A SHORT RANGE
RADIO TELEMETRY SYSTEM
FOR ARCTIC ACOUSTIC EXPERIMENTS

Carl Alzen Wales

S.B.O.E., Massachusetts Institute of Technology
(1976)

S.B.M.E., Massachusetts Institute of Technology
(1976)

Submitted in Partial Fulfillment

of the Degree of Master of Science in Ocean Engineering

and the Degree of Ocean Engineer

at the

Massachusetts Institute of Technology

Signature Redacted

Signature of Author____________________
Department of Ocean Engineering
8 June 1982

Signature Redacted

Certified by____________________
Thesis Supervisor

Signature Redacted

Accepted by____________________
Chairman, Department Committee on Graduate Students

A SHORT RANGE
RADIO TELEMETRY SYSTEM
FOR ARCTIC ACOUSTICS EXPERIMENTS

by

Carl A. Wales

Submitted to the Department of Ocean Engineering in June 1982 in partial fulfillment of the requirements for the Degree of Master of Science in Ocean Engineering and the Degree of Ocean Engineer.

ABSTRACT

A telemetry system was developed for use in conducting acoustic experiments in the Arctic Ocean. The system relays an analogue of the waterborne acoustic signal by a radio frequency path to a receiver located a few kilometers across the Arctic ice pack. Multiple systems could be used to supply the inputs to a multi-channel data acquisition system. The criteria for chosing among the various systems considered was developed, and led to the choice of a frequency-modulated-carrier, concert-hall wireless microphone. The selected system performed adequately at a 10 kilometer range using a 50 milliwatt output power from the transmitter. The laboratory and field tests showed the system met initial requirements; however, additional testing would be necessary for individual applications.

LM=10 RM=71 LS=2

ACKNOWLEDGEMENTS: The greatest sacrifice for this thesis was made by my family. My wife Brenda and my children Cheri, Tethra, and Bradford, had to live with the clutter of my work, with the inconvenience my schedule imposed on them, with the neglect I gave them resulting from the hours spent on the entire FRAM project including, but not limited to, the remote sensor work. The price my family paid was extreme and, in retrospect, more than they should have been subjected to. My family knew I am filled with an adventuresome spirit, longing to go North. They were willing to live with the physical problems of my involvement. I am forever indebted to my family for their support for my involvement in FRAM IV. Repayment to them is impossible. My wife stands alone as the highest example of courage,patience, tolerance, strength, and support.

Words cannot express the contribution made to my thesis and the FRAM IV project by my dear friend. Dr. George B. Foote, Jr., gave of his time, effort, and ability far more than a friendship deserves--yet George gave his time and effort out of friendship. I know--but am unable to express--how much George contributed. Few others--if any--will appreciate what his involvement meant and what it cost George in time and effort. Without George's aid very little of this thesis work would have been done by me.

I was given unselfish assistance by personnel of three organizations. The engineers of Telex who worked with me put their extra effort into the modifications of the Telex units as they became more involved than business required. A gentleman at the Naval Air Developement Center (NADC) willingly spent a day in person and additionally many hours on the telephone educating me into the basics of sonobuoys and their use, capabilities, and associated equipment. Numerous individuals at Sparton Electronics devoted their day to me during my visit to their offices and plant. In addition these people and others at Sparton provided countless hours of

engineering assistance to unselfishly answer my requests. Also Sparton generously donated some electronic components and hydrophone suspension equipment to the project.

Captain David Burke, my academic adviser at MIT, and my Commanding Officer, saw me through the eighteen months of involvement in FRAM IV. I cannot over emphasize his importance as a source of guidance and motivation. His support was always there when I needed it.

Allan Gill, a most helpful British gentleman with vast polar experience, willingly gave his assistance whenever asked and willingly taught me how to accomplish many tasks in the Arctic environment. Allan was a joy to work with and to talk to again (having known him from eight years ago on Ice Island T-3). I have aged since T-3 days and much more appreciate Allan's ability, helpfulness, personality, and presence. He taught me more than I know about the Arctic. Thank you "Sir" Gill.

The personnel at FRAM IV from the Naval Research Laboratory most graciously allowed me essentially unlimited use of their Hewlett-Packard Spectrum Analyzer and HP-85 (to make hard copy of the spectrum analyzer plots). Thanks Bob, George, and TC.

There were many other people involved with this thesis. They cannot all be mentioned and some are innocently overlooked.

****

The remote sensing system was developed as part of contract between the Office of Naval Research and the Woods Hole Oceanographic Institution. The contract provided the financial support for the system equipment. The Office of Naval Research funded the entire FRAM IV field operation through contracts with various organizations and agencies.

Financial support for this author while attending graduate school came from the Navy's postgraduate program for active duty Engineering Duty officers, and did not come from the Office of Naval Reseach, WHOI, or MIT.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION:

Recent experiments conducted in the Arctic to understand better the various aspects of Arctic acoustics have used hydrophone and geophone arrays to exploit the advantages of array processing. The hydrophones and geophones comprising the array have been connected by wire to an equipment hut which contained the multichannel, digital data acquisition system. Because of the low frequencies and resulting large size of the array many thousands of feet of wire must be laid out across the icepack. More importantly, however, with the wide aperture array, the probability of any local ice fracturing resulting in broken wires is high. Broken wires will either reduce the size of the array and decrease the quality of the data or result in lost data while repairs are made. This will become an ever increasing problem as future experiments move towards the marginal ice zone. For experiments conducted at the marginal ice zone there will not be flows big enough to hold, even initially, the wired, wide aperature arrays needed.

A desireable solution is a system to telemeter the data by a radio frequency link to a remote collection site such as a ship or centrally located ice camp. This is the concept that sonobuoys employ and that sees routine daily use in the open ocean by various Navy forces and to a much smaller extent by various research organizations. Standard sonobuoys do not provide the desired low frequency response and the high dynamic range which is desired for the Arctic acoustic experiments. An additional and extremely important requirement is the ability to determine the location of each of the remote telemetry sensors.

An important constraint on the telemetry system is that the transmitters be of sufficently low cost to be considered expendable. In this regard production sonobuoys are ideal as the large quantity production results in very low unit cost.

Initially, the task was to determine the requirements for the remote sensing system. The problem had to be defined and the priorities of the various specifications had to be considered. Various possible systems were considered. Initially, the sonobuoy concept was studied in detail in order to provide a better benchmark upon which to base further study. With the requirements better delineated, the specifications of the various standard production sonobuoys were reviewed. Consideration was given to what modifications would be necessary to alter the performance of a standard sonobuoy to give it the desired capability. Also considered was doing a complete design and development of a system as opposed to starting with an off-the-shelf item. The possibility of transmitting digital data instead of analogue data was reviewed. The marketplace was researched in an effort to locate a production system which would meet the requirements. Other radio frequency link systems were considered for modification to meet the desired specifications. A system was chosen as the one to be developed for testing in the field in the spring of 1982.

The system selected for development was based on a frequency-modulated-carrier, concert-hall wireless microphone. The acoustic dynamic range of the fm wireless microphone was the major selling point. The specificed dynamic range of a production unit was high as the unit is designed for use in opera and symphony concert halls. The design range between transmitter and receiver was much shorter than the remote sensor required and the low frequency response needed improvement. Modifications were made to improve these two areas and four systems were built to field test at FRAM IV during EAST ARCTIC 82. Recommendations for further development resulted from the field tests so that an improved system could be built for future use in Arctic experiments.

II. PROBLEM DESCRIPTION:

Conducting Arctic acoustic experiments with multi-element arrays installed in the sea ice presently requires connecting each sensor (hydrophone or geophone) to the acquistion system by wires sometimes many kilometers in length. To remove the risk of damage to the array by local ice fracture, a wireless system would be ideal. The overall concept is shown in Figure 1. A new problem with the use of a wireless system is having continuous knowledge of the location of each sensor as it may drift in relation to other sensors. The location problem is a separate issue with a positioning system using acoustic signals under development by Woods Hole Oceanographic Institution (WHOI) personnel. This system under developement at WHOI is a modification of the STRAP system developed by the Naval Ocean System Center in San Diego, California for locating sonobuoys within a group of deployed buoys (1).

The major parameters for the wireless, remote sensor system are:

a) 80 db of dynamic range in the frequency range of 5 to 500 hertz (dynamic range is defined for this purpose as the range in decibels from the system self noise level to the largest signal which does not exceed one per cent total harmonic distortion). High dynamic range is also desirable in the range of 10 kilohertz to 20 kilohertz for use by the positioning system, but a specific value cannot be assigned until the positioning system is fully developed and operating.

b) the remote (transmitting) part of the sensor system should operate unattended for a period of 500 hours.

c) the remote sensor must be usable for data collection purposes with a 10 kilometer separation between the transmitter and the receiving antenna and operate at ranges up to twenty kilometers

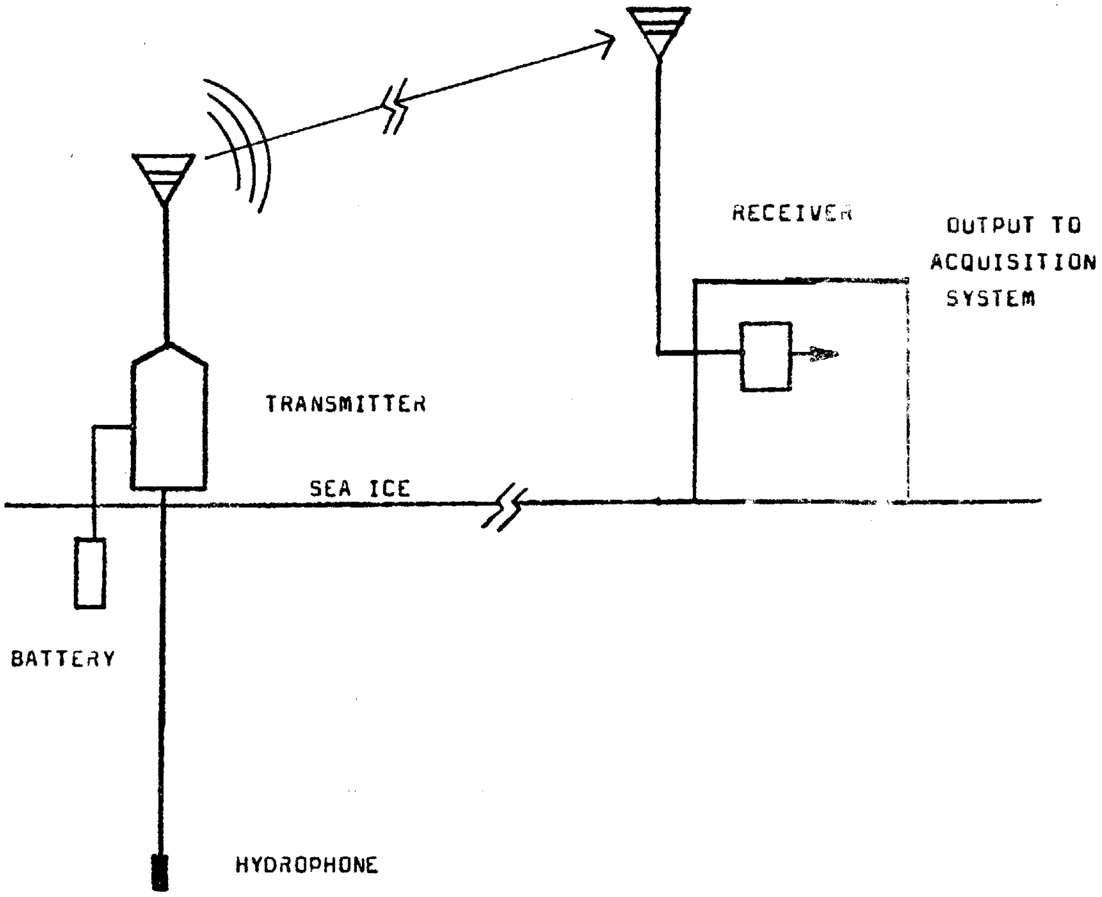


FIGURE 1.

Block Diagram of Overall Wireless System Concept for direction finding to locate the transmitter for repair, recovery, or replacement.

d) the remote transmitter must be low enough in cost to be considered expendable (while recovery is desirable many factors will contribute to considerably less than one hundred per cent recovery). Additionally the receiving system must be useable with more than one transmitter of the same frequency--that is no "matched pairs" are permitted to achieve the desired performance. An initial estimate of cost was $750-$1000 for the transmitter in quantity purchase.

e) the transmitter must operate in ambient air temperatures of minus forty degrees Celsius to zero degrees Celsius.

f) of lesser importance and not as quantifiable, but still necessary considerations:

- i) the transmitter must be easy to set up at the remote location
- ii) a simple method to test proper transmitter operation while at the remote site during sensor deployment is necessary
- iii) high reliability since field repair of the transmitters is not practical
- iv) the physical size and weight of both the transmitter and the receiver should be small.
- v) the receiver cost should not be excessive while still maintaining the dynamic range, fidelity, and the phase response.
- vi) Systems had to be developed and put in final form

for field testing at FRAM IV during EAST ARCTIC 82 in the spring of 1982. The systems were to be completely developed (and not a breadboard or prototype version) for the field test so that only problem areas discovered during the field test would need correcting before the intended operational deployment of the system in the 1983 Arctic experiment season.

These initial specifications were an accurate description of the initial design concept. Issues still remaining to be resolved but which did not impact the design of the field test units were areas such as how many units (and thus how many different radio channels) would be in use at any one time, how many replacement channels would be needed, etc..

These specifications were determined with the desire to find a production system which could be modified to meet the specifics. To build a system starting from the begining which would extend existing sonobuoy technology would insure adequate performance but would involve too much of a learning and experience curve and thus prevent a fully developed system being ready for testing in the spring of 1982. In addition the developement of a totally new system would introduce reliability problems which would already have been worked out in production systems.

