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FEASIBILITY STUDY FOR A NON-PRINTING PORTABLE TELETYPE

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13. ABSTRACT

This report describes the feasibility study of a visual message terminal (non-printing portable teletype) which is envisioned as a small, lightweight communications device that would attach to Army voice radios and allow communications without the generation of audible sounds. The device would be teletype compatible and would store its messages in internal logic circuitry and display them on a lighted display.

The study concludes that a system to accomplish the above is indeed feasible and could be fabricated from components available with the present technology. The system would consist of a small size, teletype-formatted keyboard for data entry into the system. The display would consist of a 96-character LED display. Once the message is inputed into the unit, it would be transmitted out at a higher rate for burst transmissions over audio lines. The unit would probably operate using a frequency shift keying mode to provide more reliable transmission over the audio channels. The unit would require approximately 1.5 watts to operate or approximately 12 watts if all 96 characters are illuminated. The production cost of the units is estimated to be in the range of $1500 to $2000.

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FOREWORD

This report represents the results of a study performed under LWL Task 06-EA-73, Non-Printing Portable Teletype. This effort was instigated in the Communications and Electronics Branch of the U. S. Army Land Warfare Laboratory in order to determine the feasibility of developing a small, lightweight addition to existing Army radios that would allow silent transmission of teletype compatible messages. The advent of the integrated circuit and the success of the small portable calculator market have indicated that a visual message terminal transmitting in teletype-compatible format could be built in small sizes.

Although the effort was aimed at providing communications over audio channels of existing Army radios, there is no reason why the same communications could not be carried over telephone lines or any other transmission media which one may care to use.

With the availability of small battery operated printers (as for example, in the Japanese battery-operated Pocketronic calculator) it appears feasible to even include printing techniques in this visual message terminal. Thus, a permanent record could be made of the message both transmitted and/or received.

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FINAL REPORT

VISUAL MESSAGE TERMINAL (NON-PRINTING PORTABLE TELETYPE)

1. INTRODUCTION

This report describes a feasibility study on a Visual Message Terminal (non-printing portable teletype), performed under Work Assignment 14 of contract DAAD05-72-C-0132. The report includes a summary of the background of the assignment, the study plan used, and a discussion of the system concepts for tactical data communications. A detailed evaluation of the factors and trade-offs involved in the choice of major subunits is also provided. Finally the conclusions of the study are given.

In order to avoid use of a trademark the term Visual Message Terminal will be substituted for non-printing Teletype throughout this report.

2. BACKGROUND

The U. S. Army Land Warfare Laboratory has determined that there is a need within the Army for a means to communicate in the field without generating audible sounds. Present methods include manual Morse code from a telegraph key attached to the standard Army radio set, and a system under development which automates the preparation of the code message and sends it at a high "burst" rate.

With the advances being made in digital electronics, it was felt that improvements could be made in the generation and transmission of tactical messages by using teletype-compatible techniques and code format. This offers more versatility and flexibility than the Morse code systems. Accordingly, Work Assignment 14 was issued for the purpose of determining the feasibility of defining a communications terminal for field utilization having these capabilities.

3. STUDY PLAN

The feasibility study was performed in five major steps to ensure that all important aspects were addressed. A brief outline of the study plan is included below, since an understanding of the aims of the various phases will be a help in interpreting the results.

3.1 Market Survey. Two important areas of consideration for the design of a Visual Message Terminal are the keyboard and the display subunits. These subunits are vital in two respects. They form the interface with the operator of the equipment and they will undoubtedly play the deciding role in determining the physical configuration of the unit. In fact, these two concerns are intertwined, since it is the size of human fingers which really decides the minimum size of a useful keyboard.

It is appropriate that the study begin with efforts to ascertain the current state of the art in both keyboard and display technology because both fields are in a period of rapid change. New designs and improved manufacturing methods are being announced frequently, as a result of the activity generated by mass commercial markets in the pocket calculator field and in computer interfaces. Some of these techniques may be adaptable to military uses.

3.2 Operational Concept. The first questions to be answered when a new piece of equipment is considered are very fundamental ones. What is this equipment intended to do? Who will use it? What are the basic functional requirements? An initial task of the feasibility study is to define an operational concept which will answer such questions as they relate to the Visual Message Terminal under study.

3.3 Functional Equipment Requirements. The next step in the study will be to define the hardware functions needed to implement the operational concept. Where the operational concept was concerned with the man and his needs, this section of the study concentrates on the "machine" portion of the man/machine interface.

3.4 Subunit Tradeoffs. A substantial portion of the effort in the feasibility study will be devoted to examining the data on various types of components disclosed by the market survey and considering their relative utility in meeting the equipment requirements. This requires evaluation of numerous performance parameters of subunits and components such as keyboards, alpha-numeric readout devices, memories, modems, and logic elements.

3.5 Unit Description. The final phase of the study will require presenting conclusions on the optimum form for a Visual Message Terminal. It will be expressed as a detailed description of the proposed unit, including specifications.

4. SYSTEM CONCEPT

Development of a system concept for a Visual Message Terminal unit is divided into two phases, one concerned primarily with the operational concept, the user-oriented aspect of the problem, and a second phase dealing with equipment design concepts.

4.1 Operational Concept. Numerous analyses and tradeoffs will be made in the course of a design study of this type, and meaningful decisions must be made with respect to a specific frame of reference. An operational concept was established by Bendix to form the reference point or baseline for this study of a Visual Message Terminal. To the extent that this concept agrees with the actual "real-world" operational requirement which will eventually be established by the Army, then to that extent will the conclusions of this study be valid. It should therefore be clear that the assumptions of this operational concept are important to anyone evaluating this study.

4.1.1 Purpose of Device. The VMT is intended to supplement or replace voice communication of the type which normally takes place between the leader of a tactical patrol or outpost, and the command post or headquarters to which he reports. It is therefore limited to point-to-point communication conducted in accordance with the procedures established for voice communication. Although the message will be in the form associated with record communication, for example alpha-numeric characters in ASCII code, it is not intended that the VMT be used directly to originate messages for transmission over the Army teletypewriter system. The practical limitation of display size makes it impossible to properly format a message to comply with the procedures governing the message switching system.

