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APOLLO LOGISTICS SUPPORT SYSTEMS MOLAB STUDIES

TASK ORDER N-37 REPORT ON

GROUND WAVE PROPAGATION ON THE LUNAR SURFACE

Prepared under Contract No. NAS8-11096 by

J. D. Hughlett, Jr.

NORTHROP SPACE LABORATORIES
Space Systems Section
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Huntsville, Alabama

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NASA - GEORGE C. MARSHALL SPACE FLIGHT CENTER
Huntsville, Alabama

October 1964

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PREFACE

This report was prepared by the Northrop Space Laboratories, Huntsville Department for the George C. Marshall Space Flight Center. The NASA Technical Liaison Representative was Mr. E. C. Hamilton of the Advanced Studies Office, Astrionics Laboratory. The work was started on 1 July 1964, and completed 1 September 1964.

This particular task was one of the current series assigned to the Huntsville Department of NSL for study of the various aspects associated with the preliminary considerations of the Apollo Logistic Support System utilizing the MOLAB Payload.

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SECTION 1.0

SUMMARY

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This document presents the continuing results of a Ground Wave Propagation Study for an over-the lunar horizon communications system. It will be applicable to the manned Mobile Laboratory (MOLAB) mission--now under consideration by the National Aeronautics and Space Administration as a Logistic Support System for the Project Apollo.

This report presents a digital computer program for an optimum frequency on the lunar surface. It is based upon mobile operations and limited for antennas resonating at frequencies less than 0.1 wavelength. Also, it is designed for the given parameters as stated in the Section titled "Computer Program". A section follows on direction finding antennas discussing the loop antenna and four vertical monopoles with a goniometer. Emphasis was placed upon the loop antenna, with findings indicating that increased efficiency can be gained by introducing low loss ferrite cores into the windings. The exact percent efficiency depending upon the material chosen.

An approach is made to the conceptual design of a solid state transmitter utilizing the state-of-the-art as it exists today. An overall block diagram is shown illustrating a proposed complete transistorized medium frequency subsystem operating at 1.5 megacycles for voice communication.

Author

SECTION 2.0

INTRODUCTION

This report is the result of an investigation of specified problems pertinent to the communications area of the lunar surface Mobile Laboratory (MOLAB)--a candidate system to be used as part of the Apollo Logistic Support System (ALSS). It represents only one assignment in the area of lunar communications, that being ground wave propagation on the lunar surface. This work was done under authorization of MSFC Task Order N-37 assigned to NSL as part of Contract No. NAS8-11096. The Task Order is titled "Ground Wave Propagation on the Lunar Mobile Laboratory".

This report is essentially divided into three (3) sections. The first section is a computer program compiled from the previous report on the Ground Wave Propagation, Report NSL E30-14, June 1964. The second section discusses the loop antenna and its construction for use as a direction finder for navigation purposes. The third section discusses very briefly the beginning of a conceptual design of an all solid state transmitter.

SECTION 3.0

COMPUTER PROGRAM

A digital computer program was written for the IBM 1620 to solve for an optimum transmitting frequency on the lunar surface. This program was based upon the work previously completed 1 July 1964, NSL Report No. E30-14 (Reference 1). The program, as illustrated in Figures 3-1 through 3-8, is useful for determining an optimum frequency with a base loaded vertical monopole when various parameters are desired. However, there are limitations to the program in that the conductivity and dielectric constants are fixed for values of 10-3 and 10-4 mhos per meter at 1.1 and 2.0 respectively. By fixing these values it did not limit itself to one particular region, but was based upon sound information derived from Senior and Siegel (Reference 2) of their studies upon the conductivity and dielectric constant of the lunar surface.

Much of the program is mathematically computed, however, some parts are entered in Table form. In some cases curve fits have been utilized to save memory storage along with graph interpolation.

Figures 3-1, 3-2 and 3-3 are the source program with Figures 3-4 and 3-5 refering to the subprograms of the Norton Surface Wave Vertical Electric Dipole. In the subprograms the four point Lagrange Interpolation Function was utilized. As was stated previously, this technique was utilized to save memory storage in order that the complete program could be run at one time. Combining Figures 3-1 through 3-5 with Figures 3-6 and 3-7, the input data on optimum frequency can be resolved.

As an example assume that an optimum distance is desired for a given conductivity of 10^{-3} mhos per meter and a dielectric constant of 2 (what ?) for a fixed frequency of 0.7 megacycles and a range of 100 kilometers. With this information and a given transmitted power of 1000 watts at a bandwidth of 2.5 kilocycles to an antenna 60 feet in length for an assumed 12 db threshold requirement for AM utility, the results will be seen from Figure 3-8 that the optimum distance is 24.98 kilometers. With this data and plotting distance versus frequency, the optimum transmitting frequency can be achieved, as illustrated in Figure 3-9.

