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A Meteor Scatter Communications System Using Digital Storage

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PROBLEM

Develop and evaluate communication equipment to be used in special tactical situations for transmitting intelligence by means of forward scattering of vhf signals from ionized meteor trails.

RESULTS

1. An experimental, one-way digital system was developed that performed extremely well ashore and aboard ship.

2. A duplex system using similar dynamic digital logic and storage can be constructed easily and in a relatively small space.

3. Semi-unattended operation is feasible.

RECOMMENDATION

A duplex, ship-to-shore meteor burst communication system, based on the techniques described herein, should be developed for service test use.

ADMINISTRATIVE INFORMATION

This project was carried out under NEL Problem NE-090602 (S-F006 02 05, NEL B1-14), beginning in July 1955. The work was done by the Terminal Equipment Section, Electromagnetics Division, and the report was approved for publication 25 November 1960. The authors wish to thank F. T. Clapsadel, J. D. D'Spain, E. G. Hedger, W. M. Oleson, F. Verteiko, H. J. Wirth, H. H. DaMoude and E. E. McCown.

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INTRODUCTION

In recent years considerable interest has been shown in the transmission of intelligence by utilizing the forward scattering of vhf signals from the ionized trails of meteors. The physics of the propagation mechanism, equipment considerations, and the results of experiments are well covered in the literature.[1, 2]

The essential difference between the usual type of communications and one that makes use of meteor trail reflections is the intermittent nature of the latter. The burst type system must sense the presence of a suitably oriented meteor trail and transmit information only during the short period (usually less than 1 second) that the electron density in the trail remains sufficiently high to provide a usable reflection.

The frequent though random occurrence of suitable trails permits a vhf communication circuit to be established between two points on the earth's surface that are separated by distances up to a maximum of about 1200 miles. Since the preponderance of meteor trails occurs at elevations between 80 and 120 kilometers, the geometry of the reflection limits the operating range. How satisfactory a communication path will be established by any specific burst is dependent upon many factors, such as the orientation of the trail and its geometric relationship to the ends of the path; the height, length, and intensity of the ionized trail; and the frequency employed. Additionally, the incidence of bursts is subject to diurnal and annual variations, the effect of each being somewhat dependent upon the latitude and direction of the communication path.

The communication system described in this report is for ship-to-shore use primarily.[3, 4, 5] In order to minimize radiation from the ship or ships, probing is done from the shore (master) station only. When a suitably oriented meteor trail provides a communication path, the ship (slave) station receives the probing signal, turns on its transmitter, and returns a signal over the same meteor trail, but on a slightly different frequency, which indicates that data is to be sent.

Since the average meteor trail persists for such a short period, special techniques are required to make efficient use of the communication path that it establishes. The method of compensating for the low duty cycle is the use of high-speed message transmission. Since the original message source and ultimate delivery are probably at some ordinary message speed, this implies that some readily accessible storage device will be needed at both ends of the link. Several types of storage devices can be used, such as magnetic cores, drums, tape, delay lines, etc.[2] A previous system developed by NEL used magnetic tape devices.[3,4] The system described herein employs dynamic data storage, using magnetostrictive delay lines, operating in conjunction with digital logic modules.[6]

GENERAL DESCRIPTION

The experimental meteor burst communication system consists of a master (shore) station and a slave (ship) station. Each station normally can transmit and receive data simultaneously (as demonstrated with a previous NEL system using magnetic tape for the storage accordion).[4] However, in order to demonstrate the technique while conserving time and material, the digital system, to be described, was developed for the flow of data in one direction only.[6] A simplified block diagram of the system is shown in figure 1.

When a message is to be sent, teletype data is read from punched tape at standard speed and inserted in the digital store. High speed read-out is controlled by digital logic and signal sensing circuits. When the presence of a suitable meteor trail allows transmission of a burst of information, the receiving station, by means of a control signal, tells the other station to send its high-speed data.

Reception of the data and operation of the storage input and output are controlled, as before, by means of signal sensing and logic circuitry. Stored data, when available, is read out of the digital device and fed to a teletype page printer at standard speed.

The rf equipment was the same as that used during previous tests and consists of commercial phase-modulated transmitters and fm receivers designed for speech use.[4] The transmitters were used with power outputs of 1.5 kw at 40.14 Mc/s and 46.62 Mc/s, respectively. During ship-to-shore tests, the transmitter at NEL was changed from 40.14 Mc/s to 49.65 Mc/s. Separate three-element Yagi antennas were used for transmission and reception at each

