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Lincoln Experimental Terminal

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Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LINCOLN LABORATORY

LINCOLN EXPERIMENTAL TERMINAL

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Group 62

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ABSTRACT

The Lincoln Experimental Terminal (LET) is a complete,
self-contained air-transportable ground terminal for testing
and demonstrating evolving space communication techniques
in a realistic environment. Its present equipment comple-
ment permits efficient, highly reliable, multiplexed digital
communication of voice and record traffic using a variety of
channels, including the moon and active satellites. Its modu-
lation system, using a 16-symbol alphabet frequency-hopped
over a 20-Mcps band, together with efficient coding, provides
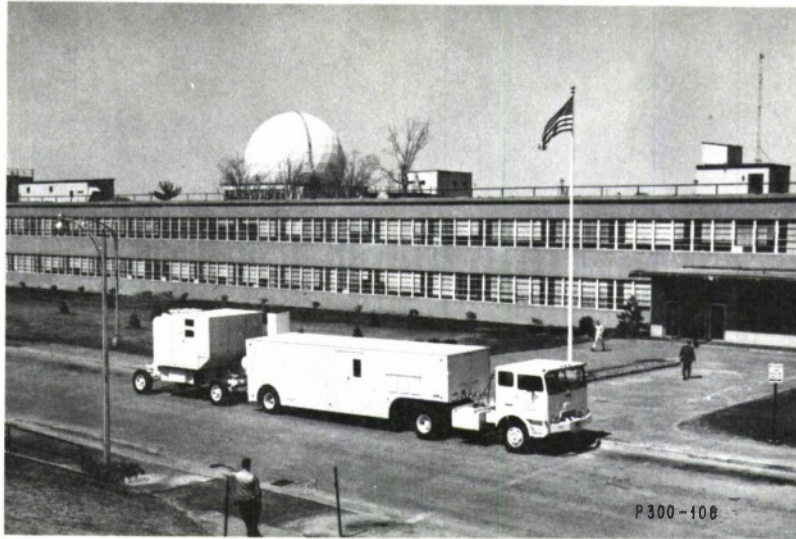multiple-access use of a wide-band satellite.

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Fig. 1. LET ready for travel.

Fig. 2. LET in operation.

LINCOLN EXPERIMENTAL TERMINAL

I. INTRODUCTION

For a number of years, the M.I.T. Lincoln Laboratory has worked on various techniques applicable to the solution of space communication problems. In addition to microwave technology and components such as cooled X-band parametric amplifiers and rapidly switchable frequency synthesizers, these techniques have included: modulation and demodulation for dispersive channels such as the troposphere, Moon and West Ford belt; digitized narrow-band speech processing with emphasis on speaker recognizability; and practical realization of coding and decoding schemes which are economically competitive with more conventional means of achieving greater information rates on a given channel.

Some results of this work have been combined to produce an experimental air transportable terminal, called the Lincoln Experimental Terminal (LET), which has a number of desirable and unique features, particularly from a military communications viewpoint. The terminal will work efficiently on both coherent and time-varying dispersive channels; it provides good quality digital speech with speaker recognizability in a reasonably narrow band; and it permits multiple access of a broad-band satellite by spectrum spreading, without the severe synchronization problems commonly associated with the use of a pseudo-noise carrier for this purpose.

II. GENERAL DESCRIPTION OF TERMINAL

A photograph of the terminal is shown in Fig. 1. The terminal is self-contained in two trailers. One of these, the so-called electronics vehicle, is a modified low-bed commercial van which contains the signal-processing equipment, a communications and antenna control console, a prime power generator and its fuel, an air conditioner, and storage for the antenna panels. The second trailer, which we call the antenna vehicle, contains the transmitter and its heat exchanger, a refrigerated parametric-amplifier receiver, low-level microwave equipment, the antenna back-up structure, feeds and servo-mechanism equipment. Figure 2 shows the terminal in operation.

The terminal has the following gross characteristics:

Transmitter frequency	~8000 Mcps
Receiver frequency	~8000 Mcps
Transmitter power	10 kw CW
System bandwidth	20 Mcps
System noise temperature	100°K
Antenna diameter	15 ft
Antenna pointing	Computer-aided autotracking
Information rates	Up to 9600 bits/sec
Information types	Multiplexed vocoded voice, teletype and data

III. SYSTEM CONSIDERATIONS IN SIGNAL-PROCESSING DESIGN

The specific implementation of the techniques mentioned previously stems from a number of self-imposed specifications. These may be listed roughly as:

    (a)   The terminal should be able to operate on almost any channel, passive or active, coherent or dispersive.