4.1.2 Profile of User. The normal user of the VMT is presumed to be the patrol leader or outpost commander, or the radio operator assigned to him. It is assumed that he has only superficial training in the use of communication equipment, no more than that necessary to allow him to operate it, and that any requirement for special training is seriously deterimental to the acceptance of new equipment. Ideally the VMT should be simple enough to be used, in an emergency, by a rifleman who had only a short field orientation in its use.

4.1.3 Conditions of Use. The unit will be carried in the field by the radio operator who is already burdened with Radio Set AN/PRC-77 or its equivalent. Size and weight are therefore very important factors in the acceptance of the VMT. The equipment will be subjected to rough handling, temperature extremes, immersion, dust intrusion, and other environmental extremes familiar to tactical military equipment. It must be operable both day and night.

4.1.4 Typical Functions Performed. The user must be provided with the following capabilities in order for him to utilize the VMT in a field environment.

a. Messages from the higher headquarters must be received and displayed. There should be selective reception capability so only messages intended and addressed to the proper station identifier or call-sign are processed. This address can be pre-programmed into the unit to be unique for each device on a particular communications net.

b. The user must be able to compose and display messages prior to transmission, entering the desired message character-by-character by way of a manual keyboard. Keyboard organization should enhance fast and accurate data entry and should permit one-finger operation. The message should appear on the visual display as it is entered. The user should be able to correct or modify the text as he sees fit until it is deemed satisfactory and complete.

c. When a message is complete, the user should be able to initiate message transmission which will then automatically proceed to conclusion. The complete transmission should take place in the shortest possible interval of time, since it is desirable to limit the duration of the transmit mode of the radio set.

d. Transmission should not destroy the message. It will remain in memory in the VMT until deliberately erased by the user, thus being available for retransmission if necessary.

e. It is assumed that the recipient will acknowledge each message with a procedural reply. When the user is satisfied, for this or any other reason, that the message previously transmitted is no longer required, he should have the capability to erase the message, thereby clearing the VMT memory.

4.1.5 Additional Considerations. Certain aspects of message communications which come to mind in considering the operational concept for the VMT appear to be potential problem areas. They will be briefly mentioned although any attempt at a solution is not within the scope of this study.

When message transmission is used to replace voice communications, one thing that is lost is the ability of the users to recognize the vocal characteristics and inflections of the man at the other end of the channel. This recognition is a major factor in preserving the integrity of information. Without this subjective verification the system becomes more vulnerable to "spoofing", the deliberate intrusion of misleading reports and orders by the enemy. Some means must be provided to supply the proper degree of communications integrity in lieu of the personal touch inherent in voice contact. This can be accomplished in numerous ways, both procedural and electronic. The selected method or technique must be considered as a subject for separate study.

A means of regulating radio activity will be necessary to prevent attempts by two or more stations to send messages at once. In data transmission such overlap will likely result in completely garbled reception. Again, there are procedural solutions to this problem as well as electronic techniques which could be used, which will not be considered here.

4.2 <u>Equipment Functional Requirements.</u> Using the guidelines of the general operational concept outlined in Section 4.1 of this report, a number of equipment requirements have been established for the Visual Message Terminal. It is believed that these requirements define a piece of equipment which will fulfill the needs of the user under the stated conditions.

4.2.1 Interface with Radio Set. The connection to the radio set will be through the 5-pin audio connector on the radio. For data transmission only the normal voice channel of the radio is used. The Visual Message Terminal must include a modem (modulator-demodulator) circuit which can operate reliably through the nominal 300 Hz to 3000 Hz bandwidth of the audio channel, at the levels which are standard for the radio set, without requiring any special setting of the radio volume control or any other abnormal adjustment. The only other interface requirement is that the VMT have control of the transmit/receive status of the radio via the push-to-talk control line.

4.2.2 Modes of Operation. Three distinct modes of operation or functional states are proposed for the VMT as described below.

a. Receive Mode. The receive mode is the normal condition of the terminal, the state it is in most of the time it is operating. In this state the unit will monitor the audio channel of the radio set for data transmissions, demodulating all signals and searching for the pre-programmed address or call sign internally assigned to the particular terminal. When the call sign is detected, the text of the contiguous incoming message will be stored in a memory and shown on the visual display as bright alpha-numeric characters. It is the responsibility of the user to take note of the message and to acknowledge receipt.

b. Off-Line Mode. This mode will be used when the user desires to compose a message for subsequent transmission. It is established by activating the OFF LINE control key, after which the user can employ the alpha-numeric keyboard to enter his message. As each character is struck it is stored in the display memory and shown on the visual display in the same way it would appear if printed on a type-writer. Editing capability is provided by a BACKSPACE control key which erases the last character entered and by a CLEAR control key which erases the entire message. A completed message remains on the visual display where it can be checked by the user for accuracy and completness. All actions in the off-line mode take place entirely within the terminal with no output to the radio set.

It is contemplated that the terminals issued to the subordinate users, as opposed to the one used at the command post, will be arranged so that it will automatically revert from the off-line mode to the receive mode if an incoming message is addressed to it. This over-ride feature is based on the assumption that orders from the higher headquarters have a pre-emptive priority.

c. Transmit Mode. When the desired message has been composed it may be sent off by actuation of the TRANSMIT key which starts an automatic series of actions. First, the radio transmitter carrier is keyed on through the push-to-talk line in the audio receptacle. A time delay in the VMT then allows the time interval required for the transmitter circuit to properly establish the carrier signal at the normal marking frequency output. After this set delay the message is automatically transmitted at the maximum data rate. As soon as the message has been sent in this burst of modulation, the radio carrier is automatically turned off. When the message is transmitted it is removed from the display memory and transferred automatically to a separate store memory. From the users viewpoint the message vanishes instantly from the visual display. However, the message is not destroyed, it is held in the store memory until after an acknowledgment is received. If retransmission is required the message can be returned to the display memory by actuating the DISPLAY STORE key and transmitted again via the TRANSMIT key. When acknowledgement is received, the user recalls the message to the display and erases it with the CLEAR key.

