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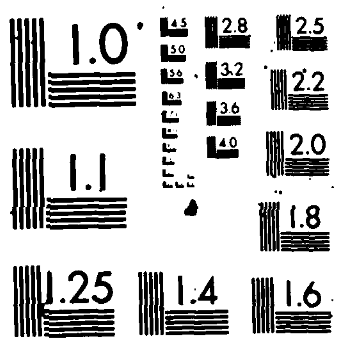

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In-House Report
July 1986

A TRANSPORTABLE VLF/LF REPEATER TERMINAL — A DESIGN STUDY

Donald G. Iram

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ROME AIR DEVELOPMENT CENTER
Air Force Systems Command
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The design of a transportable, rapidly erectable VLF/LF repeater terminal is considered. Operational parameters bound the performance requirements. The total system must be transportable on standard vehicles over hard surface roads. The system must be erected and operated within a nominal 8-hour day. Each subsystem must be composed of available hardware and existing (proven) technology. The terminal must also radiate 5 DW at 36 KHz. The system performance criteria are used to define the system design. These are translated into the design of the subsystems. Alternative implementations to satisfy each design are explored. The most satisfactory implementation is obtained by an elimination process. Once an operational system design is achieved, the problem of demonstrating the feasibility of that design using existing experimental assets, inventory hardware and manufactured components is addressed. The design of a demonstration system results from this second level analysis.

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Richardson TX, under Contract F30602-81-C-0017 and by engineers assigned to the Long Wave Communications Section (DCCL) at RADC.

PREFACE

The study presented in this report was conducted under Project 3350, Task 33500202. The project was sponsored by the Defense Communications Agency, Command Control Engineering Center (DCA/CCEC). The engineering effort was performed by Electrospace Systems, Inc., Richardson TX, under Contract F30602-81-C-0017 and by engineers assigned to the Long Wave Communications Section at the Rome Air Development Center (RADC), Griffiss NY.

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INTRODUCTION

A reliable, long range, land-based VLF/LF communications system is required to support the strategic forces in the period following a nuclear attack. This system must be capable of receiving messages transmitted from land-based and airborne command posts over a variety of transmission media to perform some processing of the messages prior to retransmission. This processing will include message verification, checks for duplicate messages, and queueing. The system must also be packaged for storage in a protected area until it is needed. When needed, the system must be capable of being deployed over hard surfaced roads to level, cleared land where it can be erected and turned on in a nominal 8-hour day.

Advances in the various technologies associated with VLF/LF communications indicated that this system could be assembled from existing subsystems without further technology development. The availability of transportable, rapidly erectable towers as high as 300 feet made it feasible to consider VLF/LF antennas in a transportable configuration. The ability to rapidly retune a VLF/LF antenna in synchronism with the mark-space output of a FSK modem made it possible to consider higher data rates without sacrificing power efficiency. Advances in airborne, high power transmitters have shown it is possible to build a rugged transmitter with 100 KW output in the 27-60 KHz band in a transportable configuration.

The WWMCCS System Engineer has determined that time can be saved by avoiding protracted studies when major hardware items, required in a system, are available or are well advanced in development. This program has been identified as a case where better information can be obtained by first designing a VLF/LF repeater terminal and then building a demonstration terminal to determine feasibility, project performance, and obtain cost estimates. The objective of this phase of the program was to prepare a set of system and prime item development specifications for a VLF/LF communications terminal based upon a set of performance specifications.

The Rome Air Development Center had an excellent VLF experimental facility located in Forestport NY. The WWMCCS office believed that the feasibility of a transportable VLF/LF repeater terminal could be demonstrated using the assets at the Forestport site in lieu of building all of the large, expensive subsystems needed for the terminal. The problem is twofold; first design and completely specify an operational VLF/LF terminal, then design and specify a terminal that can demonstrate the major characteristics of the operational terminal using the facilities at the Forestport site. This report will discuss the performance requirements and the tradeoff analyses that lead up to the design specifications of a demonstration terminal that will demonstrate the capabilities of the system.

PERFORMANCE REQUIREMENTS

The VLF/LF repeater terminal must be capable of being transported over hard surfaced roads on wheeled vehicles to cleared, reasonably level land. The terminal must be erected in a nominal 8-hour day once it arrives on site. It must also be capable of self-sustained operation for a 30-day period. Incoming messages must be received on UHF air-to-ground radio, UHF and SHF satellite circuits, HF radio channels, and from other VLF/LF stations. The messages are assumed to have originated at surviving command posts and must be broadcast, in one of the MEECN modes, to the forces. Messages must be verified, checked for duplicates, stored, formatted, encrypted, and then retransmitted. In order to have any confidence that the messages will be received, the station must radiate a minimum of 5 KW at 36 KHz. The design goal was to achieve 8 KW. The system can be divided into subsystems and the system requirements can be translated into subsystem technical requirements. The subsystems are the tower and antenna, the amplifier and tuner, the remote message entry terminal (RMET) and the primary power module. The approach taken was to start with a baseline system that satisfied the technical requirements and then consider alternative implementations that would improve performance and reduce costs. The subsystems are all interrelated to some extent, but none so much as the antenna and tower and the amplifier and tuner subsystems. The design of the latter is dependent upon the design of the former. The largest technical risk, in the program, is associated with the design of a transportable, rapidly erectable antenna subsystem.

ANTENNA/TOWER SUBSYSTEM

In order to arrive at a realizable antenna configuration certain initial conditions had to be assumed. The first of these assumptions was that a 100 KW transmitter of the type used in airborne applications is the largest transmitter that could be considered transportable for the purposes of this program. VLF/LF antennas almost always take the form of a vertical tower on a base insulator or an array of towers supporting the radiating elements. The second assumption made was that the tallest tower considered for this program would be 500 feet. Any tower larger than this could not be considered both transportable and rapidly erectable. Another assumption was that the maximum voltage at the base of the antenna was limited, by transportable insulators, to 100 KV. Finally, we assumed that the antenna current through the tuning circuit had to be held to less than 300 amperes.

Several antenna configurations were considered. Among them were a dispersable antenna (ref. 1), a long horizontal wire (ref. 2), and vertical monopoles. The radiated power and the power handling capability of an antenna are both a function of the effective height of the tower. It was obvious that only the vertical monopoles could satisfy the transportability, erectability, and reliability requirements of the terminal. The design problem is to come up with a top-loaded, vertical monopole antenna configuration that is transportable, rapidly erectable, and will radiate more than 5 KW. Radiated power is the parameter we wished to maximize within the constraints of rapid erection and transportability. The power radiated increases, with the tower height, h, the ratio of the projection of the active portion of the top hat to the physical height of the tower, h'/h, with p, the radial distance from the tower base to the top hat anchor point and with N, the number of top hat elements. The magnitudes of h, p, and N all impact the time it takes to erect the antenna and to some extent the transportability of the system. Tower height has been limited to 500 feet. For initial baseline purposes, N was fixed at 12 and p was fixed at 1.5 times the height of the tower. The h'/h parameter was set at .76 to assure that the insulator marking the end of the active portion of the top hat would be high enough off of the ground to preclude the onset of corona under worse case sag conditions.

The baseline antenna is shown in Figure 1. Three antenna heights were considered: 300 feet, 400 feet, and 500 feet. The parameters calculated for the three antennas are listed in the following table. All of the calculations were made at 36 KHz.

h	300	400	500
h'/h	.76	.76	.76
V	100	100	100
r	.054	.097	.151
X	-658	-487	-378
I	161.6	205.4	264.9
P	1.241	4.092	10.596

The parameter V is base voltage (KV), r is radiation resistance, X is reactance at the base of the antenna, I is antenna current, and P is power radiated (KW). The calculations were made using the equations and curves found in ref. 3.

The power radiated from both the 300-foot and the 400-foot antennas is limited by the 100 kilovolt maximum base voltage. The power input was less than the available power because the voltage build-up reached the base voltage limitation before all the available power could be used. The 500-foot antenna, on the other hand, reached the base voltage limitation at just about the point where all the available input power was used.

A single antenna of 300 feet or 400 feet will not satisfy the system requirements. The power radiated from multiple antennas, due to mutual inductance, is proportional to the square of the number of antennas. In order to achieve the design goal of 8 KW radiated at 36 KHz, the transmit terminal would need either three 300-foot antennas, two 400-foot antennas, or a single 500-foot antenna. Each of these antennas would have to be driven by a 100 KW transmitter and its associated primary power subsystem. The three 300-foot antennas' configuration was dropped from consideration at this point because three 100 KW transmitters are just too many to consider for this application.

Inquiries were made to 77 companies to determine if they built or were interested in building a transportable tower, 400 to 500 feet high, that could be erected in a nominal 8-hour day. Four responses were received. Three of these: Advanced Industries, Inc.; Andrews Towers, Inc., and Compagnie Generale de Telecommunications International (CGTI), were considered realistic possibilities.

The Advanced Industries tower is in the military inventory. The technical manual is T.O. 31R4-2TRN-102; the Government nomenclature is

UMBRELLA ANTENNA CONFIGURATION

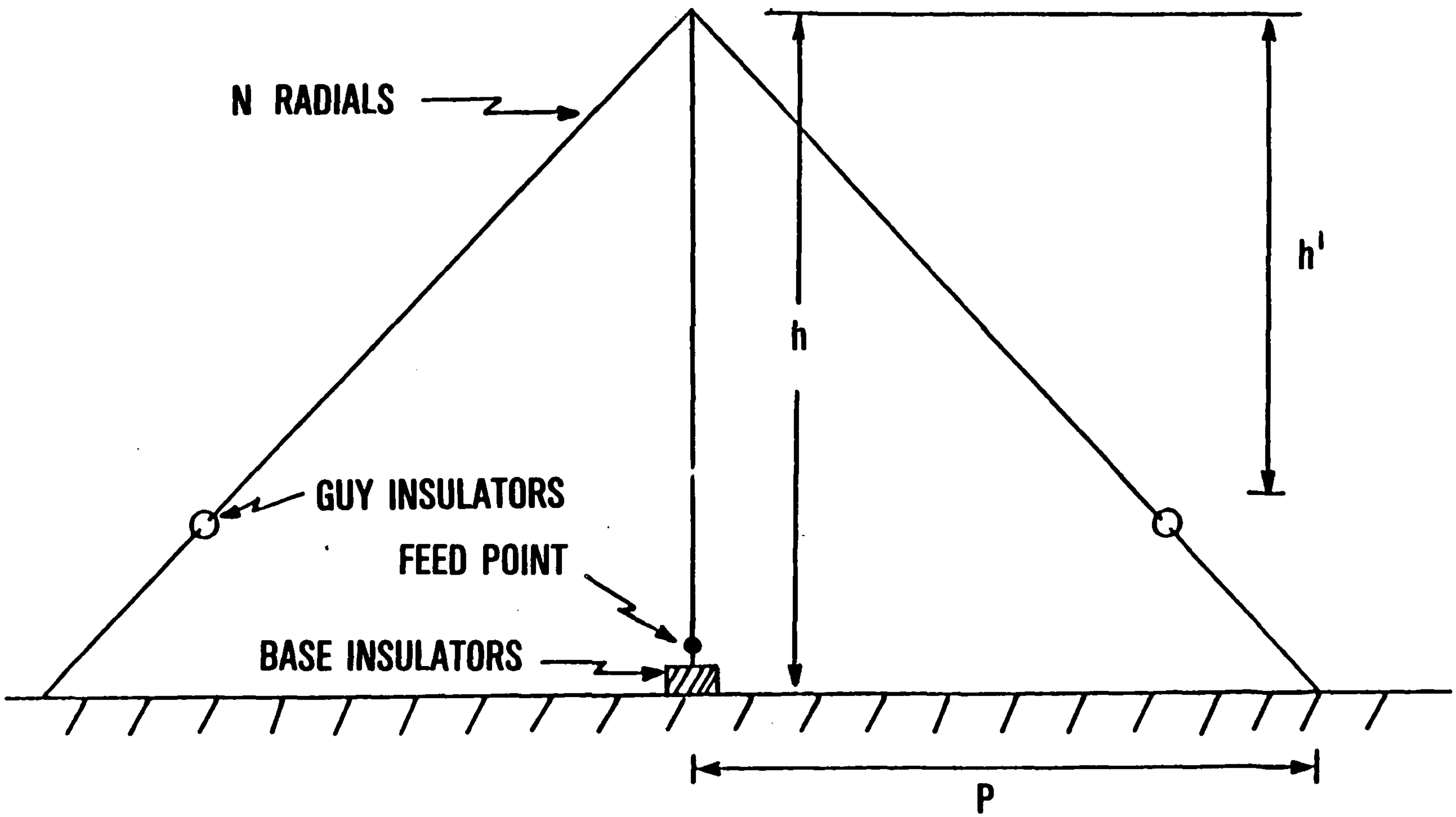


FIG 1

AS-3129/TRN-39(U). This tower requires approximately 24 hours to erect with a 10-man crew (two climbers) using the present design. A different erection approach, using an elevator, a scaffold, and an automated guy management technique was investigated. The elevator lifted a 10-foot tower section high enough off the ground to insert a second section underneath it. The crewmen on the scaffold would then bolt the two sections together. The tower guys, wound on anchored drums, would be payed out under the control of a microprocessor (see Figure 2). Subsequent tower sections would be inserted from the bottom, "like a cartridge", as the tower is lifted and the automated guy management units maintain the proper tension of all of the guys. The initial analysis indicated that this approach could erect the tower in 8 hours with a crew of 8 men. The complexity, however, increased when wind loading and other environmental conditions were introduced. In addition, the expense involved in developing the system, the training level required of the crew, and the risk, both technical and safety, made it impractical to consider this tower any further.

