (accepted as a correspondence in Proc. IEEE).
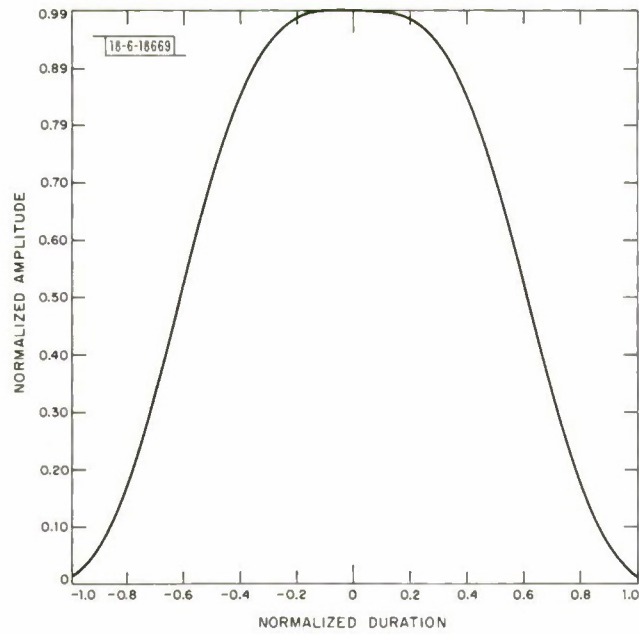
Fig. 3. Window which minimizes integrated mean-square crosstalk for $2 \leqslant \Delta_f/R \leqslant \infty$.
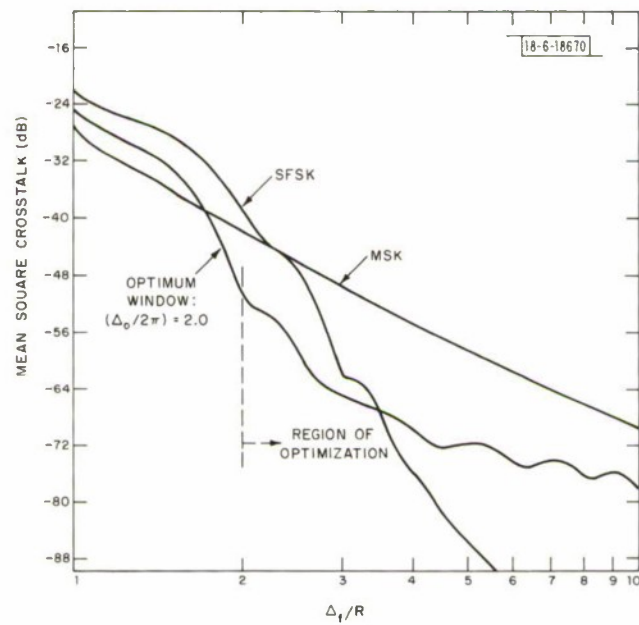

Fig. 4. Crosstalk characteristics for optimum window shown in Fig. 3.

approaches one packet/slot, and the downlink utilization approaches 100 percent (as in TDM). From a practical viewpoint, n need not be very large before substantial gains in throughput are obtained. Figure 5 shows that for n ⩾ 3, 75-percent throughput can be achieved, and for n = 10 nearly 100-percent efficiency is achieved.
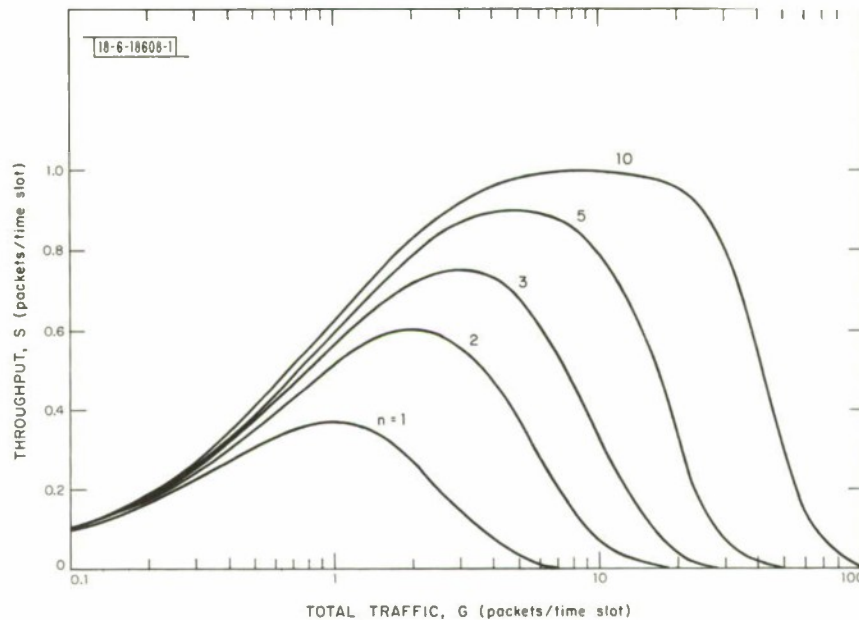

Fig. 5. Throughput for slotted ALOHA in processing satellite with n uplinks and 1 downlink.

These results are valid for the case of n FDMA uplinks and one TDM downlink, all signaling at the same rate. It was assumed that if two or more packets are successfully received at the satellite during any one time slot, only one of them (chosen at random) would be routed to the downlink while the others would be discarded (i.e., blocked packets are cleared).

More recently, these results have been extended to include the cases in which blocked packets are cleared on a frame-by-frame basis (rather than time-slot-by-time-slot) and in which packets are queued in the satellite. Computer simulations give results that agree quite closely for blocked packets cleared.

Additional numerical evaluation of theoretical results (e.g., framing and queuing) is proceeding, and computer simulations are being used to verify the theory. The detailed application of these results to present or future MILSATCOM systems has not yet been considered. However, we feel at this time that the pervasiveness of packet communications in terrestrial systems, coupled with the increased efficiency available with a processing satellite, merits further study of this subject.

VI. A DISTRIBUTION FUNCTION FOR A SUM OF SINUSOIDS

Using both analytic techniques and computer simulation, cumulative amplitude probability distribution functions for the sum of N, equal-amplitude sinusoids were obtained. The frequencies were chosen so that no one sinusoid's frequency was rational-fraction related to another's.

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We were interested in addressing two questions:

    (a)   How many sinusoids are required to model Gaussian noise to high accuracy (at least 4σ)?

    (b)   What is the most likely peak value expected from the sum of N sinusoids?

The answers to such questions have application in such areas as modeling for multitone jammers and voltage breakdown specifications for RF multiplexers and antennas which must carry multiple transmitter outputs.

    We found that 12 sinusoids very accurately modeled the cumulative amplitude distribution function for Gaussian noise out to and beyond 4σ. With 6 sinusoids, the agreement was good only out to 2σ. As a result, with 4σ (down 80 dB on the distribution tails) chosen as a measure of expected peak value for Gaussian noise, the peak value for N sinusoids with $N > 12$ rises only as 8N. For $N < 6$, we found the peak value to rise as N^2.

    A plot of the expected peak voltage or peak power ratios for the sum of N, equal-amplitude sinusoids is given in Fig. 6 for a 4σ limit. As the number of sinusoids in the ensemble increases beyond 8, the peak-power margin increases as $N/8$.
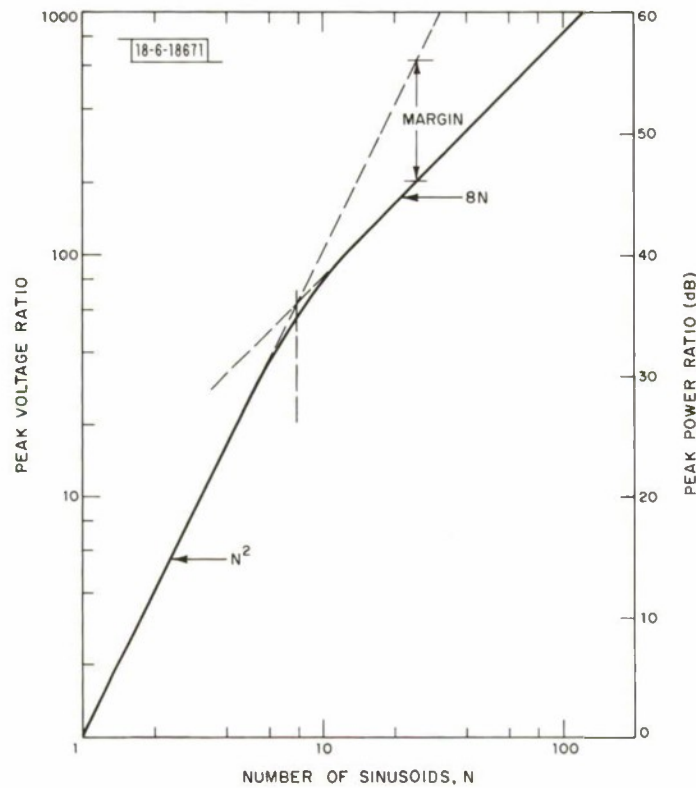

Fig. 6. Expected peak voltage or peak power for a sum of N, equal-amplitude sinusoids normalized with respect to voltage and power of a single sinusoid. Frequencies are nonrational-fraction related.