    (b)   The terminal should continue to operate with high efficiency in the presence of fortuitous or deliberate interference.

    (c)   The terminal should operate with very high efficiency, i.e., it should provide very reliable, highly accurate output with low-input signal-to-noise ratio.

    (d)   The terminal should provide digitized, good quality (speaker recognizable) vocoded voice.

    (e)   The terminal should be usable with a variety of inputs ranging from record traffic to voice, easily and flexibly multiplexed.

A conventional way of meeting the requirement that a terminal continue to operate under severe interfering conditions is to use a pseudo-noise carrier in a broad-band system. Unfortunately, the ability to do so is in conflict with the desire to operate on dispersive channels. However, a frequency-hopped modulation scheme which minimizes intersymbol interference, and is therefore well suited for high-rate modulation on dispersive channels, can also have excellent resistance to interference if used with efficient coding. The basic signal-processing system[1] in LET is shown in Fig. 3. The elementary channel symbol used is a pulse of 200 μsec duration. This pulse is selected from a 16-ary alphabet; that is, every 200 μsec one frequency of a group of 16 frequencies is transmitted. Each 200 μsec, a pseudo-random sequence generator selects a different group of 16 frequencies from the 4096 available frequencies within a 20-Mcps band. The information rate is 4800 or 9600 bits/sec, corresponding approximately to one or two information bits per transmitted pulse. In the event of extremely severe interference, an alternate operating rate of 200 bits/sec is available.
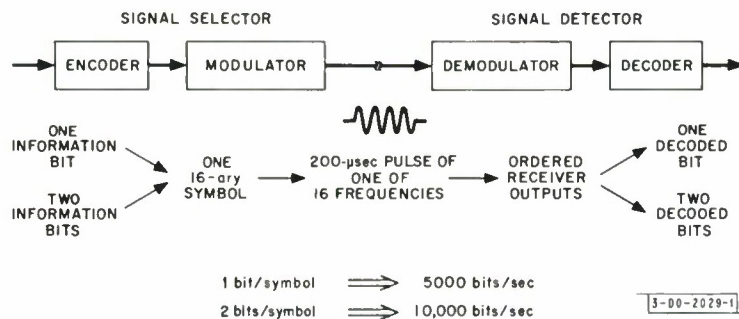
Fig. 3. Signal-processing system.

The frequency-hopped modulation system, using a 16-ary alphabet together with a sequential coder-decoder,[2,3] provides very low error rates at E/N_o = 6 db on a coherent channel, and E/N_o = 10.5 db on a dispersive channel. The use of sequential coding and decoding permits such efficient operation in the face of input error rates as high as 10 to 15 percent, thus providing multiple access or anti-interference performance comparable to that achievable with noise-carrier modulation.

Digitized speech (multiplexed with two 100-wpm teletype) may be transmitted at either the 4800- or 9600-bits/sec rate by using an experimental vocoder[4] designed as part of the terminal. The vocoder, whose design reflects emphasis on speaker recognition, operates in a pitch-excited mode with high quality input when used at the lower rate. At the higher rate, the vocoder is used in a voice-excited mode, allowing the use of degraded input, including a "phone patch" connection to the commercial telephone plant.

A small, general-purpose digital computer (UNIVAC 1218) is used as an integral part of the communication terminal, and performs several simultaneous functions. Given the orbital parameters of the satellite to be used, it computes pointing commands for the antenna during the satellite acquisition phase; it also simultaneously computes and delivers Doppler and range information to the communication system control. Concurrent with its orbital computations, the computer is also used to multiplex and demultiplex the terminal input data which consist of digital voice, teletype and high speed data. Although the computer is programmed at present to multiplex (and demultiplex) one voice channel, two teletype channels, and data up to a total of 9600 bits/sec, the mixture of inputs may be changed with relatively minor program changes rather than by extensive equipment retrofit.