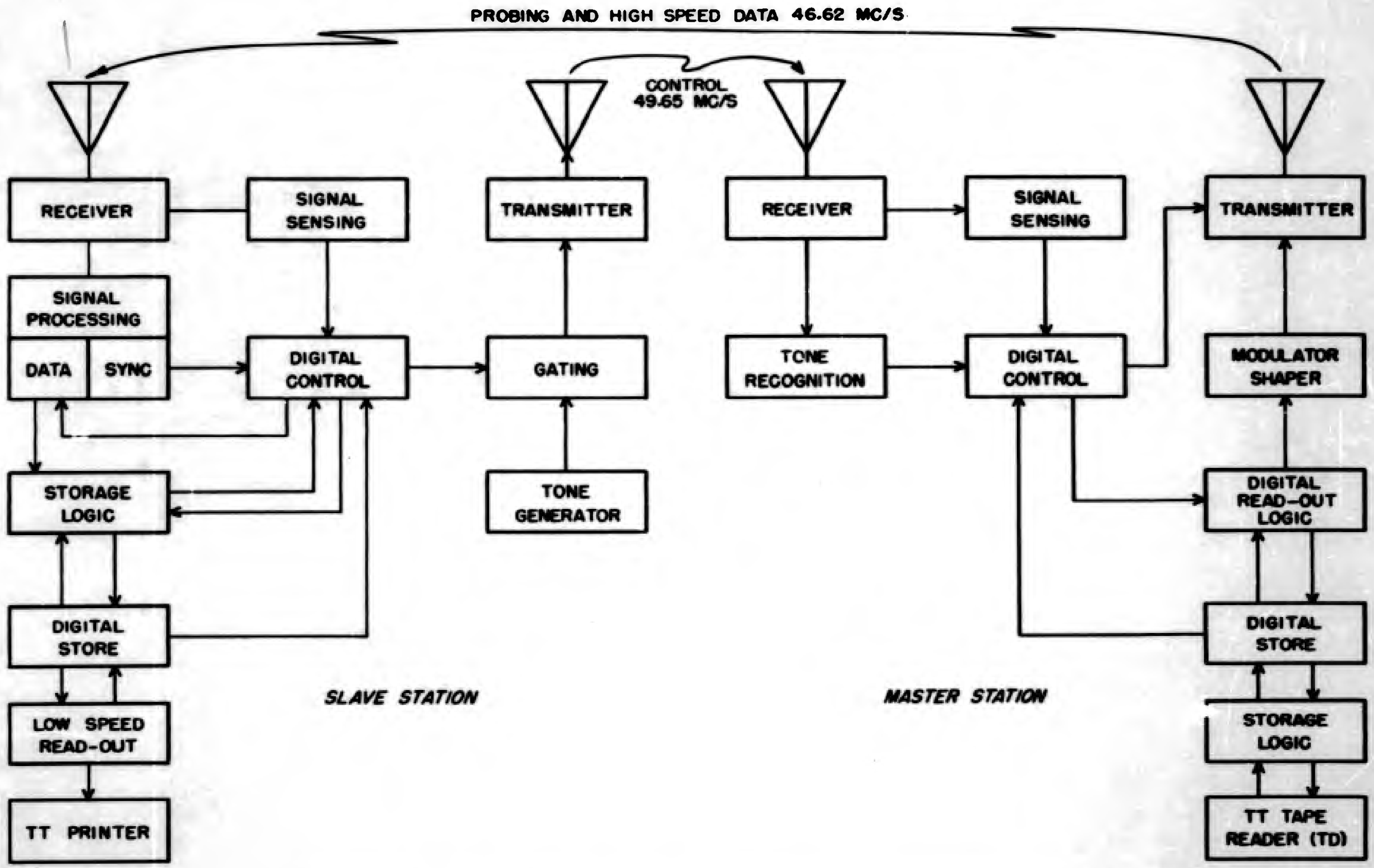

Figure 1. Simplified block diagram of experimental meteor burst system with one-way data flow.

end of the link. The standard 15-kc/s bandwidth was used in the receiver i-f strip, and no attempt was made to improve the receiver front-end noise figure. However, post-detection processing was employed. Details of the signal sensing, control, processing, logic, and digital storage are covered in the following sections.

DATA FLOW

Data flow from the transmit into the receive system is shown in figure 2. The 60- or 100-wpm teletype information from a tape reader is fed into a bank of dynamic digital storage lines (magnetostrictive delay lines) where it continues to circulate until read-out in parallel-to-series form in the shift registers at 2900 wpm during the meteor burst. The information that has been transmitted and received in serial form is stepped down through the shift registers and, at the proper time, is fed in a series-to-parallel fashion into the receive storage lines, where it again circulates until read-out at the 60- or 100-wpm rate.

In order to effect the data processing, numerous control functions are provided that determine just when, and under what conditions, the several processes will occur.

DIGITAL TRANSMIT SECTION

The basic functional circuit elements of this portion of the digital system are the six dynamic circulating storage lines and the corresponding six shift registers. The other portions of the digital logic serve primarily as adjuncts, in general, providing timed control of the data storage, circulation, and/or read-out. A one-Mc/s master clock provides timing for the dynamic logic.

Five of the storage lines are used to store the five data bits associated with each teletype character. The sixth storage line is employed to store the "index" pulses, one pulse being used with each character. The index pulse accompanies the five data pulses throughout the high-speed digital system and is used to develop control logic employed in the handling

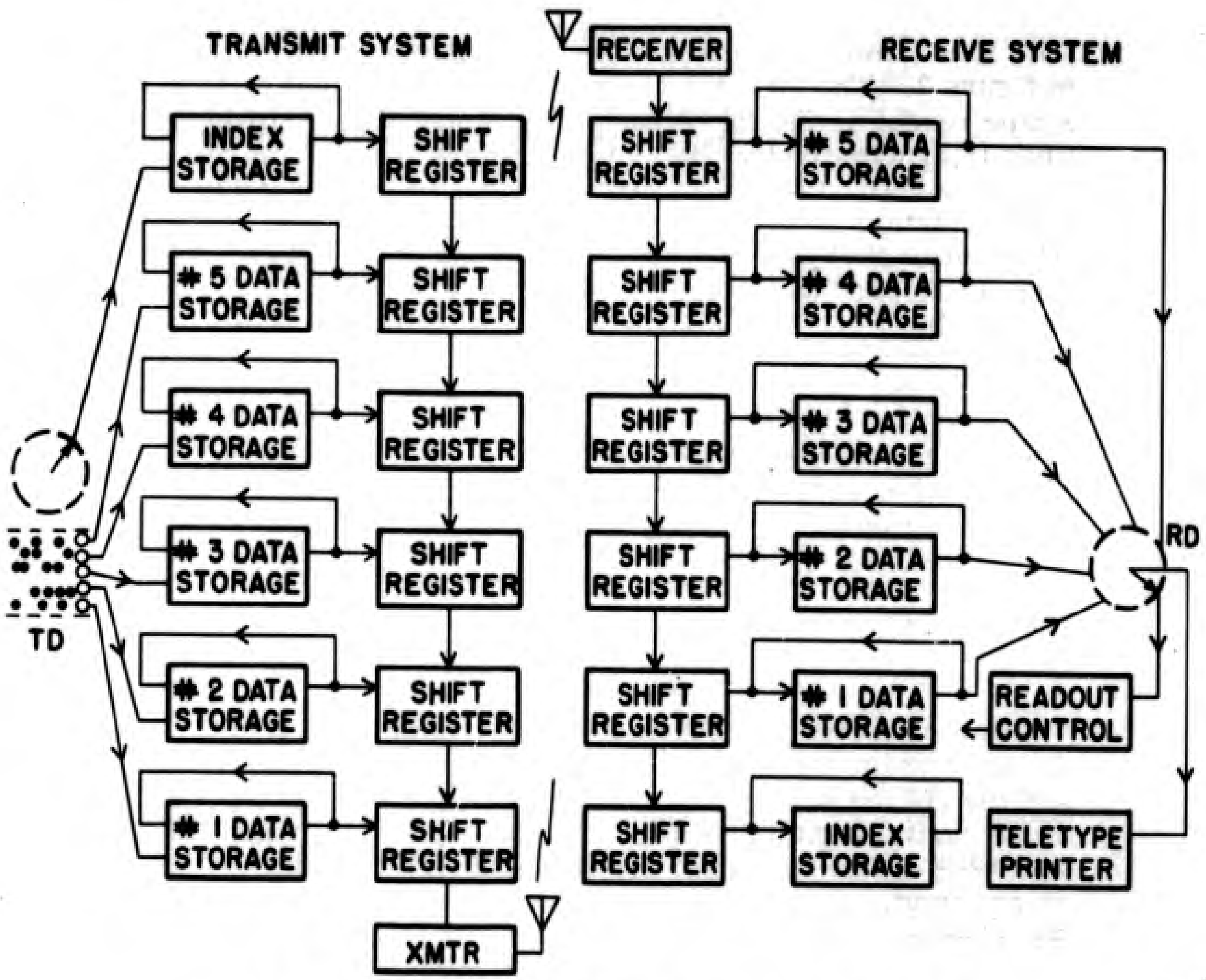

Figure 2. Simplified block diagram of data flow.

of data. Thus the standard seven-baud* teletype character is reduced to a six-baud character (frame) within the system.

Each of the six storage lines and its associated input-output logic provide for the insertion and recirculation of 1-microsecond bits, each bit representing a particular part of a teletype character. The over-all loop delay in all lines is 565 μsec; thus, the parallel line storage system can retain 565 teletype characters.