SPACECRAFT TECHNOLOGY
GROUP 68

I. INTRODUCTION

The recent reorganization of Division 6 resulted in Group 68 assuming a new set of responsibilities. In particular, the Group is now charged with the development of the brassboard analog feedback adaptive nulling antenna system.

The remaining months of the formal LES-8/9 Test Program are also the responsibility of Group 68, along with planning for the transition of the satellites to operational use by the Services at the conclusion of the Test Program (now scheduled for 1 October 1977). The upgrading of LESOC (Lincoln Experimental Satellite Operations Center, at Lexington) for long-term service is under way.

The ongoing development of command/telemetry technology for advanced satellite control systems continues. The results of studies of attitude-control systems for possible GPSCS satellites culminated in the publication of a Technical Note. The automated radiation test facility is nearing operation. The developmental magnetic bearing is being assembled.

II. FEEDBACK ADAPTIVE NULLING

A. Control Unit

The digital control unit for the analog feedback version of the adaptive antenna nulling system has been more completely specified, and a preliminary functional configuration has been chosen. The processor has been operationally divided into a series of individual antenna channel control units, data acquisition and storage units, and a central-processor control and interface unit.

The channel-control units are currently in the preliminary design phase, and parts selection and purchasing are in progress for breadboard electronics fabrication. The central-processor control and interface unit is in the preliminary system-definition phase.

B. Multiplier

Development work on a four-quadrant transconductance multiplier has begun. The multiplier will be used in the brassboard analog feedback adaptive nulling system. The multiplier is required to have a 44.2-MHz bandwidth at 120 MHz IF. Feedthrough and gain errors are required to be at or near the 1-percent level. At this time, it appears that these requirements can be met, but it will require some attention to detail in design and implementation.

C. Test-Bed Simulator

Support is being provided to Group 61, which has responsibility for the test-bed simulator which will be used to evaluate the two adaptive antenna nulling systems under development in Division 6 (analog feedback system in Group 68, block-processing digital system in Group 69). The UHF components have been ordered. The L-band components will be ordered next.

III. COMMAND AND TELEMETRY

A. Serial-Time-Code-to-IEEE-488-Bus Converter

A prototype unit of a LESOC serial-time-code-to-IEEE-488-bus converter has been completed and demonstrated. This unit provides accurate coordinated date and time information for use in laboratory measurement systems. Production of several units for specific test systems is likely.

B. Data Generator-Controller

Checkout of the controller, started in the last quarter, has been completed. A set of MACRO definitions has been developed to facilitate assembly of programs to operate the data generator. This data-generator facility provides a basic capability for a variety of test applications, including simulation of command and telemetry data streams.

C. Time-Sharing Computer Interface

The concept of a routing box as described in the Division 6 Microprocessor Committee Report has been breadboarded and demonstrated for the case of the ASCII serial-asynchronous side port. Some additional buffering and protocol would be required to handle the case of a peripheral with a lower baud rate than the host computer line. The availability of a reproducible hardware box with this capability could enable easy use of the Laboratory's central-time-sharing computer system in support of individual microprocessor and minicomputer operations.

D. Analog-to-Digital (A/D) Converter

During the past quarter, a prototype model was completed of a unique integrating A/D converter that has been under development for several months. Although a complete characterization has yet to be made, the basic specifications are:

Resolution	16 bits
Cycle time	1.6 msec; 1.2-msec conversion, 0.4-msec reset
Signal-integration time	0.4 msec
Scale	±6.5536 V; 1 LSB = 200 µV
Linearity	Within ±1/2 LSB
Autocalibration	Performed periodically to correct for errors in scale factor, offset, and differential linearity

The primary purpose of the prototype was to demonstrate the feasibility of this conversion technique, and this has been achieved. The converter's accuracy is nearly an order-of-magnitude better than standard dual-slope integrating converters operated at comparable speeds. The next step is to obtain more complete data on the converter's error-pattern and noise characteristics. Toward this end, a tester has been designed and built to semiautomate (and later, to completely automate) these measurements.

E. Microprocessor Evaluation

A commercially available I^2L microprocessor is under evaluation as a possible flight-qualified part. Some simple programs have been written and run using a single-board evaluation kit, but more thorough experience in using the chip will have to wait for cross-support software. This software will run on our IBM 370 and will assemble microprocessor programs and

simulate their execution. The package is scheduled for October 1977 delivery. Our impression thus far is that this microprocessor is very powerful, with computational and architectural features that make it well-suited to interrupt-driven, multi-tasking operations, such as process control.

IV. CONTROL SYSTEMS

A. Attitude-Control-System (ACS) Studies

A study of attitude-control concepts applicable to candidate GPSCS satellites was completed with the publication of Technical Note 1977-30.*

The ACS proposed in this report addresses three major problem areas:

(1) Tolerance to various high-torque environments, since the external geometry of the vehicle has not been defined and may change from mission to mission.

(2) The preservation of vehicle attitude in the event that the optical attitude sensors are destroyed by external means.

(3) Longevity, the need for the vehicle to remain operational for periods in excess of 7 years.

It is shown that for a given momentum-wheel capacity, an orthogonal-triad, zero-momentum configuration allows greater margin for growth in the disturbance-torque environment than a biased-momentum system. Orthogonal-triad torquing is thus preferred for a vehicle whose external geometry (and therefore torque environment) is undefined, but likely to be quite large.

Primary attitude sensing is accomplished by IR earth sensors for pitch and roll, and processed sun-elevation-angle information for yaw. The normal operating mode uses these sensors to update a redundant inertial unit made up of six SDF (single-degree-of-freedom) gyros. Automatic update algorithms are suggested, designed to prevent a malfunctioning optical sensor from de-erecting the inertial system.

In the event that the inertial system suffers total failure, a backup mode allows the optical sensors to feed the control system directly. The inability of the sun-elevation-angle sensor to provide yaw information for short periods centered on local midnight and noon means that the yaw channel must operate in an open-loop mode during these periods. A small pitch momentum, together with a compensating roll/yaw torque couple, is used to stiffen the yaw axis during these "coast" periods.

B. Attitude-Sensor Studies

Work has continued on the understanding and evaluation of the electrostatically suspended gyro (ESG), with regard to its applicability as a sensor in a space-borne ACS. The manufacturer has built several such devices, primarily for ground use. The prime attraction of this gyro is that it appears to be devoid of mechanical-failure mechanisms such as bearings, and should therefore be capable of 7- to 10-year lifetimes. No other inertial technology promises such longevity.

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* J. R. Vernau, "An Attitude Control System for a Large Geosynchronous Earth-Pointing Satellite," Technical Note 1977-30, Lincoln Laboratory, M.I.T. (5 July 1977), DDC AD-A044822.

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C.   Pulsed Plasma Thrusters (PPTs)

The Laboratory's R&D activities in the area of PPTs were formally concluded with the transfer to the Air Force Rocket Propulsion Laboratory, Edwards AFB, California of the flight-qualified units that had been stored for possible future use.

V.   DEVICE PHYSICS

A.   Radiation-Hardening Technology

Primary inputs in the area of hardening technology this quarter came from visits to AFAL and the IEEE Conference on Nuclear and Space Radiation Effects. An extensive effort to optimize hardening technology and produce hardened devices is virtually industry-wide, and substantial progress is evident as the field matures. Both bipolar I^2L and CMOS-SOS technologies seem capable of producing megarad-hard LSI devices with substantial tolerance for neutron fluence and $\dot{\gamma}$ levels related to nuclear transients. Some healthy competition is already evident between these two technologies. Current research continues to push for higher-density and higher-performance LSI, with efforts to maintain or improve radiation tolerance.

B.   Radiation Test Facility

Most of the effort this quarter has gone into integrating the automated test system. The interface system for low-frequency stimulus/response measurements is nearing completion, with tests anticipated early next quarter.

A detailed analysis, begun last quarter, to define the high-frequency, functional test system for digital devices was completed this quarter. A flexible approach was selected which permits either stimulating devices with a computer-controlled pattern generator (64 bits wide × 1 kbits deep) or monitoring tandem test/reference devices operating in their own specialized system. For parametric error analysis and potential device diagnostics, outputs from the device under test will be compared with reference values in large exclusive-OR banks. When errors are found, relevant data will be captured and stored in real time (at rates up to 10^7 samples/sec, each yielding a 32-bit data word). Following the specific test, error information will be transferred to the computer-controller for analysis, display, and permanent storage.