A block diagram of the system is shown in Fig. 4. Digital signals multiplexed by the computer are encoded and sent to the frequency synthesizer where the selected one of 16 frequencies is translated under control of the pseudo-random sequence generator to the wide bandwidth with appropriate receiver timing and doppler changes. Another translation of this wide band of signals to microwave frequencies is followed by amplification to the kilowatt level and fed to the antenna. Received signals (in another frequency band) enter the low-noise parametric amplifier and are then translated in frequency back to IF for further amplification. The sync pulse is recovered in order to control the timing of the receiver sequence generator which tracks the frequency hopping introduced at the other transmitter, thereby recovering the narrow band of 16 tones for the 16-channel receivers. After detection, the signals are decoded, separated and delivered to the vocoder and teletype machine.
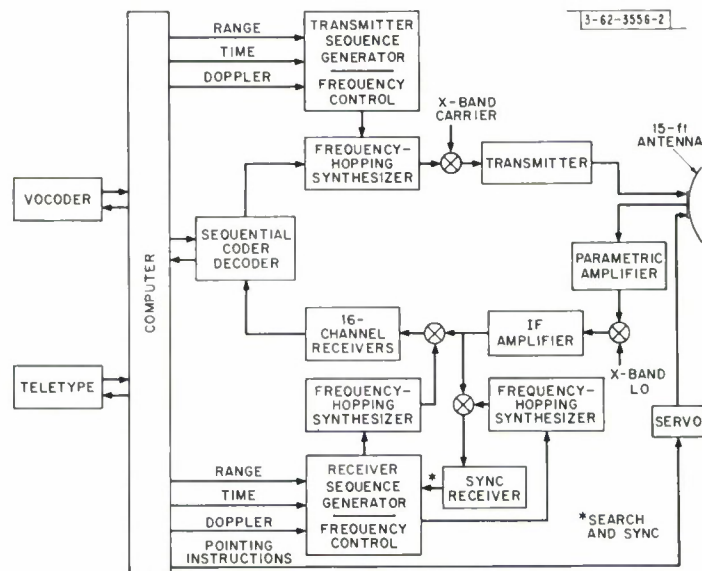

Fig. 4. LET system.

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An example of LET performance, when operating in an environment requiring multiple access to a satellite, may be useful. The following satellite characteristics are assumed:

Altitude	23,000 mi
Frequency	8,000 Mcps
Receiver noise figure	10 db
Power output	2.0 watts
Antenna gain (receive)	0 db
Antenna gain (transmit)	6 db
Bandwidth	20 Mcps

The signal and noise levels are computed in Table I for both the up and down links; then the number of LET terminals that could use the same satellite is computed. The assumption is made that all terminals radiate the same power, and that they are equidistant from the satellite.

TABLE I
GROUND-TO-SATELLITE LINK

Transmitted power	+70 dbm (10 kw)
Ground antenna gain	48 db
Satellite antenna gain	0 db
Space attenuation	−202 db
Received carrier power	−84 dbm
Noise power density	−199 dbm/°K/cps
Receiver noise temperature (2700°K)	34 db
Receiver bandwidth (20 Mcps)	73 db
Receiver noise power	−92 dbm
Carrier to noise ratio	8 db

TABLE II
SATELLITE-TO-GROUND LINK

Satellite transmitter power	33 dbm (2w)
Satellite antenna gain	6 db
Effective radiated power (ERP)	39 dbm (8w)
Space attenuation	−202 db
Ground antenna gain	48 db
Received carrier power	−115 dbm
Noise power density	−199 dbm/°K/cps
Receiving system noise temperature (100°K)	20 db
Matched-filter bandwidth (5 kcps)	37 db
Receiver noise power	−142 dbm
Required signal-to-noise ratio (5-kbit rate)	6 db
Minimum required received carrier power	−136 dbm
Excess received carrier power	21 db
Margin for link degradation	5 db
Excess carrier power to minimum required power ratio (excluding link margin)	16 db
Number of additional possible users	~39

From Table 11, it may be seen that LET needs only about 63 mw of the 8 watts ERP available from the satellite. The implication is that even under degraded link conditions (5 db) as many as 40 users (20 duplex circuits) could communicate simultaneously, provided that they used the satellite power intelligently by spreading their signals across the 20-Mcps satellite band. One may then ask how much the effective receiving system noise temperature rises under the circumstances postulated above. The worst case, i.e., where all the satellite power appears at the receiver as interfering noise, is computed as

Received carrier power	−115 dbm
Satellite bandwidth	73 db
Interfering noise power density	−188 dbm/cps
Receiving system noise power density	−179 dbm/cps
Interference-to-receiver noise ratio	−9 db
Increase in receiving system noise	~12.7°K

where it is seen that the effective receiving system noise temperature is increased by only 12.7°K.