4.2.3 Keyboard Requirements. The keyboard is unquestionably the most difficult element of the VMT to optimize, since it is the point at which two totally conflicting goals meet head on. On the one hand the unit should be as small as possible because it will be added to the burdens of an already heavily loaded radio operator. Opposed to that is the fact that the keyboard must be used by a man who may have large hands, who on occasion will be wearing gloves, who is often fatigued - sometimes to the point of near-exhaustion, and who may be under extreme pressure due to enemy action. It is obvious that no single keyboard configuration can satisfy both viewpoints. The first criterion requires the minimum number of closely spaced keys, while the second demands widely spaced keys in the most functional layout possible.

Consideration was given to the question of what would constitute the absolute minimum keyboard. For alpha-numeric characters alone there are 37 functions required, and by using each key three ways they could be done with 13 keys. It means having an up-shift, down-shift and no-shift combination required on every key: a novel concept for data entry devices in the sense that it is not used in any keyboard device currently in use and one that would require considerable learning since the technique of fingering two keys at once would be required about half the time on a statistical basis. Adding about six keys for control functions brings the minimum to about nineteen keys. On the other extreme a keyboard which more or less duplicates the familar teletypewriter Baudot keyboard takes 39 keys with up-shift used only for numerals and punctuation marks. So there is about a two-to-one ratio between the smallest and largest number of keys which can be reasonably considered.

After due consideration of the conflicting factors of keyboard arrangement it is felt that size must give way to ease of use. To force the user into a complicated and unfamiliar keyboard use-pattern which would involve a lengthly learning process seems to be inviting trouble. The key arrangement used in the Baudot teletypewriter keyboard is familiar to many Army personnel and is basically similar to the standard typewriter key layout which is almost universally known. Therefore, it is recommended that the key layout for the Visual Message Terminal follow this basic pattern, providing a separate key for each alphabetic character and each control function.

The minimum spacing between keys which can be used without excessive double-keying is a factor subject to fairly straightforward analysis. Rather than attempt to go through all the human engineering statistics from scratch, advantage can be taken of the research which went into the design of the many pocket calculators now on the market. The most sophisticated of these is the Hewlett-Packard HP-45, for example. Making some allowance for the use of gloves, it is felt that the minimum "footprint" allowed for the finger tip should be an oval area approximately 1.00 inch wide and 0.75 inch high. There should be only one key within the boundary of this area.

The keyboard of the VMT must be able to resist immersion under water without leakage. While the environmental seal requirement naturally applies to the entire unit it is particularly important that it be considered for the keyboard which will be the most difficult component to keep sealed.

4.2.4 Display Requirements. The visual display must first of all be legible under a variety of conditions, which means that it should have a useful contrast ratio in all ambient light from daylight to complete darkness. It needs to be read only from short range, approximately two to three feet. The number of characters required in the display cannot really be fixed: the larger the display capability, in terms of number of characters, the more useful the terminal will be. It seems clear that the size of practical space allowance in the unit and the size of available readout devices will limit the number of characters well below what would be desirable from the operational standpoint.

Characters in the display need not be larger than about 0.12 inch high, the size of common typewriter font, to be legible at the distances required provided character shape is suitably distinct. An ideal display format would be 80 characters per line, the same as the standard Teletype format.

5. DETAILED SUBUNIT ANALYSIS

This section of the report describes the studies made to determine the best device or the most suitable design approach for several of the major subdivisions of the Visual Message Terminal.

5.1 Keyboard. A great many different design approaches are being used in the keyboard market, with most of the effort being aimed at the commercial communication and computer interface market. The requirements of that market are unfortunately quite different from the needs of the Visual Message Terminal, although there are some products which appear useful.

5.1.1 Survey. A listing of the keyboard types studied is given below.

a. The majority of available keyswitches and keyboards use a conventional mechanical contact actuated directly by the input motion of the key through a cam or some snap-action mechanism. Intended for low cost application in commercial equipment, they are unsealed and occupy a great deal of space. These units are quite unsuitable for the Visual Message Terminal.

b. A type of mercury switch which uses a sealed elastic tube filled with mercury as the switch conductor is offered by Mechanical Enterprises, Inc. By stretching and pinching the tube the mercury is made to separate, opening the electric circuit. Bounce-free operation and very long life are claimed for the approach, and the switch element is completely sealed. In the present configuration this device is too large for consideration and it is not certain whether it can be successfully scaled down.

c. Optical switches with built-in encoding are available from Collimation, Inc. The keys move coded masks which either pass on interrupt light beams, detected by photo-diodes. The life of this kind of keyboard is primarily governed by that of the light source. Existing models are too large and the construction would not be easy to adapt to sealing against immersion.

d. Keyboards which operate on the basis of a capacitive element are offered by some suppliers. A typical example is the unit from Raytheon Company which features very high life expectancy. Because of the critical low-level signals involved, these units are available only as standard complete keyboard assemblies. The present design are too large and do not seem adaptable to sealing against immersion.

e. A unique approach designed by Magic Dot, Inc., uses a touch sensitive switch featuring exceptional reliability, sealed low profile keyboard surface, and bounceless output. However it depends on the operators body capacitance and the prevalance of power-line ambient voltages for normal operation. Portable battery operated conditions offer problems, and wearing of gloves can make proper switch functioning a question mark.

f. Some mechanical contact type switches do appear to be adapted for portable units. Wild Rover Corporation has an "electrical grating" contact of resilient wires which is specifically suited to low profile sealed keyboards. A snap-disc type switch unit is offered by Colorado Instrument Division of Mohawk Data Sciences Corporation which also features a low profile and has potential for sealed applications. Another type of essentially mechanical switch is an array of crossed wires, laminated in flexible plastic sheets, which provides a cross-point switch element at each intersection.

g. A conductive elastomer is the basis for a keyboard design supplied by Chomerics, Inc. Actuation compresses the elastomeric contact material through openings in an insulating mask, contacting a screened circuit board. The keyboard can be quite thin and can easily be sealed against immersion. Life of 100 million operations is claimed.

h. Datametrics Corporation manufacturers an elastic diaphragm switch which consists of a layered, environmentally sealed structure of conductive surfaces separated by a dielectric sheet. Depressing a key joins the conductive surfaces and completes the circuit. This concept produces a very low profile keyboard.