The data-collection scheme relies on an in-house-constructed comparator box and several logic analyzers to acquire the data. The comparator box was designed and constructed during this quarter. Recent tests of this circuit indicate satisfactory performance well in excess of 10 MHz, the design goal. Based on these satisfactory results, orders for the pattern generator and logic analyzers are now being prepared.

C.   Instrument-Bus Interface

A board to implement a complete, general-purpose talk/listen interface to the IEEE-488 instrument bus has been built and debugged. This is an important component in the automated test facility under development, as it will allow bus compatibility for many instruments with a minimum amount of extra hardware design and construction. This board is now in use in a serial-time-code/IEEE-bus receiver and in a controller for a data generator, both of which will be incorporated in the completed test system (see Secs. III-A and -B above).

VI. POWER

A. Flywheels and Magnetic Bearings

The brassboard magnetic bearing is now being assembled for test. Magnetic stators are assembled and being tested for field uniformity. A test system of rotors, shaft, flywheel, and touchdown ball bearings will be built up over the next quarter and tested for stiffness and drag. This bearing should allow extremely low-drag, high-speed operation of rotating equipment for extended periods over wide temperature ranges.

A subcontractor has partially completed a motor-generator design for use with such rotating equipment. It employs samarium cobalt magnets in a brushless high-speed machine which has very light weight, high efficiency, and low side loading on the magnetic bearings. Brassboard hardware is now being built to verify the magnetic circuit.

System-level studies of flywheels for spacecraft have been conducted, and results drafted for a future report. It appears that a high-speed, electronically gimballed momentum wheel with magnetic bearings is now feasible for future satellite ACSs of the momentum-bias type.

B. Relays

An industry survey of high-reliability DC relays is almost complete. Results show significant differences in magnetic-circuit design, pivot caging, linkage from magnetic rotor to contact, and contact geometry. The resulting measured parameters show a clear choice of designs for any given end use. These results will aid in future purchases of a traditionally troublesome type of component.

C. LES-8/9 RTGs

A detailed examination of the orbital characteristics of LES-8/9 has uncovered the following reasons which help explain the apparent discrepancies between the predicted and measured RTG performance:

(1) The periodic and now-diminishing sun-elevation angle for our orbit changes the RTG peak daily solar heating such that the maximum daily case temperature will be ~5° warmer at peak-elevation-angle periods than at other times. The increase in case temperature at those times reduces the daily minimum power.

(2) The yearly variation of solar flux density due to the earth's orbital eccentricity has a similar effect, although to a lesser degree.

(3) Because of physical differences between the spacecraft, these effects will be more pronounced on LES-8 than LES-9. The sum of these effects explains the apparent differences between the predicted and measured RTG performance at those times of the year.

This means that confidence can continue to be placed in predicted long-term power availability, and therefore in the long-term availability of the spacecraft for communications.

D. LES-8/9 Converter

Converter A9 testing has been terminated (17 August 1977) after 3 months of temperature cycling from 37° to 80°C six times per day without a mishap. This was done to investigate

possible temperature effects on LES-8 reliability. Converter A9 worked flawlessly with loads of 25.5 W on the 5-V bus, and 30.5 W on a simulated ±15-V bus.

E. Spacecraft Batteries

The nickel-hydrogen boiler-plate battery has been received and is ready for testing. Test equipment is on order, and preliminary evaluation results should be available by next quarter. An external ultra-long time-base generator has been designed to facilitate characterizing the battery and will be constructed during the next quarter.

VII. LES-8/9 COMMUNICATIONS-LINK TESTING

During this reporting period, the following milestones were achieved in the continuing program of communications-link experiments associated with the LES-8 and -9 satellites. This test program is complete except for two conferencing-link tests that require participation by AFAL. Those tests are scheduled to be accomplished soon.

A. ABNCP-Terminal Data Transfer

We have successfully accomplished a direct computer-to-computer transfer of satellite ephemeris data from the Lincoln Laboratory command-post terminal to the AFAL command-post terminal on their 662 aircraft while in flight. The experiment demonstrated the capability of having a ground station (or other ABNCP) update the computer of an in-flight command post. In this case, the transfer contained actual 9th-order polynomials used to describe the satellite orbit. However, the transfer could be representative of any computer-to-computer transfer via the conferencing channel (such as situation or status displays and other computer-resident data bases).

B. UHF Force-Element Terminal

The period 31 May through 3 June 1977 saw the final flight-testing of the Lincoln Laboratory-built UHF force-element terminal (FET 3) on-board AFAL aircraft No. 12662 based at Wright-Patterson AFB, Ohio. A system ground checkout was successfully completed on 31 May. The 1 June flight provided in-flight report-back to LES-8, and then via the crosslink to LES-9. The report-back messages were received via the LES-9 K-horn downlink by the K-band ABNCP terminal on-board the aircraft. With LES-8 at the most northerly part of its orbit, the aircraft flew racetrack patterns over southern Maine, while maintaining UHF line-of-sight communication with Lincoln Laboratory for test-coordination purposes. During the eight passes, narrowband UHF report-back messages were transmitted in the HELP and HOP uplink modes using the forward-blade, the Lincoln Laboratory crossed-slot, and the Dorne-Margolin crossed-dipole antennas.

A successful forward-link handoff from LES-9 to LES-8 was accomplished during a 2/3 June 1977 flight northwest of Wright-Patterson AFB. In order to minimize the westward flying time required to accomplish the handoff, the flight occurred with LES-9 near the most southerly part of its orbit. The Lincoln Laboratory K-band Navy terminal transmitted continuous forward messages through LES-9, while the Lincoln K-band ABNCP terminal transmitted continuous forward messages through LES-8. As the aircraft flew into cloud cover and turbulence with LES-9 at approximately $-2.5°$ elevation angle, the Lincoln UHF FET lost lock on two occasions, but it reacquired the LES-9 hopped UHF downlink each time. Finally, with LES-9 at

approximately $-2.8°$ elevation angle, the terminal stopped printing the LES-9 forward messages (i.e., the signal was below the communication threshold), but it continued to track the UHF downlink. Handoff occurred 1 min. later, with subsequent receipt of forward messages from LES-8.

The AGC and clipping levels have been changed in FET 2 to meet the antijamming specifications. Accordingly, the acquisition and tracking thresholds have also been reset. Using the new threshold settings, automatic tracking has been demonstrated at a (P_r/N_o) of 29 dB-Hz. At 28 dB-Hz, the FET will reinitiate the acquisition algorithm provided the signal remains below this level for longer than 6 sec. The acquisition thresholds were set to achieve near-minimum time-to-acquire at moderate (P_r/N_o) (e.g., 30 dB-Hz) while maintaining the probability-of-acquisition vs (P_r/N_o) performance shown in Fig. 7. Figure 8 shows the order in which the time/frequency space is searched and the time-to-acquire as a function of initial time and frequency offsets.

C. Airborne Command/Telemetry Tests

In conjunction with the 31 May through 3 June 1977 flight-testing of the UHF FET 3, joint Lincoln/AFAL/ESD satellite-command tests were successfully accomplished. Using the Lincoln Laboratory command/telemetry status panel and the AFAL K-band command-post terminal onboard aircraft No. 12662, commands were sent via the alternate (MFSK) command channel. LES-9 commanding (1 June) was successful both on the ground and in flight, while LES-8 commanding was only successful on the ground (31 May and 2 June). Problems with the AFAL K-band terminal prevented successful in-flight LES-8 commanding during the 2/3 June flight. The test command (No. 511, execute only) and command of the downlink synthesizer from HOP to HELP and back to HOP (both data and execute commands) were exercised several times. A LES-9 change of downlink modulation (from T to F^u) and a partial change of the LES-9 satellite from the forward (Mode 34G) configuration to the report-back (Mode 2B) configuration were also accomplished.

VIII. LESOC OPERATIONS AND EQUIPMENT

The responsibility for LESOC rests with Group 68, though many people from other Groups participate in its activities. The LES-8/9 communications testing involving Lincoln Laboratory terminals was discussed in Sec. VI. Much LESOC effort is devoted to support of tests for the benefit of non-Lincoln terminals and experiments.

In addition to communications testing, LESOC has had ongoing activities in connection with many other LES-8/9-associated enterprises, including:

    (a) Evaluation of the TGG on LES-8 by the Charles Stark Draper Laboratory (CSDL),

    (b) Evaluation of the RTGs on both satellites by GE and ERDA,

    (c) Test of the LES-9 stationkeeping system,

    (d) Maintenance and dissemination to all users of up-to-date orbital data on both satellites.