SECTION 4.0

DIRECTION-FINDING ANTENNAS

Direction finding at broadcast and lower frequencies (300-3,000 kc) is normally accomplished by use of loop antennas, Adcock antennas, or four vertical antennas with a goniometer. In this section the primary importance will be palced on the loop antenna and the four (4) vertical elements with the goniometer for MOLAB use.

4.1 LOOP ANTENNA

Direction finding can be accomplished with the loop antenna at the medium and low frequencies when the energy of the transmitted wave is vertically polarized. The passage of a wave in the direction toward which a loop is turned induces in the loop a voltage expressed by

(1) $E = 0.021\,\mu eNAf$ (Reference 3)

where E = induced voltage, μv

μ = effective relative permeability (ratio of flux in coil with magnetic core to value without core).

e = field strength, μv per M

N = number of turns in loop

A = Area of loop, sq M

f = frequency, M_c

The "effective height" of the loop antenna is expressed by

(2) $$\text{Effective height} = \frac{E}{e} = 0.021\,\mu NAf$$

which by definition is the series voltage in the loop divided by the field strength. This is similar to the effective height of an open antenna. Normally, the effective heights of loop antennas are small in comparison with open antennas, such as vertical monopoles. The loop antenna being small compared with the wavelength, normally a single turn loop, the conductor will be less than 0.08 wavelength long.

The real problem that makes loop antennas inefficient is the fact that the loop antenna cannot given the correct direction to the transmitter without the aid of another simultanious fix from some other station. This being impossible on the lunar surface, a small vertical antenna (commonly called a sense antenna) placed with the loop offers the solutions to the problem.

The purpose of the sense antenna when combined with the loop is to produce an output having only one null. For this to be accomplished there must be a 90 degree phase difference between the outputs of the loop and sense antenna with the signal strength remaining the same. The phase shift is achieved by tuning the sense antenna slightly off frequency. Since the sensitivity of the sense antenna is greater than the loop, this problem can be minimized by changing the resistance. The length of the sense antenna should be approximately four (4) times the loop diameter of a wire wound and then be pruned until a radiation pattern similar to that of a 1/4 wavelength at right angles to the wire (car diod pattern) is achieved.

4.2 ANALYSIS

The loop antenna was approached for study by first considering a single turn low-impedance loop. The results noted were that a single turn loop would be approximately 25 feet in diameter at 1.5 mc, being too large for mobile purposes. Considering next a loop with a given diameter and a multiple of turns a radiation resistance was calculated for the antenna at a fixed frequency by the equation

(3) $$R_R = 31,200 \left(N \frac{A}{\lambda}\right)^2$$ (Reference 4)

where R_R = radiation resistance in ohms

N = number of turns

A = Area of loop in square meters

λ = wavelength in meters

The results indicated that the larger the diameter and the fewer number of turns, the higher was the radiation resistance. To achieve the highest efficiency and reduce the probability of error the efficiency is a critical item, as was illustrated in NSL Report No. E30-14 dated June 1964 (Reference 1). It is to say that the efficiency of the antenna is a function of the radiation resistance.

Further study reveals a newer concept in loop antenna design, that of replacing some of the windings with a ferrite core. The loop antenna is, therefore, capable of being made smaller in diameter, thus allowing it to be adaptable for mobile use. This magnetic core will thus increase the equivalent diameter of the loop antenna, however, at an additional weight increase to the antenna as compared to that of a complete air-core loop. The ferrites are crystals having the general chemical formula $M_N(Fe_2O_4)$, where M_N represents any divalent metal or mixture of such metals. A precaution will need to be observed in that above certain temperatures, depending on the grade of ferrite being used, change of inductance will be substantial and deturning of the antenna circuit will lower the sensititity of the receiver. With the lunar surface temperature predicted at approximately 250°F, a grade of ferrite will need be selected which will withstand this temperature. Considering not only the temperature but also that of the magnetic material utilized, the magnetic core increases the flux, the coil inductance, and the coil Q in varying amounts, so that it will be necessary to consider these variations together in order to determine optimum performance.

The increase in flux in a narrow coil at the rod center may be defined as the apparent permeability of the rod. The permeability depending upon the rod dimensions and the intrinsic permeability of the rod material when measured in a toroid. Similarly, the increase in inductance may be expressed as an increase in the coil permeability. This will be greater for longer coils. It is to be remembered that the Q decreases as the coil is lengthened. The sensitivity of a rod and coil antenna varies with the coil length. Since loop antennas must generally be tuned with a specific condenser, the number of turns are adjusted to produce the same coil inductance for each different length. From this, it is clear that short coils will be most desirable. Therefore, to achieve a high efficient antenna coil for the medium frequencies, it is desirable to have a low-loss ferrite tuning core with high permeability to gain a very high Q coil for maximum signed pick-up.