The CGTI tower is an existing design. It is built in France and several of these towers have been deployed in Europe and the Middle East. Individual tower sections are 3 meters long. An external elevator, running up one side of the tower and controlled by a ground level winch, is used to lift the sections. Each new section is supported by a vertical pole on the elevator. After a new section is raised to the top of the tower it is rotated 180 degrees about the axis of the pole, lowered into place, and then fastened to the previous section. CGTI advertises that their trained, 5-man crews can erect a 100-meter tower in 8 hours. The CGTI literature also says that any or all of the three faces of the tower can be equipped with one or several elevators. In order to reduce the time for the erection of a 400- or 500-foot tower of this design, a dual elevator configuration was analyzed. This approach allowed a section to be lifted by one elevator as the other elevator is being lowered. A second crew was added, with each crew working off one of the elevators. A key member of each crew is, of course, the climber. Only one climber can work on the tower at a time. The second climber is held in reserve to relieve the first climber. They would change places by riding the elevators. This approach, theoretically, would allow a 500-foot tower to be erected in a nominal 8-hour day.

The availability of skilled climbers is critical if the system is to be implemented with this approach. The operational use of this system is to restore emergency essential communications to the strategic forces in the post attack time frame. Presumably, this system would be deployed and operated by Reserve or National Guard units. The Air Force Skill Category Code (AFSC) for an Antenna Systems Installation and Maintenance Specialist is 36150. Climber availability and authorization to Guard and Reserve units was discussed with Air Force personnel specialists in the Airmen Assignments Section at Randolph AFB TX. They told us that the 36150 skill category is the most difficult AFSC fill. There is an Air Force shortage world-wide in this skill. We reached a conclusion at this point that this system should avoid a design that requires climbers, if at all possible.

GMU-FUNCTIONAL DETAILS

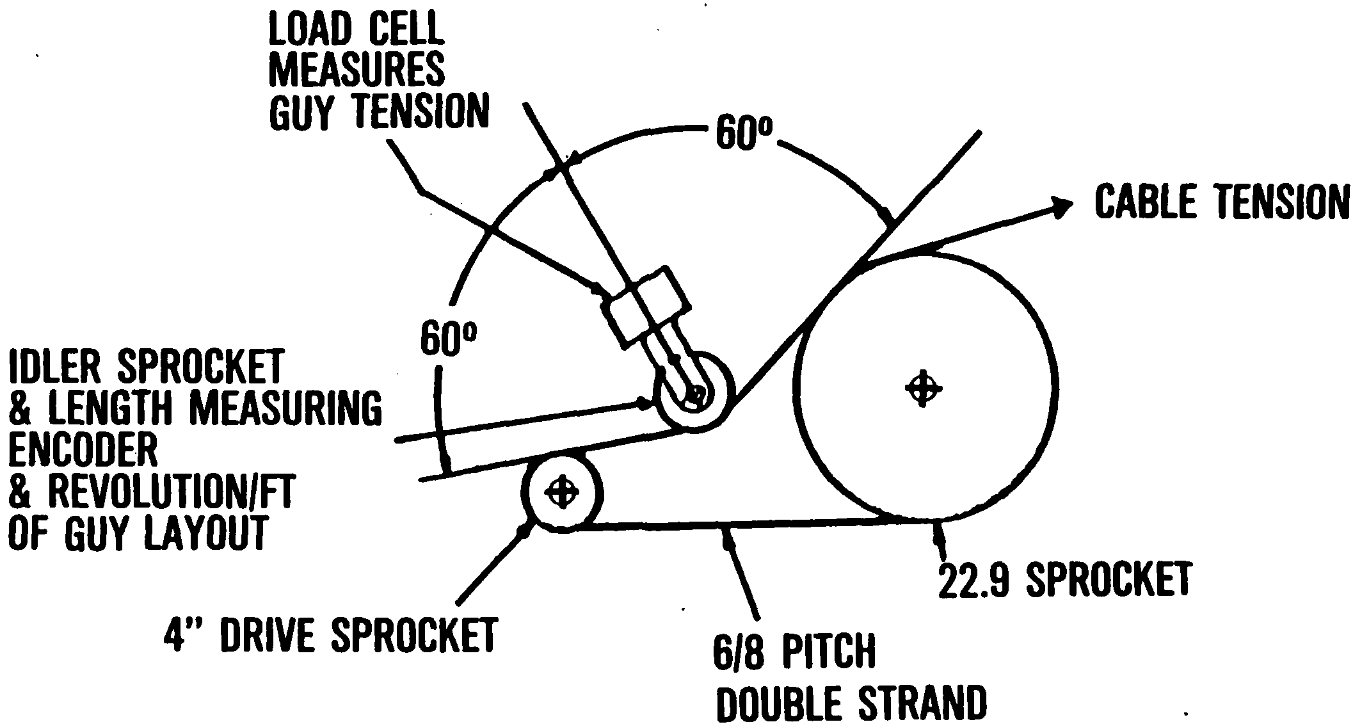


FIG 2

The Andrews Quick-Erect tower is a telescoping tower consisting of nested, square sections. Each section is 48 feet long and varies in width from 24 inches for the innermost (top) section, to 54 inches for the outer (bottom) section. The tower is designed to fit upon a 55-foot long by 8-foot wide trailer. A trailer mounted hydraulic mechanism tilts the nested sections onto a base plate. Jacks mounted on the bottom section are used to level the nested stack. The stack is then guyed using guys connected to the top of the bottom (outermost) section. The remaining nested sections are then raised out of the bottom section with a trailer mounted winch. When full extension of the stack is achieved, a latching mechanism is engaged that locks the bottom of the now outermost section to the top of the bottom section. The stack is again guyed using pre-attached guys on top of the now outermost section. This process is repeated until all of the nested section have been extended. The tower can be erected with a trained crew of 8 men, none of whom are required to climb the tower. The Andrews Tower Company has sold seven of these quick-erect towers: five of them were 300 feet high and the other two were 100 feet high. Mr. John Andrews, company president, believes that the Quick-Erect design can be extended to 500 feet. His analysis indicates that the 8-man crew can raise a 500-foot version of the tower in 6 to 10 hours. The design limitation of 500 feet is based upon the ability to mount the nested tower on a standard, commercially available tractor-trailer truck, and not by any structural limitations. It is not feasible to consider oversize vehicles that must travel over U.S. highways in a post attack time frame. The time analysis is based upon extrapolating the present time experience for 300-foot towers to include the additional sections needed to achieve 500 feet.

Mr. Andrews was asked to analyze the transportable VLF/LF antenna requirements based upon using 400- and 500-foot versions of his Quick-Erect tower. An edited copy of the report he submitted is contained in Appendix 1.

The Quick-Erect tower was designed as a support tower for microwave and radar antennas. It has not been used as a radiating tower. Several changes must be incorporated into the design of the present tower to satisfy the requirements of the transportable VLF/LF system. The present tower sits on a ground plate. A base insulator assembly must be designed. The initial approach was to fabricate an inverted pyramid to fit on the bottom of the tower. A single base insulator would then be connected to the point of the inverted pyramid. A socket would also be designed in the ground plate to receive the bottom of the insulator. This approach was rejected for two reasons. The present tower is tilted off the flatbed trailer onto the base plate. The ability to bolt items to the bottom of the tower is limited by the vertical distance between the ground plate and the bed of the trailer. The height of an inverted pyramid plus a single base insulator is too large to fit under the present tilt-bed mechanism. A new hydraulic system that could lift the nested tower stack before setting it down is beyond the scope of our "no new development" assumption. The inverted pyramid-single base insulator design would also defeat the present jacking mechanism used to level the tower. An alternative approach was taken where a saddle shaped plate is bolted to the bottom of the tower. The perimeter of this plate is shaped to act as both a rain shield and a corona ring. The tower base will fit into the saddle portion of the plate. Four post insulators are placed under the rain shield-corona ring portion of this plate and outside each of the four corners of the tower. The four simplex leveling jacks are then connected, through the top of this plate, to the top of the post insulators.

A second design change is required for corona considerations. The present tower legs are right angle, aluminum members measuring 4"x4"x3/8". The corona/rain shield will provide protection for the lower portion of the bottom tower section. Reference 4 provides some formulae for calculating corona onset voltages. The equations are admittedly inexact--depending upon an assumed roughness factor, a frequency factor, and estimates of the density of the air. The corona onset voltage for a smooth cylinder .09 meters in diameter and 15 meters off the ground was calculated using these formulas as 509 kilovolts. If metal tubes of at least 9 centimeters diameter can be fitted to the legs of the bottom section of the tower, after erection, sufficient corona protection should be provided.

A final consideration for the antenna and tower subsystem is the ground plane. The transportable system must be capable of being erected on all types of soil. The ground plane must be designed for use over soils with poor conductivity. It must also be designed for rapid installation. The ground plane was defined as 120 radials, each .125 inches in diameter, spaced every 3 degrees, extending out to a distance equal to 1.5 times the height of the tower. An 8-man crew is used to install the tower anchors, the top hat anchors, and the ground plane. The ground plane and all tower anchors must be in place before the tower can be brought onto the site. There are 8 tower anchors: 4 at a radius of 180 feet from the tower base and 4 more at a 300-foot radius. The 12 top hat anchors are placed at 30-degree intervals at a radius equal to 1.5 times the height of the tower.

To install the ground plane, the center of the site must first be established and marked. A transit operator sites his equipment over the center point, aims north, and directs the stake crew to their perimeter points, a distance of 1.5 tower heights from the tower base. The transit is then rotated 180 degrees and the south point is located. This procedure is repeated, rotating counter clockwise in 3 degree intervals, until all of the ground plane stakes have been spotted. The north-south and east-west tower anchors in the 180- and 300-foot rings are spotted at the same time. The top hat anchors are also spotted during this procedure. Power equipment is needed for the tower anchors. The "Pole-cat" PC 1300 was chosen for this purpose. It is a 2-speed digger manufactured by the Pitman Manufacturing Company. This machine will install anchors of adequate strength in soil classes 2 through 5 in the shortest installation time. It must be mounted on a vehicle of 27,000 GVW or larger.

The ground plane stakes are 5/8-inch diameter by 18-inch long copper weld or equivalent. The ground radial wire is wound on spools which can be mounted on a cable spool rack on a vehicle or on a vehicle-hauled trailer. This vehicle can begin laying the ground plane as soon as the first few ground stakes are driven on either side of the perimeter of the ground plane. A clamp will be used to electrically connect the ground wire to each ground stake. A crimping tool and fittings will be used to splice the wires together as they are deployed. The time required to deploy the ground plan is approximately 2.5 hours. The tower anchors will take about 3.5 hours to install. These times are not additive, the two functions are done at the same time. The top hat anchors are smaller and will require approximately 3.5 hours to install 12 of them. These anchors are installed concurrently with the tower erection. This will not create a problem because the crew setting the anchors are outside the working perimeter of the tower crew.

The time analysis for deploying the ground plane and setting the anchors showed that it is about 3.5 hours before the tower can be brought onto the site. This analysis was done without considering the size of the ground plane (1200-foot diameter for the 400-foot tower and 1400-foot diameter for the 500-foot tower). The time will be a little less than 3.5 hours for the 400-foot tower and a little more for the 500-foot tower. When Mr. Andrews' estimate of 6 to 10 hours to erect the 500-foot tower is added to this figure, we see that the 500-foot tower and ground plane cannot be deployed and erected in a nominal 8-hour day even when our most optimistic time estimates are used. Two 400-foot antennas can be erected, using two complete crews, in a nominal 8-hour day. For that reason, the two 400-foot antennas approach was chosen for this program.

AMPLIFIER/TUNER

The antenna design has already assumed a transmitter that will put out 100 KW in the 27-60 KHz band. Several other performance parameters were also pre-specified. The transmitter efficiency, primary power into the amplifier to power delivered to the tuning circuit must be 80%. Harmonics, spurious, and broadband noise must be at least 60 dB below the carrier. It must accept primary power from a transportable source and it must fit into a standard sized van. The amplitude response must be within 1 dB in any 1600 Hz bandwidth in the 27-60 KHz spectrum. Four power amplifier alternatives were considered; they are a Tyler design (Class F) vacuum tube amplifier, a Class D solid state amplifier, a Class D vacuum amplifier, and a vector summation amplifier.