5.1.2 Evaluation. There are several keyboard designs which appear to be potentially suitable for use in the Visual Message Terminal. These are the ones that can be made up as a thin assembly with a continuous flexible front surface providing immersion sealing. The types which are included in this category are the conductive elastomer design from Chomerics, Inc., the elastic diaphragm of Datametrics Corp., and to a lesser degree the mechanical grating contacts of Wild Rover Corp., the snap-disc of Colorado Instruments, and the laminated cross-wire design.

To obtain the sealed front surface and small size needed for the Visual Message Terminal, several keyboard features will have to be sacrificed. Key travel on this type of switch is usually very small and the actuation "feel" of the keys is very different from the familiar touch of a typewriter or teletype machine. To a considerable degree these key-switches are force actuated rather than movement actuated devices, lacking over-travel and auditory or tactile feedback. This is the price paid for miniaturization and immersion sealing.

5.2 <u>Display.</u> Alpha-numeric readouts other than the familiar cathode ray tube computer interface unit are just beginning to appear on the market in any variety. The prime mover in establishing an attractive mass market for visual readout devices has been the great commercial success of the pocket calculator, and to a lesser extent the development of the electronic digital wristwatch. Unfortunately these devices require only numeric characters so most of the design effort has gone into the seven-segment display. Alpha-numerics require either a 16-segment configuration or a 5 X 7 dot matrix for adequate character definition.

5.2.1 Survey. The display types studied are discussed below.

a. Incandescent readouts are the oldest type. They are only useful for large characters, in the range from 0.50 inch up. Power requirement is excessive, a minimum of about 40 milliwatts per segment being required.

b. Gas discharge readouts operate on the same principal as the familiar Nixie tube but now offer various planar configurations more suitable for small characters. The planar segment type manufactured by Sperry Rand provides good brightness at moderate power drain, but the process is best suited to large character size. Small multi-character arrays are not presently available in alpha-numerics. The multiple character sequential scanning panel unit offered by Burroughs Corporation, on the other hand, is specifically designed to fill the requirement for displays of more than sixteen characters. It provides lines of characters each composed of a 5 X 7 dot matrix. Inherent scanning operation reduces the demand for associated drive circuitry. Ruggedness may be a problem with the gas display panels because they require glass enclosures to seal in the gas. Present standard products have an operating temperature range of only 0 to +50^{o}C and there may be some difficulty extending this to the full military range.

c. Light emitting diode (LED) readouts are relatively new and are in a state of rapid technological development. Numeric readouts are receiving priority at the present time but all progress in that area will be directly applicable to alpha-numeric characters such as required by the Visual Message Terminal. When processing techniques are developed the LED display should be available in arrays of a group of characters at reasonable cost. The technology lends itself to inclusion of selection logic in the same package since both display and logic are semiconductor devices. Temperature limitations should inherently be similar to those of other semiconductors, although current displays are specified for the industrial 0 to +70^{o}C temperature range.

The main drawback of the LED is the low efficiency of light production. For a given power input the display brightness is low compared to a gas discharge display, for example. It may be difficult to obtain sufficient contrast for use in bright sunlight unless significant developments are made in improved efficiency. Power requirements of the Dialight Corporation device, for example, is 16 milliwatts per dot of the 5 X 7 dot matrix, typical for existing readouts.

Hewlett-Packard produces an assembly of five 5 X 7 matrix characters in a single package. These are about 0.25 inch high characters, really too large for the Visual Message Terminal needs, but it shows what can be done in multiple units. The package is 1.8 inches long and about 0.75 inch wide.

d. Liquid crystal readouts are basically different in that they do not produce light, but operate on the principle of variable reflectivity to produce adequate contrast using ambient light. For use in low light or total darkness some artifical light source must be provided. Power consumption is very low, typically 20 microwatts per segment. The liquid crystal technology is very new and there are, presently, numerous problems in the way of its use in the Visual Message Terminal. Temperature range is a definite problem and may be insurmountable since the liquid material itself is the temperature sensitive element. Life expectancy is currently rated at only 10,000 hours. Switching time is quite slow with a decay time of about 150 milliseconds, precluding multiplexing of character coding.

e. Electroluminescent film displays and fluorescent displays are two techniques which may have to be considered in the future. At this time there are insufficient information on practical applications to make any determination for this study.

5.2.2 Evaluation. None of the displays now available is optimum for the Visual Message Terminal. To find a practical readout it is necessary to project the logical development of technology and specify a display that should be available by the time it would be required. There is little doubt that the characteristics of the display will be limited by the state of the art rather than by operational requirements.

It is felt that the LED display is the most likely to evolve into an acceptable type for the Visual Message Terminal. Research and development effort is being put into improving light-generation efficiency by a number of manufacturers and potential probably exists for a ten-fold improvement. It is a logical step from small numeric arrays to equally small alpha-numeric arrays, packaged so they can be grouped for longer messages. Integrated decoding, multiplexing and driving circuitry in the same package is technically feasible. Ruggedness and reliability are inherent features of LED's since they are semiconductor devices. For the same reason, temperature limitations should be overcome with improvements in processing and packaging. What is predicted for use in the Visual Message Terminal is a module containing eight 16-segment characters, with 0.12 high characters. Module length will be about 1.25 inches and width about 0.5 inch. Power consumption will be about 1 watt per module, with heat sinking provided.

5.3 Modem. The communication medium for the Visual Message Terminal is given in the work assignment as the AN/PRC-77 radio. For maximum flexibility it is felt desirable to use the normal voice channel of the radio, assuming a nominal 300 Hz to 3300 Hz bandwidth, rather than the "wideband" input which is also available on the AN/PRC-77. By designing the VMT to operate through the normal voice bandwidth it can be used with any radio set or telephone link capable of passing voice signals, providing only that the proper levels are available.

A modulator-demodulator subsystem (modem) is necessary to transmit digital data through a voice channel. This section of the report covers the various types of modem considered and the reasons for the choice made.