4.3 GONIOMETER ARRANGEMENT

The necessity of rotating a loop antenna to obtain a bearing canbe avoided by employing four vertical stub antennas or two fixed loop antennas oriented 90° with respect to each other, with their outputs combined in a goniometer. This section will be primarily oriented towards the use of the four vertical monopole antennas. This arrangement permits use of fixed antennas that can be made much too large to rotate, and furthermore these fixed antennas may be connected to the goniometer coils by relatively long transmission lines. This permits physical separation between the antenna system and the equipment that must be manipulated.

The vertical monopoles employed in this arrangement are essentially whip antennas tuned to resonance (base loaded)at the desired frequency. Their length being about five feet for 1.5 Mc when extended, however, this will primarily depend upon the transmitter power output on the LEM and most important, the success of the surface wave transmission based upon the conductivity and dielectric of the lunar soil.

Another consideration in employing this method would be the horizontal diagonal distance between the antennas.

SECTION 5.0

CONCEPTUAL DESIGN

The conceptual design of the MOLAB Medium-Frequency Communications Subsystem was determined by the weight, power, volume, and environmental constraints. Optimization of transmitter power was achieved upon the theoretical conductivity and dielectric constant of the lunar surface for a given distance of 100 kilometers. A technical approach was made by first making a brief survey of the state-of-the-art of medium-frequency radio systems. The results indicate that a solid state, light weight, one (1) kilowatt transmitter is feasible for voice communications or navigation purposes between the LEM and the MOLAB.

A conceptual design of the MF communications payload is depicted in the block diagram of Figure 5-1. This figure shows a proposed solid state transmitter and receiver utilizing the technique of modular construction. The basic elements of the system include, on the transmitting end, a modulator, a low level exciter, a power amplifier, and a power supply. At the receiving end, the components parts are amplifiers, demodulators, and power supplies. All but the RF power amplifier have been solid state constructed. In order that a high efficiency be gained from an MF transmitter, recent significant solid state circuit developments have resulted in the capability to produce high efficiency linear amplification. Through the use of this method efficiencies on the order of 90% are obtainable. The high efficiency is achieved through switching techniques, using both silicon controlled rectifiers and power transistors resulting in high power amplification.

The MF communications system illustrated in Figure 5-1 will operate on an assigned frequency of 1500 kc $\pm$ 20 cps. The oscillator being crystal controlled offering a high degree of stability, as compared to a variable oscillator giving flexibility. This assigned frequency is based upon the analytical results of the moon's conductivity and dielectric constant. When the system is used for voice communications, the voice quality will be poor, the bandwidth being 2. 5 Kc. The unit also has the capability of a navigation system by switching from the whip antenna to a loop antenna on the receiver. When used for voice communications, the unit will operate in the simplex mode with a push-to-talk arrangement. Consideration was given to the choice of modulation, and it was determined from the assigned frequency and the high degree of efficiency desired that amplitude modulation was the better choice. It also has the advantage of transmitter simplicity, which is important in mobile equipment. However, single sideband could be used should a narrower bandwidth and less power consumption be desired. Utilization of single sideband would require more complex circuitry and be more difficult to tune. The MF communications system will also contain its own power pack, utilizing 28 volt dc from the required operating voltage of the transmitter. Similarly, a power wupply will be utilized with the receiver performing the same function.

With the state-of-the-art as it exists today, Westinghouse has developed a transmitter that could be adapted for over-the-horizon communications. The physical characteristics are illustrated in table I & II.

TABLE I

Westinghouse solid state Modular Power Transmitter

Volume	21,600 in^3 less than 12 ft^3
Width	30 inches
Length	24 inches
Depth	30 inches
Power Consumption	Approximately 1400 watts
Percent Efficiency	80% AC-RF, 90% DC-RF
Power Output	1 KW
Modulation	AM
Reliability	Failure rate of 1.252%/1000 hours.

TABLE II

Receiver

Volume	163 cubic inches
Power Consumption	10 watts

This transmitter as reported, is completely solid state making use of modular construction and utilizing power transistors in the place of power tubes. With the power module as the heart of the unit, the linear power module or power amplifier developed by Westinghouse has the capability of a nominal 350 watts output at an operating efficiency in excess of 90% for DC to RF conversion. By paralleling the power modules, a 1 kw output is very simply achieved. Through the use of complete solid state construction, the transmitter is capable of better than 80% efficiency, making the approximate input power at 1300 watts. At this efficiency the loss is about 300 watts compared to 500 watts or more for a conventional tube transmitter. Through the use of solid state construction the warm-up time of the transmitter is reduced, thus reducing the amount of power drawn from the fuel cells. This also results in a saving of power needed for cooling. Since the transmitter dissipates less heat. Similarly, the mean-time between failures is approximately 500% better than tubes. This allows for a greater percent in reliability at a slight increase in cost. However, the increased cost is more than compensated for in the high reliability of the transmitter and the amount of power saved combined with the reduced amount of heat to be removed.

Table III illustrates the estimated weights for the medium-frequency communications subsystem. It will be noted that this includes the transmitter, receiver, and the antenna system. The estimated weights of the transmitter are based upon actual weights of a solid state transmitter developed by Westinghouse.