The Tyler amplifier was developed and tested by RADC. It is a special concept of Class C amplification which provides a more favorable ratio of useful output power to peak plate current than conventional Class C techniques. The input sinusoidal waveform is hard limited to approach a square-wave that is used to drive the amplifier plate voltage to its minimum value quickly. A harmonic trap in the final amplifier stage introduces a second harmonic voltage, in the proper phase and amplitude, that flattens the plate voltage and holds it for a longer period. This allows a greater voltage swing in the resonant tank circuit than occurs at the anode. The result is a larger voltage swing with less dissipation and a final amplifier plate efficiency of about 90%. The RADC owned 56Z-1 and the Navy TACAMO IVB airborne VLF system are examples of Tyler amplifiers that have performed well for several years.

The Class D switching amplifier can be implemented with either solid state devices or vacuum tubes. It acts as a two-pole switch that defines either a rectangular voltage or rectangular current waveform. An output circuit, tuned to the switching frequency, removes harmonics so that the output is sinusoidal. The need to suppress transients and shape waveforms increases the complexity of this type amplifier. The sensitivity of solid state versions of this amplifier to voltage transients and their poor record of operating into reactive loads make this implementation a poor choice for this program. The complexity, particularly in the control of the output spectrum, ruled out a vacuum tube version of this amplifier for this program.

The vector summation amplifier adapts technology from the power generating industry. Two sine waves are generated using solid state switching devices. These sine waves are then vectorially added in an output transformer. Power output is controlled by phase shifting the two sinewaves. The Navy has developed vector summation power supplies for providing highly regulated power for shipboard electronic and fire control systems. They are presently studying the adaptation of this technology to the VLF range. This technology was considered too immature for this application.

The Tyler amplifier was the only amplifier considered that requires tuning. The others are inherently broadband. This was not considered a problem for this application. It was apparent that the Tyler amplifier, and particularly the 56Z-1 implementation, required the least amount of design or non-recurring engineering costs for this program. A matching transformer will be used to provide the proper impedance match between the output network of the 56Z-1 and the antenna. The secondary of this transformer will be tapped to match the terminal impedance of the antenna over the 27-60 KHz range.

Two design changes were made to the 56Z-1. A Pi network low pass filter section was added to the output network to meet the harmonic suppression requirements. A third 4CX250R tube was added to the driver-amplifier circuit. The plate current in the present circuit was recorded at 255 to 282 ma in a test demonstration. The tube manufacturer recommends a maximum plate current of 250 ma. The addition of the third tube, in parallel, reduces the current per tube to 190 ma.

The design of the tuning circuit is a straightforward operation once the antenna and the power amplifier designs are determined. A tuning coil is needed that can tune the antenna across the 27-60 KHz band. An antenna modulator is required to allow a FSK modulated signal to be transmitted by the narrow bandwidth antenna. The RADC developed AMBS can satisfy this requirement. A trim tune variometer will also be needed to account for variations in top hat sag and for fine tuning of the helix. The tuning circuit is shown in Figure 3. The size of the inductor needed to tune the antenna at 27 KHz, based upon the impedance at the base of the tower, is easily calculated. This figure was increased to account for the stray capacitance of the walls of the tuning van and the antenna feed to a total inductance of 4.2 milli-henries.

VLF/LF ANTENNA TUNER

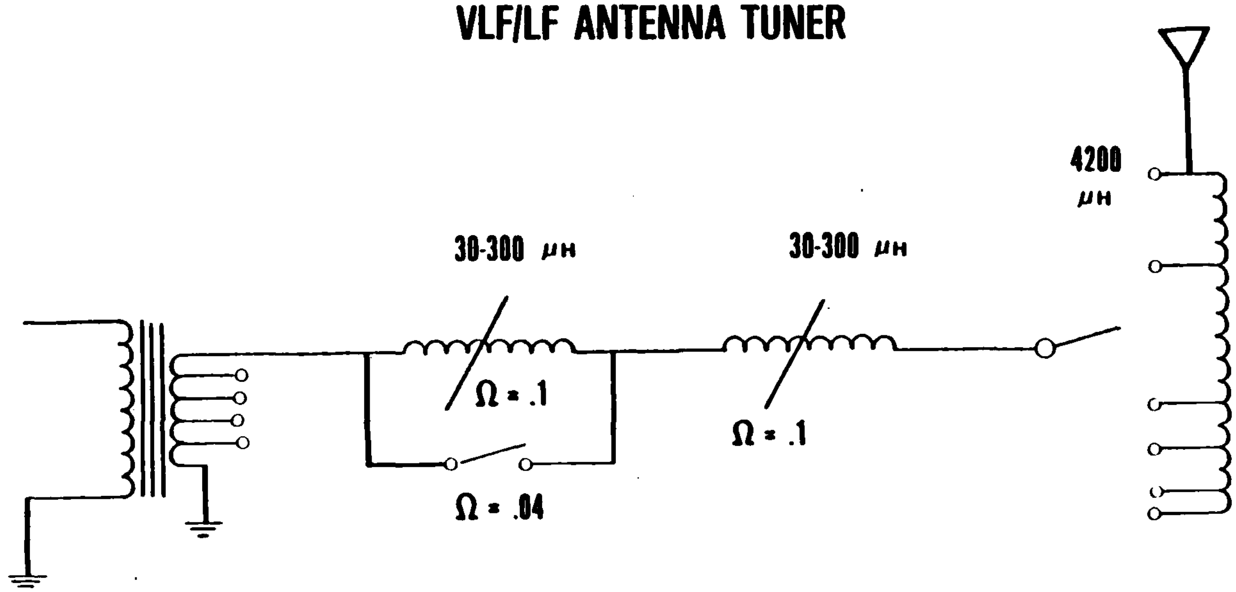


FIG 3

The possibility of an automatic tuning circuit was considered. As it was initially conceived, the main tuning coil consisted of two parts: a fixed helix with an inductance of 2 milli-henries and a variometer with an inductance range of 360-2600 micro-henries. A manually operated switch would switch in the fixed helix for all operating frequencies below 36 KHz. The variometer, in this automatic tuning concept, would also satisfy the trim tune requirements. It was this variometer that created the design problems. At the referenced 36 KHz frequency it had a resistance of .91 ohms. Of the 100 KW available from the amplifier more than half would be lost in the variometer. There was also some question whether the variometer would fit into a standard 8-foot wide van. The voltage build-up across the variometer would require a minimum 2-foot distance between the circumference of the variometer and the walls of the van to prevent arcing. Full automatic tuning is not provided by this approach since the taps on the secondary of the matching transformer must be manually changed with the frequency to match impedances across the 27-60 KHz band. This task is at least as time consuming as a manual change of taps on a fixed tuning helix. The automatic tuning capability provided by this design was not sufficient to consider it further.

The tuner design chosen uses a fixed helix that is tapped binarily, i.e., at turns of 1, 2, 4, 8... This allows any inductance from the maximum value of 4.2 milli-henries to the minimum value provided by a single turn to be included in the circuit by a judicious shorting of selected taps. A trim variometer with a range of 30-300 micro-henries will correct for the variations among turns in the helix and changing environmental conditions.

An additional function of the antenna tuner circuit is to minimize the load impedance phase angle as seen by the transmitter output. The trim tune variometer is used to keep the antenna tuned to the upper frequency of the FSK output of the modem. The delta L variometer is used to tune to the lower frequency. These two functions do not translate directly into mark and space load phase angle information. The control system has two inputs: mark and space load phase angles and two outputs: delta L variometer and trim tune variometer element motion. Movement in either of the variometers will cause changes in both the mark and space load phase angles. The control signal for the delta L variometer will be the difference between the mark and space load phase angle signals. The control signal for the trim variometer will be the sum of the two phase angle signals. These sum and difference signals are then applied to the compensation network for each of the variometers. The objective is to keep the load impedance phase angles seen by the transmitter output terminals to less than 45 degrees.

A site processor has been proposed for the amplifier/tuner subsystem to monitor performance data (antenna current, voltage levels), housekeeping information (temperatures, fuel levels), and for site signal processing. A processor is also required at the message entry terminal. Consideration was given to specifying a software package and a specific processor. Several of the functions at the entry terminal can be performed either by a processor under software control or by hardware. It was determined that the system can better be developed by specifying the requirements and allowing the system fabricator to make the implementation decisions. A couple of guidelines are necessary. The processors at the entry terminal and at the amplifier/tuner sites must be software compatible. The MEECN Message Processor Mode (MMPM) program has qualified several processors. The processor and the software prepared on this program must be MMPM qualified.

REMOTE MESSAGE ENTRY TERMINAL (RMET)

The entry terminal must provide the capability to receive, process, store, and reformat input messages; control and monitor the operation of two VLF/LF transmitter sites, and provide a modulated VLF/LF drive signal of the proper phase and frequency to each of the transmitter sites. Message data must be received on HF radio, UHF and SHF satellites, and on three VLF/LF downlinks. In addition, a UHF line-of-sight (LOS) downlink is required.

The input subsystem was designed to use equipment in the current DoD inventory to satisfy the requirements of a given link. In cases where no suitable existing equipment met the requirements or more suitable equipment was known to be in development, performance specifications were listed in lieu of specific equipment nomenclature. Figure 4 is a block diagram of the RMET input subsystem. Major equipments, recommended as a result of this study, are identified by nomenclature. Figure 5 is a more detailed block diagram of the HF and VLF/LF receive links and Figure 6 presents similar details of the SHF and UHF SATCOM links.

The UHF LOS input link is required to receive Emergency Action Messages (EAMs) transmitted from the Emergency Rocket Communications System (ERCS). That is, it must receive amplitude modulated voice signals at LOS ranges.

The performance requirements of the UHF LOS antenna can be satisfied by the AT-197/GR, manufactured by the Technical Appliances Corporation. This antenna provides vertically polarized, omni-directional coverage with a gain of 1.5 dB plus or minus 0.5 dB over a frequency range of 225-400 MHz. The AT-197/GR is a discone that weighs approximately 6 pounds and has a volume of 19x19x27 inches.

The receiver for the UHF LOS link was chosen so that it would also satisfy the requirements of the UHF SATCOM input link. This choice would reduce system logistic requirements and improve overall UHF link availability. The AN/ARC-171(V), configuration RT-1A with LOS control unit, manufactured by the Collins Telecommunications Products Division of Rockwell International was chosen. This receiver is capable of operating in any of 7,000 channels, in 25 KHz increments, between 225 and 399.975 MHz.

The HF input link is required to receive single channel, FSK modulated, encrypted transmissions. It must also be capable of being upgraded to requirements of the planned MEECN frequency hopped HF data network.

The antenna for the HF input link is a V-4235 manufactured by Hy-Gain Electronics Corporation. It is a 35-foot fiberglass whip which