Agreements have been reached within the DoD for the time when the formal LES-8/9 Test Program will be over (1 October 1977) and the satellites become available essentially full-time as residual communications assets. In that era, the hour-to-hour scheduling of LES-8/9 users will be shifted from ESD's Test Management Facility (TMF) at Bedford, Massachusetts to AFCS's
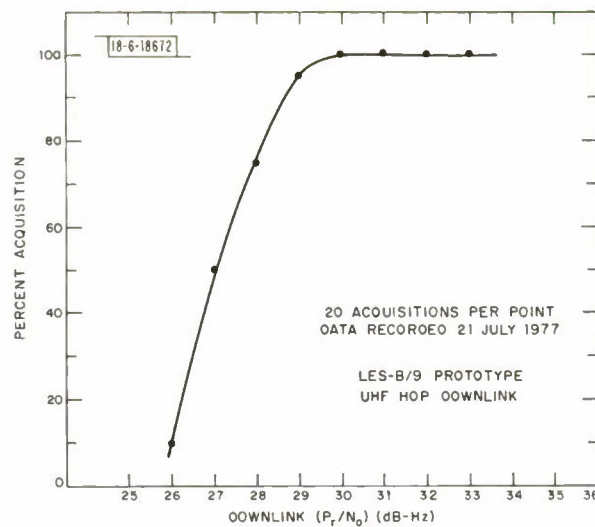
Fig. 7. Acquisition probability vs signal-to-noise-density ratio (replaces Fig. 3 on p. 9 in the Space Communications Quarterly Technical Summary dated 15 December 1976).
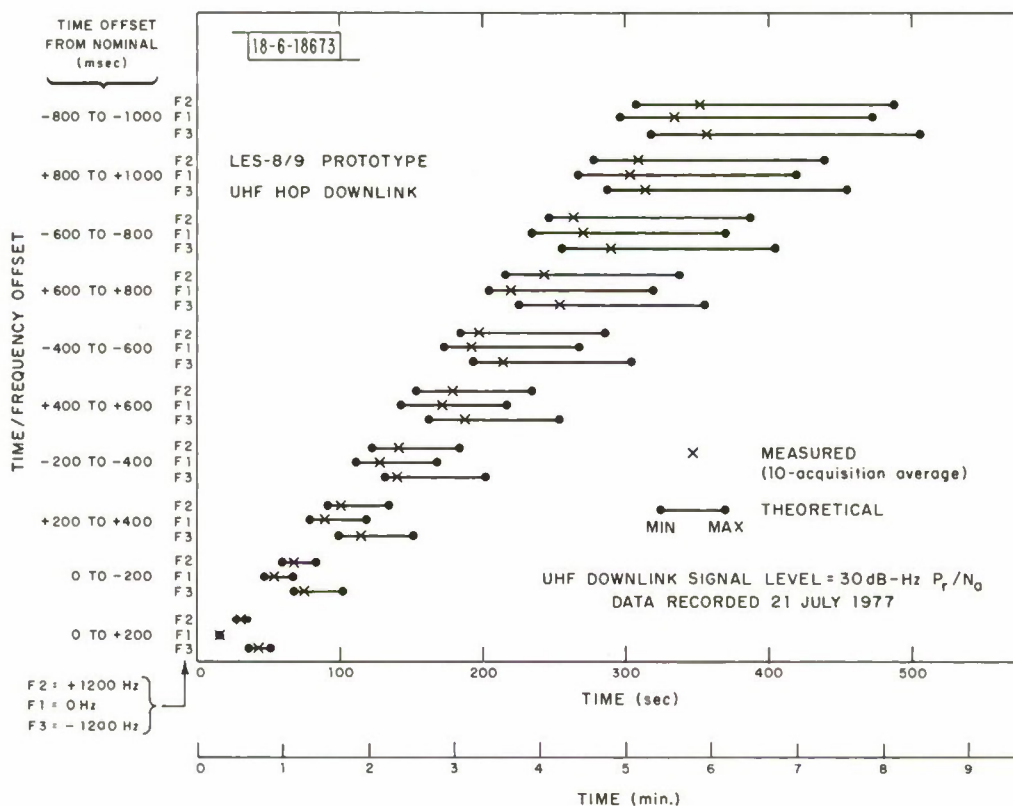

Fig. 8. Acquisition time vs time/frequency offset (replaces Fig. 4 on p. 14 in the Space Communications Quarterly Technical Summary dated 15 March 1977).

Tactical Relay Operations Center (TROC) at Brandywine, Maryland. The responsibility for LES-8/9 command and telemetry functions and all housekeeping-system actions will remain with Lincoln Laboratory and will be exercised through LESOC. The official name for this utilization of LES-8/9 is SCOPE DAWN.

Some of the activities associated with the operation of LESOC and its modification to a configuration suitable for long-term use in support of the SCOPE DAWN program are described in the following sections.

A. Command Experiments

Two demonstrations were conducted to establish the feasibility of having remote terrestrial locations send commands to LES-8 and -9. The first experiment demonstrated the command capability of the Lincoln Laboratory-designed telemetry/command panels resident at ESD's TMF. Representative commands were sent to both satellites over the UHF prime command channel via a data link from TMF to LESOC. Subsequent to this test, we have interposed a command repeater in the data link, which will recognize only command 285 (transponder-mode command). This device will allow untrained personnel to use the TMF command panel to satisfy a SCOPE DAWN alert without compromising other functions on the satellite.

The second experiment (see Sec. VII-C) demonstrated the command capability of the Lincoln Laboratory-built command/telemetry panel installed on the AFAL aircraft No. 12662. This experiment showed the feasibility of having an ABNCP control the satellite resources directly via a communications link without support from a ground station. Telemetry and command data were both transferred using the K-band communications downlinks and uplinks, which are normally available to a command-post terminal.

B. Orbit-Fitting Activities

An orbit-fit was prepared for LES-9 to provide calibration of the stationkeeping system, which was activated on 4 May 1977 with the satellite at about 46°W longitude, with the commanded control location 40.4°W longitude. The stationkeeping system was within normal limits until 4 July 1977, when an anomalous event on the satellite drastically changed the state of the drift-rate register. This caused the satellite to experience an unscheduled thrusting period. When the thrust history was loaded into the thrust model for PEP (Planetary Ephemeris Program), the predicted and measured rates differed by an unacceptable amount. We have turned the stationkeeping OFF so that we can do a "free fall" orbit-fit and get an accurate calibration of the actual thrust levels on LES-9 (as was done for LES-8 early in the test program). The satellite will be allowed to drift until after the next scheduled series of communications-system tests, at which time the stationkeeping may be reactivated, giving us the opportunity to check the thrust-level calibration.

C. LES-8/9 Ground Terminal

Two new command sources have been configured for LES-8/9 commanding. They will replace the TATS synthesizers currently used in the LES-8/9 ground terminal. Normally, one source will be dedicated to each satellite, but they are both capable of commanding either satellite. The new command source consists of a commercial frequency synthesizer, a synthesizer controller (Lincoln Laboratory-built), and a BFSK/MFSK modulator (also Lincoln Laboratory-built). The command capability for each source is (1) prime command (UHF BFSK) and

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(2) backup command (UHF MFSK) at the HELP uplink frequency or in the TCXO mode. One of the command sources has been used successfully to command both LES-8 and -9. Final testing of both sources is about to take place.

A major upgrading of the 30-ft dish and control system is under way with the help of Division 7. Two sets of optical shaft encoders have been purchased for the 30-ft dish, one for elevation-angle readout and the other for azimuth readout. Gear boxes for data pickoff have been fabricated and are now being installed. Circuitry for serial transfer of the angle data from the encoders to the control room is also being built. The small UHF/S-band array antennas are being modified to correct problems encountered with the drive mechanisms during snowstorms.

A new antenna selector for the telemetry receivers has been designed to expand the selection capability. The main addition is switchable antenna selection for the backup receiver in place of the existing patch-panel arrangement. There is also the capability to select a UHF antenna for the prime LES-8/9 UHF downlink receivers. This last addition is for support of UHF BPSK telemetry when a satellite is in the wideband UHF transponder mode. An additional UHF plug-in was purchased to provide UHF-transponder-mode telemetry from both satellites simultaneously.

Six VCXOs in the 68-MHz range were purchased for the telemetry receivers. They will be used as LOs for S-band telemetry and will replace the Laboratory-built LOs, which did not have adequate long-term stability. Four VCXOs for UHF operation are on order.