IV. ANTENNA AND FEED SYSTEM[5]

The LET antenna is a 15-ft-diameter paraboloid employing a Cassegrainian feed system. Some of the more common antenna and feed parameters are given below.

Antenna gain (50% efficiency) including losses	48 db
Half-power beamwidth	0.58°
First side lobes	⩾20 db
Transmission polarization	RHCP
Receiving polarization	LHCP
Isolation between transmit and receive modes	>20 db
Axial ratio	<2 db
Operating frequency band	7200 to 8400 Mcps

V. ANTENNA VEHICLE

The antenna vehicle is basically an elevation-azimuth pedestal carrying an equipment shelter as well as the antenna. The shelter contains the antenna drive system, the RF receiver, the transmitter and its power supply, receiver and transmitter cooling, microwave excitation equipment and test equipment. Road transportability is achieved by attaching a fixed wheel and axle assembly to one end of the pedestal base and a steerable wheel and axle assembly to the opposite end. During over-the-road travel, the antenna is disassembled and stowed inside the forward compartment of the electronics van. The equipment shelter mounted on the pedestal is about 8 × 10 ft and rotates with the antenna in azimuth. Prime power and signal frequencies up to the IF (60-Mcps) are brought into and taken out of the equipment shelter through slip rings.

VI. RF TRANSMITTER

The LET transmitter, designed to operate at X-band with an instantaneous bandwidth of 20 Mcps, develops 10 kw of CW power. Its tube, a Varian type 885 B klystron, has a tuning range of 7700 to 8400 Mcps. Modulating signals from the electronics van are sent via coaxial cable at the 60-Mcps IF to the antenna vehicle, where these signals are translated to X-band in the transmitter driver. The transmitter power supply has an output capacity of 38 kw at output voltage of 16 kv, and various taps permit transmitter outputs of 10, 5, 2-1/2 and 1.25 kw, respectively. A Varian type 849 klystron operating at a fixed frequency can also be used in this transmitter with no change in power supply. Control of the functions involved in adjusting or

tuning the transmitter are carried out in the antenna trailer shelter. RF drive and monitoring of transmitter operation are accomplished in the electronics van. Hence, an operator is needed in the antenna vehicle only for a short time at the beginning of an operational period. A photograph of the transmitter is shown in Fig. 5 and the exciter, receiver IF amplifier and test equipment are shown in Fig. 6.

VII. RF RECEIVER

The Laboratory-designed receiving system uses a refrigerator-cooled, tunable parametric amplifier[6] as a front end, followed by a mixer for translation to the 60-Mcps IF. The frequency range and the bandwidth of the parametric amplifier are 7.2 to 8.4 Gcps and 20-Mcps, respectively.

An Arthur D. Little Model 340 gaseous helium refrigerator is used with a very-slow-speed (75 strokes per minute) regenerator. The refrigerator operates at about 17°K when loaded with a two-stage parametric amplifier (Fig. 7). Under these conditions, with the parametric amplifier's output connections properly terminated, the noise temperature at the terminating flanges is about 55°K. The overall receiving system noise temperature is about 100°K. A second receiving channel is also included for the autotrack error signal, but it uses an uncooled parametric amplifier similar to the one previously described, running at about 300°K. Control, calibration and measurement of receiver performance is accomplished by remote control in the electronics vehicle at the operations console.