TABLE III

Medium-Frequency Communications Subsystem Weights

1 kw RF Unit and Power Supply	est 50 pounds
Control Unit	est 10 pounds
Driver Unit	est 10 pounds
RF Filter & Matching	est 6 pounds
Antenna-whip 50 ft	est 5 pounds
Receiver, Voice	est 10 pounds
Estimated total	91 pounds

In the figure the transmitter weight is broken down into components giving their estimated weight in pounds. The weight of the receiver and the antenna system are estimated on the present day state-of-the-art. It is well to remember that the estimated weights of the antenna system and the receiver are conservative. However, these weights are possible to achieve depending on how closely the designer selects the component parts.

SECTION 6.0

REFERENCES

1. J. D. Hughlett, Jr., "Ground Wave Propagation on the Lunar Surface", NSL E30-14, July 1964.

2. T. B. A. Senior and K. M. Siegel, "A Theory of Radar Scattering by the Moon", J. Res NBS, Vol. 64D, No. 3 May-June 1960.

3. "Radio Engineering Handbook", Fifth Edition, edited by K. Henney, McGraw-Hill Book Co., Inc., New York 1959.

4. Kraus, "Antennas", Page 167, McGraw-Hill Book Company, Inc. New York, 1960.

```
      DO 20 ID=250,500,250
      D=ID
      D=D*1.E-03
      DO 20 IA=10,30,20
      F=IA
      F=F*1.E-01
      DO 20 IAL=10,60,10
      AL=IAL
      DO 20 IBW=25,60,35
      BW=IBW
      BW=BW*1.E+02
      CA1=17.*AL
      CA2=2.3*.4342945*LOG(24.*AL/D)-1.
      CA3=1.-(F*AL/246.)**2
      CA=CA1/(CA2*CA3)
      RR=273.*(12.*AL*F)**2*1.E-08
      F=F*1.E+06
      W=2.*3.1415*F
      BL=1./(CA*W**2*1.E-12)
      Q=F/(BW)
      RT=W*BL/Q
      EFF=RR/(RR+RT)
      F=F*1.E-06
      PUNCH 8,D,F,AL,BW
      PUNCH 9,CA,RR,W
      PUNCH 10,BL,Q,RT
   20 PUNCH 11,EFF
    8 FORMAT (7H INPUT=,4E15.8)
    9 FORMAT (4H CA=,E14.8,4H RR=,E14.8,7H OMEGA=,E14.8)
   10 FORMAT(3H L=,E14.8,3H Q=,E14.8,4H RT=,E14.8)
   11 FORMAT(13H PERCENT EFF=,E14.8/)
      END
```

```
C       GROUND WAVE PROPAGATION ON THE LUNAR SURFACE
        DIMENSION ANW(10,10), BETA(2), VEPD(10,10), CA1(10,10), CA2(10,10)
        COMMON MAXR,JAA,ANW,IR,KILO,VEPD
        READ 101,MAXC,MAXR
   101  FORMAT (2I10)
        READ 102,((ANW(I,J),J=1,MAXC),I=1,MAXR)
   102  FORMAT (5E16.8)
        READ 101,IC,IR
        READ 102,((VEPD(I,J),J=1,IC),I=1,IR)
        READ 101,JC,JR
        READ 102,((CA1(I,J),J=1,JC),I=1,JR)
        READ 101,KC,KR
        READ 102, ((CA2(I,J),J=1,KC),I=1,KR)
    25  READ 3, CON,FMC,E,D
     3  FORMAT (4E16.8)
        READ 401,ERP,BW,RSN
   401  FORMAT (4XE14.8,5XE14.8,6XE14.8)
        READ 4,AL
     4  FORMAT (3XE14.8)
        READ 204,KOL
   204  FORMAT (1I10)
        S=18000.0*CON/FMC
        TV=SQRTF(SQRTF((E-1.0)**2+S**2)/(E**2+S**2))
        FMC3=FMC**(1.0/3.0)
        FKV=0.0302/(TV*FMC3)
        DIST=FMC3*D
        DO 104 I=2,MAXC
        IF(FKV-ANW(1,I)) 146,145,104
   145  AT=BEESON(DIST,I)
        JAA=JAA
        GO TO (107,199),JAA
   199. PUNCH 188,FKV,DIST
   188  FORMAT (21H EXTRAPOLATION AT KV=E16.8,2X5HDIST=E16.8//)
        GO TO 25
   146  IF(I-2) 147,147,105
   147  PUNCH 190, FKV
   190  FORMAT (10H SMALL KV=E16.8)
        GO TO 25
   104  CONTINUE
        PUNCH 191, FKV
   191  FORMAT (10H LARGE KV=E16.8)
        GO TO 25
```