D. Telemetry Control System

The purpose of the telemetry control system is to centralize the control of the LESOC telemetry resources. The resources to be affected are: the S-band and UHF antenna outputs, the B-penthouse baseband outputs, and the B-224 baseband outputs. There will be four remote control stations, which can control the above resources through a master control station. The telemetry control system will utilize the data-recording bus, which is a single-cable, multiplexed data-transfer bus interconnecting various pieces of ground equipment.

Electrical design of the remote stations was completed and parts were ordered. Electrical design has started on the antenna master control and the telemetry master control sections. Modifications to Group 68's wirewrapping program have been completed, and the first of five Universal boards has been wrapped, debugged, and is being tested on the data bus. A data-bus simulator/test unit should be complete within a few weeks.

E. Programming for LESOC

An improved version of the LIMITS program is under development. This software will provide automatic monitoring of critical spacecraft telemetry data and will generate alarm signals when appropriate.

A tape-recording program has been completed that extracts selected words from the telemetry format for magnetic-tape recording. This permits extended periods of high-rate telemetry operation without requiring an operator to change tapes. This is used for special-purpose experiments that require high-rate sampling of a limited number of words.

Provisions are being developed for automatically restarting the LESOC computers and tape drives after power-line transients.

F. Miscellaneous LESOC Activities

The fourth K-band traveling-wave-tube (TWT) amplifier has completed its final tests at the vendor's plant and should be delivered soon to support operation of the Lincoln Laboratory ABNCP terminal and the Lincoln Laboratory Navy terminal. A degraded spare TWT will be returned to the vendor for remanufacture if possible.

A second diesel-driven generator to supply emergency power to LESOC has been ordered GFE. Both generators will be installed on concrete pads for long-term backup service. An alarm system for detection of smoke or fire within B-209 and B-224 has been put under contract.

IX. LES-5/6 ACTIVITIES

There were no activities connected with LES-5 during this quarterly period. LES-6 activities were limited to verifying (by angle-tracking the beacon signal with the 30-ft antenna on Building B) that the satellite had drifted west (to farther than 90°W longitude) of its nominal station (38°W longitude) during the year since the satellite was last thrusted under manual control to hold station. It is planned to test the LES-6 transponder and to measure and evaluate the satellite's communications capabilities before making an attempt to return it to the vicinity of its nominal station. The operating logs indicate that the supply of on-board propulsion fuel must be nearly exhausted by now (LES-6 was launched 26 September 1968).

SPACECRAFT COMMUNICATIONS PROCESSORS
GROUP 69

I. ADAPTIVE ANTENNA NULLING

A. Introduction

Group 69 continues its major emphasis on the digital block-processing approach to adaptive antenna nulling, although some effort related to the alternative analog feedback approach has also been expended. Major issues which were delaying the purchase of components of the demonstration block-processing system have been resolved, and we have placed orders for the buffer memory and the central processing unit. A purchase order for high-speed A/D converters will be placed very shortly. Variations on the present approach to block processing, with promise of improved performance or simpler hardware, are being investigated.

B. Analog Feedback Nulling System

Much of the analysis of feedback nulling systems in the engineering literature is motivated by detection problems, such as radar. For a communications application, the modulation of user signals by time variations in the weighting vector must be considered. In some of the examples we have investigated, this spurious modulation has been broadband so that it can cause users from opposite ends of the communications band to interfere with one another. This can be a major source of crosstalk and therefore must be taken into account when parameters of the nulling system are selected. In the digital block-processing system, the weights, once selected, are held constant for an entire hop period — therefore, this spurious modulation does not occur.

We are presently engaged in further analysis of this degradation in performance and the relationship of algorithm parameters and signal structure to the amount of this spurious modulation.

The design of an experimental, reset-corrected transconductance multiplier with potential application to an analog nulling system operating at baseband, rather than IF, has been initiated. The error of the usual transconductance multiplier circuit approximates 1 percent of maximum output, and results from mismatching and ohmic resistance of the various transistors used in such a design. The approach to reducing these errors that is being investigated involves expanding the error pattern in a two-dimensional Taylor series and applying test inputs that allow the coefficients of the error terms to be determined. Appropriate correction terms are then introduced. The error correction is updated periodically as environmental conditions change.

C. General Analysis of Nulling Systems

Nulling algorithms can be designed to respond to a jamming scenario such that either:

    (1) Each user has his own weight vector appropriate for optimum (maximum) user power-to-interference ratio for that user; or

    (2) Each local geographic area (cluster of users) is given near-optimum directive gain, thereby giving each user within that cluster a near-optimum user power-to-interference ratio; or
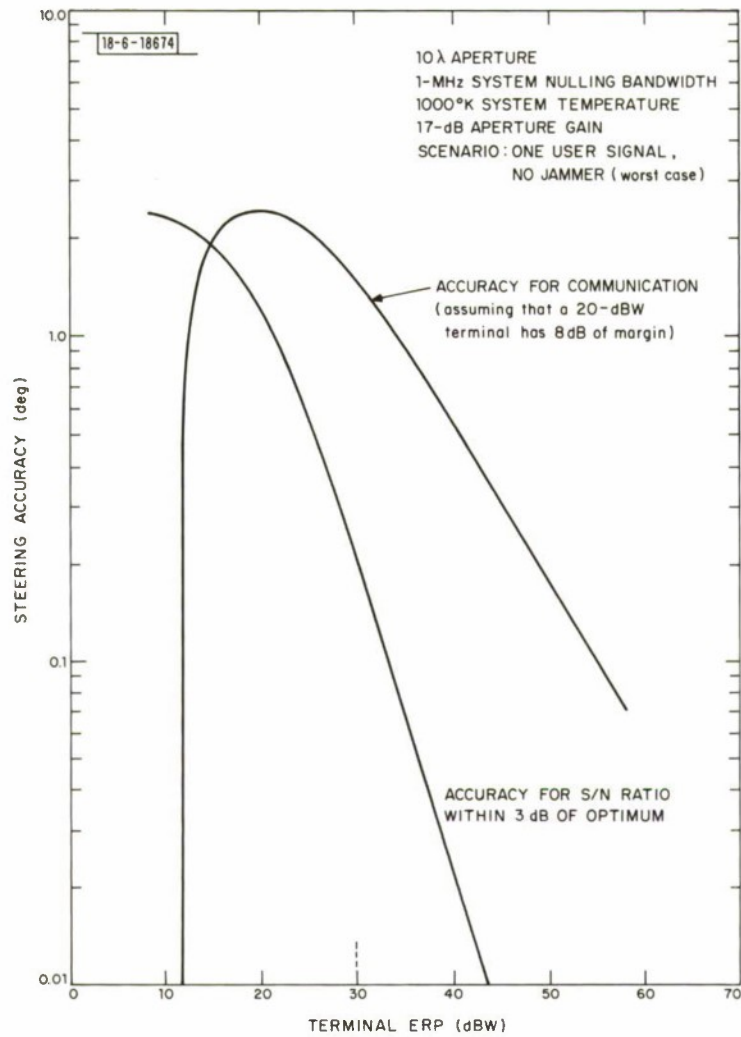
Fig. 9. Angular pointing accuracy vs terminal ERP.

(3) The local geographic area is extended to the entire earth — thus, the available aperture gain is more uniformly distributed over the entire earth except for nulled directions, with each user receiving a less-than-optimum (but presumably adequate) gain.

Of the three approaches, the first requires the most hardware but gives the best performance, while the third requires the least hardware but gives the least-satisfactory performance. The second approach represents a compromise between performance and complexity.

In order to assess these three possibilities in terms of performance, we pose the equivalent question: With what accuracy do we need to know the position of a particular user to put optimum, or at least adequate, directive gain on that user? We may assume that the nulling system derives the weight using either the $R^{-1}\overline{V}$ algorithm or the feedback LMS algorithm, since they are known to be equivalent. It evolves that a strong user may resemble a jammer to the nulling system. Therefore, there is "competition" between the steering vector ($\overline{V}$) attempting to put gain in the direction of the user, and the nulling system attempting to put nulls in directions corresponding to the eigenvectors of R. We could therefore have the paradox that a strong user will be less successful than a weak user if the nulling system is operating and the user's location is not known precisely. Figure 9 shows that the tolerable error in position information needed to provide a user with near-optimum gain decreases sharply with increased user power. The error tolerable for just enough directive gain to permit communication also decreases for terminals with more than 20-dBW ERP. It is highly likely that we will know the terminal locations to these accuracies, so that if each user has his own set of weights there seems to be no problem. However, if we provide nulling for clusters of users, there will be instances in which one set of weights per cluster will be inadequate. This problem is eliminated if a signal-suppression filter can be provided, so that the user signals are suppressed from correlation matrix (R) calculations and do not affect the nulling algorithm.