VIII. PRIME POWER

Prime power is furnished at 400 cps, 3 phase, 120/208 volts from one of several alternate sources. Distribution of this power is controlled from a power distribution panel in the electronics van, where the power is distributed to four main trunks. One design objective of this power distribution system is to isolate, as much as is practical with one generator, the loads
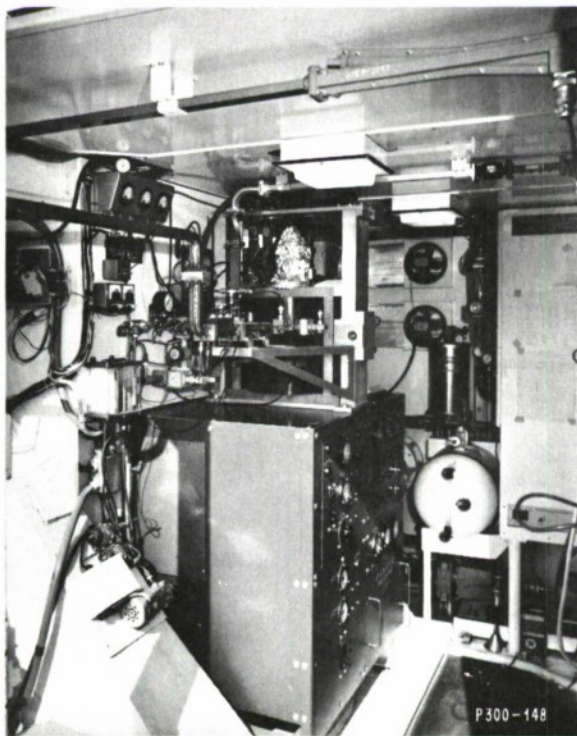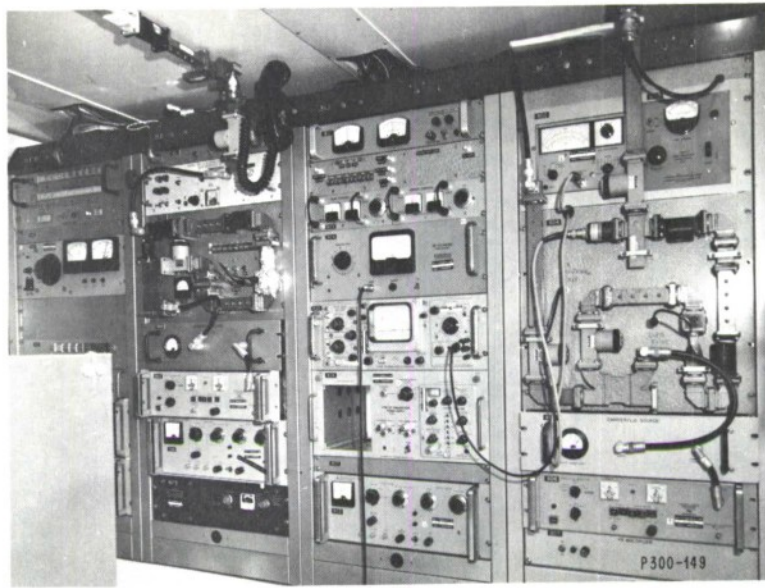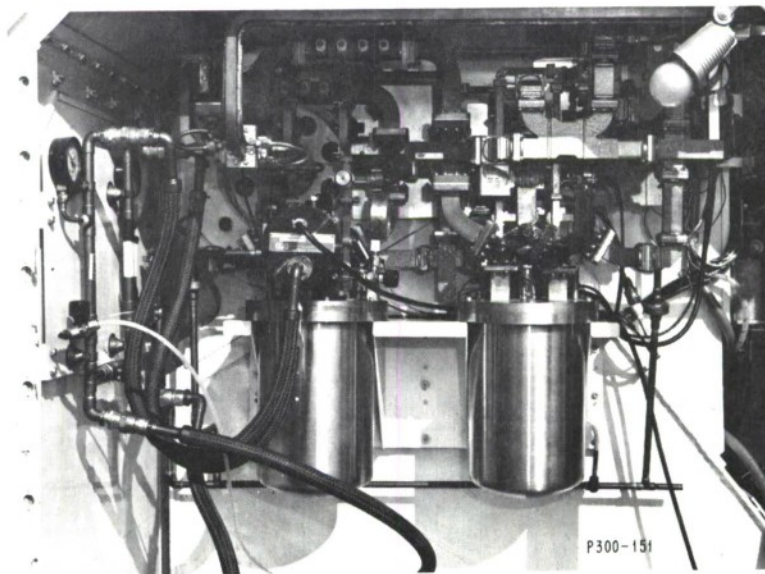

Fig. 5. Transmitter.

Fig. 6. Exciter-receiver.

Fig. 7. Parametric amplifiers.