Data input for the transmit system is derived from a standard punched teletype tape, operating in a slightly modified 100- (or 60-) wpm transmitter-distributor (TD). The five data switches in the TD, actuated by the holes in the tape, are directly connected to the corresponding driver inputs for the five "data" storage lines.

Operation of the TD is permitted when the transmit storage contains less than a full store of data. At each rotation of the TD wiper, a new set of five bits of information (representing one character) is read from the tape and made available to the storage line drivers. At the appropriate microsecond, this set of information is loaded into the respective lines and appended to the trailing end of the train of information that may already be in each line. In addition, an index pulse is invariably loaded into the index storage line for each character. The loading process continues until the storage lines are full, at which time the TD is stopped.

Up to this point the data bits have been handled in a strictly parallel fashion. Since the information is to be transmitted over a single-channel system, it logically follows that the six bits associated with each teletype character should be ordered up and sent in chronological sequence. To accomplish this, a set of six "shift registers" is employed, one

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*In this report the term "baud" is used to denote a unit component of a teletype character. At the 60 wpm rate this baud will be 22 (or 33) milliseconds in duration; at the 2900 wpm transmission rate the baud is 0.565 milliseconds in duration. It is recognized that this usage is not in strict conformity with its definition as a signaling rate. The term "bit", as well as "pulse", on the other hand, is generally used to signify a 1 μsec data element within the storage and logic circuitry.

register being associated with each storage line. The shift register, having two "stable" states, can "hold" a bit of information ("mark" or "space") until further instructions are received. This allows one bit to be "read-in-parallel" from each storage line into the corresponding register at the appropriate time. The output of each register is connected to an input gate on the adjacent register. Through the repetitive action of the so-called "shift-right" pulses, the bit of information held in each register is transferred to the adjacent one in a "bucket-brigade" manner. The end register (No. 1) is the one that furnishes the transmitting system with a series of bits, a group of six bits representing the information in one character. It is evident that a new set of six bits of information will be taken from the storage lines only when the previous set has been shifted-right six times. The read-in-parallel timing is such that one set follows "right on the heels" of the previous set, the bauds occurring in regular sequence without any break.

Since the data transmitting portion of the experimental system was assigned to the master station, the "probing" signal is continuously transmitted from that end, prior to the verification that a path exists to and from the slave station. This probing signal actually consists of a continuous series of teletype "line-feed" characters. These characters are generated within the shift registers by "artificial" means, that is, not involving the stores. Eventually, a signal will be received from the slave station, indicating "Your line feeds recognized, and signal-to-noise ratio is satisfactory." The master station thereupon starts sending data.

As soon as several characters have been read out of transmit storage, the TD will start and refill the stores at the 100-wpm rate. During read-out the stores are emptied at the rate of 2900 (2885) wpm. This means that a full store of 565 characters, plus an additional 12 to 20 characters loaded during the transmission period, could be sent in approximately 2 seconds, assuming a burst of at least that length.

The high-speed teletype rate is determined through a character period relationship:

$$\text{High-speed rate} = \frac{163 \text{ ms/char. @ 60 wpm}}{3.39 \text{ ms/char. @ high speed}} \times 60 = 2885 \text{ wpm}$$

The decision to stop the transmission of data is made when the signal-to-noise ratio falls below a preset threshold, when the transmit store is empty, or when an order to shut down is received from the other station.

RECEIVE SECTION

Digital Storage-Control and Signal Processing

When a suitable meteor burst occurs, the probing signal, transmitted by the master station, is satisfactorily received at the slave station. This received signal is nominally synchronous with the information received and stored during previous bursts, but may differ by a fixed but unpredictable time displacement due to a different path being taken by the signal for each burst. In order to reconcile the timing of these two signals, a "baud clock" is employed, which is started at the beginning of each burst in baud synchronism with the signal being received. To establish just when the baud clock should be started, a "mark-baud recognition" circuit is employed that "measures" the length of the "mark bauds" in the received signal. When one is recognized that is of proper duration, the circuit then delivers a pulse which starts the baud clock.

During the majority of the bursts, the receiver will be operating with a relatively low signal/noise ratio. Integration, shaping, and peak clipping is therefore employed before the signal is delivered to the mark baud recognition circuit.

Since baud synchronism with the received signal is established at the beginning of each burst, considerable post-detection improvement in the S/N ratio of the detected signal (from the receiver discriminator) is achieved by long time-constant integration of the signal and synchronous quenching by the baud clock. The resulting "mark-space" decision is irrevocable for each baud, and each baud is exactly 565 μsec in length.

The process of storing information at the receive end of the system resembles the inverse of the read-out process taking place at the transmit end. The discrete mark-space information bits are passed cascade-style through the string of shift registers (fig. 2) and at the proper time inserted in the parallel storage lines, where they continue to recirculate.

Read-Out Circuits

Discussion of the digital receive system so far has been concerned with the reception and storage of information. It should be recalled that such information as has been received and stored continues to recirculate in the storage lines, regenerating itself each 565 μsec. The final operational phase concerns the manner in which the data is read out of the data storage lines and again formed into typical seven-baud teletype characters at the 60- or 100-wpm rate.

The leading end of the pulse train in the receive index storage line represents the information that is to be read out; it was the earliest received. This is recognized and used to control the simultaneous read-out of the corresponding pulses from each of the five data storage lines into the five static flip-flops.

Initially, the outputs of the five static flip-flops were directly connected to the corresponding five "data" segments of a modified teletype transmitter-distributor (now called a receiver-distributor, RD). The voltage that each flip-flop places on its associated segment determines whether that baud information shall be "mark" or "space". The commutator has seven segments corresponding to the baud structure of the standard teletype code character. As the RD wiper starts a rotation, the read-out from storage actually occurs, and the appropriate voltages are placed on the five data segments simultaneously. The "start" and "stop" segments have predetermined voltages applied. In its one rotation (in 163 milliseconds for 60-wpm operation) this wiper has voltages applied to it, successively, which reform the original seven-baud teletype character. The voltages appearing on the wiper are amplified and applied to a teletype line-relay, which keys the actual teletype line.

An electronic receiver distributor (teletype code regenerator) was subsequently developed and placed in operation in lieu of the mechanical device described above. The 163-millisecond character period and the seven individual baud periods are established by transistor multivibrators. As before, the output pulses are amplified and applied to a teletype relay.

Signal Sensing

This unit monitors receiver signal-to-noise (S/N) ratio and delivers digital output levels for equipment control when the S/N ratio exceeds the preset threshold. The "operate signal level" threshold provides a control for starting "receive" functions and for "transmit" functions in general. A lower S/N threshold provides a control for stopping receive functions.

Another control is provided by strong impulse noise being recognized and used to hold the equipment inoperative for extended periods when its energy and repetition rates are sufficient to cause appreciable errors in the received information.

Auxiliary Equipment

Various control functions, too detailed to discuss in this report, are required to regulate the various parts of the system. In addition, auxiliary units were developed for use during system tests in the laboratory and for periodic local testing during the course of field operations. These units shown (figs. 3 and 4) occupy a sizable portion of the rack space.