Investigations of the effects of nonlinear distortion in the "front end" of the nulling system have also been carried out, with regard to their limitation of achievable null depth. The front end, consisting of preamplifiers, bandpass filters, and down-conversion mixers, generates distortion products, the most significant of which are the second- and third-order products. Certain harmonics in these products fall back into the nulling band, and may appear as new jamming sources requiring additional degrees of freedom for adequate suppression. Nonlinear distortion should be kept below a level commensurate with the desired null depth so that it does not consume degrees of freedom that would otherwise have been available for true jammers.

D. Block-Processor Floating-Point A/D Converters

While it is practical to use 12-bit 1-MHz A/D converters in a test system, a flight system for digital block processing would need to be designed for minimal size and power consumption, and availability of A/D converters meeting these specifications would be questionable. As pointed out in the last Quarterly Technical Summary (15 June 1977), a variable gain (AGC) is required. The most promising approach to such an AGC seems to be the use of a floating-point A/D converter.

A floating-point A/D converter takes an analog input and converts it to a floating-point digital number with coefficient $\underline{M}$ and exponent $\underline{p}$. The floating-point format need not be binary, but can also be quaternary, octal, etc., in which case the output can be represented as $M \times 2^{-Gp}$, where G is an integer. By contrast, a fixed-point A/D converter gives only a coefficient,

and the exponent p is fixed at p = 0. The spectral power density (SPD) of clipping noise included when the input signal exceeds the maximum input capability of a floating-point A/D converter is the same as that encountered with a fixed-point A/D converter. However, the quantization noise SPD is less and varies with input power variation. As a consequence, floating-point A/D converters can be designed for significantly greater dynamic ranges than can be handled by fixed-point A/D converters.

A generalized analysis of the noise power ratio (NPR)[*] performance of a floating-point converter was conducted in which the number of coefficient bits $\underline{N}$, the maximum exponent choice p_{max}, and the parameter $\underline{G}$ were varied. The input signal was assumed to be Gaussian noise with standard deviation σ. To illustrate combinations of N, p_{max}, and G which could meet a specific requirement, NPR vs σ is plotted in Fig. 10 for five cases for which NPR $\geqslant$ 43 dB over a minimum dynamic input range of 42 dB; some other cases can also meet this requirement, but those indicated are the most logical choices in this particular example. As can be inferred by comparing parameter values for curves 1 and 2 and also for curves 4 and 5, trade-offs can be made between N and p_{max} provided that the minimum NPR is maintained.
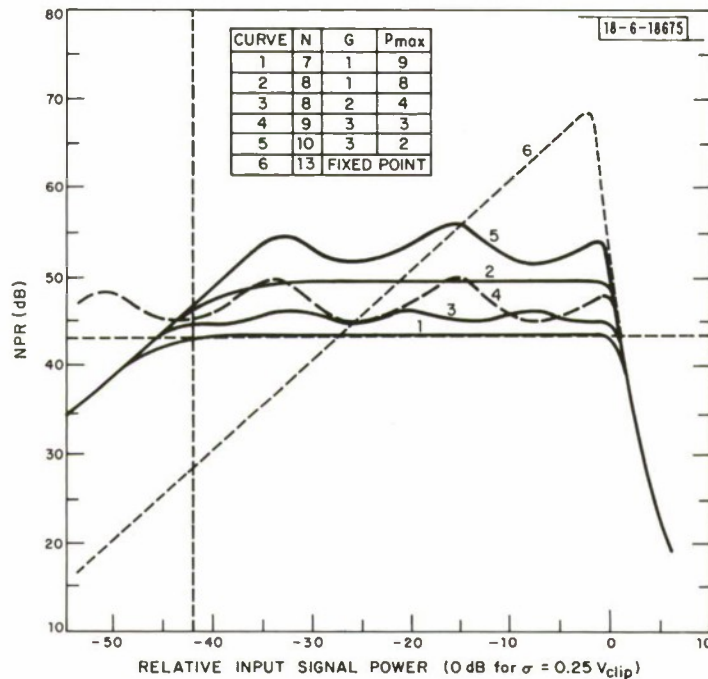

Fig. 10. Relative input signal power.

The NPR curve for a 13-bit fixed-point A/D converter is plotted in Fig. 10 for comparison. Note that although the maximum NPR is much greater than 43 dB, the dynamic range over which NPR > 43 dB is 14 dB less than required.

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[*] $\underline{NPR}$ is the ratio of output signal spectral power density to spectral power density of noise added by the A/D converter. For a uniform power density signal process which is low-pass filtered and then sampled at Nyquist rate, the NPR is constant over the band for all practical purposes.

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E.   Block-Processor Demonstration System Components

1.   A/D Converters

A vendor for high-speed 12-bit A/D converters has been selected, and a purchase order is being processed. We expect that these A/D converters will not be delivered until well beyond the expected beginning of demonstration system integration. A much less expensive set of A/D converters, with only 8-bit accuracy, will be used initially.

Work is continuing in the area of developing A/D converter testing capability. A static test card has been built and is presently being tested. Specifications have been written and purchase requisitions are being processed for equipment to be used for dynamic testing of A/D converters.

All parts for the A/D converter employing a subranging scheme, using two 8-bit converters to produce an equivalent 12-bit conversion of a 1-MHz throughput rate, have been received and the control card has been built. It is awaiting testing.

2.   Signal-Suppression Filter

Techniques for implementing a user signal-suppression filter have been systematically explored. The accordion filter previously described can be designed according to performance criteria which are now well understood. The objection can be made that the accordion filter scheme requires each user to hop with a slightly different pattern from each other user. A signal-suppression-filter concept which overcomes this objection has been explored. With this concept, the signal-suppression-filter characteristic is randomly changed, not from hop-to-hop, but from sample-to-sample, and the random characteristic is constrained to filter out all user frequency bands, but any given characteristic is allowed to reject, also, a portion of the user-free band. Interfering signals in such a rejected band would likely be caught with a different sample. The random-choice signal-suppression filter is more complicated than the accordion filter, and gives slightly poorer performance for equivalent computational complexity, but it would be adequate. A hardware design capable of implementing either the accordion filter or the random-choice filter is being undertaken.

3.   Correlator

Detailed design of the correlator is complete, and construction is under way. A setup for testing the IC multiplier used in the correlator has been built which uses switches for test inputs and displays the resulting product in lights. Several multipliers have been tested and their performance confirmed.

4.   Data Buffer

A purchase order for the buffer memory has been placed and delivery is expected shortly.

Error-correction logic has been designed, and a prototype card has been built. A card which will allow testing of the error-correction logic by an Intel 8080 microcomputer has been built and tested. Test programs are currently being written and are 50-percent complete.

Detailed design of a memory exercisor which will test the buffer memory with and without error correction is in progress.

5.   Central Processor Unit (CPU)

The purchase order for the CPU has been placed, and delivery is expected in October 1977. Much of the instruction code for the $R^{-1}\overline{V}$ algorithm has been written, and the code for computing

the contents of the combiner memory has been written. Interfaces between the CPU and the correlator and the combiner are defined, and test equipment needed to facilitate the checkout of the interfaces has been defined and ordered.

6. Combiner

The detailed design of the combiner has begun. To save mechanical construction, the combiner circuitry will be designed to plug into the backplane of the CPU, as an I/O card. It will also draw power from the CPU. Several improvements in the earlier conceptual design of the combiner have been incorporated.

F. Alternative Formulation of the Block-Processing Nulling Technique

Instead of computing a correlation matrix from observations of interference, we can compute the optimum weight vector from the steering vector and the observations themselves. Suppose the signal at the ith antenna is $x_i(t)$. At times $t_1, t_2, \ldots, t_M$ we observe the raw data arranged below in a matrix X:

$$X = \begin{bmatrix} x_1(t_1) \ x_2(t_1) & \cdot & \cdot & \cdot & x_N(t_1) \\ x_1(t_2) \ x_2(t_2) & \cdot & \cdot & \cdot & x_N(t_2) \\ \cdot & & & & \cdot \\ \cdot & & & & \cdot \\ \cdot & & & & \cdot \\ x_1(t_M) \ x_2(t_M) & \cdot & \cdot & \cdot & x_N(t_M) \end{bmatrix}.$$

If this matrix of observations is multiplied by its transpose, the N-by-N correlation matrix used in the $R^{-1}\overline{V}$ computation is formed. However, it is common for the correlation matrix to be "ill-conditioned," which means that computations involving R must be performed with exceeding accuracy to get answers of moderate accuracy.