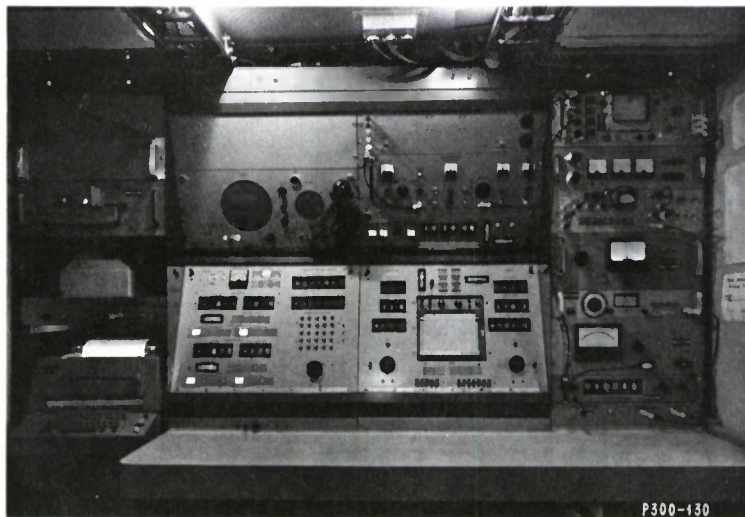Fig. 8.   Electronics vehicle in operation.

Fig. 9.   Console.

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with large transient currents from those with relatively steady current requirements. When LET is used as a self-sufficient terminal in the field, prime power is furnished by a gas turbine driving a 100-kw, 3-phase, 400-cps alternator. JP4 fuel for the turbine is stored in a 350-gallon fuel tank which forms the floor of the prime mover compartment in the rear of the electronics van. Fuel consumption at rated load is about 230 lb/hour providing about 15 hours of operation on one tank filling.

The following turbine-alternator specifications may be of interest:

Turbine alternator weight	1100 lb
Fuel weight	2450 lb
Turbine shaft speed	40,000 rpm
Alternator speed	6000 rpm

For those occasions where full prime power is not needed, a 5-kw gasoline-engine-driven 400-cps, 3-phase alternator is provided.

IX. ELECTRONICS VEHICLE

The electronics vehicle is a commercial quality, 30-ft 6-in. semi-trailer. Dimensions are such as to allow loading in a C-130 E aircraft. The total inside length is 30 ft. Full width opening doors are provided at both ends. Inside the body, two lateral partitions divide the body into three compartments:

(a) The prime power compartment in the rearward 8 ft of the body contains the turbine driven alternator, the auxiliary gasoline-engine-driven alternator and fuel for both turbine and gasoline engine.

(b) The electronics compartment in the central 15 ft contains all the operating controls for LET plus all the electronics for that part of the terminal operating below 60 Mcps.

(c) The air conditioning/storage compartment in the forward 7 ft contains the electronics compartment air conditioner plus storage racks for the panels and secondary reflector of the 15-ft antenna.

One possible problem with this configuration is control of noise generated by the gas turbine alternator. To keep this noise at a reasonable level, the turbine exhaust is directed upward into a 6-ft-high chimney with sound-absorbing walls. The turbine inlet manifold is lined with sound-absorbing material and is baffled to eliminate direct line sound paths from the turbine compressor inlet to the outside. The electronics trailer is insulated on all sides with about three inches of sound-absorbing material. The partition and the hatch between the prime power and the electronics compartments has six inches of sound-absorbing material.

Figure 8 shows the inside of the electronics vehicle, looking toward the control console. Figure 9 shows the control console with teletype equipment to the left, communications and computer control in the center left, antenna control in the center right and microwave receiver control and test equipment at the far right. The signal-processing equipment is shown in Fig. 10, with the computer at the far right. An operator is adjusting the tape recorder located just above the four drawers that constitute the vocoder. Below the vocoder is the encoder/decoder plus its memory, located at the bottom of the rack. In the rear rack are located the channel receivers and the frequency synthesizers.