III. SYSTEM ALTERNATIVES:

The general specification listed above would immediately suggest modified sonobuoys. Sonobuoys are not expensive as a result of their mass production, but dedicated sonobuoys receivers are expensive[1]. Standard sonobuoys would require modification to their standard 10 hertz to 20,000 hertz acoustic frequency range to achieve the necessary frequency response down to 5 hertz (ref. 2). The necessary modifications to achieve this would require only changing the capacitors in the audio circuitry. Sonobuoy sonic amplifiers are built with a response which, with the ambient noise of the open ocean (primarily the north Atlantic) as an input the output amplitude response is flat with respect to frequency (see Figure 5 of reference 3). Correction of this performance requirement for use in Arctic acoustic experiments would be necessary. Another simple, but necessary modification to sonobuoys, would be to change their design lifetime from a termination in minutes or hours to one of at least five hundred hours. The more complex modification to production sonobuoys would change their acoustic dynamic range from approximately 65 db to the required 80 or more db[2]. The gain in dynamic range in a sonobuoy must come from reducing the minumum deviation of the frequency modulated carrier as channel separations and practical considerations prevent gaining the necessary increase in dynamic range by raising the maximum carrier deviation. To reduce the minimum deviation the system noise would have to be reduced by at least 10db--modifications which would then replace most, if not all, of the audio circuitry. Such modifications would no longer be considered minor and practically a new buoy would have to be designed. (Sonobuoys with most of the desired parameters were manufactured by Sparton as the SP-VLF buoys under a special purchase by the Naval Air Development Center (ref. 4). These buoys are no longer availible and while their design is still in files an order for the very small quantities needed for Arctic acoustic work would make the unit cost almost an order of magnitude higher than acceptable for this project.) In addition sonobuoy receivers would have to be modified to demodulate and output the larger dynamic range without signal distortion.

A different approach which would achieve all of the desired performance parameters would be to convert the acoustic waveforms to digital data at each remote location and telemeter the data back in digital form. In addition, benefit from the gains in signal-to-noise ratio of the received rf signal would be realized. Researching the market place did not turn up any production systems which performed as required so this approach would require complete development locally[3]. Such development would preclude having a bench tested, high reliability system for field testing in the spring of 1982.

An approach which might be a compromise between use of a production system and developing a new system would be to incorporate some of the recent voltage-to-frequency and frequency-to-voltage integrated circuits into the front end of a production system. In this manner dynamic range of the production system could be traded for frequency response since the necessary dynamic range is available in the v-to-f and f-to v chips [4].

As a result of inquiries to very high frequency (VHF) receiver vendors[5], Telex Corporation proposed their concert hall frequency modulation (FM) wireless microphone system for consideration. This system in its production form achieves the high dynamic range desired by using a logarithmic compression amplifier in the audio circuit before the transmitter and a matched logarithmic expansion amplifier in the audio section of the receiver[6]. The frequency range needed lowering to five hertz and the limited lifetime of the production transmitter would require a change in transmitter power source. An increase in rf power from the transmitter was considered a probable necessity. This system was selected for modification and field testing.

IV. DESCRIPTION OF THE SELECTED SYSTEM:

The standard Telex FM wireless microphone has a flat frequency response from 50 hertz to 15 kilohertz and a dynamic range of 80 db. The standard radio frequency output is specified as not greater than 50 milliwatts. The complete list of standard unit specifications is given in reference 5.

The areas of the standard Telex system which do not meet the requirements for the remote sensor were:

a) the frequency response must be lowered to 5 hertz while maintaining the dynamic range over the entire frequency range.

b) the output power should be as high as possible without requiring the addition of more amplifier stages.

c) a different battery pack must be used to provide the required 500 hour life.

The Telex system is shown in general block diagram form in Figure 2. The transmitter block diagram is shown in Figure 3 and the standard receiver block diagram is shown in Figure 4. The requirement for the additional frequency coverage was met by a change in components in the audio circuitry. The changes lowered the low frequency end to 5 hertz and raised the upper end to 20,000 hertz. To achieve the maximum dynamic range three outputs were installed. The first output was the low band pass (LBP) which covered the frequency range of 5 to 500 hertz. This output was selected to carry all of the acoustic low frequency data[8]. A middle band pass (MBP) output covered the range of 10,000

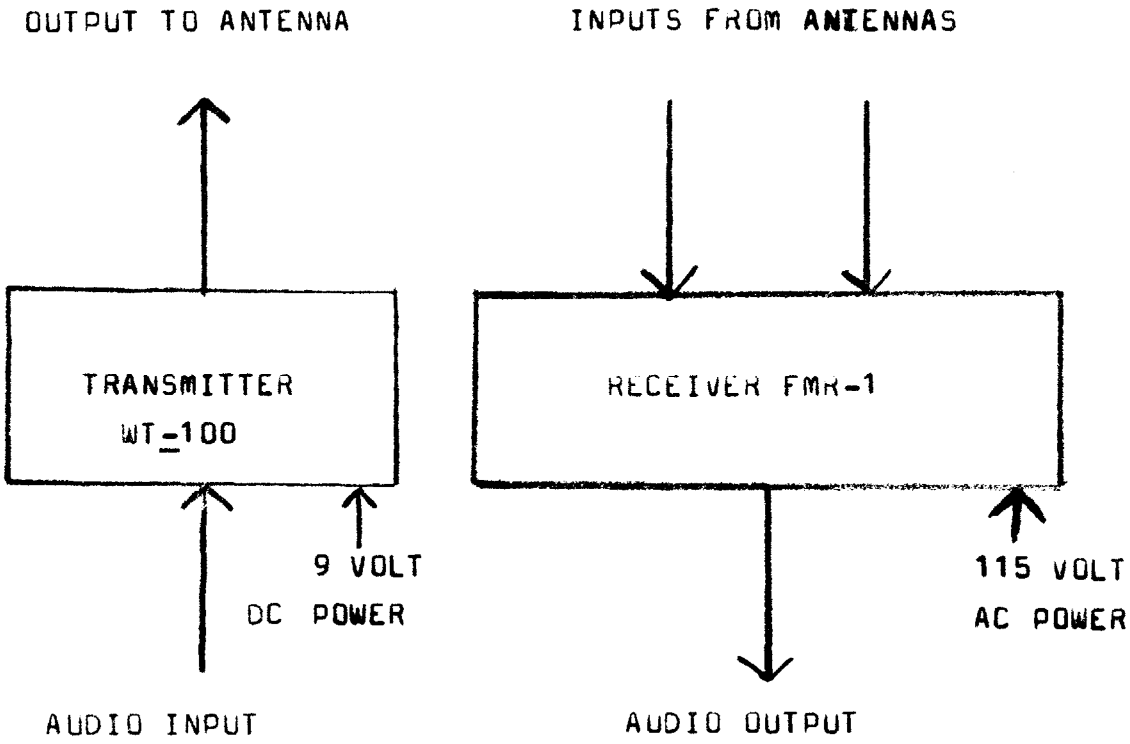
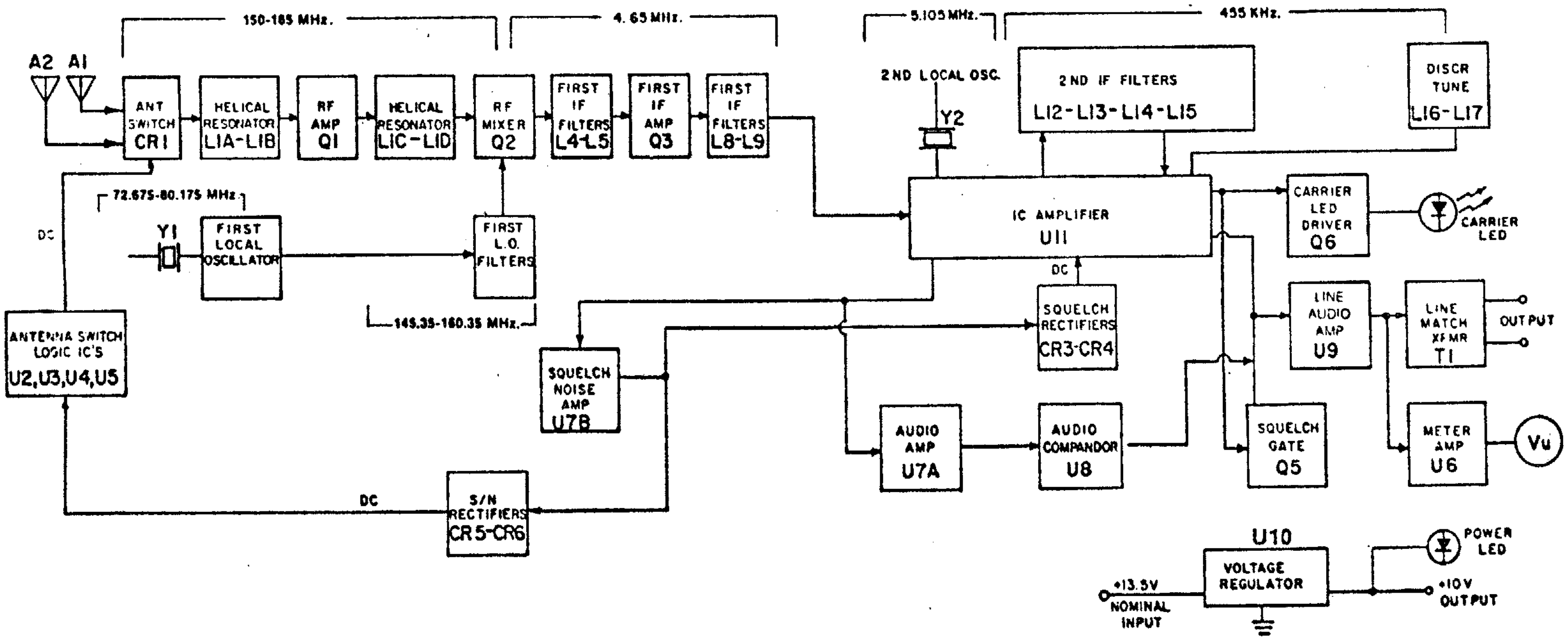


FIGURE 2

General Block Diagram of the Telex FM Wireless Microphone



Block Diagram, FMR-1 Receiver

("U" CIRCUIT SYMBOLS REPRESENT
INTEGRATED CIRCUITS)

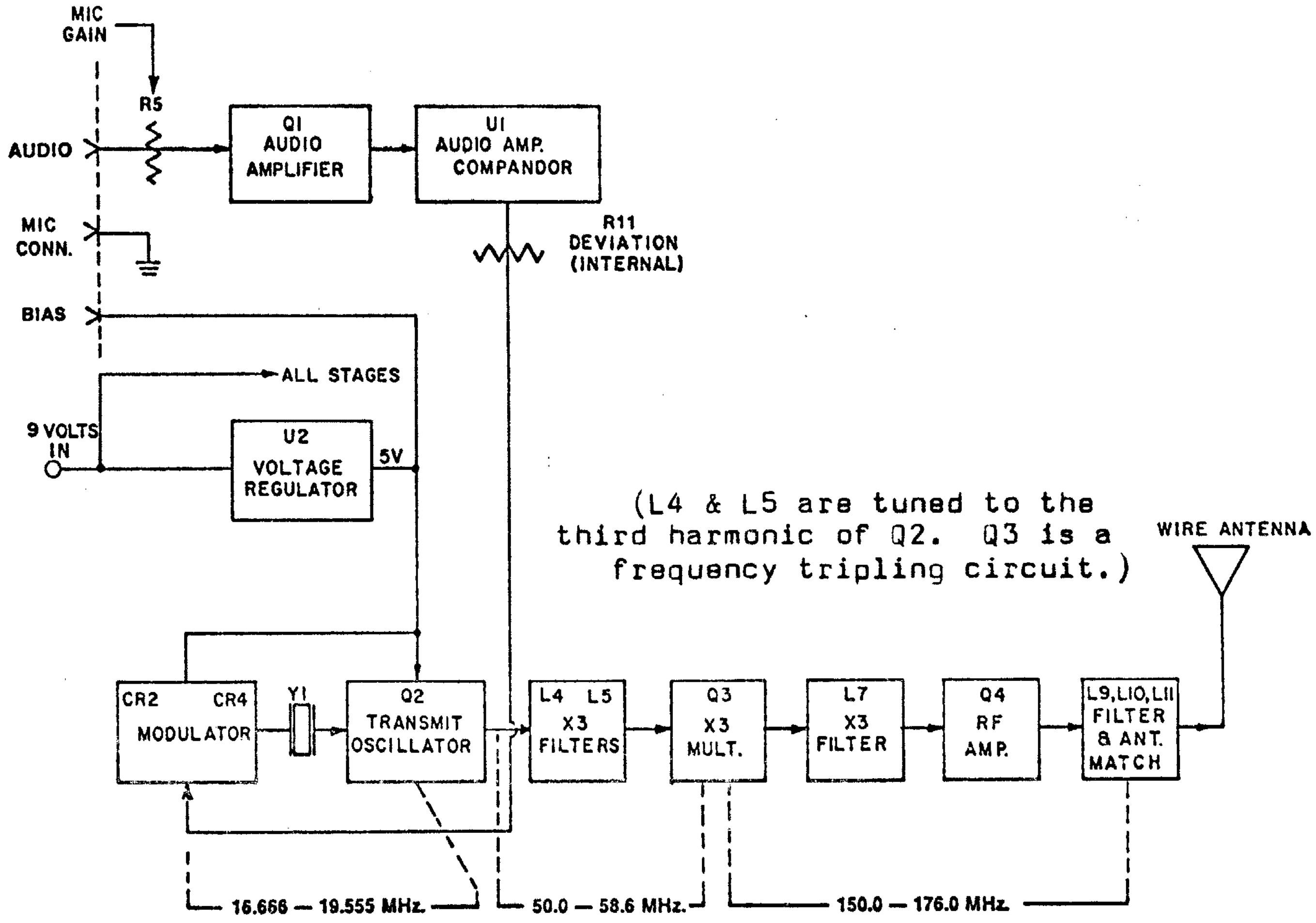
Revision C

FIGURE 4
Block Diagram of the Standard Telex Receiver
(Reprinted with permission)

FIGURE 3

Block Diagram of the Standard Telex Transmitter

(Reprinted with permission)



(L4 & L5 are tuned to the third harmonic of Q2. Q3 is a frequency tripling circuit.)