RMET INPUT SUBSYSTEM BLOCK DIAGRAM

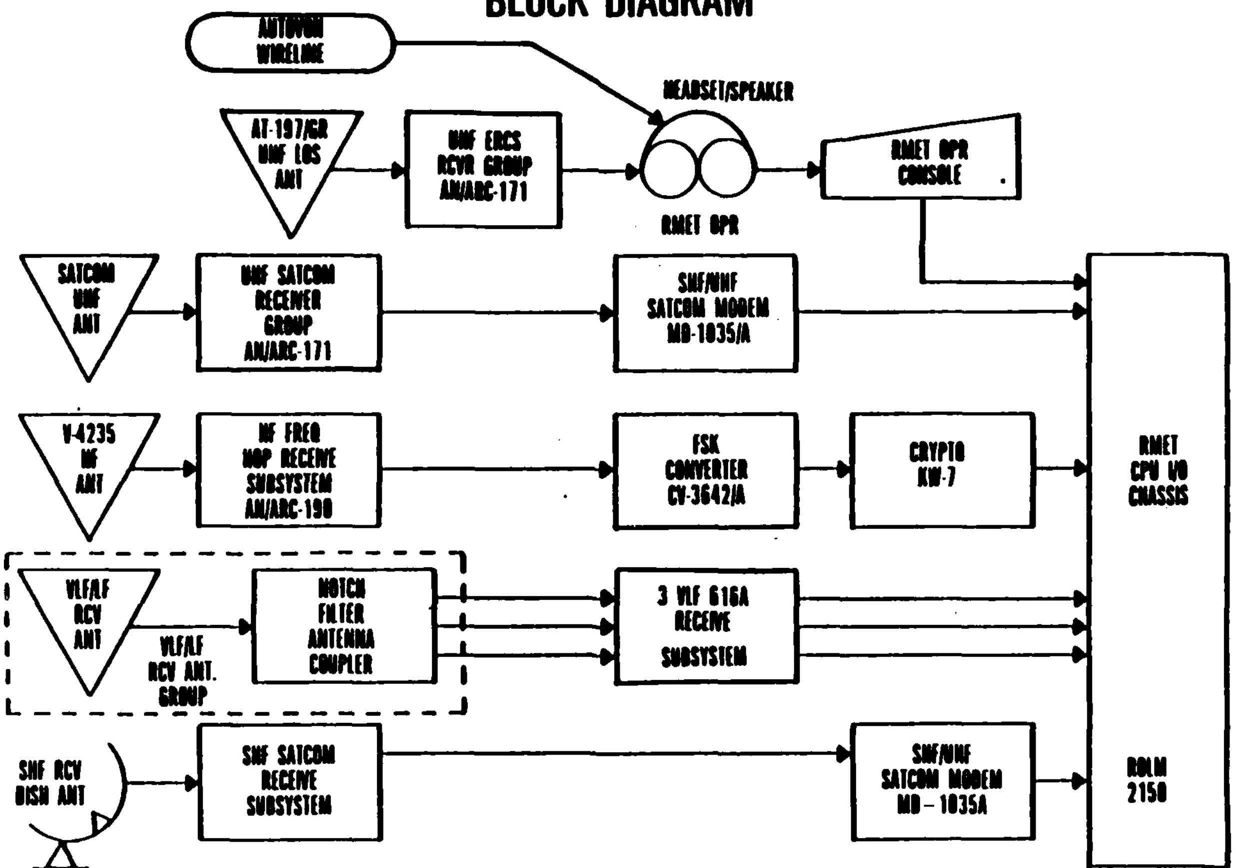


FIG 4

RMET HF & VLF/LF RECEIVE LINKS BLOCK DIAGRAM

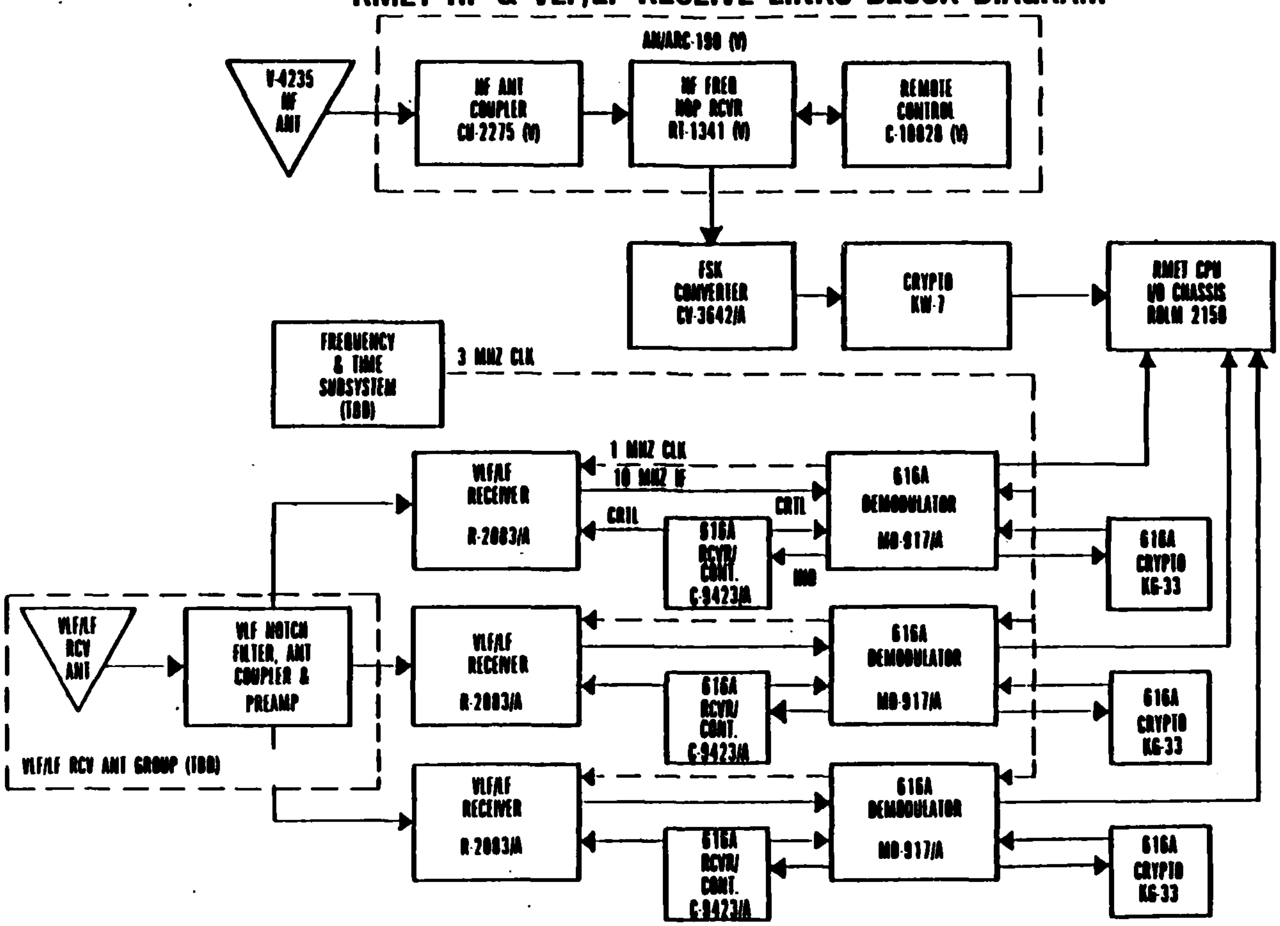


FIG 5

RMET SATCOM INPUT LINKS BLOCK DIAGRAM

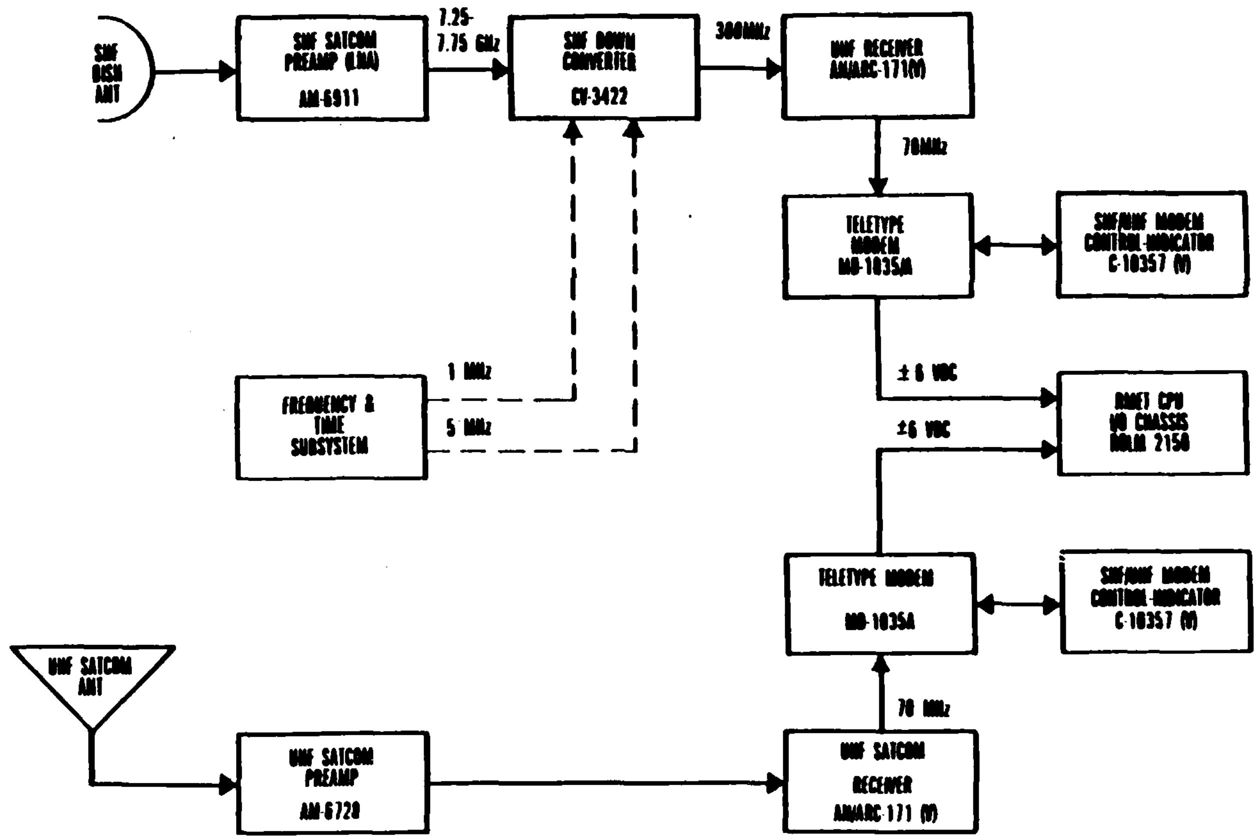


FIG 6

provides an omni-directional azimuth antenna pattern over the 2-30 MHz frequency range. It is transportable in three pieces and weighs 69 pounds.

The HF receiver is the AN/ARC-190(V) manufactured by Collins Telecommunications Products Division of Rockwell International. The AN/ARC-190 system includes a CU-2275(V) antenna coupler, a C-10828(V) control unit, and an RT-1341(V) transceiver. The transceiver operates over the 2.0 to 29.999 MHz band in 100 Hz increments. It also provides for 30 preset channel frequency settings.

The modem recommended for the initial HF downlink is the CV-3642/A FSK Converter manufactured by Magnavox. This modem is small, lightweight, and reliable. It will have to be replaced by an appropriate MEECN specified modem when the frequency hopped network is implemented.

The KW-7 cryptographic unit was chosen for the HF input link. It is the standard military HF netted FSK link cryptographic device. It, too, will have to be replaced when the frequency hopped network is implemented.

The RMET must also receive data from three VLF/LF receivers. Two of these links will receive messages from distant transmitters such as TACAMO, ABNCP platforms, and Air Force or Navy fixed VLF/LF transmitters. The third receiver will monitor transmissions from this repeater terminal. The VLF/LF terminal equipment chosen for the RMET is the 616A Air Force equipment. The alternative, the Navy's VERDIN equipment, could also have been chosen since both systems are capable of operating in the MEECN VLF/LF modes. The VLF/LF input subsystem will consist of an antenna group and three 616A receive units.

The VLF/LF input antenna group will consist of an antenna, an antenna coupler, a pre-amplifier, and a notch filter. The selection of the specific units for each of these functions has been left to the system contractor. The antenna group shall be selected such that the output of the receiver has a S/N value of no less than 0.0 dB when operated in a field of 1 microvolt/meter at 60 KHz and 6.4 microvolts/meter at 27 KHz with a bandwidth of 200 Hz in the absence of atmospheric noise. These figures are based upon the lower decile atmospheric noise levels for the northern United States as published in CCIR Report 322, Xth Plenary Assembly, 1964.

Each of the three 616A receive units will consist of an R-2083/A receiver, a C-9423/A receive control unit, a MD-917/A demodulator, and a KG-33 cryptographic unit.

The RMET must receive messages transmitted at 75 baud in Baudot format from both the DSCS III SCT SHF channel and the AFSAT/SDS SCT UHF channel. In order to achieve maximum commonality, the AN/ARC-171(V) receiver (RT-1A configuration), the MD-1035/A modem, and the C-10357(V) control-indicator panel were chosen for both of these links. The ARC-171 is also used for the UHF LOS channel. The modem and the control-indicator panel are both made by the Linkabit Corporation.

The UHF and SHF satellite antenna choices have been left to the system contractor. The UHF SATCOM receive antenna group has been performance specified as having a gain of at least 0 dBic with a VSWR no greater than 1.6:1 over a frequency range of 225-400 MHz, when operated with a nominal 50 ohm impedance. The SHF satellite antenna has been specified as lightweight, manually steerable, with a diameter between 2 and 8 feet and a G/T value of at least 2.6 dB at 450 degrees Kelvin.

The UHF SATCOM and the SHF SATCOM link calculations are presented in the following three tables:

UHF CALCULATIONS

Item	Value	Note
EIRP (Signal)	+24.3 dBw	
Polarization	-4.1 dB	Circularly polarized
Fade (Multi and Scint)	-6.0 dB	
Aiming Loss	-3.0 dB	
Absorption	-3.7 dB	
Free Space Loss	-127.7 dB	
Elevation Angle	-1.4 dB	Elevation Angle = 3
Antenna Gain (G)	0.0 dB	Omni-directional
(Noise T)-1	-26.0 dB/ok	400ok temp. value
K^{-1}	+228.6 dB	
B^{-1}	-37.0 dB/Hz	5 KHz bandwidth
$(1+N/kTB)^{-1}$	-0.2 dB	
C/kT (1+N/kTB)	+35.8 dB/Hz	1
R_b^{-1}	-18.8 dB/Hz	75 bps data rate

UHF CALCULATIONS

Item	Value	Note
E_b/N_o Available	+17.0 dB	
Required E_b/N_o	+9.5 dB	2
E_b/N_o Margin	+7.5 dB	
E_b/N_o for $P_e = 10^{-5}$	-1.7 dB	
Effective Margin $P_e = 10^{-5}$	+5.8 dB	3

NOTE 1: Sums of previous entries not in parentheses ().

NOTE 2: For $P_e = 10^{-5}$, actual link performance could be 11.2 dB.

NOTE 3: Margin could be increased by 3.7 dB allowed for absorption.

SHF CALCULATIONS

Frequency	7297 MHz
Slant Range	22531 NM
SAT EIRP	30.00 dBw/chan
Path Loss	202.11 dB (0^o elev.)
Other Losses	1.74 dB
Rcvd. Isotrophic Power	-173.85 dBw
System G/T	-2.60 dB (recommended)
P_R/N_o	52.15 dB-Hz
Available E_b/N_o	33.40 dB
Required Thermal E_b/N_o	11.25 dB (for BER of 10^{-5})
Thermal Noise Margin	20.80 dB

(Thermal noise set intentionally high to allow for variable path losses and EIRP values.)