If the matrix X premultiplies the (unknown) weight vector $\overline{W}$, the resulting M-element product vector represents the outputs of the nulling system at times $t_1, t_2, \ldots, t_M$, and should ideally be zero. If we append one more row to X, consisting of the elements of the steering vector $\overline{V}$, then premultiplying $\overline{W}$ by X would give M + 1 components, the last of which would ideally be unity. We now pose the problem of finding the weight vector $\overline{W}$ for which the difference between the product $X\overline{W}$ and the ideal output is minimized in a mean-square sense. It can be shown that the solution is identical to $R^{-1}\overline{V}$, even though neither R nor R^{-1} is ever explicitly computed.

There are well-established techniques for solving such least-squares problems in ways which are numerically stable and satisfactory. One of these methods has been adapted to real-time computation and simulated with arithmetic whose precision can be varied in the simulation to determine the word length required for a result of given accuracy. The same variable precision arithmetic has been applied to the older scheme for computing $R^{-1}\overline{V}$, and comparisons of the algorithms have been made. Initial results demonstrate convincingly that the newer algorithm outperforms the older algorithm for modest word-length arithmetic (16 to 24 bits) and is equivalent to the older algorithm, as both approach perfection with long word-lengths.

Unfortunately, the new algorithm requires approximately twice as many operations as the older algorithm, which detracts somewhat from its superior performance.

G. Floating-Point Computations on Spacecraft

We are beginning to explore the size and weight issues for a floating-point CPU implementation. So far, we have been able to distinguish the requirements of the floating-point CPU for an $R^{-1}\overline{V}$ algorithm from the requirements typically incorporated in the floating-point arithmetic unit of a general-purpose computer. In particular, we believe that unnormalized floating-point representations of sums should be retained until it is necessary to use those sums in other operations. This simplifies the design of a floating-point accumulator, since the difficult operation of normalization can be deferred to the end of a chain of additions.

II. COMMUNICATIONS PROCESSOR

A. Signal-Processing Demonstration System

A test plan has been developed for a system which will demonstrate the signal-processing and routing techniques which have been studied over the past year and which seem suitable for a GPSCS application. The satellite-processing techniques to be demonstrated include simultaneous demodulation of multiple frequency-division-multiplexed (FDM) uplinks with several data rates and types of modulation, frequency dehopping, adaptive downlink slot assignment, and multiple time-division-multiplexed (TDM) downlinks. The uplinks and downlinks will be at UHF, and communication to and from existing terminals (e.g., WSC-3's) will also be demonstrated. This demonstration system can be combined with either of the adaptive nulling systems now in the design or construction phase. The system will enable us to characterize bit error rates as functions of uplink power levels, noise or jammer levels, or frequency spacing of the uplinks.

Responsibility for most system components has been assigned, long lead-time items have been ordered, and we expect that a minimum system, without RF uplinks or downlinks, will be operational in about 6 months and the full system in about 9 months.

B. Simulated Multiple-Uplink Terminals

In order to test the multiple-FDM uplink demodulation capability of the group demodulator in the Signal Processing Demonstration System, a test signal generator which can simulate up to 16 independent uplink signals is being constructed. Each of the 16 channels will have fully programmable center frequency, amplitude, bit timing offset, data rate, and modulation type. Each channel can transmit data from any of three sources — an external asynchronous RS-232 device, a synchronous source such as a bit-error-rate tester, or an internally stored message which is transmitted repeatedly. The 16 channels are all under the control of a microprocessor which, in turn, can be controlled by the Demonstration System Test Controller.

C. Group Demodulation

The group demodulator for phase-comparison sinusoidal frequency-shift-keying (PCSFSK) modulation has progressed to the final schematics and wirewrapping stages. Recent work has concentrated on total simulation in order to answer questions on (1) input scaling as a function of bandwidth and data rate, (2) decision region implementation, and (3) sensitivity to time and frequency offsets. Input scaling is used to prevent accumulator overflow when a user would require 64 or more samples/bit to be accumulated for demodulation. In this case, the normal

7-bit-plus-sign multiplier output is truncated to 6, 5, or 4 bits as the number of samples/bit increases to 64, 128, or 256.

The decision region implementation, requiring examination of the real part of a complex conjugate multiplication, was complicated by the need to accommodate a wide dynamic signal range caused by multiple users in a single AGC loop. This variability could be accommodated by using many bits of input quantization (up to 12) in the decision multiplier, or by using fewer bits and sliding the multiplier window up and down the 12-bit accumulator range on a user-by-user basis. The latter scheme proved more viable since the cost of a smaller multiplier and the shifting logic is much more reasonable than the cost of a 12-bit complex number multiplier. Simulation of the group demodulator showed that two real 4-bit multipliers followed by a 4-bit adder would be sufficient if controlled to operate on the 4 bits from the accumulators containing the most information. The simulation is also helping to define that particular algorithm.

A study of the sensitivity of probability of error to time and frequency offsets in PCSFSK is being made to aid decisions on acquisition and tracking algorithms and to size the frequency and time accumulator interfaces. Results around 10-percent probability of error show a ±1/2-dB tolerance out to 25-percent timing offset and 40-Hz (at 600 bps) frequency offset. More data will be collected for lower probabilities of error, where uncoded operation is practical.

With regard to the hardware implementation, a decision to use the TRW MPY-8AJ multiplier was made firm. That part is now available in a lower-power technology reducing power consumption from 1.8 to 1.2 W. Additional savings are realized by the internal storage buffers which allow easy pipelining. The total group demodulator, including A/D but excluding acquisition and tracking algorithms, is implemented with about 140 packages of 16-pin ICs, 20 packages of 20-pin ICs, and two 40-pin ICs, consuming a total of about 12 W. In terms of rough power usage, the multipliers, other arithmetic operators, and random-access memories (RAMs) each consume about 2.5 W. On a lower plateau, the buffer stores (4 bits/package), multiplexers, and read-only memories (ROMs) each consume about 1 W.

D. Microprogrammed Adaptive Routing Controller (MARC)

The MARC is under test. Micro code routines are being tested, and some of the instruction decode is written.

A detailed description of the MARC instruction set has been written, and an assembler for MARC code is almost complete.

MARC debug software is being written which will provide for loading and examining memory and registers, break points, and real-time trace.

The detailed design of the Communications Output Processor (COP) is nearly complete. The COP backplane is fabricated, and the panel for the COP is being fabricated.

DIVISION 7
ENGINEERING

I. TECHNOLOGY PROGRAM

A. Electromechanical Deployment Device — Powered Hinge

A design consisting of a single torque motor, torque amplifier, and resolver has been selected as a baseline configuration for development of the powered hinge. This design represents a reduction in size and weight over the configuration described in the previous quarter. Provision has been made to include a rotary RF joint, and to permit removal and substitution of various configurations of resolvers.

Requests for quotations have been issued for the motor; responses are being evaluated. Requests for quotations for the resolver and torque amplifier are being prepared.

B. Mechanical Subsystems — Energy Storage Wheel

The development model energy storage wheel, described in the 15 June 1977 Quarterly Technical Summary, has been fabricated. Test and assembly fixtures have been designed and fabricated. Assembly of this unit started in late July and continued through August. The initial assembly will not include the motor/generator assembly which is scheduled to be delivered in late September 1977.

After characterizing the magnetic bearing, the motor/generator will be installed and tested. No problems have been encountered at this stage of development.

C. Analyses

Dynamic and static structural analyses have been conducted to support the design, fabrication, and testing of graphite/epoxy structural components.

In addition, computerized analyses to optimize the weight-to-stiffness ratio of aluminum tubes have begun. This effort is designed to compare aluminum sections to composites in antenna design.

D. Electronic and RF Support

1. Interactive Graphics Design System

Technical and cost proposals have been evaluated and a vendor selected for procurement of a three-terminal refresh system which will enhance the Laboratory's capabilities in logic diagram documentation, producing a wirewrap tape to drive a semiautomatic wirewrap machine and to aid in the design of two-sided and multilayer printed-circuit boards.

2. RF Box Design Concepts

A series of RF box designs has been released to fabrication and will be used in a number of tests to determine the effectiveness of many of the packaging techniques presently being used:

- thick vs thin covers for RF cavities;
- number and spacing of cover mounting screws;

- tiedown techniques of RF printed-circuit boards;

- plated thru holes vs non-plated thru holes for the mounting of RF boards in a cavity;

- egg-crate cover techniques to provide RF isolation between stages of an RF circuit;

- sandwich-board mounting techniques of RF boards;

- RFI effects on boards with connector mounted on-board and assembled through cutout in chassis. This method would allow the removal of a board without removing wiring to the I/O connector.

3. RF SMA Connectors

An effort with a contractor has been under way to develop an RF connector for semi-rigid coaxial cable that would allow the connector outer housing to be crimped onto the cable instead of soldering the housing to the cable. This is the final and critical step in the assembly procedure. Heat applied to solder the outer housing can cause a large extrusion of the Teflon dielectric which, in turn, can cause overstressing of the connector joint.