At the NEL end of the link, the majority of the equipment is located in the main Laboratory building while the transmitter, receiver, and antennas are at a relatively quiet field site 3 miles distant. Telephone lines linking the two locations require weighted amplifiers in order to preserve the data waveforms. Remote transmitter control and monitoring facilities are also provided.

The other end of the link is normally housed in a van and hauled to the Humboldt Bay site during field tests. However, during sea tests, the equipment was removed and installed aboard ship.

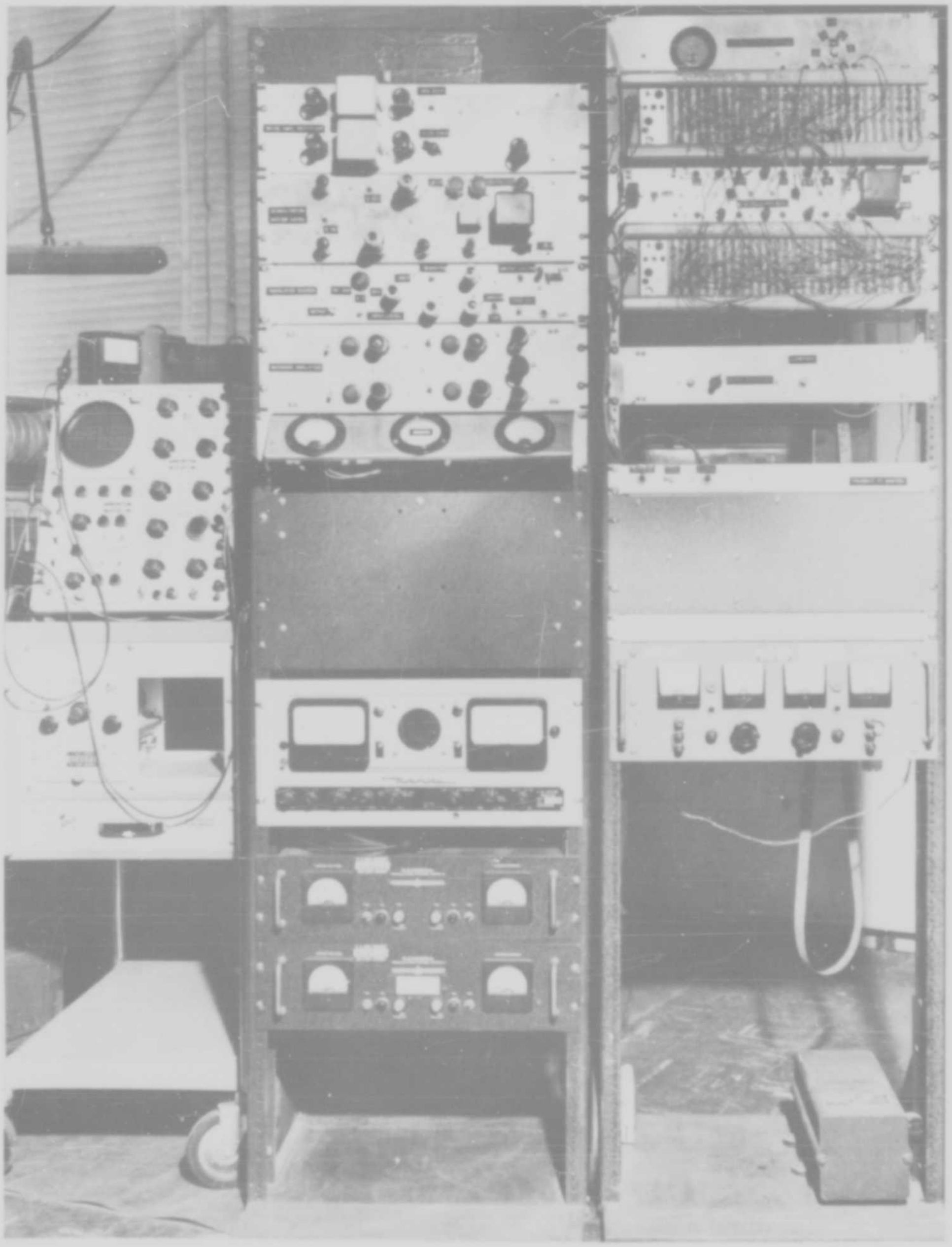

Figure 3. Transmit storage and control racks.