5.3.1 Discussion. The attributes of several different kinds of modem were studied for use in the Visual Message Terminal, as follows:

a. Baseband Systems. The typical binary bit stream of encoded characters is a baseband signal in that it has frequency components extending down to dc. Therefore transmission of the bit stream directly requires a channel with response to dc, which the audio channel of the radio set does not have. There have been systems developed which circumvent this restriction by elaborate compensation techniques but they are not satisfactory for radio usage.

b. Binary Amplitude Modulation. One of the simplest modem techniques is on-off keying of an audio tone in accordance with the binary information signal. Using envelope detection this system is theoretically capable of an error rate of 10^{-4} at a signal-to-noise ratio of 14.9 dB. Implementation is very simple.

c. Phase Modulation. Binary keying between two carrier phases differing by 180 degrees can produce a theoretical error rate of 10^{-4} with a signal-to-noise ratio of 8.4 dB, a substantial improvement over the 14.9 dB of amplitude keying under the same conditions. However the detector complexity required will increase considerably, and the requirement for coherent detection means that synchronism is necessary between transmitting and receiving stations.

d. Frequency Shift Keying. Binary keying between two carrier frequencies is theoretically capable of an error rate of 10^{-4} with a signal-to-noise ratio of 11.7 dB, thus being intermediate in performance between amplitude modulation and phase modulation. This type system can be considered as two on-off keyed carriers at different frequencies, with the binary information signal determining which of the two carriers is on at any given time. Since amplitude limiting can be used this system is relatively insensitive to variations in received signal strength. The implementation is fairly simple and envelope detection can be used, avoiding any need for coherent detection or synchronization.

e. Other Systems. There are many variations on the types of modulation methods listed above, such as suppressed carrier AM, single sideband vestigal carrier, differential phase modulation, etc. They all involve greater complexity of the modulation and detection circuitry. Most of the more sophisticated systems are intended to squeeze the maximum possible information flow into a given bandwidth, often by the use of more than two modulation levels.

5.3.2 Evaluation. The problem in the Visual Message Terminal is to transmit digital information over an audio channel at a satisfactorily high data rate, do so reliably, that is, with reasonable assurance that the message will be error-free, and finally to do so without too much equipment complexity.

A message length of about 100 characters will be assumed for evaluation of the VMT situation. A character error rate of 10^{-4} would then mean an average message error rate of 1% or, expressed differently, communication reliability of 99%. This is believed to be good enough under the operational conditions where real-time conversational mode communication is usually possible and questionable passages can be rapidly verified. The character error rate specified above involves a bit error rate of approximately 2×10^{-6}.

Data transmission rate for the VMT should be high enough so transmission of a message involves breaking radio silence for the shortest possible interval. This needs to be considered in terms of the time required to activate the transmitter, which is not known at the time of this report, and also in terms of the practical minimum. For example, 2400 baud is practically the maximum standard data rate in the audio bandwidth, and 1200 baud is the maximum for the less complex modem types. At 1200 baud a 90 character message would take 0.75 second to transmit in start-stop ASCII code. Lowering the rate to 600 baud would improve the reliability of transmission and only increase the transmission burst interval to 1.5 seconds, still a short time period. It is felt that 600 baud is the best choice of data rate for the Visual Message Terminal. The lower data rate allows the shift frequencies a greater margin of clearance to the band edges, avoiding the increased envelope delay and phase distortion problems which occur near band edges. It also permits more frequency separation to lessen intersymbol interference, and provides more cycles or carrier per bit for more reliable detection at the lower shift frequency.

It is felt that a binary FSK modem is the best choice for the Visual Message Terminal. It can be implemented simply and inexpensively, yet provides good performance when used at 600 baud in a voice channel. FSK provides better protection against fading signals than the amplitude modulation systems, since both shift frequencies are affected equally. While fading in the sky wave sense is not a problem with the short-range tactical Army radios used with the VMT, they are normally used with short antennas which are affected by proximity of objects and people, causing variation in signal strength as these objects move with respect to the antenna.

The desired bit error rate of 2×10^{-6} can be related to a requirement for a signal-to-noise ratio of 16 dB in a theoretical frequency shift keyed (FSK) modem optimized for minimum bandwidth, zero intersymbol interference, and rectangular shape detection filters. (See Data Transmission, Bennett and Davy, page 189). A practical system will obviously require a better S/N ratio for the same performance. Experimental work reported by the National Bureau of Standards in Technical Note 100 showed that an audio channel with 33 dB S/N ratio provided 90% voice intelligibility while under similar conditions a digital character error rate of 10^{-4} was obtained with a S/N ratio of 28 dB. This indicates that a satisfactory voice channel has to have a S/N ratio good enough to provide highly reliable digital communications when a FSK modem is used.

5.4 Logic Circuits. Consideration was given to various general categories of digital logic circuitry for use in the Visual Message Terminal. The two predominant types of circuit to choose from are bipolar transistor logic (TTL) and metal oxide semiconductor (MOS). TTL circuitry is characterized by high switching speed capability, good load driving ability, and high power consumption. Various forms of MOS elements are available, generally characterized by low power consumption and limited operating speed. MOS is also highly adaptable to large scale integration in units where external interfacing is limited.

The Visual Message Terminal application places a high priority on minimum power drain to obtain reasonable battery life. It is basically a self-contained system with only audio input and output at the modem interface with the radio set, plus the push-to-talk control input. Because much of the activity of the unit is paced by the operator, logic speed requirements on the average are quite low with most clock rates below 1 KHz. This combination of requirements leaves no room for doubt that the best logic circuits for the VMT will be one of the MOS family or perhaps a combination of several MOS techniques, as applicable.

6. CONCLUSIONS

This section of the report outlines the final results of the study effort by describing in some detail a possible future implementation of the Visual Message Terminal, explaining the rationale of the proposed design concept, and providing a rough estimate of production cost of the unit.