Block Diagram, WT-100 Transmitter

Revision C

to 14,000 hertz. This output was an example of the band for the positioning system. (The exact frequencies of the positioning system had not been determined at the time the Telex specifications had to be finalized.) The third output--the all band pass (ABP) covered the entire range from 5 hertz to 20,000 hertz. The idea was that by reducing the width of the bands the system noise level would be reduced thereby increasing the dynamic range for each band separately. The data band (LBP) and the positioning band (MBP) were the narrower bands with the all band pass output included for comparison to the narrower bands (in an effort to determine if the additional cost of the narrow bands was justified) as well as for use in ambient noise studies[9]. If the ABP output proved adequate for positioning and data outputs than future systems would not incorporate the LBP and the MBP.

The standard Telex transmitter operated on a common nine volt transistor radio battery. As the preamplifier in the hydrophone (which would serve as the input to the Telex system) required twelve volts for normal operation the higher voltage level was selected for powering the Telex unit also. Extending the operating life was then possible by connecting a sufficiently large battery to provide the required current for the five hundred hour design life. In addition by raising the supply voltage, the rf output level would be raised. Battery selection was completed after the laboratory tests of the Telex units.

The detailed specifications for the modified Telex FM wireless microphone units as modified for this project were written. A copy is included as Appendix A.

V. OUTPUT POWER, OPERATING RANGE, AND LINK BUDGET:

The desired operating range was an initial system parameter. How to meet that requirement while remaining in the area of practical alternatives could not be fully established before field testing. No known publications discuss the propagation of VHF signals across the Arctic ice pack and its many and varied pressure ridges. The maximum output from the Telex transmitter without significant modification was specified from the manufacturer. A second power level was also included for field testing by a special order amplifier from Lunar Electronics which, when driven by the Telex unit's output, would give a 12 db gain. Since the operational use of the remote sensor would include up to 30 remote sensors in operation at one time, the cost effective approach would be to invest more heavily in improving the much smaller number of receiving equipments which would be common to all the receivers.

Methods of improving the receiver capability consisted of use of higher gain antennas and/or use of a preamplifier. Two different antenna types were considered and obtained for the field test. The first type was a 5/8 wavelength, omni-directional antenna (Model V2 manufactured by Telex, and the equivalent ISOPOLE made by AEA). The second was a 10 element, directional yagi antenna manufactured by TACO. Since system noise would be a controlling factor in amplifing the received signal a 20 db gain, very low noise, rf preamplifier (Model PAG manufactured by Lunar Electronics) was included in the equipment. With this equipment and associated parameters the link budget was completed.

The remote sensor propagation path will be from tens of meters up to 20 kilometers. The frequencies used--1 separate channel for each hydrophone--are between 162 megahertz and 174 megahertz. The intended path is direct line of sight.

Since the transmitters at the remote sights are battery powered and are to operate for five hundred hours, the lowest possible transmitter power is desired as battery capacity to operate at -40 degrees Celsius is very expensive. To determine the minimum necessary rf output of the transmitter a link budget was constructed. The transmitter design was fixed with the exception of adding on power stages. Thus the basic rf power of the transmitter will be used.

The estimate of path loss would normally be very straight forward. The frequency of interest is VHF and the intended path is that of line-of-sight. The radio horizon for a transmitter antenna height of 10 feet and a receiving antenna height of 45 feet is 14 miles (22.5 kilometers) (ref.8 page 28-13). However, whether the path is unobstructed is a variable since a large pressure ridge could exist or form between the transmitter and the receiver (a pressure ridge might exist or grow to a height of as much as eighteen meters). Whether this would affect the transmission or not is also a variable since the pressure ridge could be largely multiyear ice which would be mostly fresh water ice or it could be first year and salt water ice or it could be some combination. (The salty first year ice has pockets of salt in it which collected as the ice froze. As the ice ages the salt pockets migrate down and eventually out of the ice leaving it essentially freshwater ice. Fresh water ice is more transparent to rf signals than salt water ice because of the differing conductivities.)

The free-space path loss (FSPL) is the loss of propagation through the line-of-sight path. The attenuation--in db--of the remote sensor signal is given by:

$$\text{FSPL (db)} = 32.45 + 20 \log_{10} f + 20 \log_{10} d$$

with f in MHz and d in kilometers. The constant is derived from the use of the megahertz and distance units.

For the remote sensor the highest frequency used at present is 173.125 MHz and the distance is 20 kilometers. The FSPL (db) is 107.4 db. Thus, the signal will be attenuated by 107.4 db just by propagation line-of-sight from transmitter to receiver. No calculations are made for the case of a pressure ridge obstacle since the necessary data is not readily availible. Shorter distances or use of lower frequencies will make the FSPL less so this worst case figure is used in the budget.

The transmitted effective isotropic power (eirp) is the power in dbm feeding an isotropic radiator which would be necessary to give the same signal at the distant receiver as the actual transmitter, feed system, and antenna in use. It is calculated by:

$$\text{eirp (dbm)} = \text{transmitted power (dbm)} + \text{antenna gain (db)} - \text{feed loss (db)}$$

For the remote sensor the basic transmitter has an output power of 50 milliwatts (17 dbm) and the unit with a single power amplifier has an output of 1 watt (30 dbm). An AEA Model Isopole 144 (5/8 wavelength) is used with a gain over an isotropic antenna of 6db. The feed line loss of two connectors (1 BNC and 1 UHF) on ten feet of Belden 9258 coaxial cable (with an attenuation of 5.4 db per 100 feet at 200 MHz.) is assumed to be 0.75 db.. Therefore:

$$\text{eirp} = 17 + 6 - 0.75 = 22.25$$

(for 50 milliwatt transmitter)

$$\text{eirp} = 30 + 6 - 0.75 = 35.25$$

(for 1 watt transmitter)

The receiving system consists of the following components:

AEA ISOPOLE 144 antenna with gain of 6db

LUNAR ELECTRONICS Preamp with gain of 20 db and a noise figure of 0.8 db

150 feet of SAXTON 8316 coaxial cable with a loss of 3.3 db per 150 feet at 200 MHz.

Telex receiver with noise figure of 8 db and a bandwidth of 60 KHz.

The system sensitivity must be determined now to complete the link budget. The system noise temperature is:

$$T_s = T_1 + (T_2 / G_1) + (T_3 / G_1 G_2) + (T_4 / G_1 G_2 G_3)$$

where:

T_s = noise temperature of the system
T_1 = noise temperature of the first stage
T_2 = noise temperature of the second stage
T_3 = noise temperature of the third stage
T_4 = noise temperature of the fourth stage
T_n = noise temperature of the nth stage.
G_1 = gain of the first stage
G_2 = gain of the second stage
G_n = gain of the nth stage

F [illegible] r receiving system:

T_1 = 290 degrees K

$T_2 = 58$

$T_3 = 354$

$T_4 = 1540$

These are calculated in the appendix.

Thus $T_s = 290 + (58/4) + (354 / 4x100) + (1540 / 4x100x0.45) = 314$ degrees K

Receiver sensitivity (RS) is related to system noise temperature by:

$$\text{RS (dbm)} = 10 \log_{10} (k\, T_s\, B)$$

where k is Boltzmann's constant,and B is bandwidth.

This determines the signal which would just give a signal equal to system noise, i.e. S/N of 1. Continuing, the above can be rewritten as:

$$\text{RS} = 10 \log_{10} B \; + \; 10 \log_{10} T_s \; - 198.6$$

With $B = 6 \times 10^4$

and $T_s = 314$

$$\text{RS} = 47.8 + 25 - 198.6 = -126 \text{ dbm}$$

The link budget can now be completed. The transmitted power minus the propagation loss must equal or exceed the receiver sensitivity.

eirp = 22.5

FSPL = 107.4

Signal at receiving antenna = -84.9

RS = -126

Therefore the signal-to-noise ratio of 41 db theoretically exists for the 50 milliwatt transmitter and 54 db exists for the one watt transmitter.

The link budget suggests that there will be a large signal-to-noise ratio at the receiver. This is a theoretical calculation and could easily be off by 3 db in the round-off errors. Also the equipment specifications may be exaggerated a little. However, this does suggest sufficient signal-to-noise ratio exists for the low power unit to work adequately.

VI. LABORATORY TESTING

Bench tests were conducted by the Telex engineers on each unit prior to delivery. The testing required was listed in the initial specifications (appendix B). The test environment was to have the receiver at room temperature and the transmitter in a cold temperature chanmber at minus twenty degrees Celsius. Initial adjustment of the transmitter was to set the deviation for 12k kilohertz with a minus thirty-four dbm at 400 hertz input signal with the input gain set to full.

The radio frequency and supply voltage testing consisted of the standard factory testing and checks of the relation of supply voltage to rf output and to supply current. Output power was measured using a Tektronix 7L14 Spectrum Analyzer. Three different supply voltages were used to correlate the rf output to the supply voltage. Also the supply current was measured at each supply voltage. The results of these tests are shown in Figures 5 and 6.

The bench testing of the acoustic aspects of the system were conducted using a Wavetek tone generator and a Hewlett-Packard 3575A Gain/Phase meter. The set up is shown in Figure 7.

The procedure was to initially set .0015 volts rms at 400 hertz as the input. The output was measured as 0.155 volts rms. These values were considered the voltage reference for all other gain measurements. All inputs were adjusted to .0015 volts rms and the resulting output was measured in db referenced to 0.155 volts rms. The phase of the output was measured relative to the phase of the input. Bench test measurements of dynamic range gave 90 db in the LBP and MBP and 83 db in the ABP. The amplitude and phase response data and maximum variation between the four units at each data point is shown in graphical form and tabular form in Appendix C. After