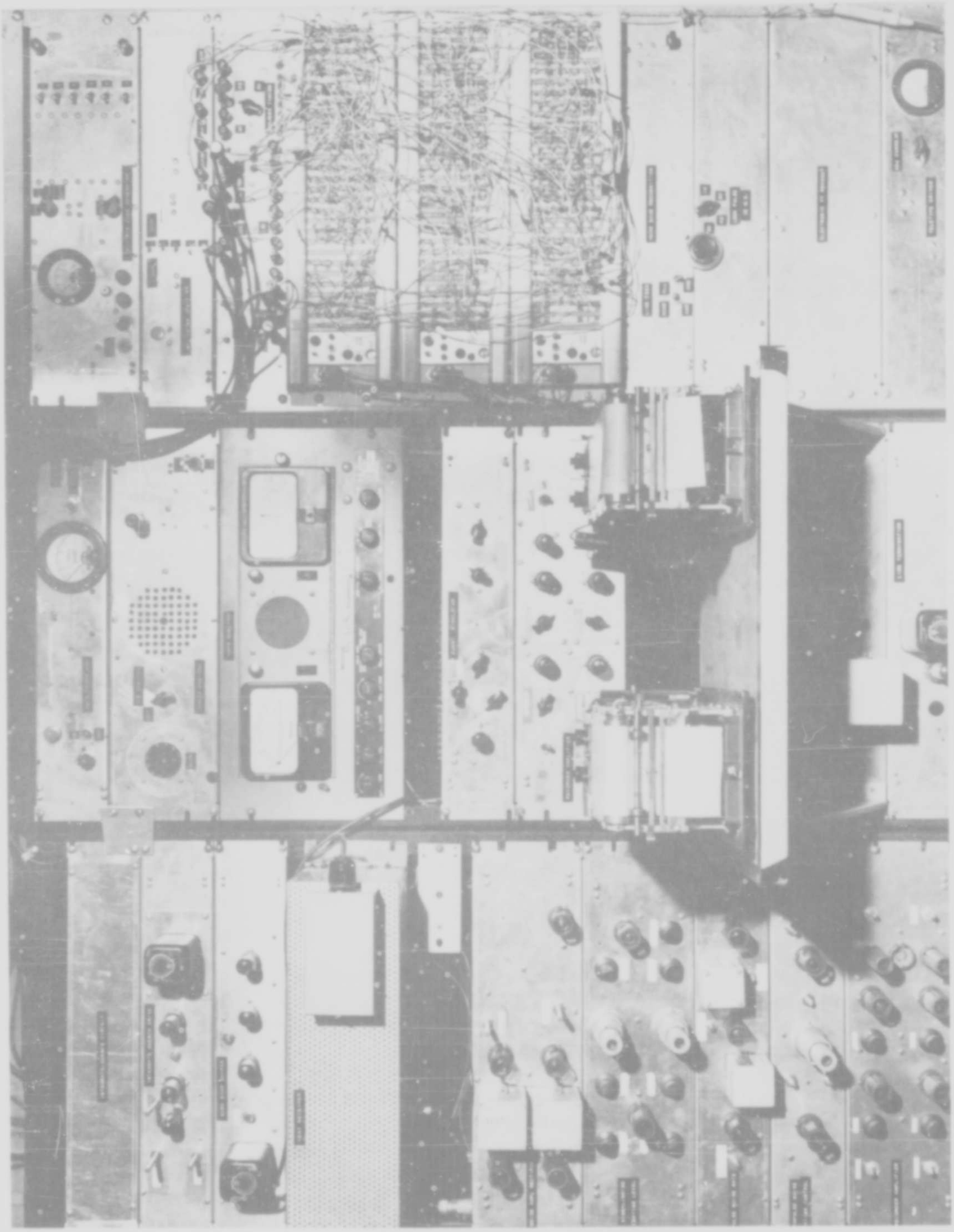

Figure 4. Receive racks.

SYSTEM TESTS

Field testing of the meteor burst communication system was conducted during the month of April 1960 over the 700-mile path between San Diego and Eureka (Humboldt Bay), California. The system was also tested during the last 2 weeks of May 1960 while one end of the link was aboard USS REXBURG (EPCER 855) en route between San Diego and Seattle, the maximum distance being 1270 statute miles.

For the 700-mile, point-to-point tests, antenna heights were adjusted for optimum vertical lobing. During the ship-to-shore tests, however, the fixed antenna heights, being fairly low because of the small ship structure, restricted satisfactory operation to a maximum range of about 900 miles. Previous tests aboard a larger ship en route to Hawaii provided meteor burst communication out to approximately 1200 miles.[4] In addition, during the May 1960 test, noise created by the system transmitter aboard ship tended to reduce the duty cycle below that attained during the point-to-point tests. At optimum ranges, however, results obtained during the two tests were comparable. Test results reported are based on the point-to-point operation since more extensive and significant data was obtained during that phase of the field tests.

During field testing of the system it was more convenient to transmit data from the remote site and to receive the data and analyze it at the laboratory. The remote station thus became the master temporarily. Although the digital equipment available was limited, it was possible to satisfactorily demonstrate the operation and reliability of the dynamic digital storage and control system using the one-way circuit. A duplex system using magnetic tape storage had previously been demonstrated with the remote station or ship normally maintaining radio silence.[4]

Results of the system tests were based on data compiled during the period 12 to 29 April 1960. After initial setup and adjustment, the system was allowed to operate continuously during the 18-day period, the equipment at both ends of the link being unattended except during normal working hours. Teletype copy was analyzed each morning for the overnight periods and hourly during the daytime.

Figure 5 shows the distribution of information rates (wpm of teletype copy received) for the daytime hourly periods during the 18-day test. The overnight results are plotted at the right. Generally, copy received during sporadic E periods was disregarded.

Although the complete diurnal variations were not recorded, the average information rate curve of figure 5 shows a distinct minimum near noon with the rate increasing at 1600 rather than the usually expected decrease during the late afternoon hours. A similar trend is shown in the curve of figure 6, representing the average hourly information rate during the last 3 days of the field test.

At the NEL end of the link the antenna pattern is somewhat restricted on the eastern side by a high cliff adjacent to the field site. This may have reduced the illumination of the hot spot on the eastern side of the great circle path sufficiently to contribute to the low information rates experienced around noon.[2]

Another factor that undoubtedly contributed to this unexpected variation in diurnal information rate was the observed tendency for the afternoon bursts, although fewer in number, to have relatively longer durations. Morning bursts were usually shorter and, in the case of the few long signal bursts, rapid fading (below threshold) characteristics were exhibited. Thus the amount of perfect copy received per operation was generally less in the morning than during the afternoon and evening hours.

Results of early NEL tests reported by Keary and Wirth[10] indicated that longer burst durations were present in the afternoon and evening than in the morning hours by a factor of approximately 2 to 1. The higher velocity meteors, occurring in the morning, ionize at a greater height. This results in a higher diffusion coefficient than the afternoon and evening meteors when the link stations are near the maximum distance from the apex of the earth's way.

More short-duration bursts, with attendant start-stop times, resulted in a greater number of operations required to exchange a given amount of information, and thus caused the morning burst utilization efficiency to be lower than that experienced in the afternoon. This factor tends to equalize the diurnal information rate of a practical system more than originally envisioned.

Also attendant with the greater number of shorter operations during morning hours were a great many occasions of rapid signal fading. These tendencies are reflected in the higher

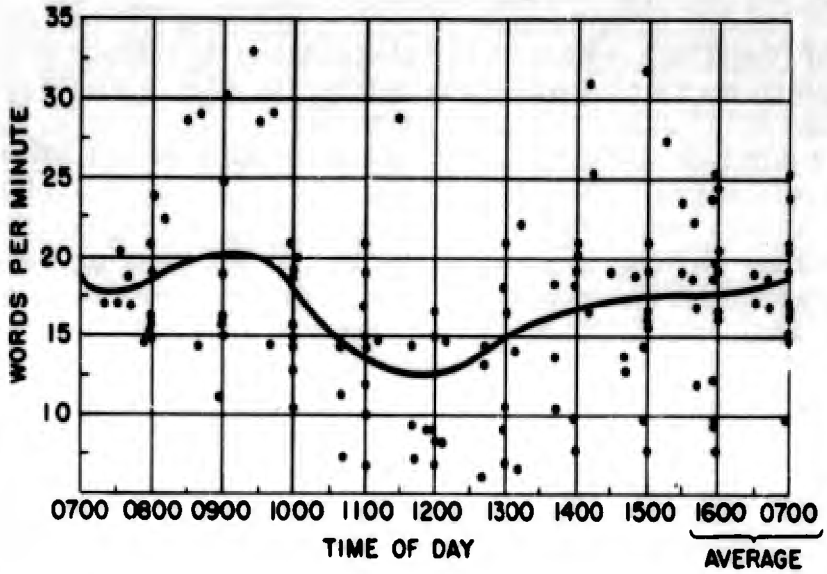

Figure 5. Information rate vs. time of day 4/12/60 to 4/29/60.