The recommended pre-amplifier for the UHF SATCOM link is the AM-67278 manufactured by Rockwell International. The recommended low noise amplifier and the SHF-UHF downconverter for the SHF SATCOM link are the AM-6911 amplifier and the CV-3422 converter, both manufactured by Rockwell International.

The time and frequency accuracy requirements of this system, which must remain in storage for an indefinite period and then be deployed with little notice, dictates that a cesium standard be specified as the time and frequency source. This standard must be kept operating, and calibrated periodically, while in the storage area. The standard will also have to operate on vehicle battery power when the system is moving to the deployment area. A cesium time and frequency standard that meets these requirements is the Hewlett-Packard model 5016A Cesium Beam Standard with the H-P model K02-5060A Power Supply joined together to form the so-called "flying clock".

A communications processing unit (CPU) is a necessity for the RMET. A fundamental requirement of this CPU is that it perform MMPM receive and transmit processing. It must also perform all of the message handling, site status, and control functions of the transportable terminal. Processors for which the basic MMPM software is compatible are adequate for all of the RMET requirements. The AN/UYK-19(V), manufactured by the ROLM Corporation and marketed commercially as the ROLM 1602B, is expected to be used on the Airborne Command Post (ABNCP) fleet for MMPM processing. The basic MMPM software will exist for the AN/UYK-19. A body of software and hardware, possibly applicable to this system, has been developed for the ROLM 1602B for use on the TACAMO program. In order to specify a CPU, the Government must also specify a software package. This package would include all the peripheral devices for the chosen CPU and the interface between the resident software, provided with the hardware and firmware, and the software specification. This design study did not place the Government in a position to confidently specify these functions. Performance for the CPU has been specified with the comment that the preferred processor for the Transportable VLF/LF Communications System is the ROLM 1602B.

The CPU will require initial loading and occasional reloading (after a hardware failure). The requirements for a program load device for the CPU are virtually the same as for the TACAMO Message Processor (TMP). The Naval Avionics Center recently completed a study to select a replacement for the punched tape reader used in the TMP. They chose the Raymond 6410 Magnetic Tape Unit. Based upon that study, the recommended load device for the CPU is the Raymond 6410.

The operation of the CPU requires that a keyboard/display device be provided for operator interaction with the CPU. The number of incoming slow speed teletype lines to be monitored is small (6). A 30-character per second printer will suffice for MMPM processing, hardcopy requirements and operator interface with the CPU. A suitable keyboard/printer for this application is a solid state teletype, the AN/UGC-120. This device can also function as an AFSATCOM terminal and as the VLF output device in the event of CPU failure. The AN/UGC-120 is an Air Force inventory item.

INTERSITE COMMUNICATIONS SUBSYSTEM

A single RMET is used to drive two amplifier/tuner modules (ATM). The ATMs are located near the base of their associated transmit antennas. A communications system is needed to send the RF signal to each ATM. There are several other intersite communications requirements. The mark-space sequence to the 616A equipment at the RMET must be sent to each ATM to drive the AMBS equipment. A monitor and control link between the RMET and each ATM is needed. Finally, an orderwire channel is required between the RMET and each ATM. The output from the 616A equipment is an RF signal in the 27-60 KHz band. A two-tone FSK keyer in the 116-124 KHz band is used to send the mark-space data to each ATM. The orderwire channel will occupy the 0-4 KHz band and the monitor and control information will be transmitted using a wireline modem (9600 bps) in the 4-8 KHz band.

Three intersite communications alternatives were considered: a coaxial cable, a fiber optic, and a microwave system. The evaluation criteria were cost, ease of installation, susceptibility to strong electric fields, number of deployment cycles, separation of sites, LOS requirement, durability, transportability, and inventory requirements.

The cost of an 8 GHz microwave system was appraised at $62,400. The corresponding estimates for the cable and fiber optic links are $49,800 and $52,500, respectively. A site separation between the RMET and each ATM of 1 kilometer was used for cost estimation purposes. If the separation is larger, the costs of the cable and fiber optic links increase by $3,740 and $4,120, respectively, per additional kilometer. The microwave system suffers a 6 dB loss for each doubling of the separation; however, there is sufficient power margin in the microwave system to allow considerable flexibility in separation distances.

The manhours required for installation were used to evaluate ease of installation. The minimum effort is required by the microwave system. It requires the erection and alignment of one-foot diameter antennas on the RMET and each ATM shelter. The cable systems, both fiber optic and coaxial, require cable to be laid. This will require a vehicle, most likely the vehicle used to deploy the ground plane. Cable and feedline connection times are assumed to be equal for all three alternatives. The microwave subsystem has an additional advantage as the distance between sites increases since its installation requires no additional effort.

Coaxial cable is very susceptible to strong electric fields. These fields have very little effect on fiber optic cable. The microwave frequencies used for transmission are far removed from the VLF/LF band. This, coupled with the size and directivity of the antennas, permits the microwave subsystem to be nearly as immune to strong electric fields as the fiber optic link.

The microwave subsystem has a distinct advantage in terms of multiple deployments. In the worst case, a short piece of flexible waveguide may require replacement after numerous connections. Both cable systems will require replacement of cables after several deployments due to bending of the cables as they are spooled and unspooled. The fiber optic cable appears to be more fragile in this regard and may not survive as many deployment cycles as the coaxial cable.

Separation of sites affects several other evaluation areas as discussed above. This criterion has very little effect on the microwave system. At a separation of 16 kilometers the carrier-to-noise ratio is 32.8 dB for the microwave subsystem. The fiber optic subsystem would require 20 amplifiers, and the coaxial cable subsystem 4, to cover this same distance.

The cable systems are relatively immune to a LOS problem. The microwave system needs a clear path. The addition of a passive reflector on the VLF/LF antenna/tower could provide clearance for any obstructions near the transmitter sites. The twisting moment of the towers is about 1.5 degrees which is well within the 4.5 degree beamwidth of the one-foot diameter microwave antennas.

Durability measures capability of the subsystem to endure its operating environment. Ice, snow, and wind are the major degrading factors to the exposed portions of the microwave subsystem. The cable subsystems have deterioration of the cables due to these factors, plus the walk-on, drive-over effects of personnel and vehicles (refueling trucks).

The microwave subsystem scores highest in the area of transportability. The antennas are small and lightweight and present no stowage problems. The cable subsystems require spooling and storage of the cables. The fiber optic cable has the advantage over the coaxial cable in this regard as it has less bulk and weight.

Microwave subsystems are fully supported by the Government inventory, particularly in the 8 GHz band. Coaxial cable systems are not as greatly used in Government facilities as microwave systems. The cable should be available from inventory. The necessary wireline entrance link may be in shorter supply. Fiber optic systems are relatively new. Spares may not exist in any large quantity in the Government inventory.

The intersite communications subsystem chosen for the transportable VLF/LF repeater terminal was the microwave alternative. Figure 7 is a block diagram of the ATM interface with the microwave intersite communications system. Figure 8 is a block diagram of the RMET interface to the microwave intersite communications subsystem.

PRIMARY POWER

The primary power system must be fully transportable and field supportable. An additional initial specification was that the generating equipment must be selected from MIL-STD-633. The choice of the 56Z-1 airborne transmitter for this terminal necessitates a 400 Hz power source. The calculated power utilization for each of the ATM modules is 158 KW (176 Kva) in the operating mode and 27 KW (31 Kva) in the standby mode. These figures include lights, heating/air conditioning, intersite communications, computer equipment, and convenience outlets. The power demand of the RMET was calculated at 23 KW in both the standby and operating modes.

BLOCK DIAGRAM, BASELINE INTERSITE COMMUNICATION SUBSYSTEM TRANSMITTER TERMINAL

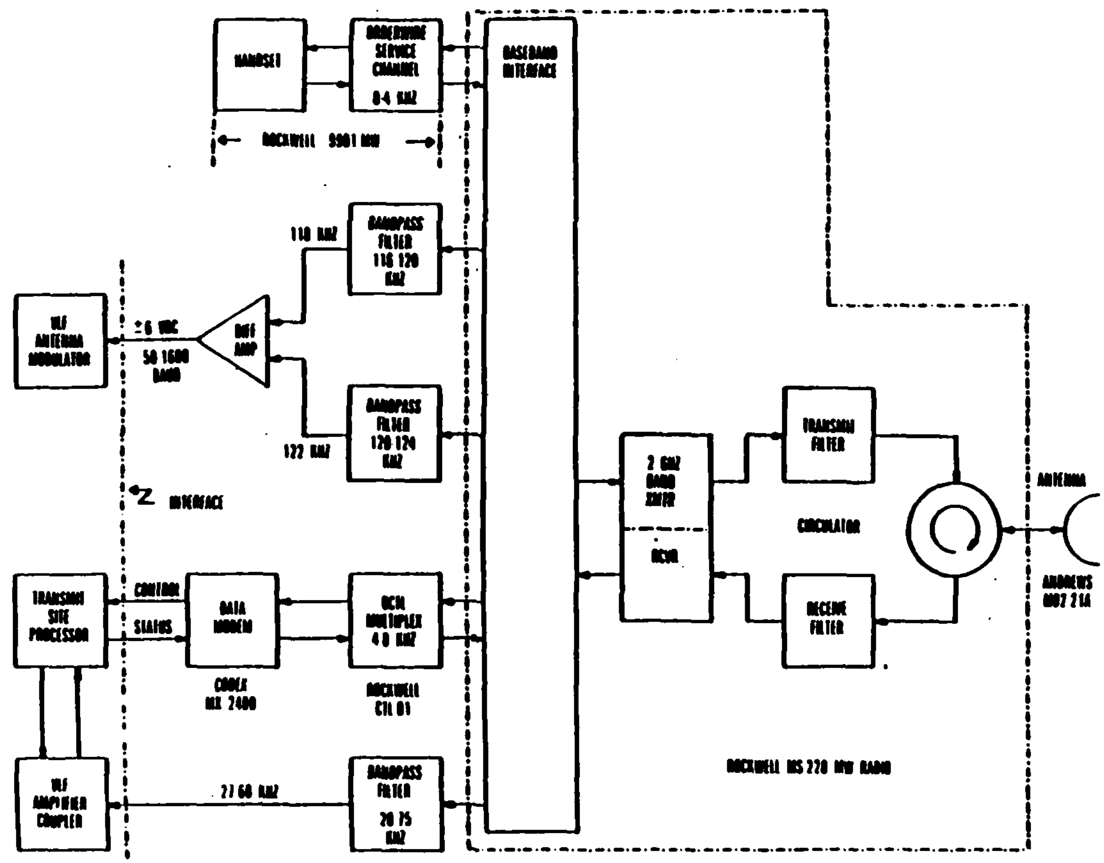


FIG 7

BLOCK DIAGRAM, BASELINE INTERSITE COMMUNICATION SUBSYSTEM RMET TERMINAL

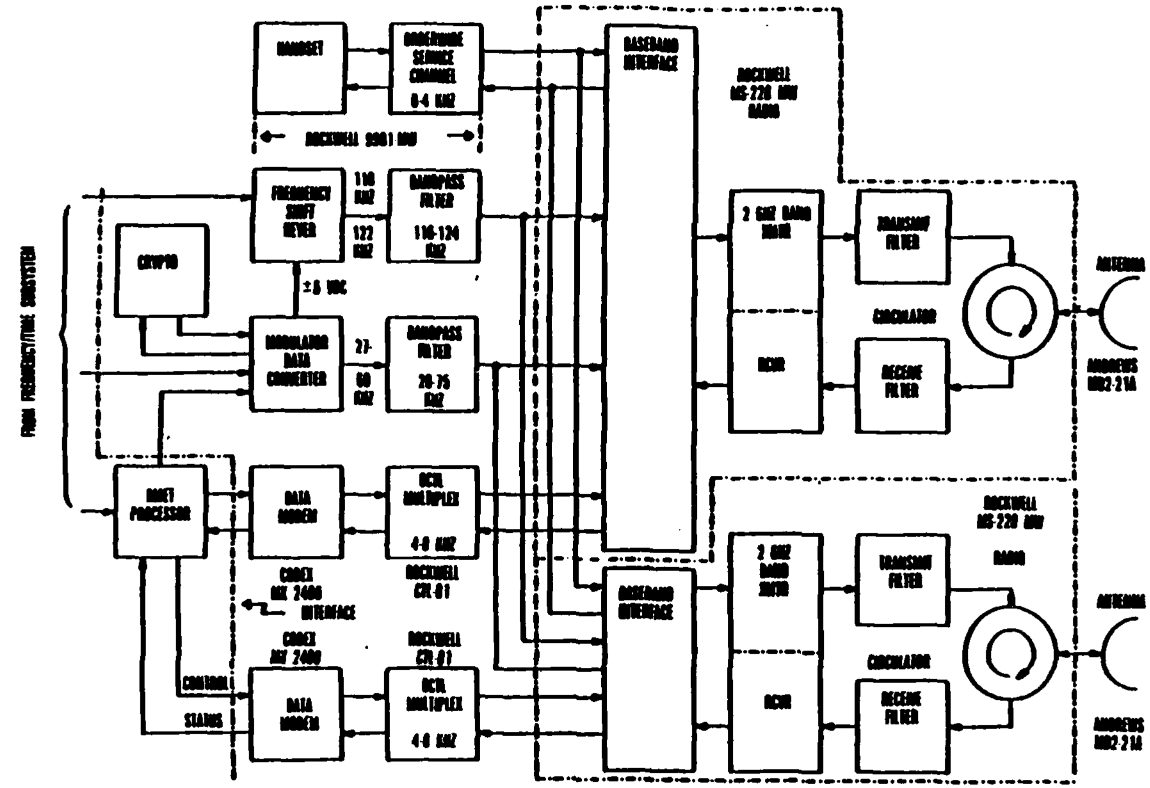


FIG 8

MIL-STD-633 allows a choice of 200, 100, 60, and 30 KW generators. The maximum and minimum power requirements for a single ATM would be a single 200 KW generator for the operation mode and a 30 KW generator for the standby mode. The most efficient utilization would be three 60 KW generators providing 180 KW under full load conditions. During standby, the system would operate at 50 percent of the capacity of one generator. The choice of engines to drive the 60 KW generators is either gas turbine or diesel. The fuel consumption of the 60 KW diesel generator is 6 gallons per hour compared to 17 gallons per hour for the gas turbine. The estimated daily fuel consumption, based upon assumed duty cycles, was 240 gallons for the diesel generators and 764 gallons for the gas turbine generators. The mean time between failure (MTBF) of the 60 KW diesel generators is 500 hours. Scheduled mission operation of the transportable terminal translates to an MTBF, due to diesel powered generators, of 46 days. The 1500 hour MTBF of the gas turbine generators provides a 138-day MTBF for the terminal due to the gas turbine generator.