The design and development work have been completed, and connectors have been purchased for our in-house evaluation.

4. Modifications to Transistor Characterization Test Fixture

This Lincoln Laboratory-designed test bed is used to obtain characterization measurements of transistors to aid in the design of RF circuits. The original test fixture was modified in the following manner:

- the rail carriage was redesigned for the capacitor probes that extend into the cavity. This was accomplished by the design of a gear drive mechanism;

- the carriage was spring-loaded so that the contact shoe makes intimate contact;

- micrometer adjustments were incorporated.

These modifications will insure control and repeatability of measurements. The next generation of this test bed is planned to be a completely automated and computer-controlled system.

E. Antenna Development

The preliminary design of the 4-element UHF receive antenna is 95-percent complete. At present, we have fabricated approximately 10 percent of the piece parts associated with an in-house structural and environmental Joint Evaluation and Testing Program. The first evaluation specimen has been completed. The test graphite/epoxy square tubes which form the antenna support structure have been procured. (Figures 11 and 12 show this design.)

A controlled, passive boom development mechanism has been developed, and a mockup of the mechanism has been made.
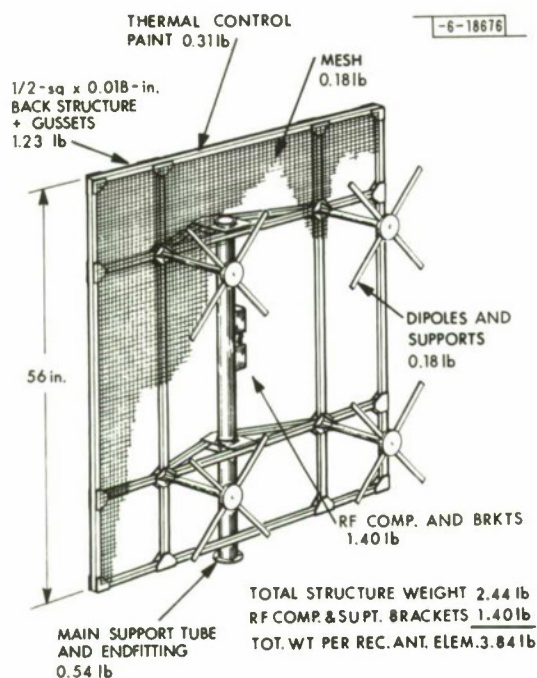
Fig. 11. Graphite/epoxy UHF receive antenna element.
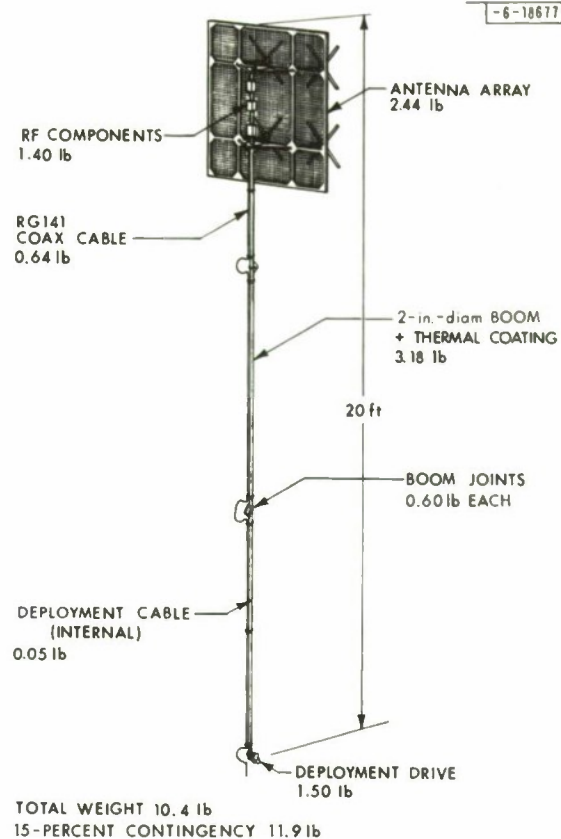

Fig. 12. Graphite/epoxy UHF receive antenna.

F.   Antenna Test Models

1.   Phase I Array

The modified quarter-scale antenna test model with an array of 14 antenna elements supported from a new steel tower has been fabricated.   Modifications to the Laboratory's antenna test range building are under way to install the model.

2.   Phase II Array

Configuration changes to the UHF antenna arrays require off-center mounting provisions in the quarter-scale model.   The support design is being modified and will be released for fabrication when the configuration is confirmed.

GLOSSARY

ABNCP	Airborne Command Post
ACS	Attitude Control System
A/D	Analog to Digital
AFAL	Air Force Avionics Laboratory
AFCS	Air Force Communications Service
AFSATCOM	Air Force Satellite Communications
AFSC	Air Force Systems Command
AGC	Automatic Gain Control
AMS	Automated Measurement System
BFSK	Binary Frequency-Shift Keying
BPSK	Binary Phase-Shift Keying
CMOS	Complementary Metal-Oxide Semiconductor
COP	Communications Output Processor
CPU	Central Processor Unit
CSDL	Charles Stark Draper Laboratory
DCA	Defense Communications Agency
DSARC	Defense System Acquisition Review Council
DSCS	Defense Satellite Communications System
ERDA	Energy Research and Development Administration
ERP	Effective Radiated Power
ESG	Electrostatically Suspended Gyro
FDM	Frequency-Division Multiplex
FDMA	Frequency-Division Multiple Access
FET	Force-Element Terminal
FLEETSATCOM	Fleet Satellite Communications
GPS	Global Positioning System
GPSCS	General-Purpose Satellite Communications System
IC	Integrated Circuit
IF	Intermediate Frequency
IMPATT	Impact Ionization Avalanche Transit Time
LES	Lincoln Experimental Satellite
LESOC	Lincoln Experimental Satellite Operations Center
LO	Local Oscillator
LSI	Large-Scale Integration

MARC	Microprogrammed Adaptive Routing Controller
MFSK	Multi-Frequency Shift Keying
MILSATCOM	Military Satellite Communications
MSK	Minimum Shift Keying
MSO	MILSATCOM System Office
NATO	North Atlantic Treaty Organization
NPR	Noise Power Ratio
PCSFSK	Phase-Comparison Sinusoidal Frequency-Shift Keying
PPT	Pulsed Plasma Thruster
RF	Radio Frequency
ROM	Read-Only Memory
RTG	Radioisotope Thermoelectric Generator
SAMSO	Space and Missile Systems Organization
SATCOM	Satellite Communications
SCT	Single-Channel Transponder
SFSK	Sinusoidal Frequency-Shift Keying
S/N	Signal to Noise
SOS	Silicon on Sapphire
SPD	Spectral Power Density
SSS	Strategic Satellite System
TATS	Tactical Transmission System
TCXO	Temperature-Compensated Crystal Oscillator
TDM	Time-Division Multiplex
TDMA	Time-Division Multiple Access
TGG	Third-Generation Gyro
TMF	Test Management Facility
TROC	Tactical Relay Operations Center
TWT	Traveling-Wave Tube
UHF	Ultra-High Frequency
VCO	Voltage-Controlled Oscillator
VCXO	Voltage-Controlled Crystal Oscillator

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19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

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optical communications	K-band	LES-8
antennas	LES-5	LES-9

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This Space Communications – Division 6 Quarterly Technical Summary covers the period 1 June through 31 August 1977. It includes satellite communications work performed within Divisions 6 and 7. Other work in Division 6 is reported separately.

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REPLY TO
ATTN OF: SULR (Diane Corazzini, 4553)   2 May 1985

SUBJECT: Approval of Reports to be Downgraded to "Statement A"

TO: AFGL/SULL
Research Library

1. The following reports have been approved by the Public Affairs Office (ESD/PAM) for downgrading to Statement A:

ESD-TR-77-270   ERASE: An Overview

ESD-TR-77-30   Theory and Operating Characteristics of TRAPATT Amplifiers

ESD-TR-77-69   Space Communications

ESD-TR-77-122   Space Communications

ESD-TR-77-229   Space Communications

2. ESD-TR-77-348 "LES-8/9 Antenna Systems. Vol 2: S-Band Telemetry" has been approved on the condition that a reference be removed. Attached is page iii, with the reference deleted, enabling this report to now be labelled "Statement A."

DIANE CORAZZINI
Research Publications

1 Atch
Corrected page for ESD-TR-77-348

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Raymond L. Loiselle

Raymond L. Loiselle, Lt. Col., USAF
Chief, ESD Lincoln Laboratory Project Office