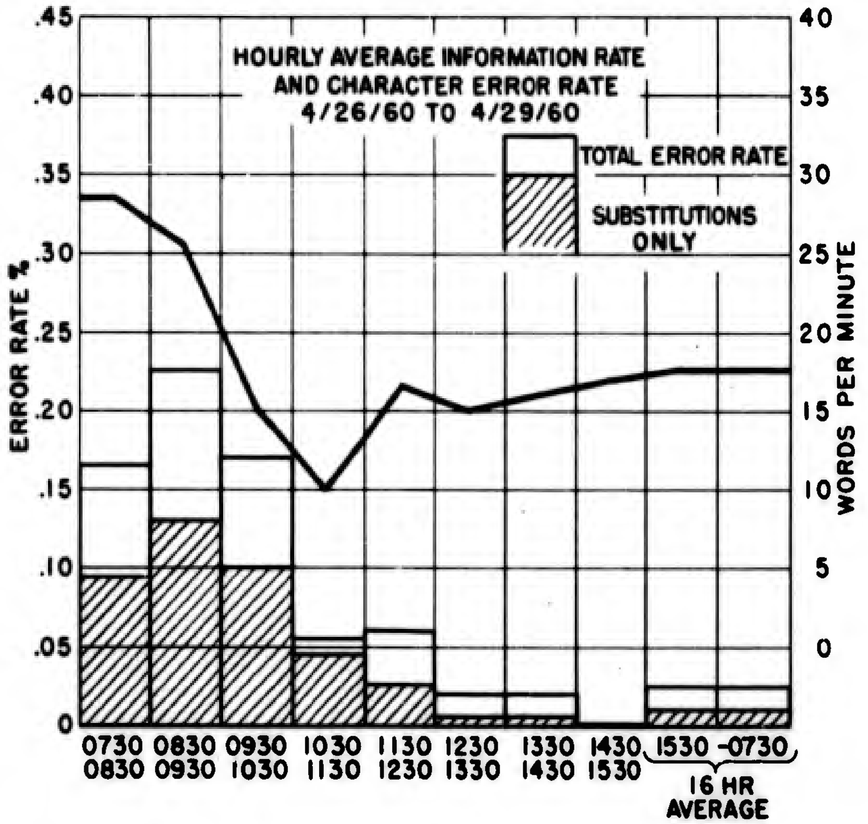

Figure 6. Hourly average information rate and character error rate 4/26/60 to 4/29/60.

morning error rates, both substitutions and deletions, as indicated in figure 6. This may be taken as indicating that these errors are predominantly end-of-burst errors. A method of reducing end-of-burst errors will be discussed later.

General results, indicating daily average information and error rates, are plotted in figure 7 for the entire test period Between 12 and 25 April 1960, minor improvements were made in the operational logic, and various threshold levels were tried in an effort to achieve a high information rate and to maintain a low error rate.

For approximately 70 per cent of the time on 18 to 19 April 1960, the threshold level was lowered 3 db below the optimum. It can be seen in figure 7 that the information rate was increased 45 per cent, but the error rate increased to 0.3 per cent, which is not acceptable. A slight enhancement of the information rate during this period, and particularly on 20 April 1960, was due to the Lyrids shower and short periods of sporadic E propagation.

As seen in figure 7, circuitry improvements and logic changes resulted in a trend toward higher information rates with fewer errors. No changes were made after 26 April 1960. With a threshold level of 0.7 microvolts,* (approximately 8 db S/N ratio) the equipment ran continuously with no malfunction until the conclusion of the field test. The average information rate of 18 wpm with a 0.048 per cent character error rate is considered representative of the system capabilities. Methods of further improving performance are discussed later.

MEASUREMENTS

The information rates (number of words per minute) and the associated error rates were taken directly from the teletype copy. Standard "FOX" test messages (fig. 8) with numbered

* Receiver input levels are based on generator (50 ohm) indicated values. Minimum signal levels used are limited primarily by receiver noise.

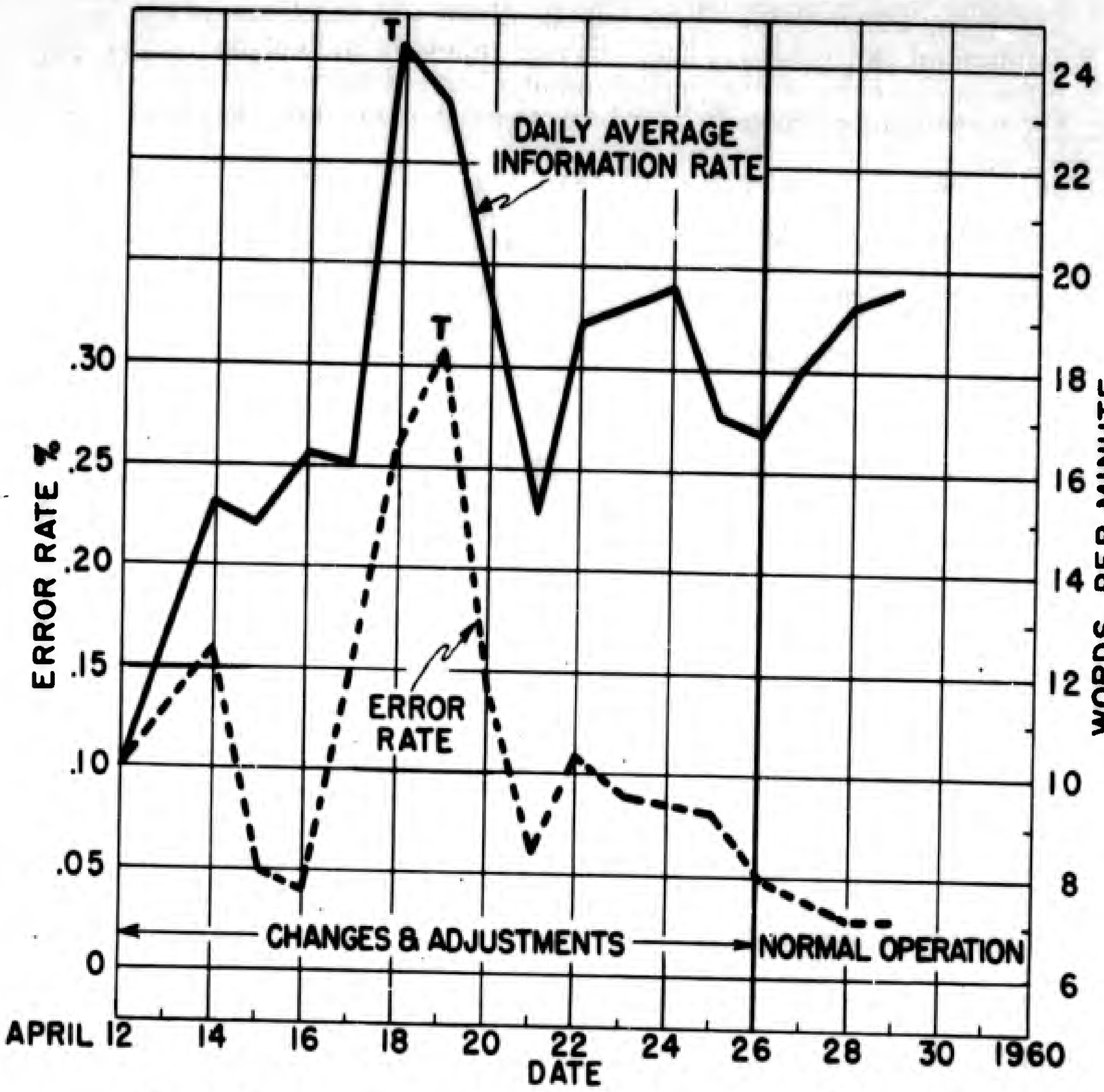

Figure 7. Daily average information rate and error rate.