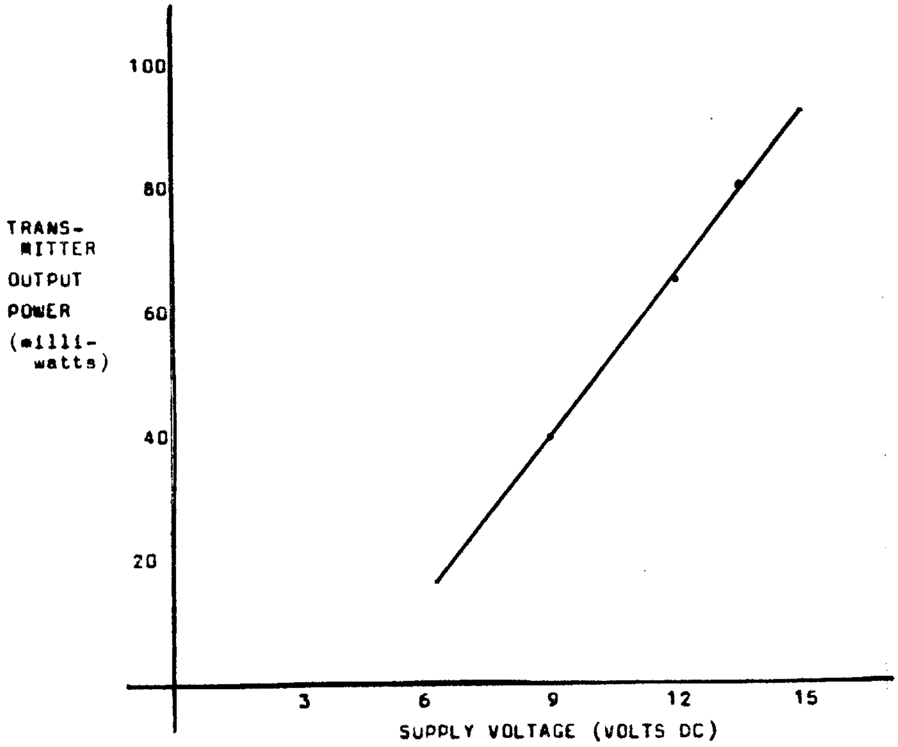


FIGURE 5

Transmitter Output Versus Supply Voltage

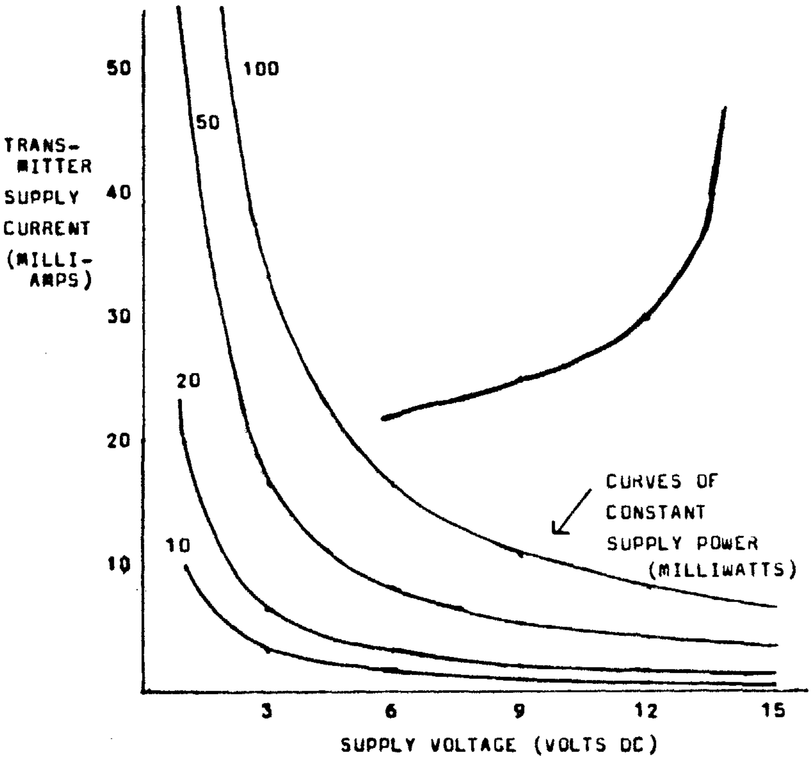


FIGURE 6

Transmitter Supply Current Versus Supply Voltage

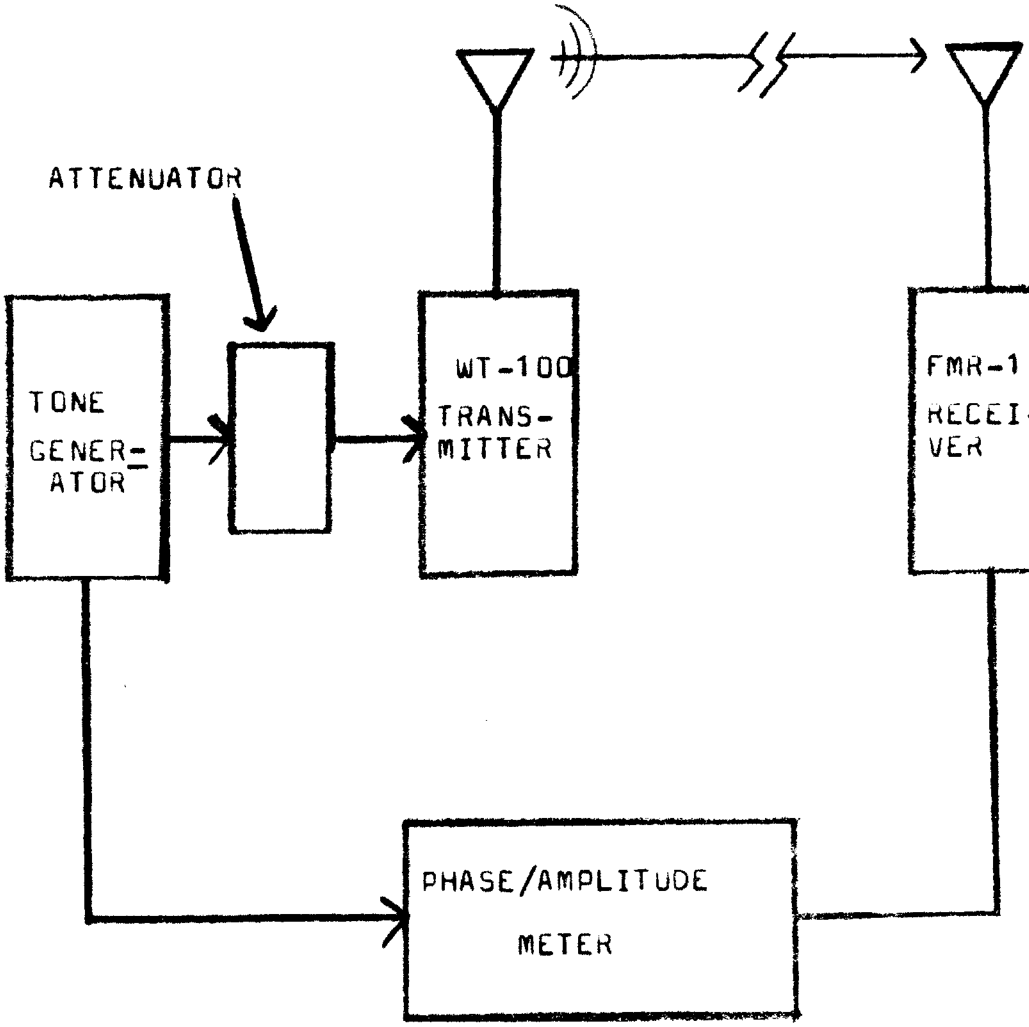


FIGURE 7

Test Set-up for Bench Testing of the Entire Acoustic System completion of the bench tests the units were delivered for the field testing.

The bench testing confirmed that the response versus frequency was within the desired variation across each of the different outputs. The dynamic range also met requirements during the bench testing at Telex.

VII. BATTERY SELECTION:

The remote sensor specifications required a five hundred hour operation. The energy source for the transmitter was specificed to be a twelve volt battery which would then need the capacity to supply the necessary current for the five hundred hours. As the transmitter output power was directly related to the supply voltage, the battery ouput voltage must remain at twelve volts until after the five hundred hour mark.

Two possible environments existed for the battery. It could be set on top of the ice where the temperature would be as low as -40 degrees Celsius and as warm as 0 degrees Celsius. Or it could be suspended below the ice in the sea water where the temperature would be approximately -1 degree Celsius. The major tradeoff between the two choices was the lower temperature above the ice versus the warmer temperature below the ice but which required making a hole through the ice to install the battery and required a watertight case for the battery.

Selection of the battery type required consideration of the total capacity needed. There were two different sensors to be powered--the standard Telex transmitter and WHOI hydrophone (which requires a 1.2 kilowatt-hour capacity) and the same system but with the Lunar Electronics power amplifier (which requires a 6 kilowatt-hour capacity). With the required capacities and the known operating environments, the various types of batteries could be reviewed to select the one for field testing. Table 1 gives some of the parameters of various types. Types exist which are not listed since such types are not commercailly availible in the necessary capacities and at reasonable cost.

TABLE 1.

Characteristics of Various Batteries[&]

Battery	Capacity		Relative	Low Temperature
System	Wh/kg	Wh/dm^3	Cost[*]	Performance
Primary				
Alkaline MnO_2	65	200	Moderate	Fair
Mercury	80	370	High	Good
Silver Oxide	130	310	High	Good
Zinc-air	200	190	High	good
Lithium	250	400	Very High	Excellent
Secondary				
Lead acid	37	70	Moderate	Poor[#]
Nickle-cadium	33	60	High	Good
Silver-zinc	100	170	High	Good

Notes:

* The costs given here are relative for the battery capacity required--lead acid batteries are low cost, but they become higher cost when the necessary number is considered. Moderate cost would be between $0 and $200 for a battery pack, high cost would be between $200 and $350, and very high cost would be greater than $350 for a single battery pack.

\# The lead acid liquid is poor at low temperature while the lead acid gelatin electrolite is good at low temperature but also much more expensive.

& Data in the table is taken from references 7 and 8 and from suppliers price lists.

The readily apparent choice if cost is not a consideration is the lithium battery. Its attributes, in addition to excellent low temperature performance, are long shelf life while being one of the most energy dense systems in terms of size while not be excessively heavy (a consideration because all equipment had to be transported by aircraft to the Arctic and then to the camp on the ice). Special shipping requirements must be met for lithium batteries which do not apply to others, but these were not a serious drawback. The safety aspects of lithium batteries have been an issue in the past, but the hazards have been proven to be minimal when reasonable care is used. Lithium batteries were <u>not</u> chosen for the field test because of their high cost--approximately a factor of three over the selected system.

The simple approach appeared to be liquid lead-acid batteries. But to achieve the required capacity four to eight (depending on the actual battery chosen) would be required because of their capacity reduction with temperature. These would weigh an excessive amount and require installation below the ice.

Lead-acid gel cells would be an improvement over the liquid lead-acid cells because they do not suffer as much degradation in availible capacity at decreasing temperatures. These batteries could in fact be installed above the ice if necessary. However, they are not availible in large capacity cells and the cost of assembling a battery pack would make their cost higher than desired.

The compromise solution was to have Alkaline D cells assembled in series and parellel to provide the required capacity. These packs were constructed by Burlington Battery to fit inside a six inch inside diameter tube for the large capacity and inside a four inch tube for the smaller capacity packs. The battery packs were then sealed into pvc pipe sections with closed ends. These served as the watertight containers which held the batteries below the sea ice.

VIII. FIELD TEST OBJECTIVES:

The four remote sensor systems were tested in the Arctic at FRAM IV during EAST ARCTIC 82. The objectives of that test (delineated prior to departure for the Arctic were):

a) prove operational performance with the WHOI hydrophones in the Arctic Ocean environment.

b) determine the maximum reliable operational range between sensor and receiver.

c) determine any degradation in performance by the Arctic environment.

d) check the five hundred hour design life.

f) conduct an operational measurement of dynamic range.

These objectives were established to prove that the bench test results and the initial specifications could be realized in an operational manner in the Arctic environment.

IX. FIELD TEST PLAN:

The test plan was divided into four phases:

a) operational local check of each unit.

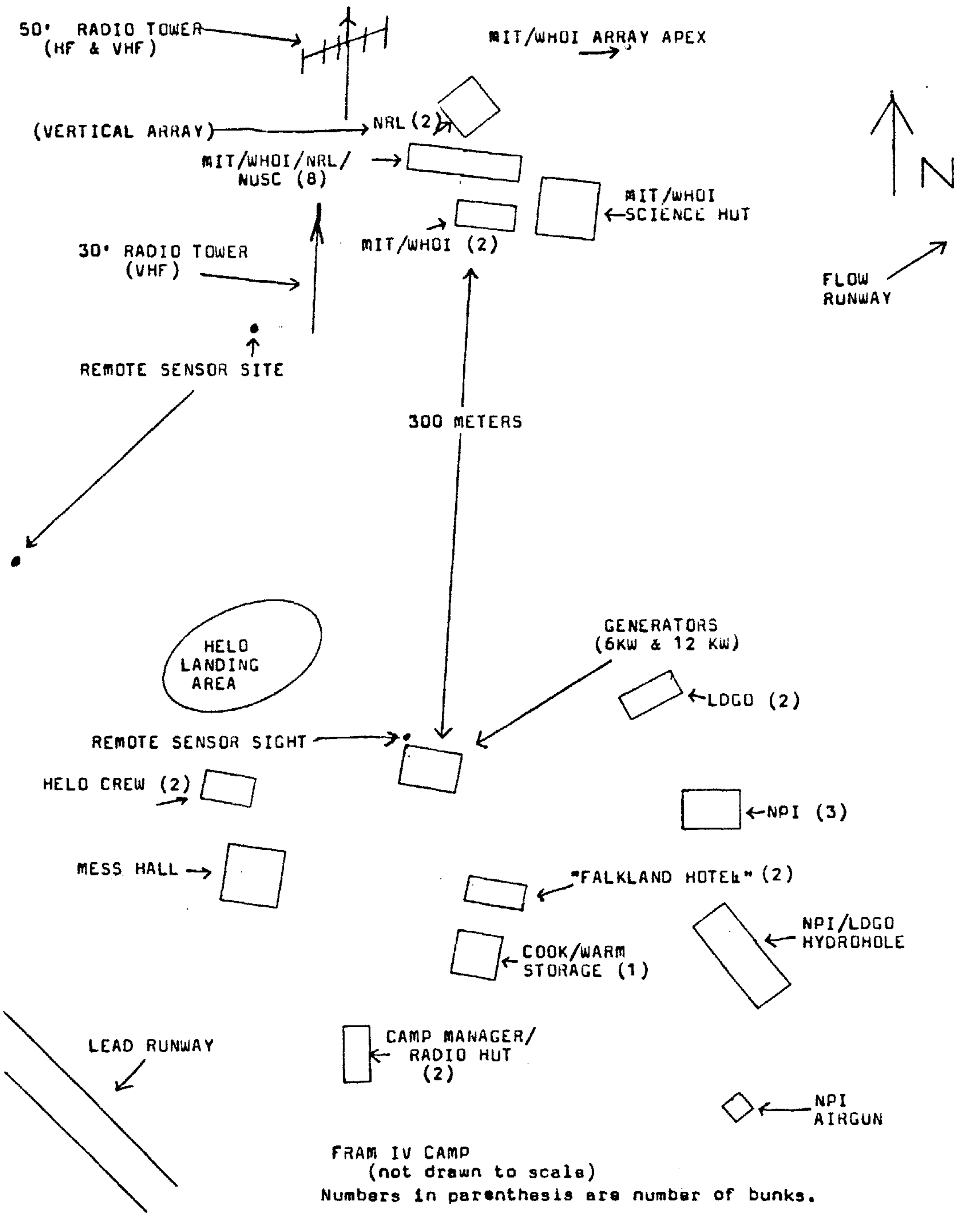
b) evaluation of VHF propagation range expectation.

c) five hundred hour test of units using extended rf path lengths.

PHASE I--Initial System Checks:

Initially the receiving systems were set up in the science hut (See Figure 8). Each transmitter was checked using the Telex supplied quarter-wave antennas. Then reception through the tower mounted receiving antennas was checked using the quarter wave antennas on the transmitters. Two tower mounted receiving antennas were used for this and all remaining field tests. A Telex Model V2 was mounted fifty feet above the ice as the top antenna on the mast of the main tower. A second V2 was installed by itself on top of a thirty foot tower. Two antennas were used as the Telex receiver was designed with for diversity reception operation (see reference 5 for a complete description). For all these checks no audio input was used as the purpose was to check the rf systems.

A WHOI hydrophone was installed through the ice sixty meters west of the science hut and a power lead was run from a power supply in the hut to the hydrophone location. One of the Telex transmitters (T23T--Telex channel 23 transmitter; the Telex units are refered to in this manner to distinguish them from a sonobuoy operating on the same channel) was connected at that location using a V2 for a



FRAM IV CAMP
(not drawn to scale)
Numbers in parenthesis are number of bunks.

FIGURE 8

FRAM IV Camp Layout

transmitting antenna. T24T was installed 350 meters to the south at the back of the generator hut, powered by a power supply in the generator hut. A WHOI hydrophone was used as the acoustic input there also. An Isopole antenna was used at this location. A third unit--T21T--was installed 300 meters southwest of the science hut, powered by a wire from a power supply in the science hut. A V2 antenna was used and a WHOI hydrophone suspended to a depth of 12 meters instead of the usual 91 meters[10]. The fourth Telex unit--T22T--failed during a preliminary check when excessive supply voltage was inadvertantly applied, burning out capacitor C11 and doing other damage which was not locatable with available test equipment. This unit was intended to replace the one nearest the science hut-T23T- and remain in operation at that location for the remainder of the project time on the ice. The loss of this unit dictated that there would not be an operating unit continuously near the installed array.

In an effort to make the best evaluation of the dynamic range The internal gains of T23T and T24T were adjusted. The gain of T21T was left at the factory setting (detailed in the specifications in ref. 5). With the input of T23T shorted the receiver output was -83 db/hz at 70 hertz. With an input of the ocean ambient noise the gain was adjusted to give -75 db/hz at 70 hertz. The input of T24T was shorted and the output of its receiver measured -85 db/hz at 70 hertz. The gain was adjusted to give -75 db/hz at 70 hertz with the ocean ambient noise as the input. (These adjustments could not be identical because the gain adjustment was very course and the adjustment was very near the end of the adjustment of the three-quarter turn pot.)