FIGURE 3-1. SOURCE PROGRAM

```
105 L=I-1
    DO 106 K=1,2
    BETA(K)=BEESON(DIST,L)
    JAA=JAA
    GO TO (155,153),JAA
153 PUNCH 157,FKV,DIST
157 FORMAT (21H EXTRAPOLATION AT KV=E16.8,2X5HDIST=E16.8//)
    GO TO 25
155 L=L+1
106 CONTINUE
    AT=BETA(1)+(FKV-ANW(1,L-2))/(ANW(1,L-1)-ANW(1,L-2))*
   1(BETA(2)-BETA(1))
107 FLB=32.45+20.0*LOGF(D)*0.434264+20.0*LOGF(FMC)*0.434264+AT
    PUNCH 181,FKV,DIST,AT,FLB
181 FORMAT (4H KV=E14.8,2X5HDIST=E14.8,2X3HAT=E14.8,2X3HLB=E14.8)
    I=KOL+1
    GL=GRANGE(FMC,I)
    KILO=KILO
    GO TO (255,253),KILO
253 PUNCH 257,FMC
257 FORMAT (22H EXTRAPOLATION AT FMC=E16.8)
    GO TO 25
255 CONTINUE
    PUNCH 290,GL
290 FORMAT (9H (LT-GT)=E14.8)
    DO 310 I=1,JR
    IF (FMC-CA1(I,1))309,305,310
309 IF(I-1)311,311,315
305 FE=CA1 (I,2)
    GO TO 307
311 PUNCH 312,FMC
312 FORMAT (14H ERROR AT FMC=E16.8)
    GO TO 25
310 CONTINUE
    PUNCH 312,FMC
    GO TO 25
315 FE=CA1(I-1,2)+((FMC-CA1(L-1,1))/(CA1(I,1)-CA1(I-1,1)))*(CA1(I,2
   1)-CA1(I-1,2))
307 PUNCH 390,FE
390 FORMAT (4H FE=E14.8)
    R=ERP-FLB-GL-FE-BW+204.0
    PUNCH 400,R
```

FIGURE 3-2. SOURCE PROGRAM (Continued)

```
400 FORMAT(11H S/N RATIO=E16.8)
    DI=10.0**((ERP-32.45-20.0*0.434264*LOGF(FMC)-AT-GL-RSN-FE-BW+204.0
   1)/(20.0*2.30258))*10.0
    DO 500 MC=2,KC
    IF(FMC-CA2(1,MC))500,501,500
500 CONTINUE
    PUNCH 607,FMC
607 FORMAT (11H ERROR FMC=E14.8)
    GO TO 25
501 DO 610 MR=2,KR
    IF(AL-CA2(MR,1))610,611,610
610 CONTINUE
    PUNCH 503,AL
503 FORMAT (10H ERROR AL=E14.8)
    GO TO 25
611 PE=CA2(MR,MC)
504 PUNCH 505,PE
505 FORMAT(13H PERCENT EFF=E14.8)
    TF=PE*DI
    PUNCH 700,DI
700 FORMAT (4H DI=E14.8)
    PUNCH 600,TF
600 FORMAT(32H OPTIMUM TRANSMITTING FREQUENCY=E14.8)
    GO TO 25
    END
```

FIGURE 3-3. SOURCE PROGRAM (Continued)

```
      TO BE USED WITH THE NORTON SURFACE PROGRAM
      FOUR POINT LAGRANGE INTERPOLATION FUNCTION SUBPROGRAM
      KF=NUMBER OF POINTS IN TABLE
      IE=1, NORMAL INTERPOLATION        IE=2, EXTRAPOLATION
      FUNCTION BEESON(T,ID)
      DIMENSION C(10,10),VEPD(10,10),Z(4),A(4)
      COMMON KF,IE,C,IR,KILO,VEPD
      IE=1
      M=2
      DO 1 K=2,KF
      IF(T-C(K,1))10,5,1
    1 CONTINUE
      IE=2
      K=KF
      GO TO 10
    5 BEESON=C(K,ID)
      RETURN
   10 DO 40 L=1,4
      LL=L+K-M
      IF(LL)20,15,25
   15 M=1
      GO TO 10
   20 IE=2
      M=0
      GO TO 10
   25 IF(LL-KF)35,35,30
   30 M=3
      GO TO 10
   35 Z(L)=C(LL,1)
   40 A(L)=C(LL,ID)
      BEESON=(T-Z(2))*(T-Z(3))*(T-Z(4))*A(1)/((Z(1)-Z(2))*(Z(1)-Z(3))*(
     1Z(1)-Z(4)))+(T-Z(1))*(T-Z(3))*(T-Z(4))*A(2)/((Z(2)-Z(1))*(Z(2)-Z(3
     2))*(Z(2)-Z(4)))+(T-Z(1))*(T-Z(2))*(T-Z(4))*A(3)/((Z(3)-Z(1))*(Z(3)
     3-Z(2))*(Z(3)-Z(4)))+(T-Z(1))*(T-Z(2))*(T-Z(3))*A(4)/((Z(4)-Z(1))*
     4(Z(4)-Z(2))*(Z(4)-Z(3)))
      RETURN
      END
```