The basic power generator chosen was the 60 KW, 120/280 volt, 3-phase, 4-wire 400 Hz diesel generator, MEP-115A. This unit will provide regulated power from approximately 10 KW to a 10 per cent overload. Three of these generators will be needed for each ATM and one for the RMET. The three generators will be mounted, along with a 350-gallon day tank on a flatbed semi-trailer. A 5,000 gallon tanker will be used to carry the fuel for an operational deployment.

SUMMARY

The transportable, rapidly erectable VLF/LF repeater terminal specified consists of four subsystems: antenna/tower, amplifier/tuner, RMET, and primary power. The microwave link used for intersite communications is considered part of the RMET. The antenna is a 400-foot top-loaded monopole with a ground plane extending out 600 feet from the base of the tower. The tower is a 400-foot nested section tower based on the "Quick-Erect" design of the Andrews Tower Company. A modified Collins Radio 56Z-1 implementation of the Tyler amplifier was chosen for the transmitter. The tuner was designed to match the transmitter to the antenna in the 27-60 KHz band with minimum power losses. The RMET contains the receivers for the downlinks, the message processing equipment, and the Air Force 616A VLF/LF terminal. The primary power subsystem is made up of 60 KW diesel electric generators. Three of these generators are used for each ATM. A single 60 KW generator is used for the RMET. Figure 9 is a modular diagram of the operational VLF/LF repeater terminal.

DEMONSTRATION SYSTEM

The design of the transportable terminal was specified in a Type A system design specification and a series of Type B prime item development specifications in accordance with MIL-STD-490. Similar specifications were prepared to define a demonstration terminal. These later specifications can form the basis for a possible follow-on effort to demonstrate the feasibility of the system. This part of the report describes the facilities at the Forestport NY test site that can be used in conjunction with prime contractor fabricated or purchased components to

TVLF SYSTEM MODULE INTERFACE, SIMPLIFIED BLOCK DIAGRAM

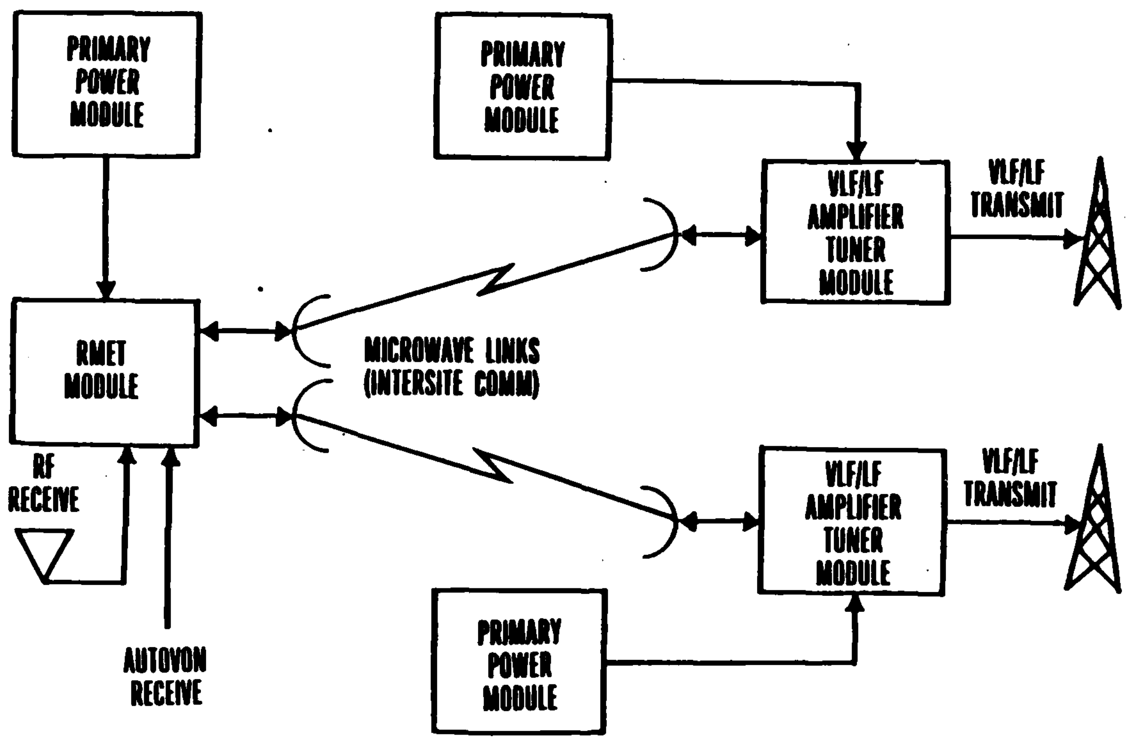


FIG 9

form the demonstration VLF/LF terminal. These facilities include equipment which can be provided as Government Furnished Equipment (GFE), as well as Property (GFP), which must be interfaced on site. The proposed demonstration system will be a caricature of the operational system. In some cases, the expected performance of the demonstration system will be less than the performance expected from the operational system. This is a result of compromises made to control potential costs by using available facilities. In these cases, it may be possible to predict performance of the operational system based upon measured performance of the demonstration system.

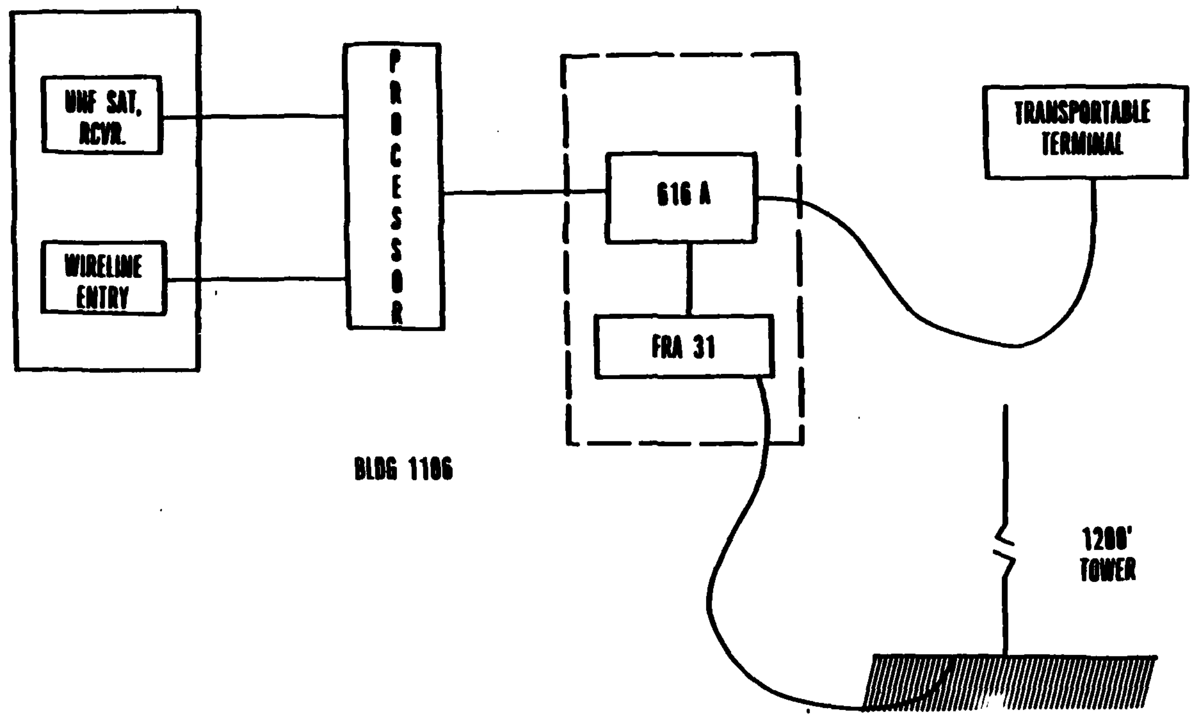
The demonstration system must demonstrate the major characteristics of the operational system. The characteristics can be separated into three general categories: mechanical (transportability, erectability), electrical (5-8 KW radiated power, field strength measurements), and operational (data rates, message formats).

The demonstration of the mechanical characteristics of the system consists of showing that the terminal can be transported on standard wheeled vehicles over hard-surfaced roads to clear level land where it can be erected in a nominal 8-hour day. The antenna/tower and amplifier/tuner subsystems are the key units to be demonstrated. We have assumed that primary power and message entry terminals for other systems are sufficiently transportable that the transportability of these subsystems is not an issue. It is not necessary to buy two antenna/tower systems to demonstrate the mechanical aspects of the subsystem, one will be sufficient. For electrical demonstration purposes, the 1200-foot top-loaded monopole at the Forestport site, suitably derated such that it appears (electrically) as a 400-foot top-loaded monopole, can be used as the second required antenna. A Collins Radio 56Z-1 VLF/LF amplifier is available at the Forestport site. It has not been modified as specified for the operational system. Performance of the modified 56Z-1 will be projected from the performance achieved on the demonstration system.

The helix and the trim tune variometer for the 400-foot antenna tuner circuit will have to be built. The output matching transformer and the AMBS can be provided as GFE. The GFE and the fabricated components of the tuner circuit will have to be integrated into a 55-foot van with the amplifier and the intersite communications terminal to form a complete ATM. The requirement for a processor at the demonstration ATM has been deleted. The ATM in any demonstration system will always be manned during powered demonstration. Performance data can be taken manually.