6.1 Description of Proposed Visual Message Terminal. A design approach has been formulated which provides a reasonable compromise towards meeting the goals set by the system concept described in Section 4, particularly the equipment

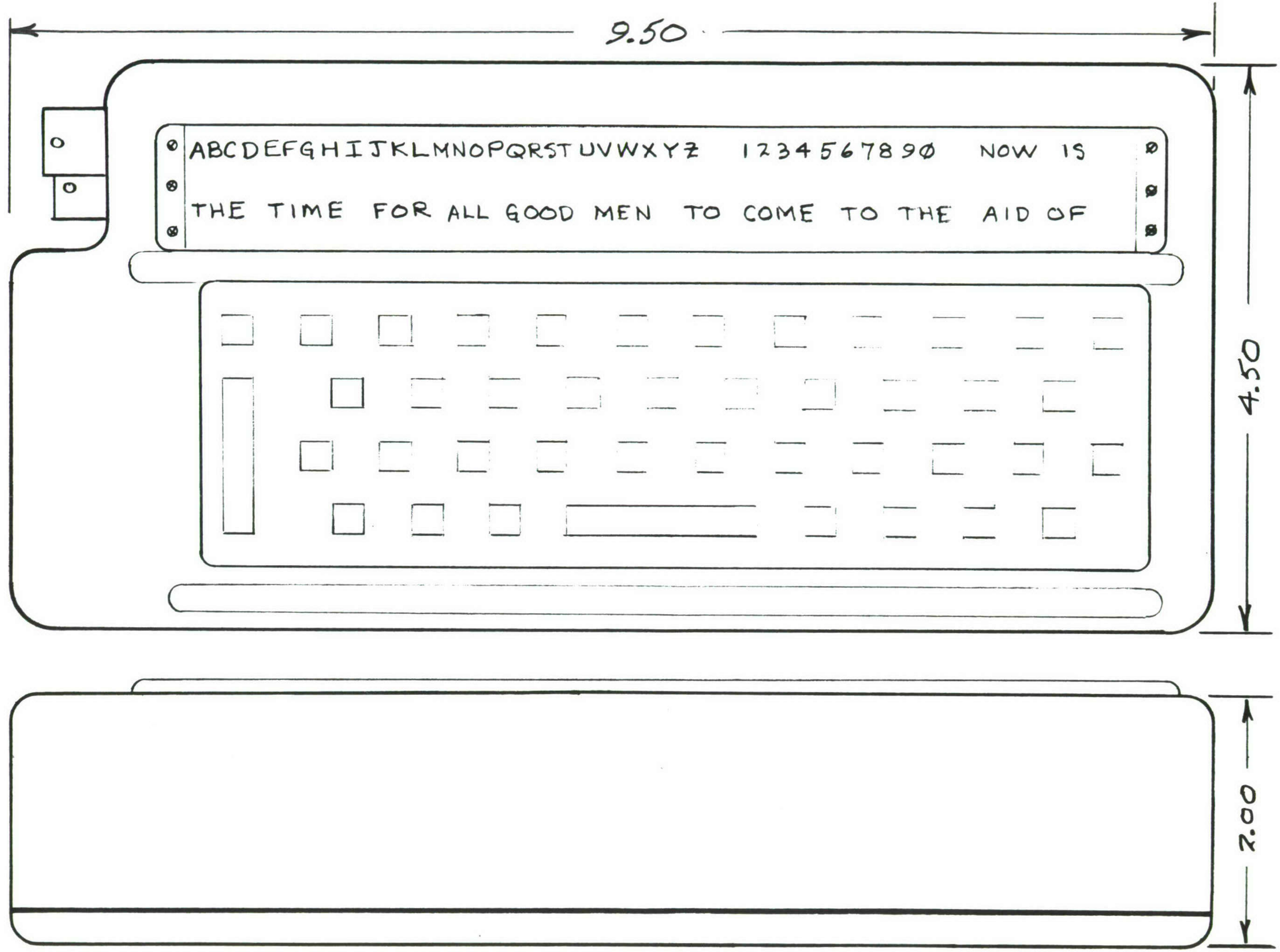


Figure 6-1 Physical Configuration of VISUAL MESSAGE TERMINAL (full size)

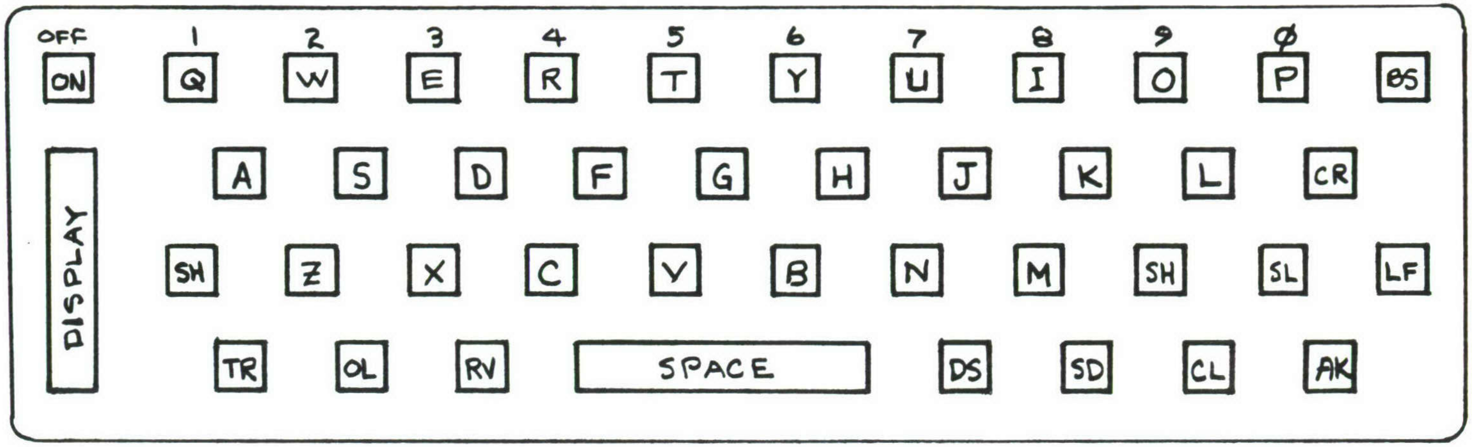
concepts detailed in paragraph 4.2. This unit will provide a user in the field with considerable capability for sending and receiving "written" messages via the voice channel of almost any field radio set.