FIGURE 3-4. NORTON SURFACE WAVE SUBPROGRAM

```
      TO BE USED WITH THE ELECTRIC DIPOLE PROGRAM
      FOUR POINT LAGRANGE INTERPOLATION FUNCTION SUBPROGRAM
      NP=NUMBER OF POINTS IN TABLE
      KK=1, NORMAL INTERPOLATION      KK=2, EXTRAPOLATION
      FUNCTION GRANGE(T,ID)
      DIMENSION C(10,10),D (10,10),Z(4),A(4)
      COMMON KF,IE,C,NP,KK,D
      KK=1
      M=3
      DO 1 K=2,NP
      IF(T-D(K,1))10,5,1
    1 CONTINUE
      KK=2
      K=NP
      GO TO 10
    5 GRANGE=D(K,ID)
      RETURN
   10 DO 40 L=1,4
      LL=L+K-M
      IF(LL)20,15,25
   15 M=2
      GO TO 10
   20 KK=2
      M=1
      GO TO 10
   25 IF(LL-NP)35,35,30
   30 M=4
      GO TO 10
   35 Z(L)=D(LL,1)
   40 A(L)=D(LL,ID)
      GRANGE=(T-Z(2))*(T-Z(3))*(T-Z(4))*A(1)/((Z(1)-Z(2))*(Z(1)-Z(3))*(
     1Z(1)-Z(4)))+(T-Z(1))*(T-Z(3))*(T-Z(4))*A(2)/((Z(2)-Z(1))*(Z(2)-Z(3
     2))*(Z(2)-Z(4)))+(T-Z(1))*(T-Z(2))*(T-Z(4))*A(3)/((Z(3)-Z(1))*(Z(3)
     3-Z(2))*(Z(3)-Z(4)))+(T-Z(1))*(T-Z(2))*(T-Z(3))*A(4)/((Z(4)-Z(1))*
     4(Z(4)-Z(2))*(Z(4)-Z(3)))
      RETURN
      END
```

FIGURE 3-5. VERTICAL ELECTRIC DIPOLE SUBPROGRAM

```
     8         9
       0.00          0.01          0.02          0.05          0.1
       0.20          0.50          1.00          1.00          40.
       28.0          8.0           -3.0          -5.0          -5.
       -5.0          10.0          60.0          48.0          30.
       18.0          2.0           -3.0          -5.0          50.
       80.0          63.0          50.0          38.0          22.
       2.0           -3.0          100.0         90.0          78.
       60.0          48.0          35.0          10.0          0.
      200.0         113.0         100.0          83.0          70.
       58.0          25.0          10.0         300.0         140.
      123.0         110.0          95.0          80.0          40.
       20.0         400.0         160.0         150.0         133.
      120.0         100.0          60.0          35.0         500.
      190.0         178.0         160.0         140.0         120.
       80.0          45.0
     5         7
        0.1           2.1           2.1           4.0           4.
        0.3           2.8           2.8           5.2           5.5
        0.5           3.2           3.2           5.3           5.8
        0.7           3.4           3.5           5.0           6.
        1.0           3.9           4.0           4.5           5.8
        3.0           5.2           5.5           2.6           3.5
        5.0           5.2           5.8           1.8           2.
     2         9
       0.10          75.0          0.30          64.0          0.5
       58.0          0.70          56.0          1.00          52.
       3.00          41.0          5.00          36.0          7.0
       33.0          10.0          29.0
     7         7
     0.0000        0.3000        0.5000        0.7000        1.000
     2.0000        3.0000        10.000        .00002        .00017
     .00068        .00286        .04413        .19073        20.00
     .00016        .00128        .00491        .02022        .25208
     .63850        30.000        .00052        .00407        .01552
     .06206        .52583        .85907        40.000        .0012
     .00924        .03483        .13226        .72640        .000
     50.000        .00228        .01744        .06446        .22677
     .84348        0.0000        60.000        .00384        .02921
     .10498        .33523        0.0000        0.0000
   .10000000E-02   .70000000E+00   .20000000E+01   .10000000E+03
ERP=+.30000000E+02   BW=+.34000000E+02   RSN=+.12000000E+02
```