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0000000000000000000000000
1 NEL METEOR BURST COMMUNICATION SYSTEM SLAVE STATION TESTING NEL NEL
2 THE QUICK BROWN FOX JUMPED OVER THE LAZY DOGS BACK 1234567890 TIMES
3 THE QUICK BROWN FOX JUMPED OVER THE LAZY DOGS BACK 1234567890 TIMES
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21 THE QUICK BROWN FOX JUMPED VVER THE LAZY DOGS BACK 1234567890 TIMES
22 THE QUICK BROWN FOX JUMPED OVER THE LAZY DOGS BACK 1234567890 TIMES
23 THE QUICK BROWN FOX JUMPED OVER THE LAZY DOGS BACK 1234567890 TIMES
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Figure 8. Sample of teletype copy received.

lines were generally used. Copy was analyzed each morning for the 1600 to 0700 unattended periods and periodically during working hours. During the last few days of operation, daytime hourly readings were made.

Other system parameters were measured by means of counters at the receiving end of the link. A one-kc/s signal was gated to the respective counters, thus indicating the total number of milliseconds the various functions were in operation. Counters were read and reset manually at the end of each sample period.

Measurements made were when:

1. The total time that the S/N level exceeded the "operate threshold," except when the impulse noise (ignition sensing) circuit held the system off, or when the system was in the process of going off due to a command from the other station. Counter A thus measured the total time that the system could have operated if all conditions had been met.

2. The total time that the operate threshold was exceeded (as in A) but the system was held off because of a full storage condition.

3. The total time that the S/N level exceeded an auxiliary threshold set approximately 3 db lower than the operate threshold.

STORAGE EFFICIENCY

The digital storage device used in the NEL system can store a maximum of 565 teletype characters. At the transmission speed of 2885 wpm the store can be emptied in approximately 2 seconds if a continuous path exists. However, bursts are usually of much shorter duration and the store is being refilled as needed at a 100-wpm rate. Similarly, the receive store will be filled in 2 seconds and cause the system to stop operating until room is made for additional information by means of the standard speed read-out to the teleprinter. Obviously, the efficiency is low during sporadic E or other periods of continuous transmission.

$$\text{Storage efficiency in percent} = \frac{A - B}{A} (100)$$

where A is the possible operation time and B is the time that operation is prevented by a full store.

The average storage efficiency as a function of time of day is shown in figure 9 for the period 23 to 29 April 1960. The variation in this parameter shows approximately an inverse relationship to the variation in information rate. A high of 100 per cent was achieved many times during low meteoric activity. One such period was observed at 1300 on 25 April 1960. The over-all average storage efficiency for the 6-day test was 84.3 per cent. This is slightly less than the predicted efficiency of 90 per cent as compared to an infinite store.[5] The advantage to be gained by using a larger store appears to be slight as compared to the added size and complexity and the slower access time.

BURST UTILIZATION

In addition to the storage time limitation, the efficient use of all meteor bursts is reduced by the time required to recognize a suitable signal and to initiate transmission and reception of information. Additional time is lost at the end of a burst. To these operational time delays is added the transit time required for a command to reach the other station. Fortunately, burst lengths are greater at long ranges, which fact more than compensates for the added transit time.[1,3]

The burst utilization factor is the ratio of the total burst time actually used to receive copy at 2885 wpm to the total burst time during which the copy might have been received. For the NEL system, a character is sent in 3.39 ms. With 73 characters per line, the time required to transmit one line of copy is 0.248 second. It follows that

$$\text{Operation Efficiency} = \frac{(0.248)(\text{Number of lines})}{\text{Total burst Time in sec.}}\ (100)$$

During the period 23 to 29 April 1960 the operation efficiency varied between 94 per cent and a low of 23 per cent, the latter being during sporadic E periods when the receive store was rapidly filled and limited the exchange of information to 3 or 4 characters per operation. The average efficiency of the system was 67 per cent for the period tested.

Another factor, which is of extreme importance for efficient operation of a meteor burst communication system, is the correlation of signal bursts as seen by both ends of the link. It was determined during early tests that terrain irregularities caused adjacent transmitting and receiving antennas to have differing vertical patterns, thus reducing the signal correlation.[3] The use of a common transmitting/receiving antenna with suitable isolation filters was found to be helpful in this respect.[4]

The signal frequencies, employed by both ends of the link, must be kept as close together as is practicable for good transmission reciprocity. A separation of about 2 Mc/s (in the 40- to 50-Mc/s region) is satisfactory. During the 1960 tests, however, it was necessary to use a 6.5 Mc/s separation, thus reducing the correlation to approximately 0.5. This fact is clearly illustrated in figure 10. Samples are shown of 40.14 and 46.65 signals received simultaneously. Since the system operates only when the two stations see the same event, it may be assumed that the operation is 50 per cent as efficient as it might be with perfect reciprocity.

During the ship-to-shore tests in May 1960, the frequency of the shore transmitter was changed from 40.14 to 49.65 Mc/s. The remote station remained at 46.62 Mc/s. Although no data is available, it is assumed that reducing the frequency difference between the two ends of the link from approximately 6.5 Mc/s to 3 Mc/s caused an improvement in correlation and therefore in system operation efficiency.

OPERATION AT LOWER THRESHOLD

The system was operated with the threshold set approximately 3 db lower than normal during about 70 per cent of the sample periods of 18 and 19 April. As shown in figure 7, this resulted in increased average information rate and error rate. Taking the data for 16 to 17 April as standard (no changes in logic were made from 16 to 19 April), the increase in information rate was about 45 per cent.

During a period of 37 hours (1600 on 27 April to 0715 on 29 April) counter-measurements were made of the duty cycle at an auxiliary threshold level approximately 3 db lower than the regular system threshold. For this period the duty cycle at this lower threshold averaged 60 per cent more than the time above the operation threshold.

The increase in error rate resulting from a lower threshold level must be considered. At the level used (0.5 microvolts) the signal was fairly clean and free of errors during most of the burst time. However, end-of-burst errors were

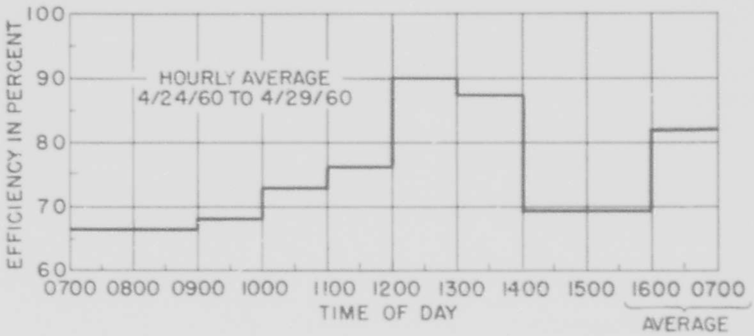

Figure 9. Storage efficiency.