The RMET must contain the 616A terminal equipment, the message processor, and representative downlinks. The demonstration RMET does not have to be packaged in a transportable configuration. The demonstration RMET equipment can be set up in Building 1106 at the Forestport site. Primary power for this equipment at both 60 Hz and 400 Hz is available in the building. Two downlinks, a wireline, and a UHF satellite circuit were chosen as representative of the two types of data that the operational RMET will be required to process. Data from the UHF satellite will be at 75 baud, FSK in an ASCII format in the 225-399.375 MHz band. Wireline data, also at 75 baud FSK, is in a Baudot format. All of the MEECN transmit modes are less than the 75 baud input rates from the two

VLF/LF TRANSPORTABLE COMM. SYSTEM



DEMONSTRATION LAYOUT
FIG 10

TRANSPORTABLE TERMINAL LAYOUT

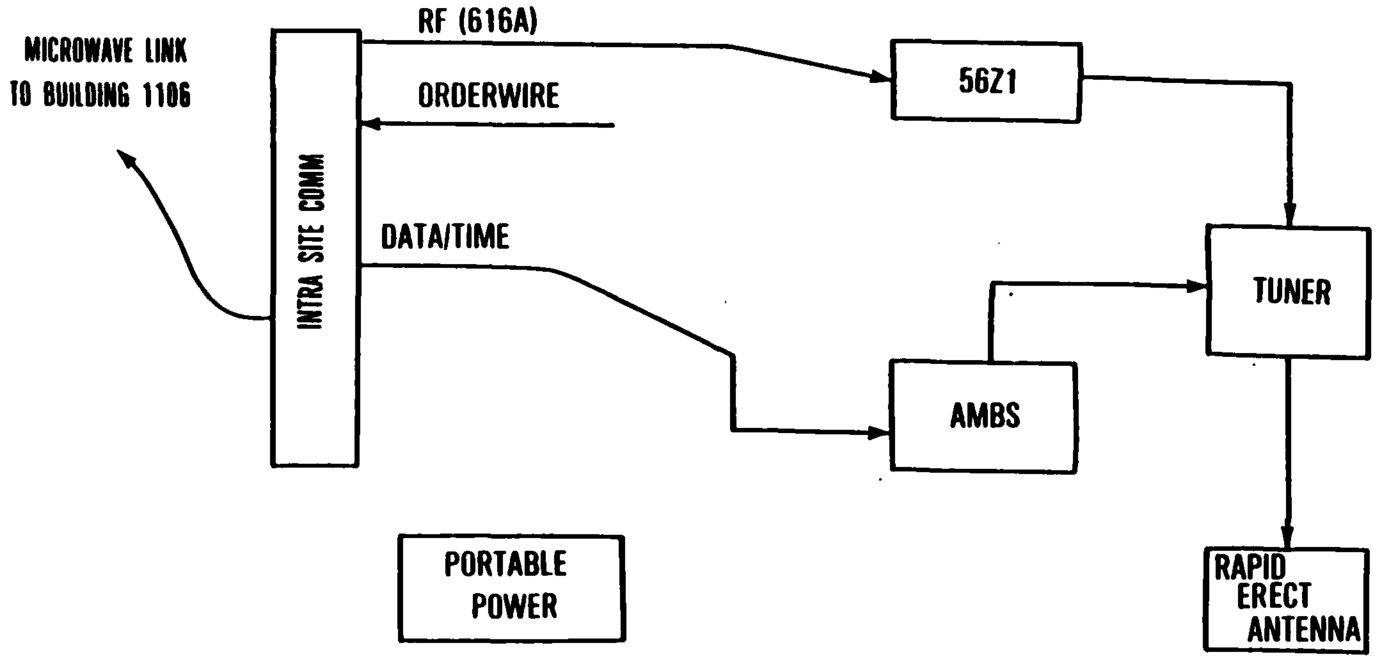


FIG 11

VLF/LF ANTENNA TUNER

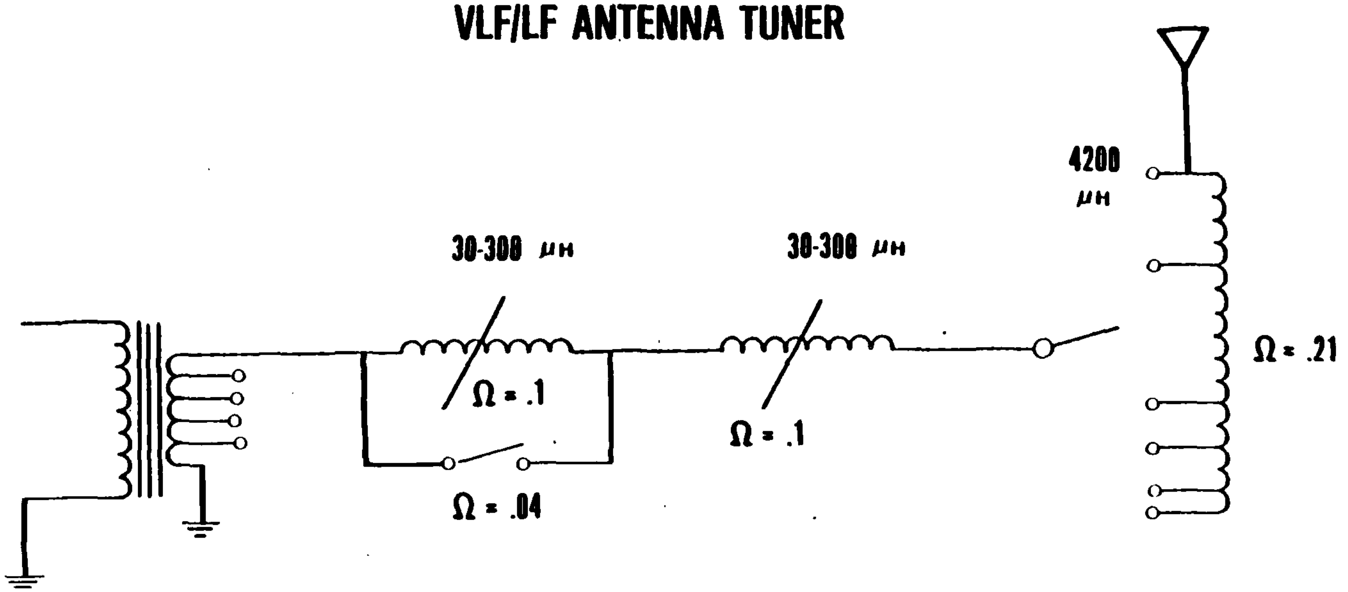
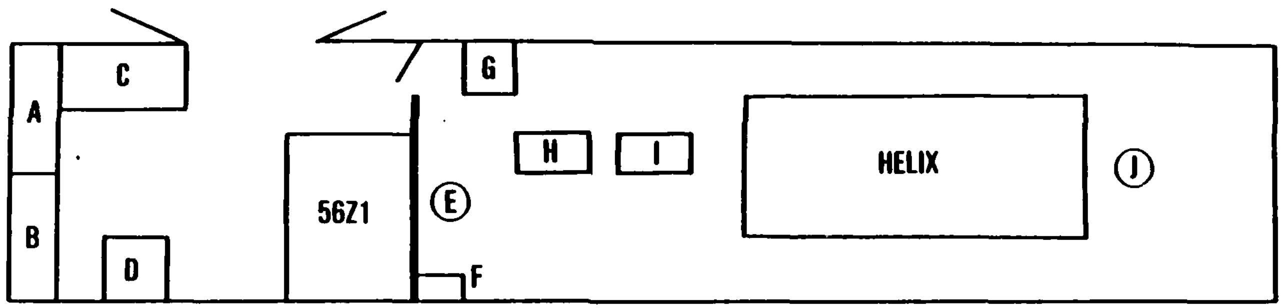


FIG 12

VLF/LF AMPLIFIER – TUNER VAN



LEGEND

A STORAGE
B POWER DISTRIBUTION
C OPERATORS CONSOLE
D INTERSITE COMM SYS
E MAGNETIC SWITCH
F MATCHING TRANSFORMER
G MAGNETIC SWITCH CONTROL
H DELTA-L VARIOMETER
I ANTENNA TRIM VARIOMETER
J TOWER LIGHTING TRANSFORMER

FIG 13

INTERSITE COMMUNICATIONS TERMINAL, BLOCK DIAGRAM

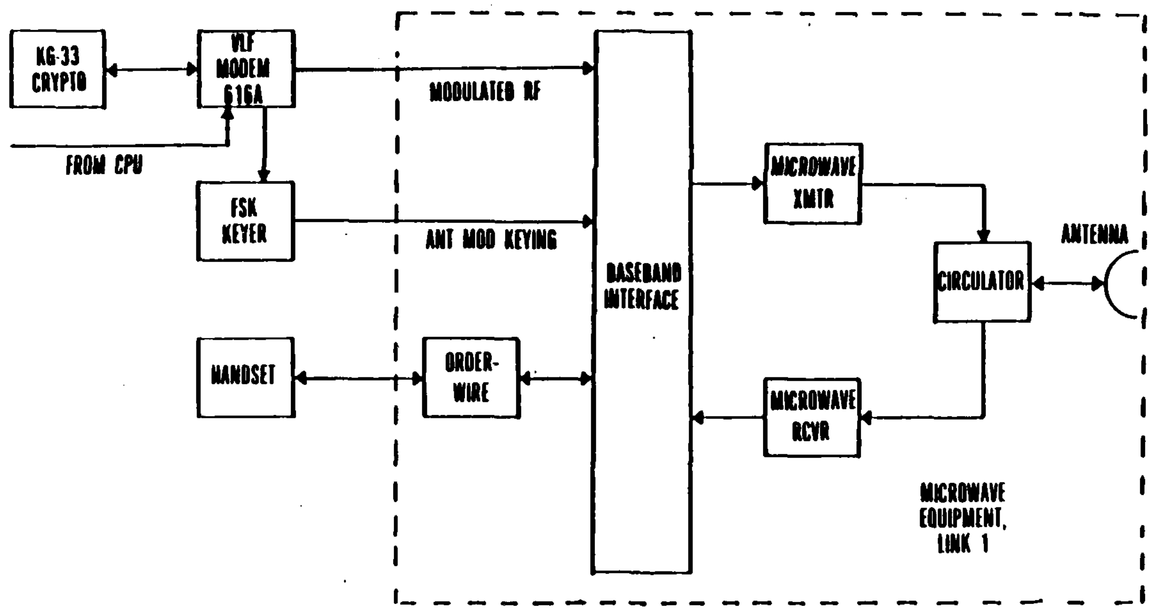


FIG 14

DOWNLOWNLINK & FREQUENCY/TIME PORTIONS OF THE DEMONSTRATION RMET

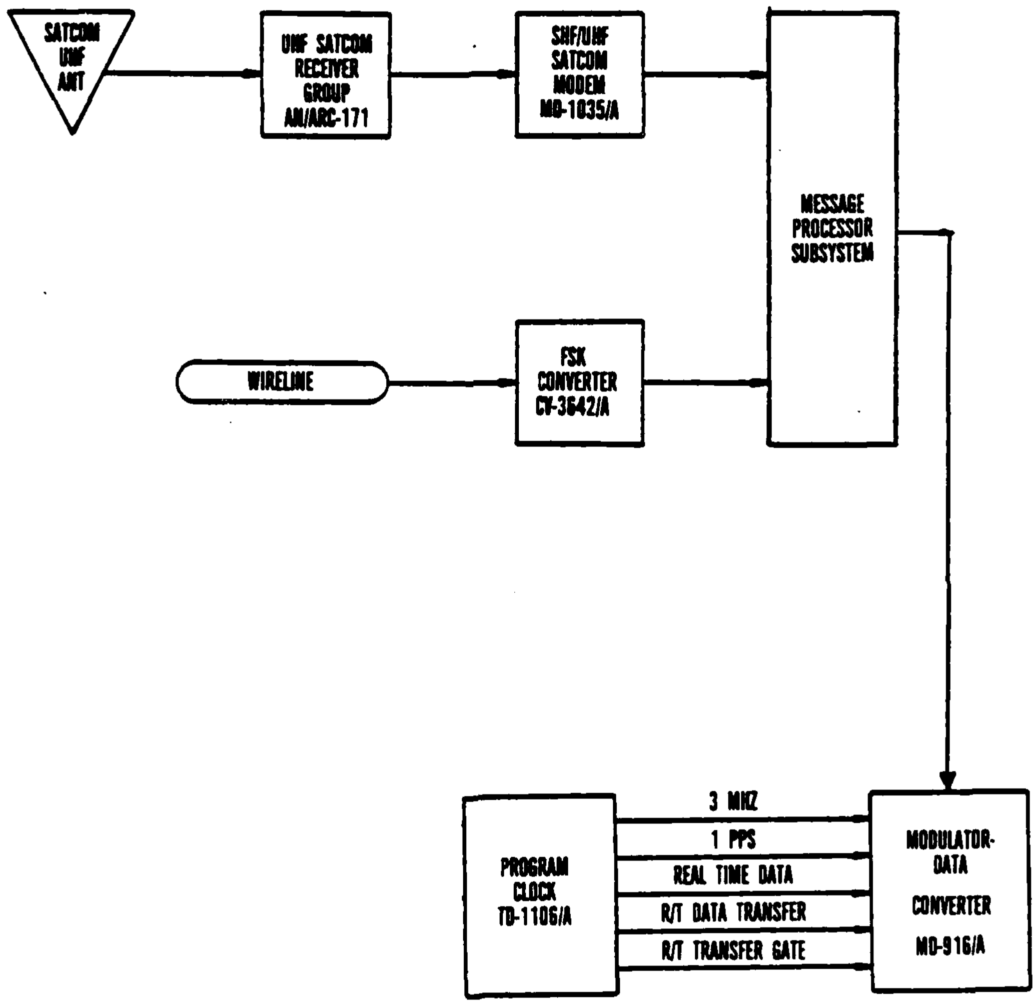


FIG 15

demonstration downlinks. It is sufficient to demonstrate the RMET can process data (recognize, verify, check for duplicates, store, and queue for retransmission) in the required data formats. Two input channels are sufficient to overload the RMET (messages coming in faster than they can be retransmitted) for short periods of time in order to demonstrate system capacity and to show that messages are not lost. The source of the input data is not critical, only the data formats. The microwave intersite communications subsystem for use between Building 1106 and the demonstration ATM will have to be purchased.

Figures 10 and 11 are block diagrams of the demonstration VLF/LF terminal. Figure 10 shows the site assets that will be integrated with procured subsystems to form the demonstration terminal. The GFE 616A equipment and the GFP Westinghouse FRA-31 transmitter are in Building 1106 with the purchased processor and the downlink receivers. The FRA-31 feeds the 1200-foot top-loaded monopole through an underground cable. The 616A equipment drives both the FRA-31 and the transportable terminal, shown in Figure 11. The 56Z-1 transmitter and the AMBS can be provided as GFE. The tuner circuit is shown in Figure 12. The matching transformer and the magnetic switch and the 0-300 microhenry variometer, an AMBS, will be provided as GFE. The helix and the trim tune variometer (also 0-300 microhenry) will be purchased. The van layout for the transportable transmitter/antenna tuner, an ATM, is shown in Figure 13. A primary power subsystem for the demonstration ATM was not specified as a deliverable item. A 180 KW source of 400 Hz power will have to be acquired for the duration of the demonstration program. The microwave interface with the demonstration RMET is shown in Figure 14. Figure 15 shows the downlink, message processor, and frequency/time portions of the RMET.