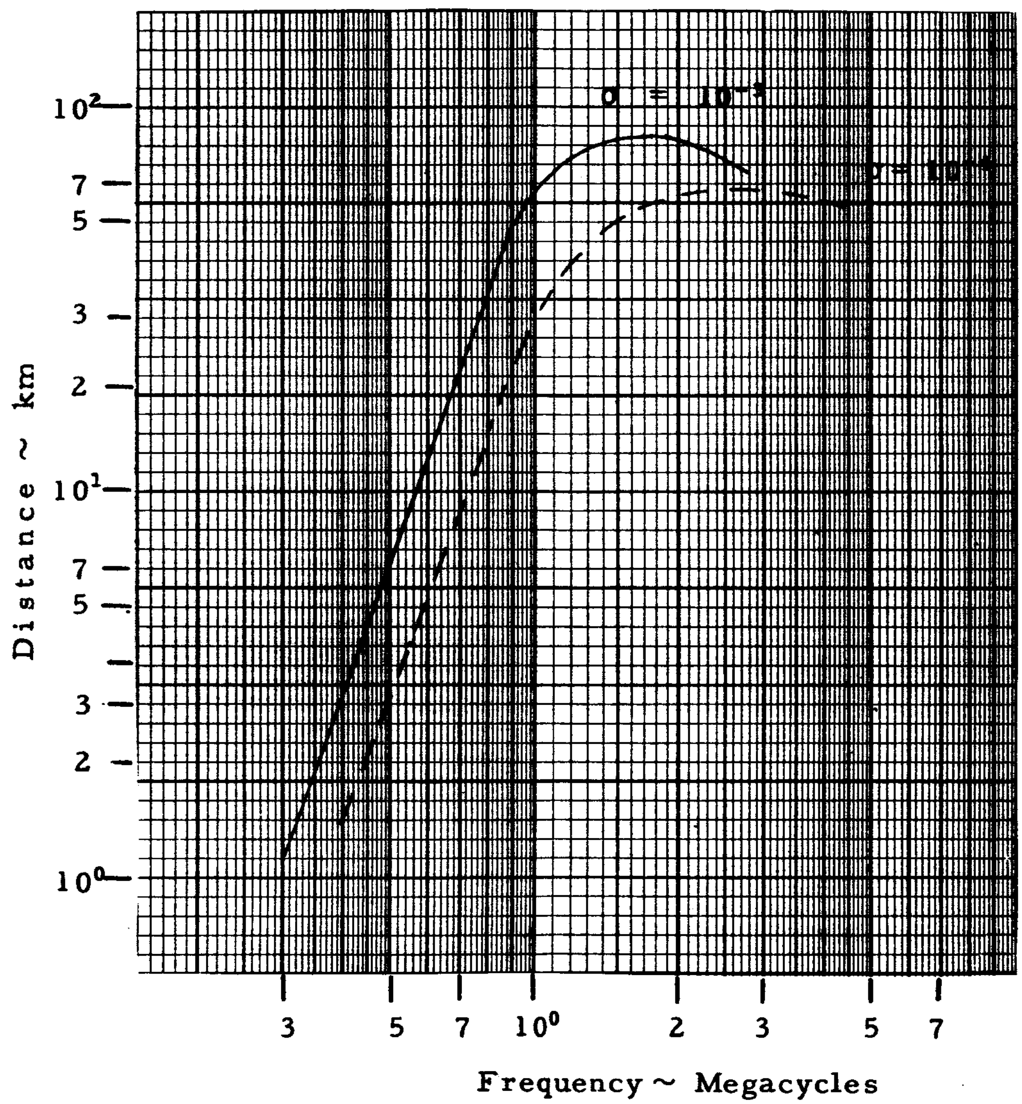
FIGURE 3-6. EXAMPLE PROGRAM INPUT DATA

```
AL=+.60000000E+02
          1
   .10000000E-02    .70000000E+00    .20000000E+01    .50000000E+02
ERP=+.30000000E+02  BW=+.34000000E+02  RSN=+.12000000E+02
AL=+.60000000E+02
          1
   .10000000E-02    .70000000E+00    .20000000E+01    .70000000E+02
ERP=+.30000000E+02  BW=+.34000000E+02  RSN=+.12000000E+02
AL=+.60000000E+02
          1
   .10000000E-02    .70000000E+00    .20000000E+01    .20000000E+03
ERP=+.30000000E+02  BW=+.34000000E+02  RSN=+.12000000E+02
AL=+.60000000E+02
          1
```

FIGURE 3-7. EXAMPLE PROGRAM INPUT DATA (Continued)

```
KV= .17293136E+00   DIST= .88790400E+02   AT= .35856247E+02   LB= .10520561E+03
(LT-GT)= .34000000E+01
FE= .56000000E+02
S/N RATIO=    .35394390E+02
PERCENT EFF= .104980 0E+00
DI= .23797625E+03
OPTIMUM TRANSMITTING FREQUENCY= .24982746E+02
KV= .17293136E+00   DIST= .44395200E+02   AT= .24231880E+02   LB= .87561074E+02
(LT-GT)= .34000000E+01
FE= .56000000E+02
S/N RATIO=    .53038930E+02
PERCENT EFF= .104980 0E+00
DI= .42555346E+03
OPTIMUM TRANSMITTING FREQUENCY= .44674602E+02
KV= .17293136E+00   DIST= .62153280E+02   AT= .29372830E+02   LB= .95624379E+02
(LT-GT)= .34000000E+01
FE= .56000000E+02
S/N RATIO=    .44975630E+02
PERCENT EFF= .104980 *E+0
DI= .32909372E+03
OPTIMUM TRANSMITTING FREQUENCY= .34548258E+02
KV= .17293136E+00   DIST= .17758080E+03   AT= .56090610E+02   LB= .13146015E+03
(LT-GT)= .34000000E+01
FE= .56000000E+02
S/N RATIO=    .91398500E+01
PERCENT EFF= .104980 0E+00
DI= .86526497E+02
OPTIMUM TRANSMITTING FREQUENCY= .90835516E+01
```