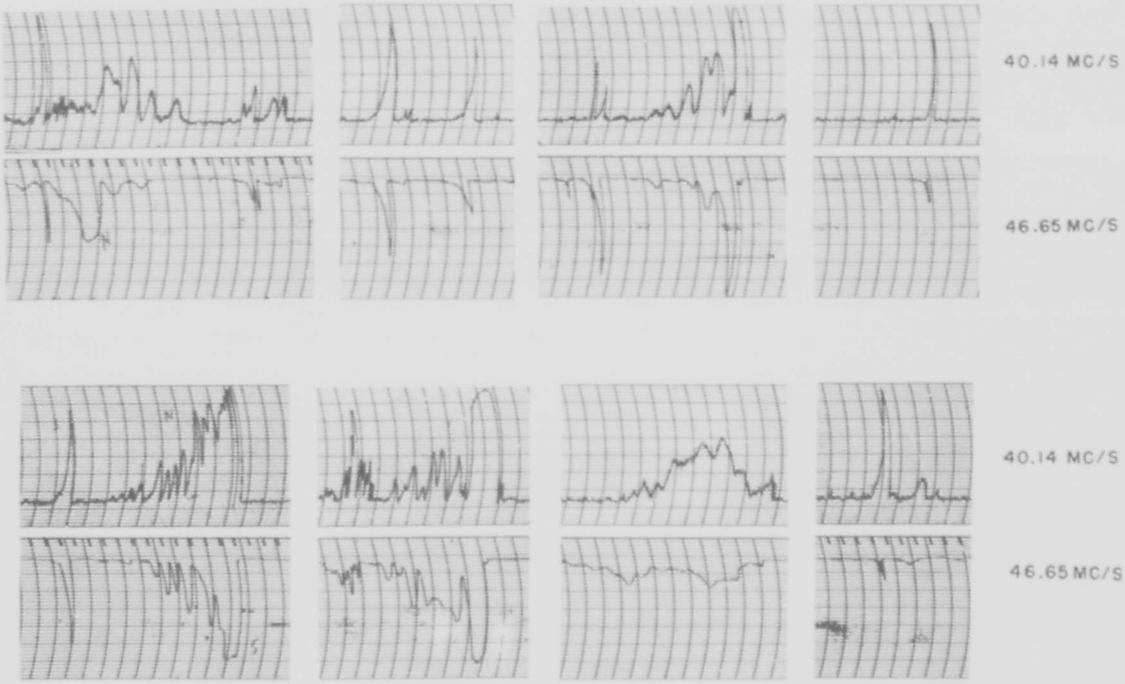

Figure 10. Samples of signals received simultaneously.

excessive as the signal intensity decayed. A technique is being considered for sending end-of-burst information redundantly at the beginning of the next burst. Such a plan may provide a significant increase in information rate without sacrificing accuracy.

SUMMARY AND CONCLUSIONS

The meteor burst communication system was tested over a 700-mile, north-south path between San Diego and Eureka (Humboldt Bay), California. The main purpose of the test was to check the digital logic and control circuitry and the storage system under operating conditions.

Teletype copy was sent in high-speed (2900-wpm) bursts from Eureka to NEL.

Each transmitter output was 1500 watts feeding a three-element Yagi antenna with 7-db gain. Similar antennas were used for receiving. Transmission line loss totals (including transmitter and receiver) for the south to north 40.14 Mc/s path were 2.7 db. Total line losses on the north to south 46.62 Mc/s path were 3.4 db.

The average burst utilization efficiency was 67 per cent, being lowered somewhat by poor correlation between the 40.14 and 46.62 Mc/s signals.

Average efficiency of the storage system (receiving end) was 84.3 per cent.

After completion of logic changes and adjustments, the continuous unattended information rate (transmitted on a 24-hour-a-day basis) was an average of 18 words per minute with a character error rate of 0.048 per cent.

The use of end-of-burst redundancy techniques, more closely spaced operating frequencies, improved receivers and some increase in system gain will provide significant improvement in information rates while retaining low error rates. Daily averages of 40 words per minute can easily be achieved.[11]

The point-to-point and ship-to-shore tests of the experimental system were sufficiently successful to indicate the feasibility of duplex meteor burst links using dynamic digital storage and control techniques.

REFERENCES

1. Stanford University Electronics Research Laboratory Contract N6-ONR-251; Technical Report 49, The Mechanism of Radio Reflections From Meteoric Ionization, by V. R. Eshleman, 15 July 1952

2. "(Fourteen) Meteor-Burst Communication Papers," Institute of Radio Engineers. Proceedings, v. 45, p. 1642-1736, December 1957

3. Chubb, H. E., "Development of Meteor Burst Communication Systems for the Navy," National Convention on Military Electronics (Second). 1958 Conference Proceedings, p. 266-269, 1958

4. Navy Electronics Laboratory Report 901, An Experimental Mobile System for Meteor Burst Communication, by H. E. Chubb and C. G. Wilhelm, 3 March 1959

5. Navy Electronics Laboratory Report 945, Meteor-Burst Communications, Special Progress Report: A Summary of Technical Progress with Emphasis on NEL Developments, Experimental Results and Conclusions (U), 18 November 1959, CONFIDENTIAL

6. Heibeck, H. L., "Application of Digital Techniques in a Meteor Burst Communication System," p. 5-9 in Conference on Dynamic Digital Logic, First Users'. Proceedings, March 14, 1960, Computer Control Co., 1960

7. Navy Electronics Laboratory Report 690, Preliminary Observations of Forward Scattering of Electromagnetic Waves by Meteor Trails, by H. J. Wirth, 9 May 1956

8. Keary, T. J. and Wirth, H. J., "The Random Occurrence of Meteors in the Upper Atmosphere," Journal of Geophysical Research, v. 63, p. 67-75, March 1958

9. Wirth, H. J. and Keary, T. J., "The Duty Cycle Associated with Forward-Scattered Echoes From Meteor Trails," Institute of Radio Engineers. Convention Record, v. 6, pt. 1, p. 127-132, 1958

10. Keary, T. J. and Wirth, H. J., "Statistical Characteristics of Forward Scattered Radio Echoes From Meteor Trails," p. 277-289 in Electromagnetic Wave Propagation, International Conference Sponsored by the Postal and Telecommunications Group of the Brussels Universal Exhibition, Academic Press, 1960

11. Navy Electronics Laboratory Report 1017, Ship to Shore Meteor Burst Communication Using Digital Storage Techniques (U), by H. E. Chubb, H. L. Heibeck and C. G. Wilhelm, May 1961, CONFIDENTIAL

Navy Electronics Laboratory
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Bits, representing teletype signals, are inserted in magnetostriction delay lines and allowed to recirculate. When the presence of a suitable meteor trail is detected, the information bits are removed from the lines and transmitted in bursts at 2900 wpm. A similar device, operating essentially in reverse, is used at the receiving site to store the bits until the information can be removed at standard speed to operate a teletype printer.

During field tests in April 1960, the system was operated continuously, being unattended except during normal working hours. Copy sent over the 700-mile, north-south path was printed at an average rate of 18 wpm, based on 24-hour-a-day operation, with character error rates of 0.04 per cent.

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