Recordings--both analogue and digital--were made of the outputs of the three Telex systems, the outputs from some of the array sensors, and the outputs of some of the standard, production AN/SSQ-57A sonobuoys (the operational specifications are listed in reference 2) installed in the ice by the scientists from Norwegian Polar Institute. Recordings were made of both the ambient noise and of the acoustic signals generated various size explosives set off underwater as sound sources. These will be evaluated by WHOI to insure acceptable performance as judged by potential users of the system for specific applications.

PHASE II--VHF Propagation checks

Two units were used for these checks--T23T and T24T. A V2 antenna on an eight foot mast served as the transmitting antenna. A standard 12 volt DieHard battery supplied the power for the transmitter in use. The helicopter was used to fly out to sites at ranges of 5, 10, 15, and 20 kilometers from camp (these were approximate to within plus or minus 500 meters).

At each site the antenna and transmitter were set up. The system was energized. After carrier reception was acknowledged (via the HF radio in the helo), the system was moved to the next location. At five and ten kilometers reception was continuous while the transmitter was energized. At 15 and 20 kilometers carrier reception was intermittent when either T23T or T24T was in use. Additionally the Lunar power amplifier was tried but showed no change in received signal reliability (the Lunar amplifier used was later determined to be defective).

PHASE III--Endurance Test at Extended Range.

One unit--T21T--was installed at a range of approximately ten kilometers (the range was the pilot's estimate of range--the Omega in the helicopter could not provide adequate resolution for measuring the range--and then an adequate landing site selected). A standard WHOI hydrophone was installed through the ice and a

Burlington battery pack was suspended through another hole about two feet below the bottom of the ice. This installation is pictured in Figure 9.

The initial plan had a second Telex unit similarly installed at a range of 20 kilometers. Beside the one at the further range was also to be the third Telex unit with a Lunar power amplifier and the necessary larger size battery pack.

The operation of the distant units was to be monitored for reception quality and also to determine if the higher gain antenna supplied the intended increase in signal level and if that increase was necessary to maintain a reliable telemetry link. These units were not installed because the performance of the unit installed at ten kilometers failed after four days for undetermined reasons.

(Picture on following page.)

FIGURE 9

Picture of Remote Sensor Installation


OY-
AE

X. FIELD TEST RESULTS:

The results of the field test were obtained in each of the four phases of the testing. Therefore the results are divided up into the same catagories.

Results of the operational local checks:

The operation of the radio frequency section of the Telex systems was successfully achieved using the Telex supplied quarter-wave antennas for both transmitting and receiving. The rf system operated equally well with the use of the tower mounted V2 antennas (except for the one Telex unit which suffered the failure resulting from the author's error--possibly reversing polarity when connecting the power source although a diode is included in the transmitter to prevent damage from a reverse polarity power source). The complete audio and rf systems of the three remaining units were operated successfully using WHOI hydrophones as inputs. Each of the units operated successfully from each of the local (60, 300, and 350 meter range) locations.

Results of the VHF range propagation checks:

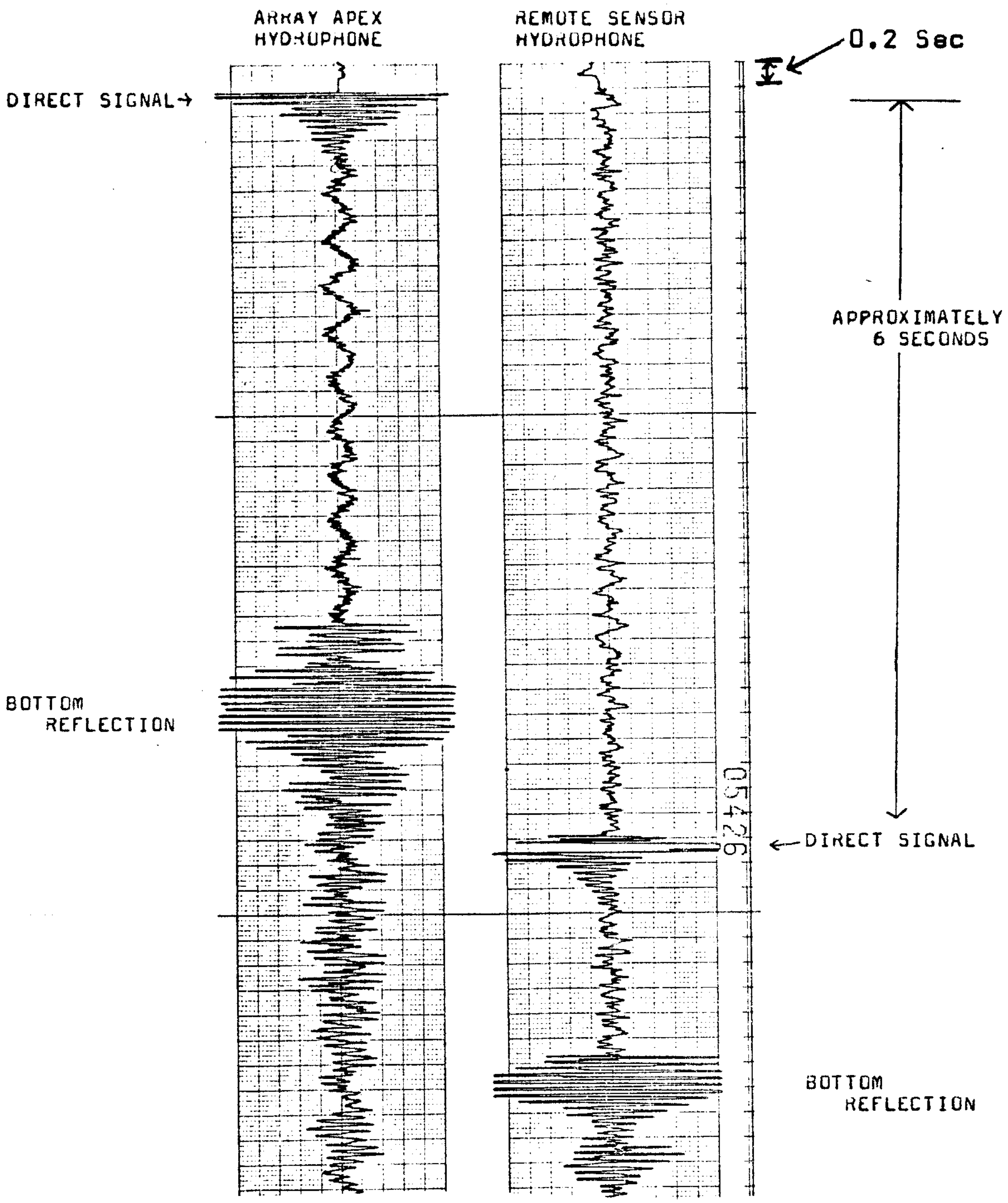
The initial range tests showed reliable reception up to ten kilometers with full quieting. This was acheived at locations which were not selected to be either favorable or unfavorable in terms of pressure ridges possibly interfering with the propagation. At the 15 and 20 kilometer ranges intermittent reception occurred. The reception was the same for either of the transmittars used for the test. The use of the Lunar power amplifier did not change the reception--however, after crude checks with an oscilloscope later it was determined that the power amplifier was not operating properly.

Five hundred hour test at extended ranges:

One unit was installed at 10 kilometers (operating with a hydrophone input and with a submerged battery for a power source), and operated succesfully for four days after which th signal was lost. The output of that sensor and the output of a sensor in the fixed array were recorded on a strip chart recorder (Figure 10). An explosive source was recorded and by analysis of the time delay between the two received signals it was determined that the sensor was at about 9.8 kilometers. The reasons for the loss of signal could not be determined without rf test equipment which was not availible. The battery was still functioning properly. Exchanging transmitters also did not restore reception.

During the operating period of the sensor at 10 kilometers reception was attempted on the directional antenna, but with negative results. The cause of no reception was determined to be the cross polarization of the transmitted signal (which was vertically polarized) and the VHF directional antenna (which was installed for reception of horizontally polarized signals). The cross polarization was effectively a 20 db loss in signal strength (ref. 8), and resulted from inadvertant installation of the Yagi antenna in its normal position rather than having rebuilt its mounting system for vertical mounting.

The five hundred hour test could not be completed as the reasons for the failure of the unit could not be determined. Without the determination of what caused the failure no other units were put out in the field. In addition there were not five hundred hours left before the camp was to be evacuated so that a complete five hundred hour test was impossible.



(TIME INCREASES FROM TOP TO BOTTOM AT 25 MILLIMETERS PER SECOND)

FIGURE 10

Record of Explosive Signal

As Sensed by a Remote Sensor and a Fixed Array Element

Dynamic range operational measurement:

The noise of the remote sensor system with no input was measured at 80 microvolts and an output caused by an explosive source measured 3.8 volts, giving a dynamic range of 20 log (3.8/.00008) or 93 db. This measurement was conducted in the data band (the LBP). The large signal level used here could not be checked for harmonic distortion; however, the measured dynamic range did not exceed that of the bench tests and was therefore assumed to be a valid measurement.

XI. CONCLUSIONS:

A. Conclusions about the bench tests:

The amplitude response at the low frequency end of the data band was not within the specified 3 db variation. Some circuitry adjustment is necessary to extend to a lower frequency the flat amplitude response versus frequency.

B. Conclusions about the field test:

The field test had four objectives. The first was to prove operational performance of the Telex system in the Arctic. This was fully established by both the operation of all working units at each of the local sites and the operation of the one unit at approximately ten kilometers.

Operation was continuously acheived but with uncertain signal quality during the brief range checks up to approximately 10 kilometers with intermittent operation (sufficient for locating by direction finding equipment) at 15 and 20 kilometers range. Operation and recording of the unit installed at 10 kilometers showed the capability of the system at that range until a complete failure occurred the cause of which could not be determined[11] as test equipment capable of measuring rf transmitted and received levels was not availible in the field. Thus ten kilometers was determined to be the reliable range in terms of propagation problems with the possibility that it may in fact be as much as twenty kilometers with all equipment properly working. (This is separated from the issue of the reliability of the hardware since the failure could not be found.) Thus, the third objective was met with some qualification.

There was no apparent degradation of performance caused by the Arctic environment. The link budget predicted that the 50 milliwatt output was sufficient for

20 kilometer operation but an undetermined failure prevented reliable reception at that range. Whatever the failure was, it is unlikely that it was the result of the environment. The tuning of the transmitter and the Lunar preapmlifiers at low temperature may have been significant in preventing any degradation in performance caused by the operation conditions.

The five hundred hour life was not demonstrated. The current drain of the hydrophone preamplifier and the Telex transmitter are known so that there is little doubt of the ability to meet any desired lifetime with proper care in the battery selection process.

Recordings or furthuring testing must be fully evaluated by potential users to insure the system meets the dynamic range requirements. Indications from system noise level as measured in the field and a large amplitude signal show the dynamic range to be adequate in the data band (LBP).

Overall conclusions:

The Telex fm wireless microphone modified to meet the specifications for the remote sensor (Appendix B) proved its capability to perform in the Arctic environment. A question can be raised about its reliability, but exactly what failed must be determined before the reliablity issue can be fully resolved.

In the opinion of this author the remote sensing system incorporating the modified Telex wireless microphones is an potentially operational system meeting all the initial requirements. The sensing system would need further tailoring for any particular use, but the system in general concept proved operational. The loss of the signal after four days of remote operation at 10 kilometers is--in the opinion of the author--a failure in the receiving system. The preamplifiers are the most logical point of failure for the given symptoms.

X. RECOMMENDATIONS:

A) The gain adjust of the Telex unit should be changed to a multi-turn pot to provide higher resolution adjustment.

B) The transmitter package should be modified to provide adequate test signals to a test jack so that with a small test unit (which needs to be designed and built) the operation of the unit can be quickly checked on site in the field immediately after installation. It should be able to check--with a go/no go indication--that the battery is ok, that the audio input in present, that the carrier is present, and that the modulated output is being sent to the antenna.

C) A high quality, calibrated, wide coverage receiver should be taken to the field to be able to check the reception of <u>any</u> channel. An example is the RG-5540 and associated equipment made by REGCO of Rockville, Maryland.

D) A high quality signal generator such as the Boonton Model 102E or 102F (which are some of the very few signal generators that provide a calibrated FM signal as low as five hertz) should also be availible.

E) Include as standard equipment for testing and operation a spectrum analyzer such as the Tektronix 7L13 or 7L14.

F) Have availible a VHF low power standing wave ratio meter.

G) Include high power electromagnetic radiation in the specifications in paragraph 5.1.3.c.

H) Improve the five hertz amplitude response.

I) The use of lithium battery packs is recommended for use of the remote sensor in Arctic conditions. Initial cost will be higher, but that higher cost will be compensated for by the greater ease of installation for lithium packs which may be subjected to the cold temperatures on top of the ice.

NOTES:

1. EDMAC Associates quoted prices in July 1981 of $16,590 for the AN/ARR-75, $73,592 for the AN/ARR-72, and $161,310 for the Instrumentation Receiver. Their use would require one AN/ARR-75 for every four channels of parallel reception or using the AN/ARR-72 with its 31 channel capability.

2. Given as approximately because this is not a standard specification for sonobuoys--which are purchased in a unique manner wherein only the performance requirements are given and the manufacturer determines the circuitry and methods to meet them--see reference 3.

3. AACOM Division of DATUM, Inc. suggested that digital encoding at the transmitter "would be prohibitively expensive." Thus commercial development could not be considered.

4. The Analogue Devices Model 454J/K is specified at greater than 86 db dynamic ranged.

5. Inquiries made in search of a lower cost receiver which could be used with sonobuoys.

6. Commonly refered to as a companding system for compression and expanding.

7. Plus 2 db referenced to the 1000 hertz level.

8. The WHOI data acquisition system as normally programmed records signals up to only 80 hertz.

9. Ambient noise studies were done either by plotting the presentation of the spectrum analyzer on paper of recording on an analogue tape recorder.