Figure 11 depicts a frequency synthesizer as an example of the construction techniques used for analog circuits. Figures 12 and 13 show the encoder-decoder as an example of digital circuit
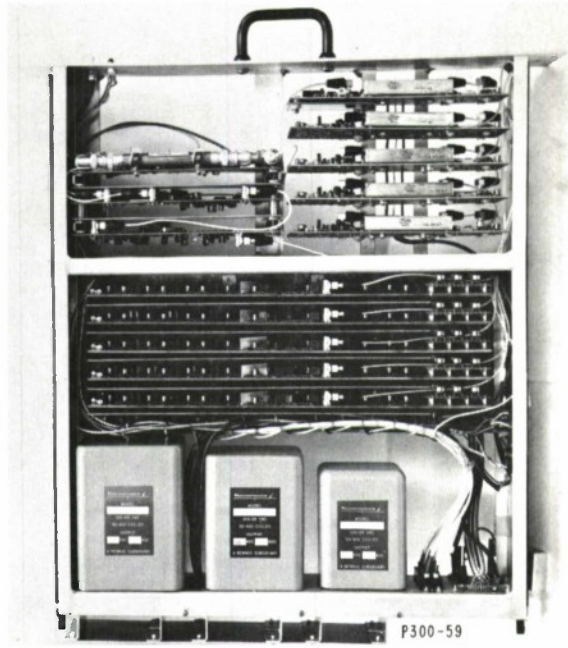
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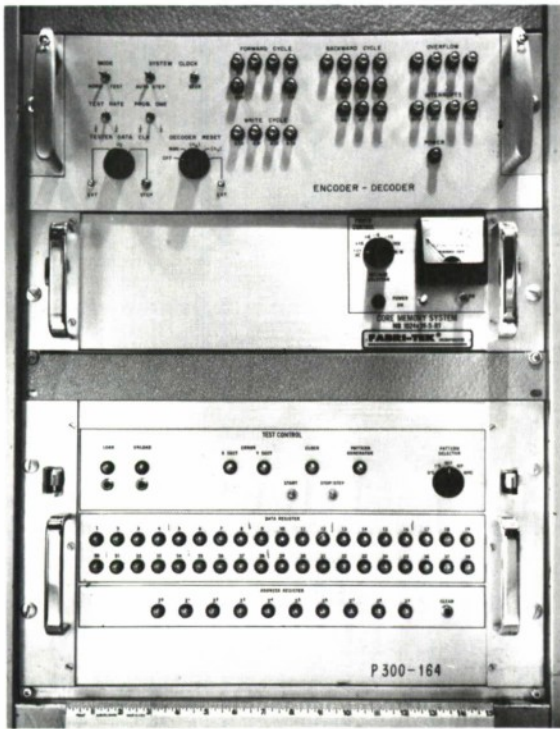Fig. 10. Signal-processing equipment.

Fig. 11. Frequency synthesizer.

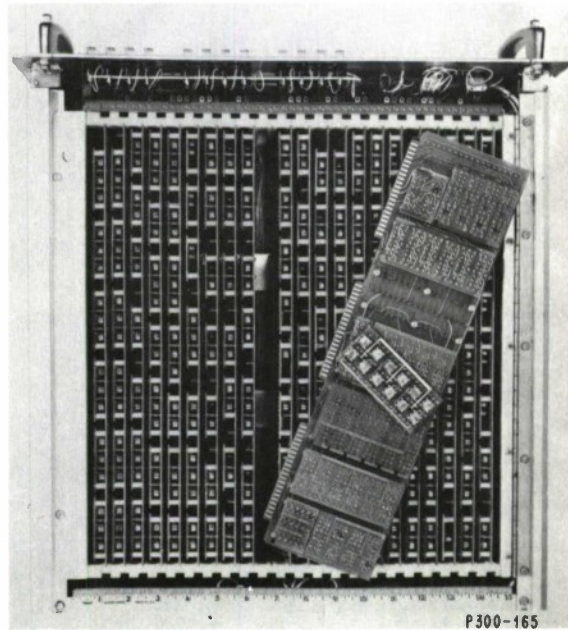Fig. 12. Sequential encoder/decoder front view.

Fig. 13. Typical encoder/decoder circuitry.

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construction techniques which use integrated circuits. Packaging in this manner allowed the entire system including test equipment to fit into four racks.

X. TEST OPERATIONS

Since the completion of the terminal in May 1965, a great many tests[7-8] have been made with the terminal (1) by itself on "back-to-back" basis, (2) up to a satellite[9] and back to itself, and (3) via a satellite, the moon, or the tropospheric scatter mode to another station with duplicate signal-processing equipment. System performance was essentially as predicted.

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13. ABSTRACT

The Lincoln Experimental Terminal (LET) is a complete, self-contained air-transportable ground terminal for testing and demonstrating evolving space communication techniques in a realistic environment. Its present equipment complement permits efficient, highly reliable, multiplexed digital communication of voice and record traffic using a variety of channels, including the moon and active satellites. Its modulation system, using a 16-symbol alphabet frequency-hopped over a 20-Mcps band, together with efficient coding, provides multiple-access use of a wide-band satellite.

14. KEY WORDS

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space technology   sequential decoding