6.1.1 Physical Configuration. The proposed construction of the Visual Message Terminal is illustrated in Figure 6-1. The molded plastic enclosure is rugged enough to protect components from damage during the rough handling the unit will receive under tactical conditions, and it permits efficient seating of gaskets for seals to protect against immersion. All controls and indicators are located on the top surface of the unit, protected by molded-in ribs.

Connectors for interfacing the Visual Message Terminal to the radio set and to a battery pack are protected by a step or set-back at one end of the unit. The section of the enclosure adjacent to the connectors houses the power converter circuitry and forms the hand grip by which the unit is held in the left hand while the right hand is free to operate the keyboard. The DISPLAY switch bar is operated with the left thumb for convenient activation of the visual display as required.

6.1.1.1 Keyboard. Details of the keyboard arrangement are shown in Figure 6-2. The basic layout is identical to the familiar Baudot five-level teletypewriter keyboard except for control keys and key spacing. Key size and spacing are reduced to the practical minimum for finger operation in order to keep the overall unit size down. In this miniature configuration it is doubtful whether the keyboard can be used for full-hand touch typing; most users will be one finger hunt-and-peck operators in any case. Control keys are identified as follows.

Label	Function	Remarks
ON/OFF	Power ON/OFF	Switch operates in push-on push-off mode.
BS	Backspace	Deletes last character entered.
CR	Carriage Return	
LF	Line Feed	
SH	Shift	Generates upper case characters while held
SL	Shift Lock	Holds shift function until shift is touched again.
TR	Transmit	Activates transmit mode.



BS = Backspace

CR = Carriage Return

SH = Shift (upper case numerals,etc.)

SL = Shift Lock

LF = Line Feed

RV = Receive Mode

OL = Off Line Mode

TR = Transmit Mode

DS = Display Store

SD = Store Display

CL = Clear

AK = Acknowledge

Figure 6-2 Keyboard Layout Details, VISUAL MESSAGE TERMINAL (full size)

Label	Function	Remarks
OL	Off Line	Activates Off Line mode.
REC	Receive	Puts unit in receive mode.
DS	Display Store	Causes contents of the "store" memory to be transferred to the display memory.
SD	Store Display	Causes contents of the display memory to be transferred to the store.
CL	Clear	Erases contents of the display memory.
AK	Acknowledge	Transmits canned procedural message acknowledging receipt of incoming message.
DISPLAY		Momentary switch which energizes the display while it is held down.

While they are not shown in the illustrations, additional upper case characters from the ASCII character set can be incorporated as desired.

6.1.1.2 Display. The visual display consists of two lines of 48 characters, a total capacity of 96 characters including spaces. LED display modules are mounted behind a plastic filter panel which improves contrast in bright ambient light conditions and also forms the immersion seal of the display. Light emitting diode indicators for signalling and status indication are also behind the panel at the ends of the message display.

6.1.1.3 Logic Elements. Integrated circuits and other electronic components which provide the necessary digital logic functions, memory, code conversion, etc., are mounted on circuit boards located behind the keyboard/display area. Two or three circuit boards approximately 4 inches by 7 inches are anticipated.

6.1.1.4 Battery. In the configuration shown, an external remote battery pack is assumed. A cable will carry battery power to the unit. Obviously, other configurations are possible in which the VMT essentially mounts on top of an Army battery pack in a manner similar to that used for the AN/PRC-77 radio.

6.1.2 System Electrical Configuration. The Visual Message Terminal electrical design concept is shown in Figure 6-3. The functional operation of the system