10. The hydrophone was at 12 meters because scientific data was not being collected and a hydrophone that had a broken lead on it could be used to that depth by cutting off at the break.

11. The different transmitters were tried at the remote site with no change in

received signal. They were all checked afterwards at a location 1000 meters from the science hut where a hydrophone and battery were installed through the ice. They all operated properly at this 1000 meter range.

REFERENCES:

1. SONOBUOY THINNED RANDOM ARRAY PROGRAM (STRAP), NUSTEN #1665, Naval Ocean Systems Center, March 1976.

2. NAVAIR 28-SSQ-500, Naval Air Systems Command, 30 November 1978.

3. MILITARY SPECIFICATION SONOBUOY AN/SSQ-41B, Naval Air Systems Command, 30 June 1975.

4. INFRASONIC SONOBUOY FINAL REPORT (7579-A002), Sparton Electronics, 1979.

5. TELEX WIRELESS MICROPHONE SERVICE MANUAL, Telex Communications, Inc., 1981

6. Fink, STANDARD HANDBOOK FOR ELECTRICAL ENGINEERS, 11TH Edition, McGraw-Hill, Inc., 1978

7. BATTERY SYSTEMS FOR MILITARY AND INDUSTRIAL USE, Eagle-Picher Industries, Inc. 1971

8. REFERENCE DATA FOR RADIO ENGINEERS, Sixth Edition, ITT., 1981

9. James Fisk, "What The Numbers Mean." HAM RADIO, October 1975, page 8

APPENDIX A

SPECIFICATIONS FOR A MODIFIED

TELEX WT-100 TRANSMITTER AND FMR-1 RECEIVER,

TELEX PART NUMBER 985

1. **SCOPE**-- The equipment covered by this specification shall be a system which inputs audio data at a remote site and relays it by a radio frequency path to a central data collection location.

2. **ASSOCIATED EQUIPMENT**-- This equipment is to be used with the associated equipment listed in section 10.

3. **APPLICABLE DOCUMENTS** -- The two documents which shall apply are TELEX form number PA2506-1 and this specification document.

4. **PRECEDENCE OF DOCUMENTS** -- When the requirements of this specification document conflict with the TELEX form than this specification shall apply. For anything not covered in this specification document the TELEX form PA2506-1 shall apply. Any issue not covered by either document shall be brought to

the attention of WHOI/MIT for resolution.

5. REQUIREMENTS

5.1 ENVIRONMENTAL REQUIREMENTS

5.1.1 NON-OPERATING SERVICE CONDITIONS

a) TEMPERATURE -- + 60 degrees C to - 60 degrees C.

b) VIBRATION and SHOCK-- normal handling for shipment which will include manhandling of crates onto and off of aircraft at remote locations.

c) STORAGE -- store unattended and unused for twelve months

d) ELECTROMAGNETIC RADIATION -- storage in the normal EMR levels of laboratories and aircraft cargo.

5.1.2 OPERATING ENVIRONMENTAL CONDITIONS FOR THE TRANSMITTER

a) TEMPERATURE -- The transmitter will experience +30 degrees C to - 40 degrees C. If operation at - 40 degrees C is unreliable the user may insulate to retain self generated heat to maintain temperature above -30 degrees C but this requirement is undesirable.

b) VIBRATION AND SHOCK -- The transmitter will be subjected to minor vibration and shock when operating because of ice movement. It is the users risk of destruction for severe hazards from ice movement.

c) ELECTROMAGNETIC RADIATION -- EM exposure will consist primarily of the radiation received from other transmitter units.

5.1.3 OPERATING ENVIRONMENTAL CONDITIONS

FOR THE RECEIVER

a) TEMPERATURE -- The receiver will be operated in an enclosed hut with temperatures ranging from 0 degrees C to + 30 degrees C.

b) VIBRATION AND SHOCK -- Commercial requirement for minicomputers,etc. should apply.

c) ELECTROMAGNETIC RADIATION -- EM will consist of other receivers operating adjacant to the units and the low level radiation from the digital processing equipment. Conducted RFI from the processing equipment will be the users responsibility.

5.2 **MARKING** -- Each unit shall be marked in an easily visible manner with the channel number and VHF frequency (which may be in smaller characters than the channel number).

5.2.1 TRANSMITTER -- Each transmitter shall be marked somewhere on its case.

5.2.2 RECEIVER -- Each receiver shall be marked on both the front and the rear panels.

5.3 SELECTABLE CONTROLS

5.3.1 TRANSMITTER -- A single on/off switch is sufficient vice one for output and one for input.

5.3.2 RECEIVER -- TELEX shall provide instructions how to change the carrier frequency. The required parts are covered under spare parts.

5.4 POWER REQUIREMENTS

5.4.1 TRANSMITTER -- The transmitter will be powered through a connector from user furnished battery packs. The nominal power requirement is 12 volts at 30 milliamps. The battery connector will be a standard 9 volt battery type connector with 12 inches of pigtail extending through the case.

5.4.2 RECEIVER -- TELEX shall provide the allowable tolerance in the ac requirement. In addition TELEX shall state the merits of dc versus ac powered use. Form PA2506-1 is understood to mean each unit comes able to be powered by either ac or dc. If deletion of either method can bring about price reduction TELEX shall appraise WHOI and seek further guidance.

5.4.3 ANTENNA SYSTEM -- The user will supply a transmitting antenna (probably 5/8 wavelength) to connect to a standard BNC connector installed on the transmitter. The receiver shall be delivered with the diversity reception capability of Form PA2506-1 and one receiving antenna (except if deletion of the antenna can cause a price reduction TELEX should advise and seek further guidance).

5.5 VHF SPECIFICATIONS

5.5.1 VHF CHANNEL AND FREQUENCIES

VHF CHANNEL	VHF FREQUENCY (MHZ)

1	162.250
2	163.000
3	163.750
4	164.500
5	165.250
6	166.000
7	166.750
8	167.500
9	168.250
10	169.000
11	169.750
12	170.500
13	171.250
14	172.000
15	172.750
16	173.500
17	162.625
18	163.375
19	164.125
20	164.875
21	165.625
22	166.375
23	167.125
24	167.875
25	168.625
26	169.375

27	170.125
28	170.875
29	171.625
30	172.375
31	173.125

5.5.2 VHF POWER OUTPUT -- The Transmitter shall radiate a minimum of 50 milliwatts with the minimum power supplied of 12 volts and 30 milliamps. The output will be into an impedance of 50 ohms. The output power will me the maximum possible and not limited to 50 milliwatts.

5.5.3 VHF RECEIVER SENSITIVITY -- minus 77 db with a noise figure of 9 db.

5.6 ACOUSTIC REQUIREMENTS

5.6.1 FREQUENCY RESPONSE -- The response shall be flat within plus or minus 3db from 5 HZ to 1000 HZ availible out the front panel connector and from 50Hz to 20KHz out the rear panel connector. The zero reference level need not be the same for the two bands.

5.6.2 DYNAMIC RANGE -- The dynamic range of the low frequency band (the data band) will meet or exceed 80 db.

5.6.3 TRANSMITTER INPUT -- The input to the transmitter shall be an impedance of 50-1000 ohms and be capable of processing an input signal of that listed in revision C of form PA 2506-1. A standard Lemo connector will be used.

5.7 NOISE REQUIREMENTS

5.7.1 ACOUSTIC NOISE -- Any electrical and mechanical noise shall be low enough to not interfere with the audio signal.

5.7.2 RF NOISE -- The receiver shall meet or exceed the levels given in FORM PA2506-1.

6.0 **RELIABLITY** -- Reliable operation in the environment described is of extreme importance. TELEX understands that warranty repair work is not a solution of lesser quality control. A transmitter which fails will probably have to be replaced with no capability of recovery and repair of a defective unit. The receivers will be subjected to a less harsh operating environment but while they will be where they can be physically removed for repair the time to repair might result in irreplacable lost data. TELEX reliability estimate is 98% with the clear understanding that this is an engineering judgement and not a calculated, derived figure. Telex will supply any useful guidance in this area if availible.

7.0 MAINTENANCE

a) No preventative or corrective maintenance shall be required of the transmitters. After use they will be considered expended. Any preventative maintenance for the receivers will be described in detail with instructions.

b) A system manual and schematic shall be provided for each part of the supplied system (these may be in the form of copies of factory manuals, engineering drawings and papers, etc.).

c) TELEX will supply a recommended spare parts list (with price quotes).

d) TELEX will provide instructions for changing the frequency of a receiver (thus allowing a smaller number of back-up receivers rather than requiring one per channel). A list of required parts and price quote will be supplied.

e) Every receiver and transmitter will meet requirements when operating with any other receiver and transmitter of the same channel.

8.0 PREDELIVERY TESTS BY MANUFACTURER

TELEX will conduct whatever tests they deem necessary to insure each and every unit meets specifications. If any additional tests are necessary to supply the required data sheets for each unit they will also be conducted.

9.0 **DATA SHEETS** -- TELEX shall supply the following data and calibration sheets:

9.0.1 A data sheet (in the form of table or graph as apporpriate) shall be supplied for each listed element. They need be supplied only once provided TELEX insures that other units are similar in performance

a) Frequency response

b) Phase shift versus audio frequency

c) Demonstrated dynamic range

10.0 **ASSOCIATED EQUIPMENT** -- The following equipment is expected to be used in the total system

a) A WHOI/MIT hydrophone and preamp (remote powered by the cable)

b) 3 conductor, unshielded, faired cable from preamp to transmitter package

c) battery pack-either lithium or lead-acid gel

d) a case for the transmitter with connectors for hydrophone cable, batttery pack, and antenna

c) a ISOPOLE 5.8 wavelength antenna with less than 10 feet transmission line.

d) a balloon supported 1/2 wavelength receiving antenna

c) two separate receiving antenna systems of:

i) a LUNAR ELECTRONICS RF preamp remote powered up the transmission cable.

ii) a second RF preamp at the ground end of the transmission cable to the balloon.

iii) a transmission line to the equipment hut (which on one line may have distributed preamps on a 700-1000 foot transmission line.

APPENDIX B:

1. Noise Factor (F) is defined as:

$$F = (S/N \text{ of ideal receiver}) / (S/N \text{ of real receiver})$$

$$F = (S_i/N_i)/ (S_o/N_o)$$

where:

S_i is signal in

S_o is signal out

N_i is noise in

N_o is noise out

But noise input is defined as $k\, T_o\, B$. Thus

$$F = N_o / G\, k\, T_o\, B$$

2. Definition of Noise Temperature (T)

$$\text{Noise Figure NF (db)} = 10 \log_{10} ((T/290) + 1)$$

so:

$$T \text{ (degrees K)} = 290 \left(10^{(NF/10 - 1)} \right)$$

3. Antenna Calculations:

From Figure 1. (taken from reference 9) the antenna noise temperature is 290 degrees K for 180 MHZ in the Arctic. The noise factor is 2.0 and G = 4

4. Preamp Calculation

The preamp has a noise figure of 0.8 db which gives a noise factor of:

$$F_2 = 10^{(0.8/10)}$$

$$\text{or } T_2 = 58 \text{ degrees K}$$

the gain is 20 db or G = 100 (where g is the power gain)

5. Transmission Line Calculation

$$T_L = (1/L - 1)\, 290 = 1.2 \times 290 = 354 \text{ degrees K}$$

or

$$F_L = ((1/.45 - 1)\, 290) / 290 + 1$$

$$F_L = 1/.45 = 2.22$$

Therefore:

$T_3 = 35 = 1/.45 = 2.22$

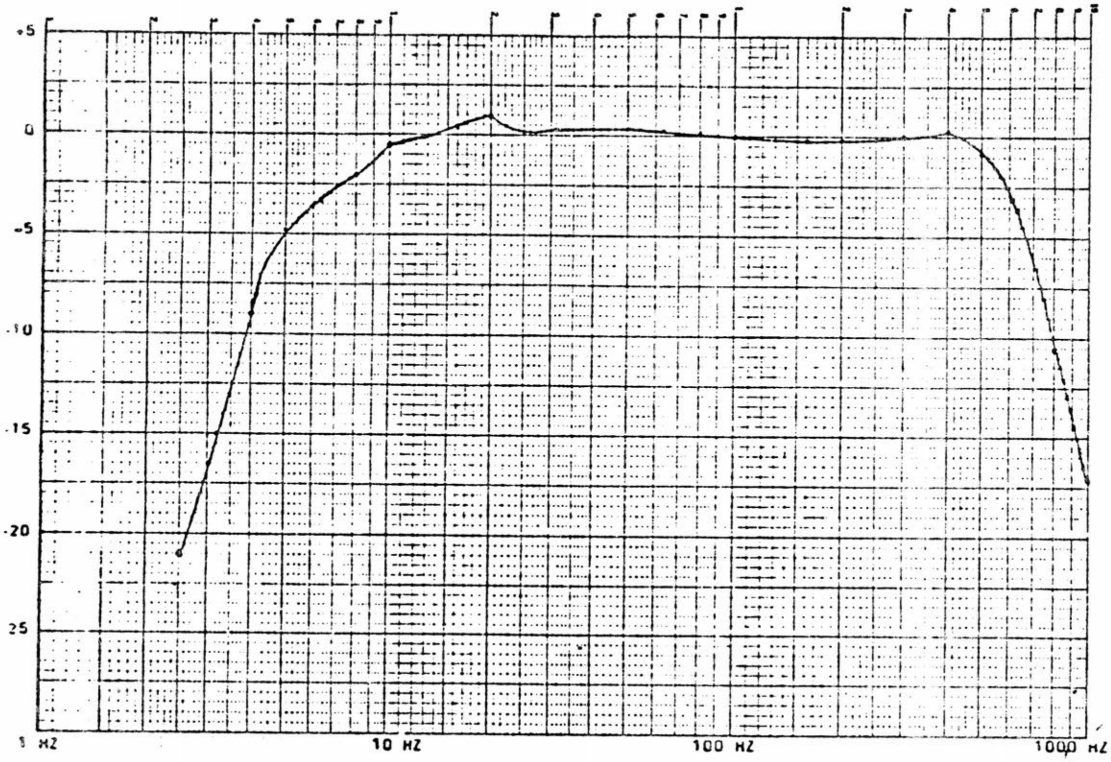
Therefore:

$T_3 = 35$

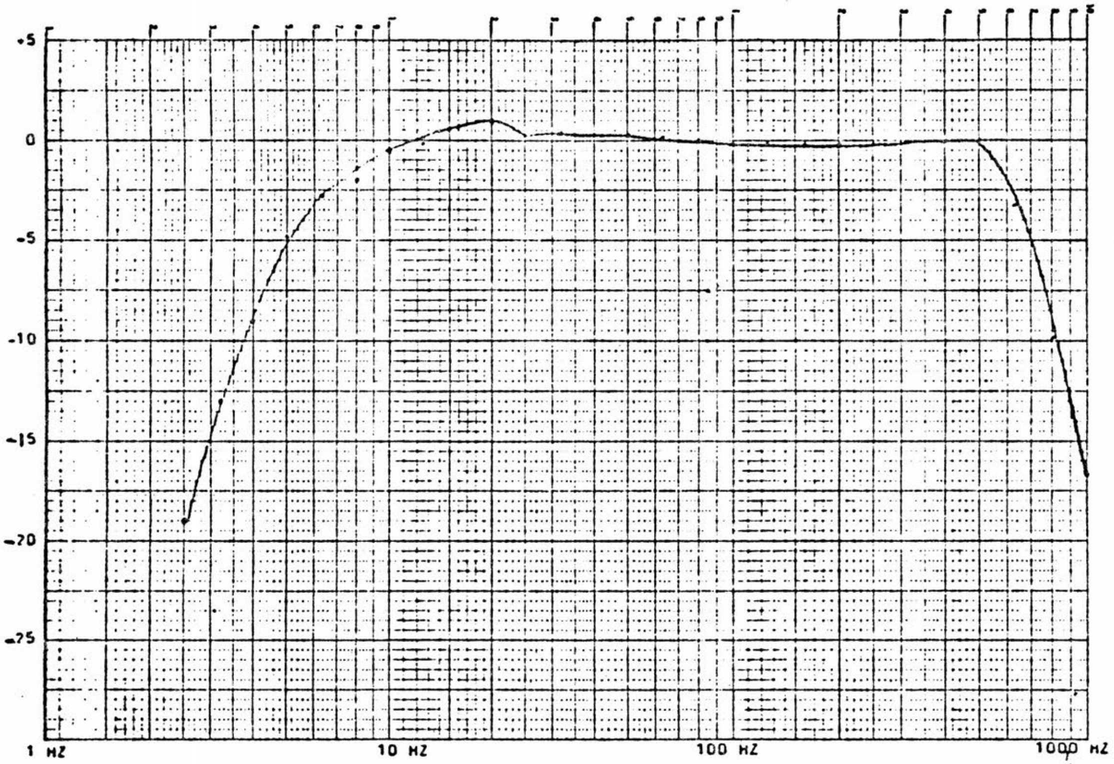
APPENDIX C

All frequencies are in hertz, all amplitudes are in db relative to 0.155 volts rms, and phase in degrees.

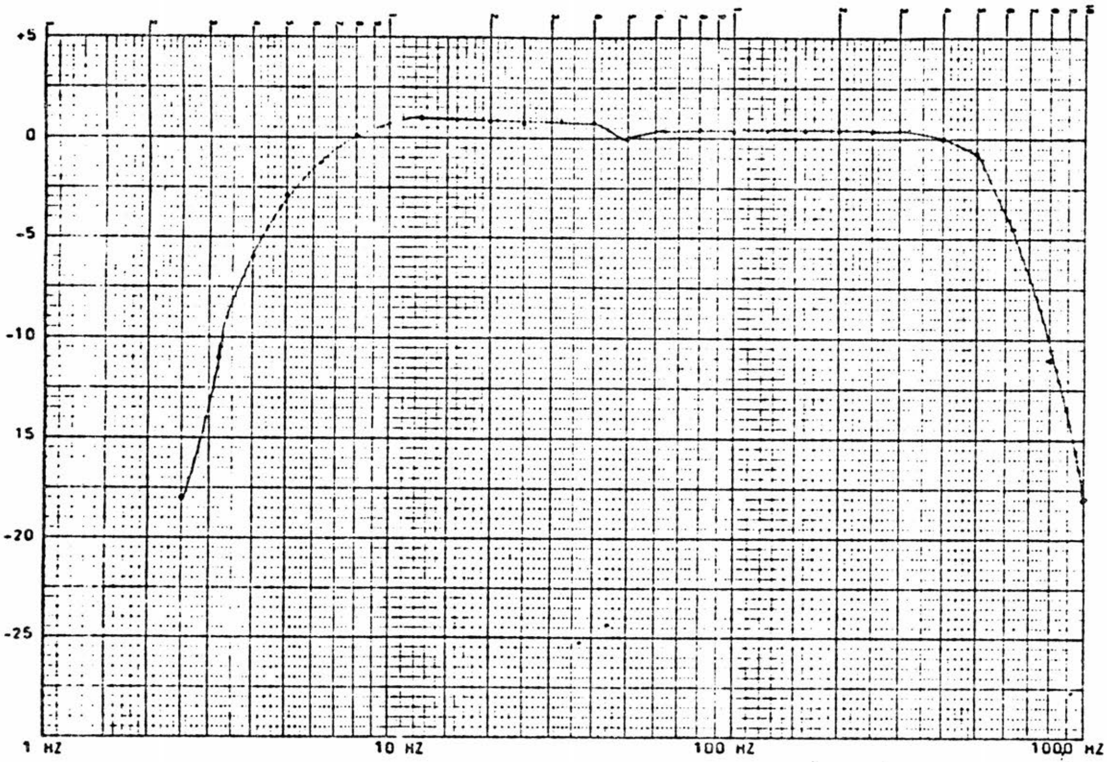
The data is graphed, and then followed by the data in tabular form.



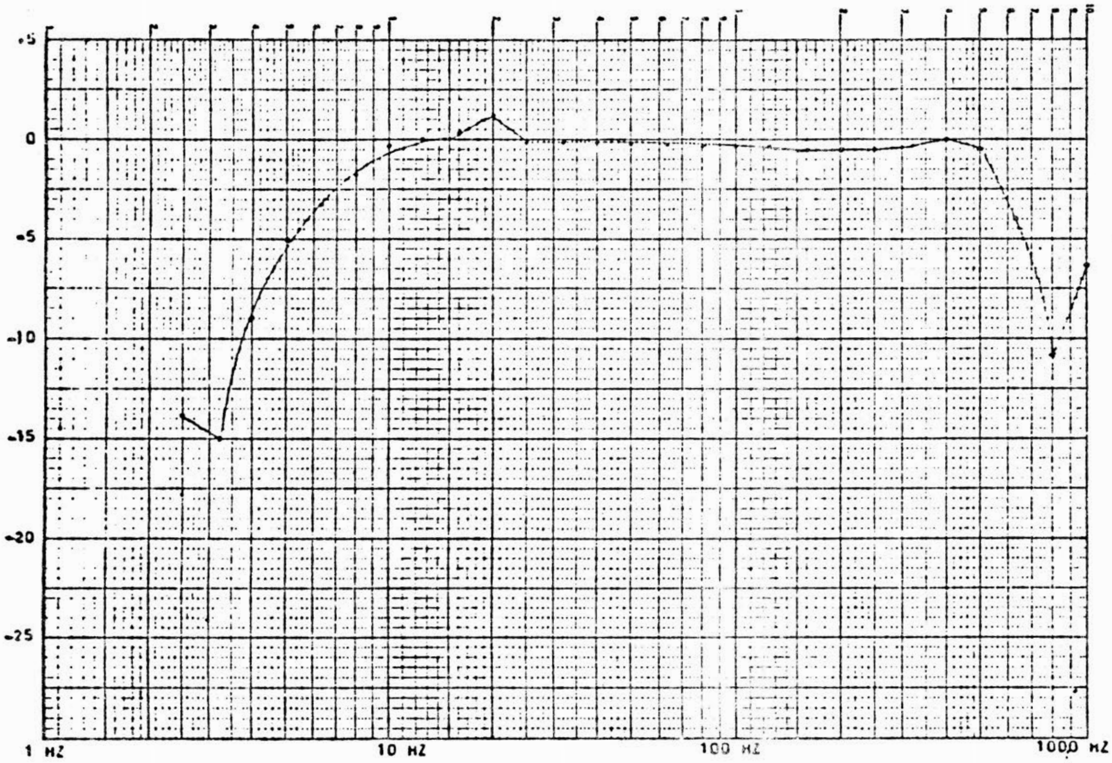
CHANNEL 21 LBP AMPLITUDE RESPONSE VERSUS FREQUENCY



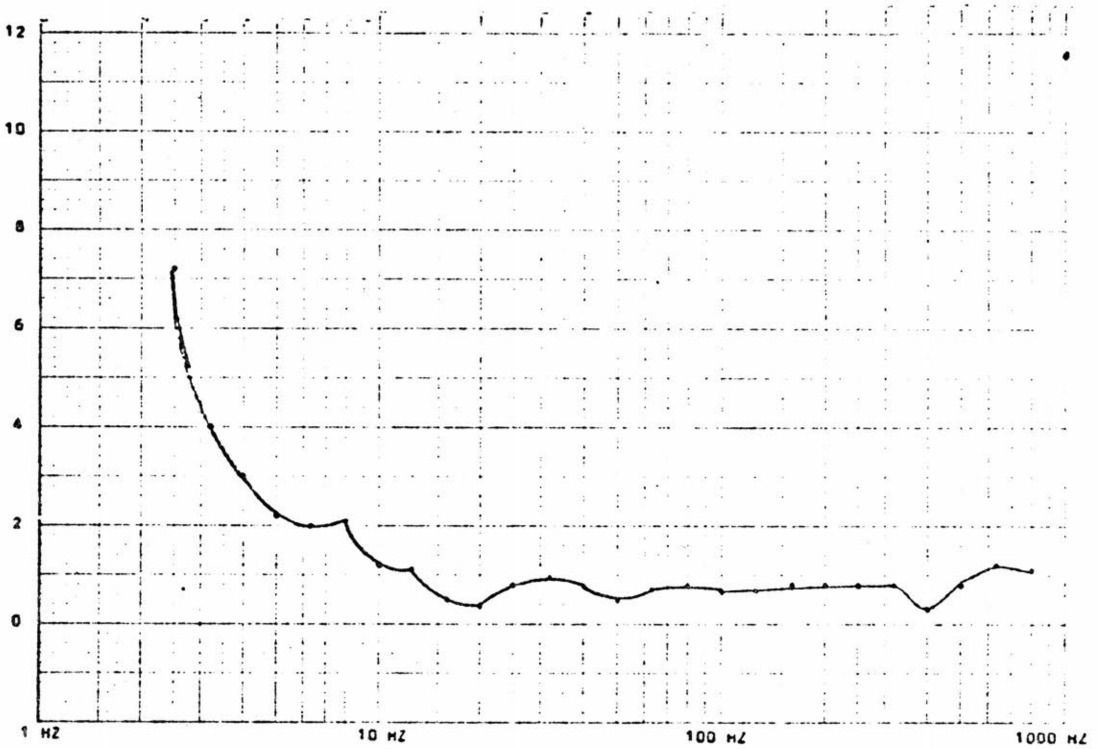
CHANNEL 22 LBP AMPLITUDE RESPONSE VERSUS FREQUENCY