FIGURE 3-8. EXAMPLE PROGRAM RESULTS



Vertical Monopole < . 1 λ
Effective Radiated Power 1 kW
Bandwidth 2. 5 kc
SNR 15 DB
ϵ_r = 2

FIGURE 3-9. OPTIMUM TRANSMITTING FREQUENCY

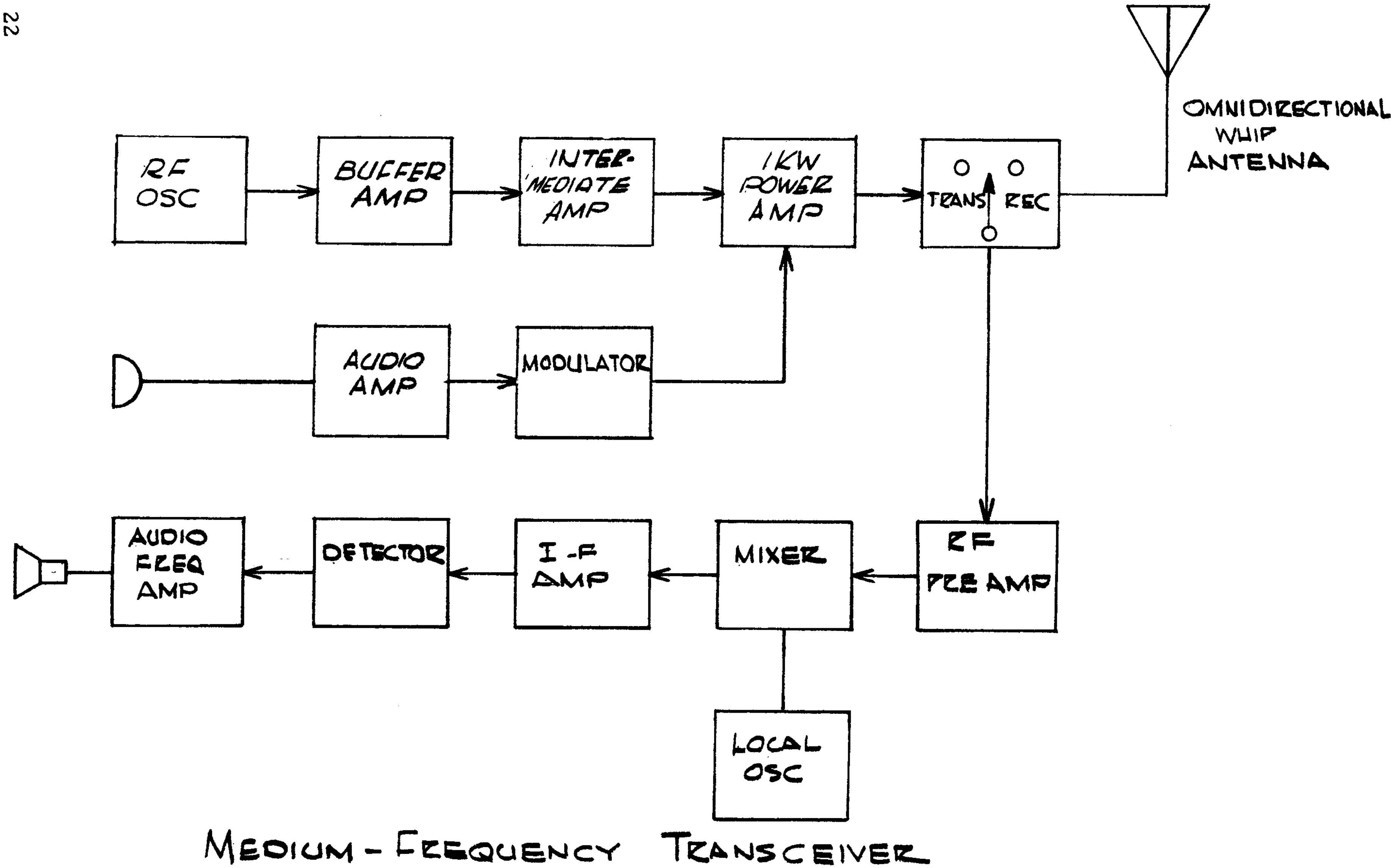


FIGURE 5-1. MF TRANSCEIVER BLOCK DIAGRAM