CONCLUSION

The results of a design study for a transportable, VLF/LF repeater terminal for use in a post-attack period have been presented. A demonstration terminal, based upon these results, has also been presented. The specifications for the demonstration terminal may be used as a basis for a future procurement. Any procurement must include the fabrication of the subsystems, integration of the GFE and the Forestport site assets, and a system test and demonstration. The specifications for the operational system should be maintained throughout the duration of any demonstration. System changes that result from engineering improvements in the fabrication stage or recommendations based upon data taken during any test and demonstration stages should also be documented in an updated operational system specification.

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APPENDIX I

Andrews Tower Company "Quick-Erect" Tower

1. EXECUTIVE SUMMARY

The establishment of VLF transmitting sites during emergency conditions necessitates the use of mobile, quickly-erectable antennas of less than desirable heights to establish communications networks.

a. WIND DESIGN

Wind loads for the mobile VLF antenna are 80 mph or 25 lbs. per square foot. The design safety factors over and above these requirements will give a survival wind tolerance in excess of 150 mph.

b. TRANSPORTABILITY

This study is based upon transporting the mobile VLF antenna using existing roads.

(1) Vehicle: The vehicle can be any standard tandem semi-tractor in commercial use.

(2) Limitations:

(a) Height - 13 feet, 6 inches

(b) Width - 8 feet, 0 inches

(c) Length - None

(d) Weight - 72,000 lbs. gross vehicle weight

c. OPERATIONS

The mobile VLF antenna is designed as a multiple-section telescoping aluminum tower erected from the lowest section up, one section at a time, each section being guyed as the tower erection progresses.

Isolation for the purpose of RF radiation is accomplished through the use of four (4) ceramic insulators and non-metallic guys. After installation of the anchors, the tower erection should be accomplished within one 6-hour daylight period or less.

d. TOP LOAD CURTAIN

The mobile VLF antenna has been designed to support a top load curtain weighing 2,000 pounds for erection and producing not more than 18,000 additional pounds thrust into the vertical axis of the tower.

e. EQUIPMENT

The mobile VLF antenna is self-contained and designed to effect a complete tower installation including:

(1) Power for night ground operations

(2) Foundation plates

(3) Erection equipment

(4) Ground support equipment

(5) Tools and hardware

(6) Leveling jacks

(7) Storage for guys

(8) Tilt mechanism

(9) Spares

Erection-reaction time is reduced by separating procedures and equipment for ground installation.

f. PERSONNEL REQUIRED

(1) Eight (8) trained and experienced men for erection.

(2) Eight (8) trained and experienced men for ground installation.

g. SAFETY PRECAUTIONS

(1) No personnel will be required to ascend the tower during erection or will they be required to work within the fall radius during the erection process.

(2) Hoisting cables do not support the tower sections after erection.

h. TOWER HEIGHTS

Heights of 400 and 500 feet are all that have been considered for this study.

i. COSTS

The production costs are expected to be approximately $380,000 for the 400-foot version and $420,000 for the 500-foot version, not to include the top hat curtain which has yet to be determined. Costs will rise for small quantities or one-at-a-time fabrication requirements. Prototypes and training models are recommended.

j. CONCLUSIONS

The mobile concept to establish a VLF radiator is both feasible and within practical grasp.

2. SITE PREPARATION

a. Proper site preparation, prior to the arrival of the mobile VLF antenna on site, will greatly expedite the installation. It is necessary to fill or level ditches and to clear trees, brush, and other obstructions. Once the site is clear, the foundation, anchors, and ground system should be installed.

b. The ground tasks may be accomplished in conjunction with the tower set-up procedure, but the tower **cannot be erected** until the anchor placement is complete.

c. Completion of the foundation and anchors well in advance of the tower crew's arrival will insure that all reaction time in the ground work is reduced. The ground system and anchors may be placed at an elevation well below grade to permit cultivation of the site after their installation. A simple marking system should be used to reveal all locations for ease and timely excavation.

d. However, if the site preparation must be accomplished under emergency conditions, the following equipment should be available:

(1) Radios to permit man-to-man communications for operation simplicity.

(2) Bulldozers for site clearing (predetermined) as required.

(3) Metallic stake markers (colored) to designate locations of various needs, e.g., tower, anchor curtain, and ground wires.

(4) Anchors and anchor rods to suit application, e.g., rock, soil, etc.

(5) Truck-mounted auger to drill holes for expansion or rock anchors up to 10 feet deep for various sizes as determined prior to site arrival.

(6) Various drill bits for auger to satisfy application.

(7) Jeep-type vehicles to transport ground wire dispensers, i.e., spools, to lay ground wires and/or large farm-type tractors to plow in these radials.

(8) Range poles, four (4) each, to enhance layout reaction time.

(9) Mechanical ground rod drivers to assist operations in reducing reaction time.

(10) Two surveyor's transits complete with stadia to reduce measurement time and 3-degree horizontal marks on cross hairs desirable.

e. Regardless of the arrival time of the mobile VLF tower, it should never be permitted on site until the ground system anchor installation is complete and the trailer tower location is clearly marked. This will permit unobstructed movement over the site by the installation crew.

3. OPERATIONS CREW

The operations of the mobile VLF tower should be accomplished by two separate and distinct crews.

a. Crew 1:

(1) Ground Operations: The ground operations crew should consist of eight (8) trained and experienced men as follows:

(a) Crew Chief - One man trained to accomplish task.

(b) Layout Crew - Two men trained in the use of surveying, stadia, and layout work.

(c) Ground System Installation Crew - Two men with a vehicle.

(d) Anchor Installation Crew - Three men.

To effect minimum reaction time, the ground wires cannot be buried. They must be laid out on the ground and clamped to a ground rod at each end.

(2) Ground Crew Equipment

(a) One-quarter to one-half ton Jeep or similar vehicle, winch equipped, with special fixture for rear ground-wire dispensing and a trailer for transit range poles and tools necessary for crew support.

(b) One and one-half ton winch-equipped truck with bed to store and transport ground wire and ground rods.

(c) One and one-half ton winch-equipped truck with power auger to install anchors. Must be equipped with means to install anchors in soil, rock, and sand, etc., with instant availability of proper tools, bits, and anchors to accomplish task. This type of vehicle is used to install power or telephone poles.

b. Crew 2:

(1) Tower Erection Crew: The tower erection crew should consist of eight (8) trained and experienced men as follows:

(a) Crew Chief - One experienced tower rigger trained on towers of this type. This person will be responsible for the direction and coordination of the entire crew; therefore, it is mandatory that he be capable of making major decisions should problems arise in access, weather, or erection.

(b) Operator (Driver) - One experienced operator that is sensitive to the overall purpose of the task and can take direction. This operator must be able to take the initiative to cease operations when problems known only to him arise until the problems are corrected.

(c) Top Anchor Man - One experienced rigger-climber whose job takes place at the hoisting anchor positions. He has the most complex task of all of the anchor crewmen. He must operate the transit and is the Number 2 man on the crew.

(d) Anchor Men - Five experienced men who are capable of taking direction without close supervision and who are also able to respond on their own initiative. These men must also be able to operate the transit.

(2) Tower Crew Equipment:

(a) Three and one-half ton tandem semi-tractor, all-wheel drive and equipped with a heavy-duty winch containing at least 2,000 feet of one-half inch cable to tow the tower trailer.

(b) Radio and winch-operated vehicle for the remainder of the crew.

(c) Two plunging-type 10-12 power transits to plumb tower and observe the erection process.

(d) Personal radios for ground communications. The receivers should be on constantly with push-to-talk buttons.

4. TOWER

a. The study of this mobile VLF antenna is based upon the Andrews Tower, Inc., Quick-Erect Tower, first fabricated in 1965 as a 300-foot microwave restoration tower.

b. The specific application of this transportable tower is very little different from the original 300-foot version. The principal differences in the current requirements are as follows:

(1) Extreme height - 400 ft. and 500 ft.

(2) Vertical radiator (hot tower)

(3) Electrical isolation (base and guys)

(4) Weight of completed structure increased

(5) Top hat-curtain loading

c. The towers are constructed of nine (9) and 12 48-foot long, square, nested, welded aluminum sections that are overlapped at least 10 percent of their length on each section.

d. Once the vertical, nested stack is guyed using the guy lines attached to the top of the bottom section the stack is extended from the bottom section to the next extension position. A set of four (4) hook-locks are extended from the bottom of the outer erected section to engage four (4) V-type hairpins (one on each section face) located at the top of the guyed bottom section. The weight of the extended tower sections now rests on these hairpins. The hoist cable is then removed from the winch and can be used as a guy cable. This extended stack is again guyed using guy lines attached to the top of the now outer section. This procedure continues, extending the stack from the guyed outer section and then guying until the tower has reached full extension. Guying as you go limits the hazard of extreme extension lengths left unguyed should sudden gusts of wind try to overturn the extending section. The Quick-Erect tower concept permits erection in moderate winds of up to 20 knots.

e. The guy pattern is a 90-degree four-way system which permits one guy to be opposed by another making vertical alignment extremely simple since only one pair of guys are used at a time.

f. The internal hoist cables are reeved to give the required mechanical advantage of 3:1 and 2:1, depending upon the weight of the extended tower. This keeps the hoist cables at approximately the same maximum load. These hoist cables extend from the tower as a portion of the guy system and become a permanent link as a guy when the hoist cycle of each section is complete. The automatic locks (hairpins and hooks) prevent the accumulated weight of the tower and pull of the guys from being supported by the hoist cables.

g. At no time during the tower extension is any person required to be under the tower and exposed to accidental consequences of tower collapse. Work around the tower base is the connection of the winch cable to the hoist cable for the next extension operation.

h. Mechanical constraints are dictated by highway width, height, and weight limits. Maximum tower section lengths are dictated by the suppliers of aluminum; in this case, 48 feet is the maximum length of heat-treated aluminum.

i. The tower shaft was considered a continuous beam on non-elastic supports to obtain the preliminary figures for member stresses, guy loads, and shear loads, etc. The section locks are located in the center of each face giving four point suspension of each section. Joint moment resistance then becomes a function of pre-load and section physical size. The pre-load caused by the action of the guys is more than sufficient to make the joints behave as if they were fixed and continuous.

j. The wind on the tower shaft is considered to be exposed on 1.75 times the area of one face with shape change factors for individual members to be 1.0 for flat members and angles and 2/3 for round members and rods. The wind is then applied uniformly throughout the tower height at 25 psf to determine initial loads and stresses. The results are tabulated in the following tables.

TABLE I - TOWER SECTION PHYSICAL CHARACTERISTICS

SECTION NUMBER	SECTION FACE INCHES	SECTION LEG DIMENSIONS	ALLOWABLE LEG LOAD LBS.
1	70	4x4x3/8	37,500
2	64	4x4x3/8	37,500
3	58	4x4x3/8	37,500
4	52	3.5x3.5x3/8	31,900
5	48	3.5x3.5x3/8	31,900
6	44	3.5x3.5x3/8	31,900
7	40	3x3x5/16	23,800
8	36	3x3x5/16	23,800
9	32	3x3x5/16	23,800
10	28	2.5x2.5x5/16	21,100
11	24	2.5x2.5x5/16	21,100
12	20	2.5x2.5x5/16	21,100

Sections 1 through 12 are used for the 500-foot tower; sections 3 through 11 are used for the 400-foot tower, and sections 4 through 11 are used for the 300-foot tower.

TABLE II - TOWER INPUT DATA (400-FOOT TOWER)

SECTION NUMBER	FACE WIDTH IN	WIND AREA SQ FT/FT	WIND LOAD LBS/FT*	SECTION WEIGHT	SECTION LENGTH	ANCHOR RADIUS
11	24	1.12	28	678	43.2	600
10	28	1.20	30	735	43.2	300
9	32	1.40	35	802	43.2	300
8	36	1.48	37	924	43.2	300
7	40	1.52	38	938	43.2	300
6	44	1.80	45	1188	43.2	180
5	48	1.84	46	1358	43.2	180
4	52	1.84	46	1380	43.2	180
3	58	2.20	55	1697	48.0	180

*an assumed wind load of 25 lbs./square foot

TABLE III - TOWER DATA

Guy Wind Load on Tower	11,368.56
Guy Weight on Tower	3,833.50
Guy Tension Load on Tower	37,360.27
Weight of Tower & Accessories	11,700.00
Total of All Vertical Loads	64,262.34
Load on One Tower Leg	16,065.58
Bending Depth of Tower Sections (ft.)	6.84
Moments Used in Tower Loads	12,039.23
Leg Load from Moments	1,761.31
Total Leg Load from All Loads	17,826.90

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