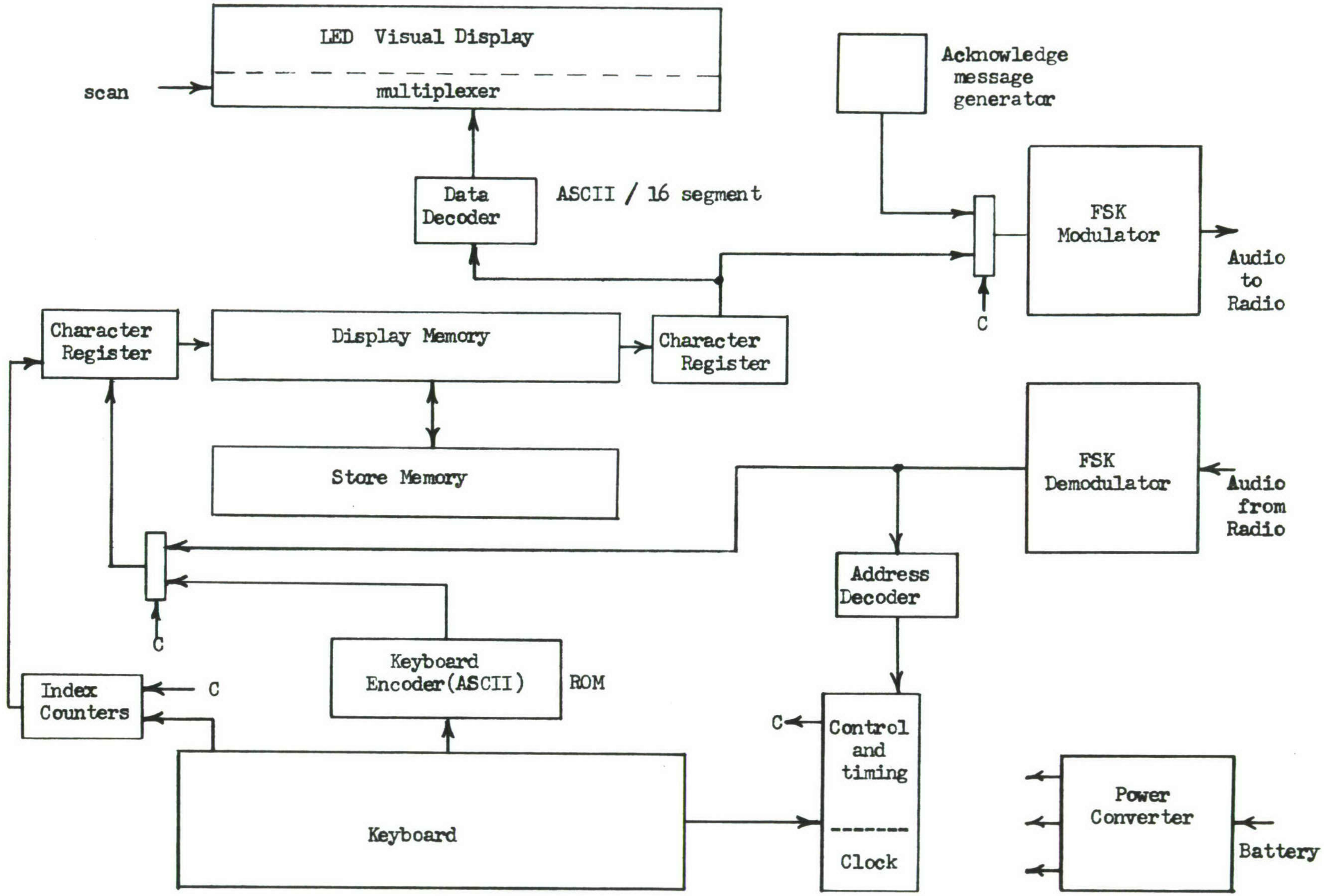


Figure 6-3 System Block Diagram, Visual Message Terminal

can best be described by individually considering each of the three modes of operation.

6.1.2.1 Receive Mode. Audio FSK signals from the radio receiver are converted to binary data at 600 baud by the demodulator circuit. It is assumed that the data consists of asynchronous (start-stop) ASCII characters, although the system could be designed to work with another code such as Baudot, without any difficulty. ASCII was chosen as the example because it has been established as the future standard code.

The received data is entered by character into the display memory which is based on an MOS serial shift register operating as a recirculating memory. The maximum of 96 eight-bit ASCII characters require at least a 768 bit shift register. Data entered in the display memory is routed by character to an ASCII-to-16 segment decoder module which is a special form of MOS read-only-memory circuit. The multiplexed display conserved interconnections by having character scanning logic built into each LED display module. This repetitive scanning of each LED character at a rate of more than 60 pulses per second also enhances apparent brightness for a given average power consumption by taking advantage of the integating ability of the eye. Power is applied to the display itself only while the DISPLAY switch is held down, in order to minimize battery drain.

6.1.2.2 Off-Line Mode. This mode is used for the composition of messages by the local user for eventual transmission. Key closures are sensed and encoded into ASCII by an MOS read-only-memory module and entered by character into the display memory. The message is available for visual display as it is generated. Editing is done by using BACKSPACE to delete the last character entered, with no limit on the number of deletions made one character at a time, and using CLEAR to erase the entire message for a new start.

The display memory contents can be transferred at will to the store memory using the SD (Store Display) key. Conversely the store contents can be later returned to the display memory by using the DS (Display Store) key.

6.1.2.3 Transmit Mode. A previously composed message contained in the display memory can be transmitted by pushing the TR (Transmit) key. The push-to-talk control line to the radio set is immediately activated. After a delay to permit the transmitter to turn on, the message is routed to the modulator circuit at 600 baud, with start and stop bits added for asynchronous transmission. When the message is finished the unit reverts automatically to the Receive mode.

A message just transmitted is not discarded, since retransmission may be desirable. Instead it is transferred to the store memory, available for return to the display memory at the operator's discretion.

6.1.2.4 Selective Calling Capability. The Visual Message Terminal is equipped to recognize an individual address or callsign at the beginning of a message, and will accept and display only those messages which carry the proper heading. The unique address for a particular unit is internally programmable.

6.1.2.5 Acknowledgment. To facilitate response to a received message, a predetermined procedural message of acknowledgment is stored in a read-only memory. This response is initiated by depressing the AK (Acknowledge) key which causes the complete message generation and transmission.

6.1.3 Power Consumption. Maximum peak power requirement of the unit is estimated to be 12 watts at full operation of the display. By employing all possible power saving techniques, particularly making the visual display a "demand only" function which requires the user to hold down a key to activate the light-emitting diodes, it is expected that the average power drain can be reduced to about 1.5 watts. A high-efficiency switching type power converter is used to change the battery voltage to the voltages needed in the unit.

6.1.4 Base Station. This study covers only the field unit of the Visual Message Communication system. The central base station or net control station located at a headquarters or command post, communicating with several field units, would be basically similar but obviously should have extended capabilities. Selection of the address or callsign to be attached to a particular message is one example. Additional display capacity, and the ability to provide asynchronous data output from storage at low speeds for hard copy printout on teletypewriter equipment, are other features needed at the base station.

6.2 Justification of Design. The proposed Visual Message Terminal system is believed to be the best compromise of conflicting requirements that can be achieved in the state-of-the-art projected for the next two or three years. It falls short of being pocket sized, principally because the keyboard is constrained to be as convenient as possible for use with fingers, even gloved fingers. The keyboard layout chosen provides a clear operating area for each key that is oval in shape with the long axis horizontal, 1.0 inch by .75 inch in size.

Choice of a visual display is limited by availability of suitable devices, with none of the types on the market being optimum for the job. The LED type was chosen because it is inherently rugged, suitable for operation at temperature extremes, and shows the most promise for improvement in technology in the next few years.

Data transmission at 600 baud is fast enough for the kind of messages involved in the Visual Message Terminal, while it can be fitted into the voice bandwidth of the radio link with good performance margins even using the simple and relatively inexpensive FSK modem. A higher data rate would not significantly reduce overall transmission times in the frame of reference of traffic conditions in a tactical radio set. A lower data rate would not achieve much improvement in error rate and would not simplify hardware requirements.

6.3 Production Cost Estimate. The Visual Message Terminal described in this report should cost in the range of $1,500 to $2,000 in production quantities, based on what are felt to be reasonably conservative projections of future developments in display, keyboard, and MOS integrated circuit technology over a two or three year period. If significant break throughs are made in one or more of these areas, making new and better techniques available, the cost could be reduced.

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