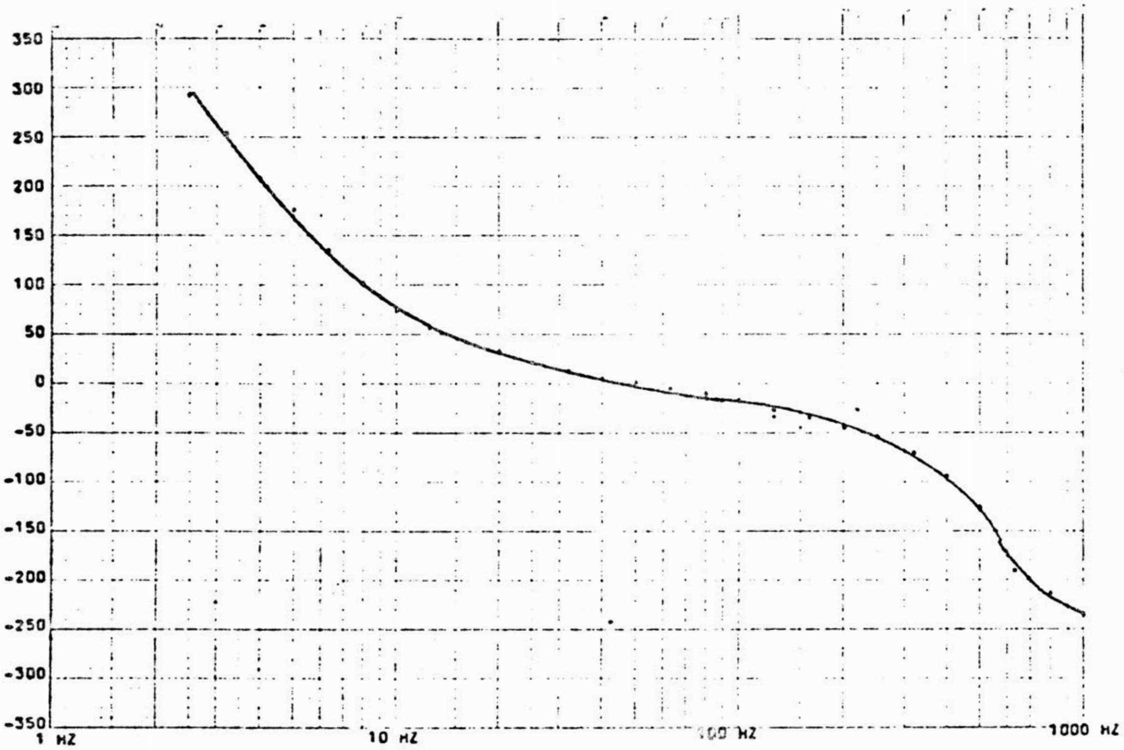
CHANNEL 23 LBP AMPLITUDE RESPONSE VERSUS FREQUENCY



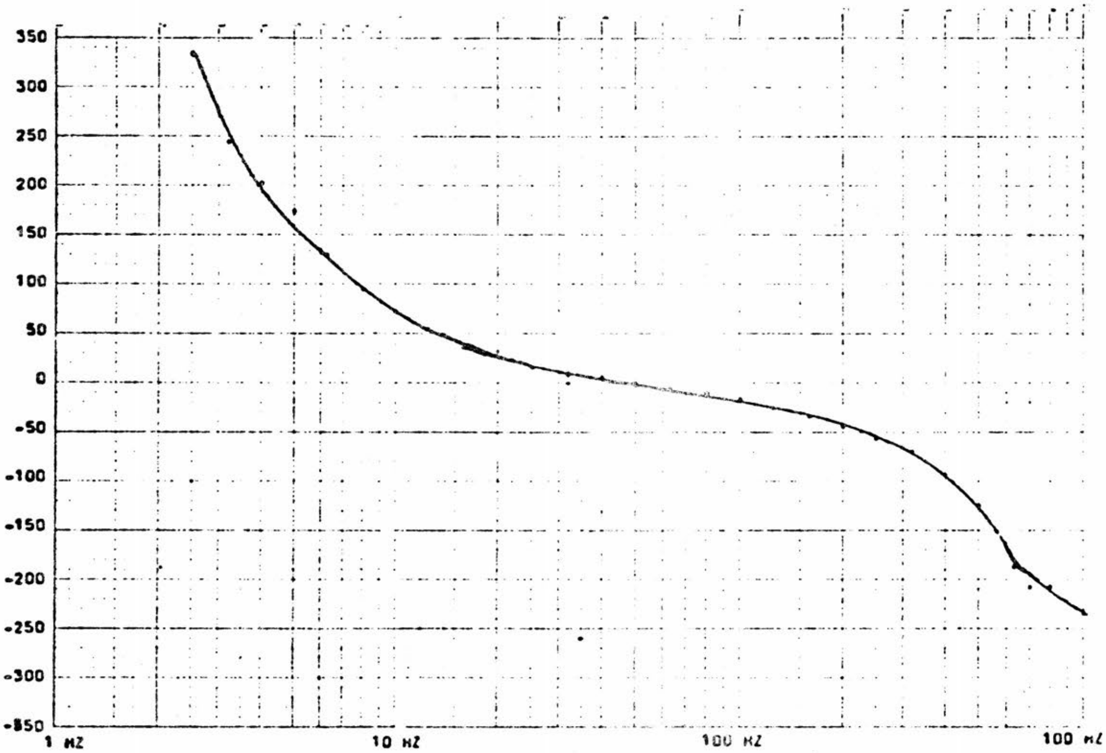
CHANNEL 24 LBP AMPLITUDE RESPONSE VERUS FREQUENCY



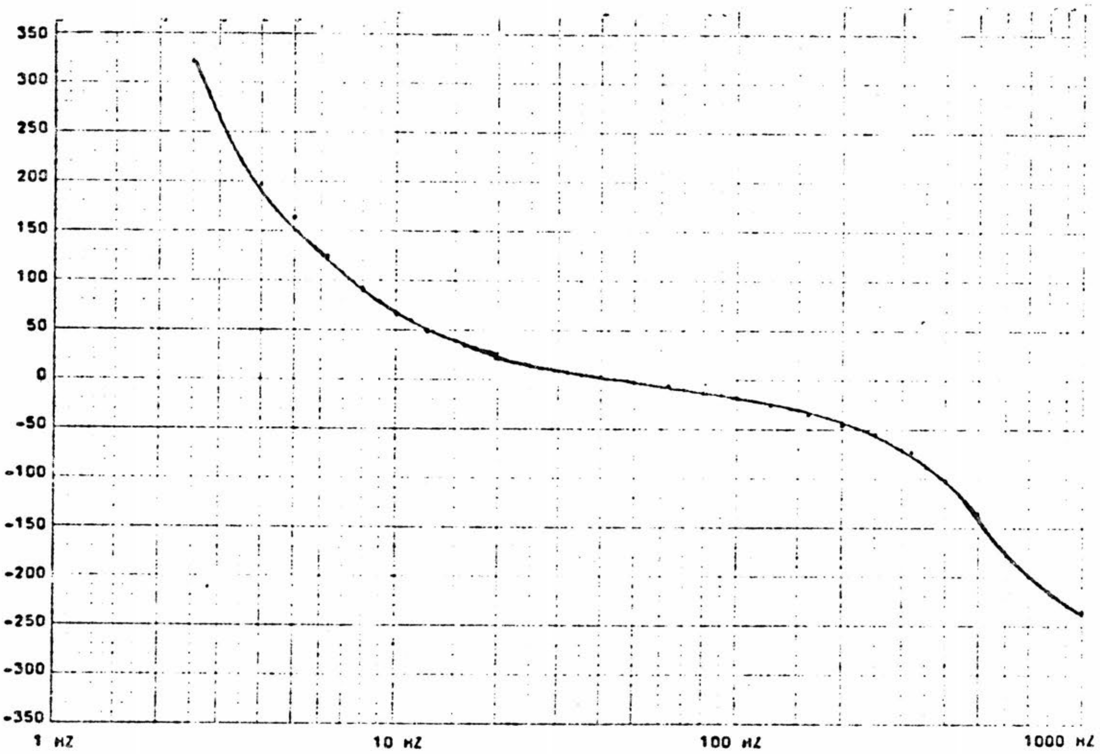
LBP MAXIMUM AMPLITUDE VARIATION BETWEEN UNITS



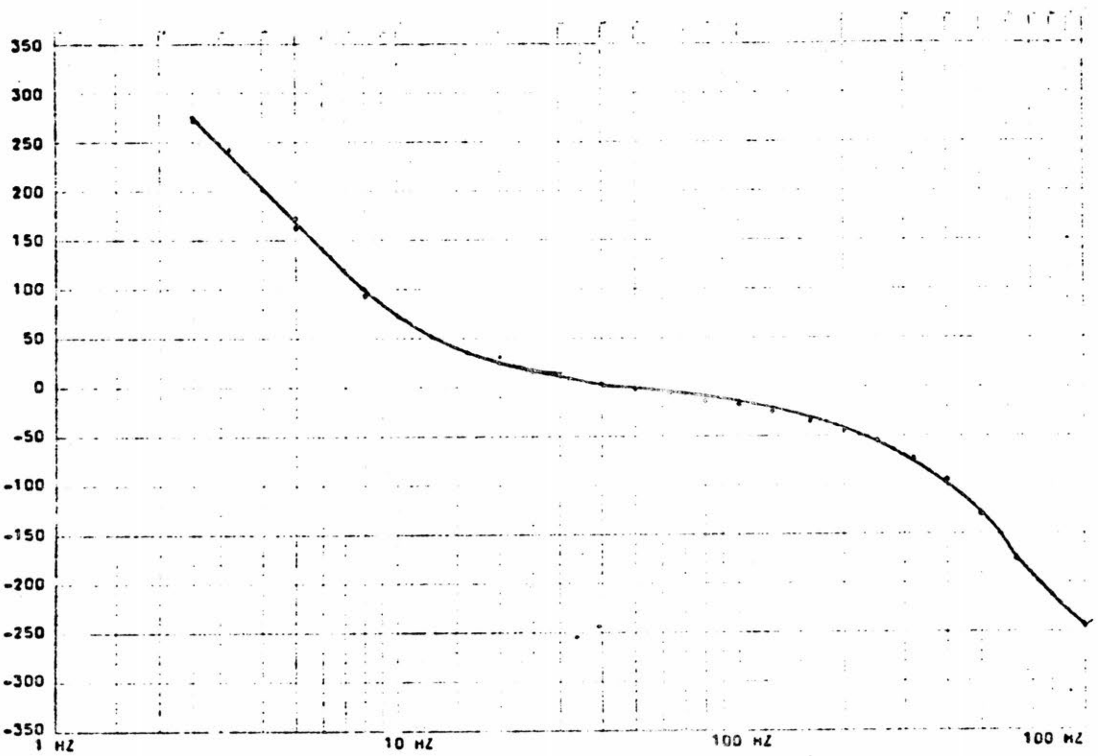
CHANNEL 21 LBP PHASE VERSUS FREQUENCY



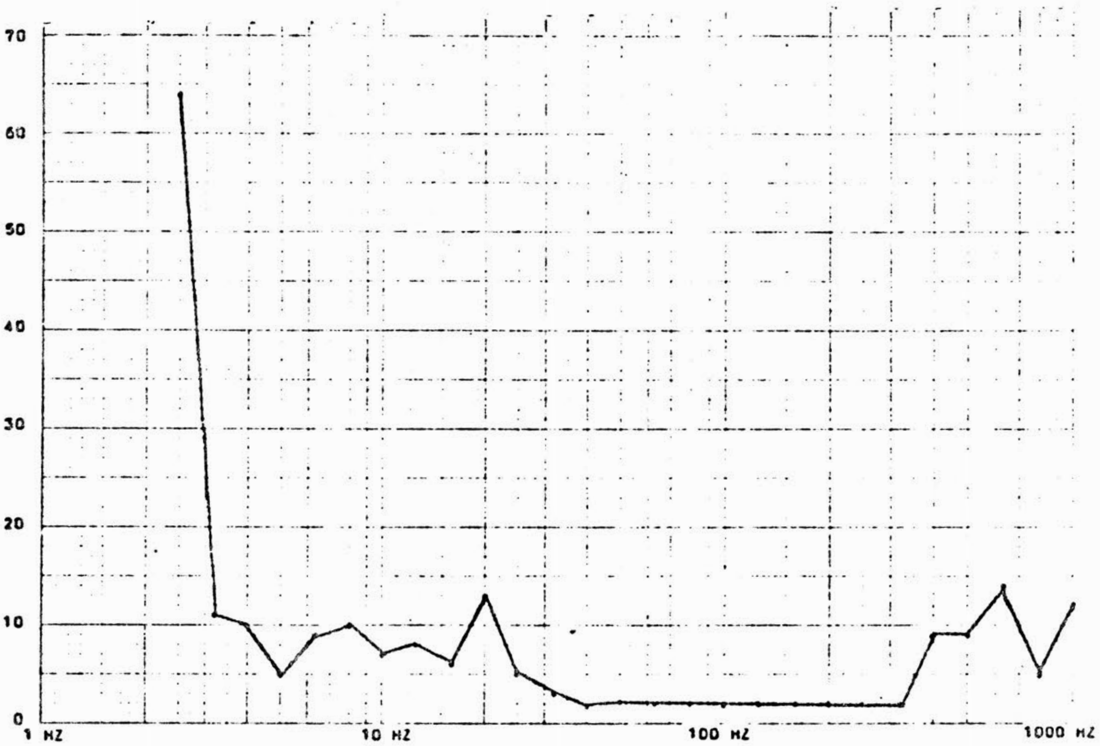
CHANNEL 22 LBP PHASE VERSUS FREQUENCY



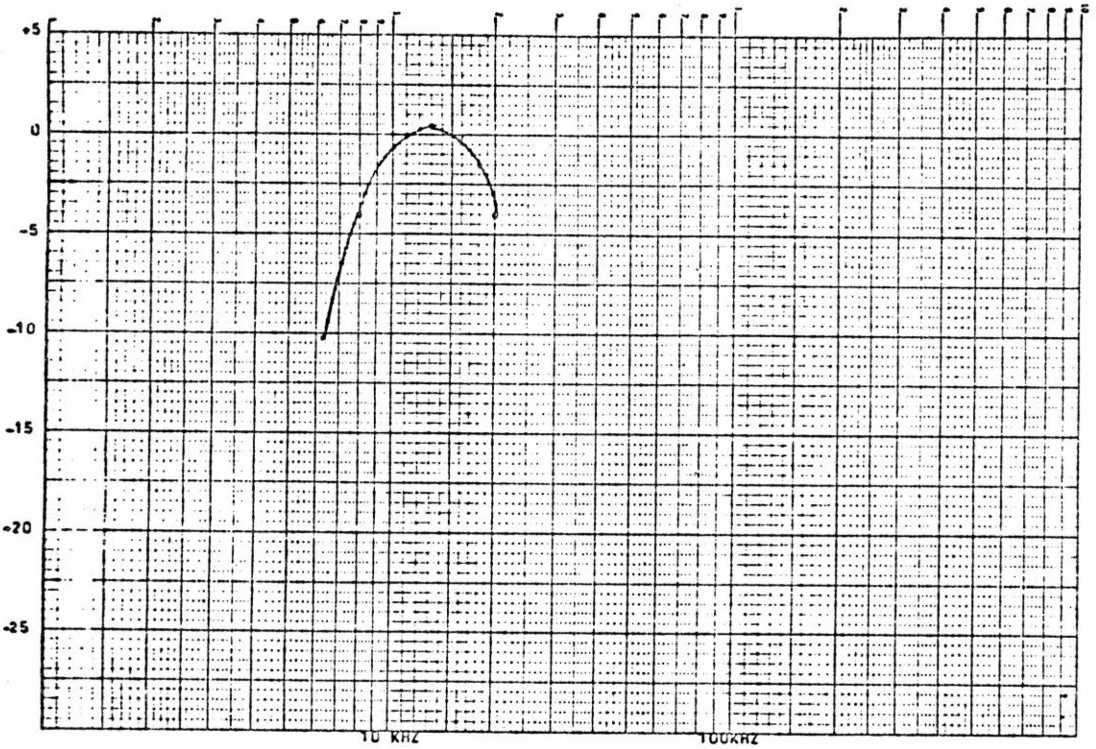
CHANNEL 23 LBP PHASE VERSUS FREQUENCY



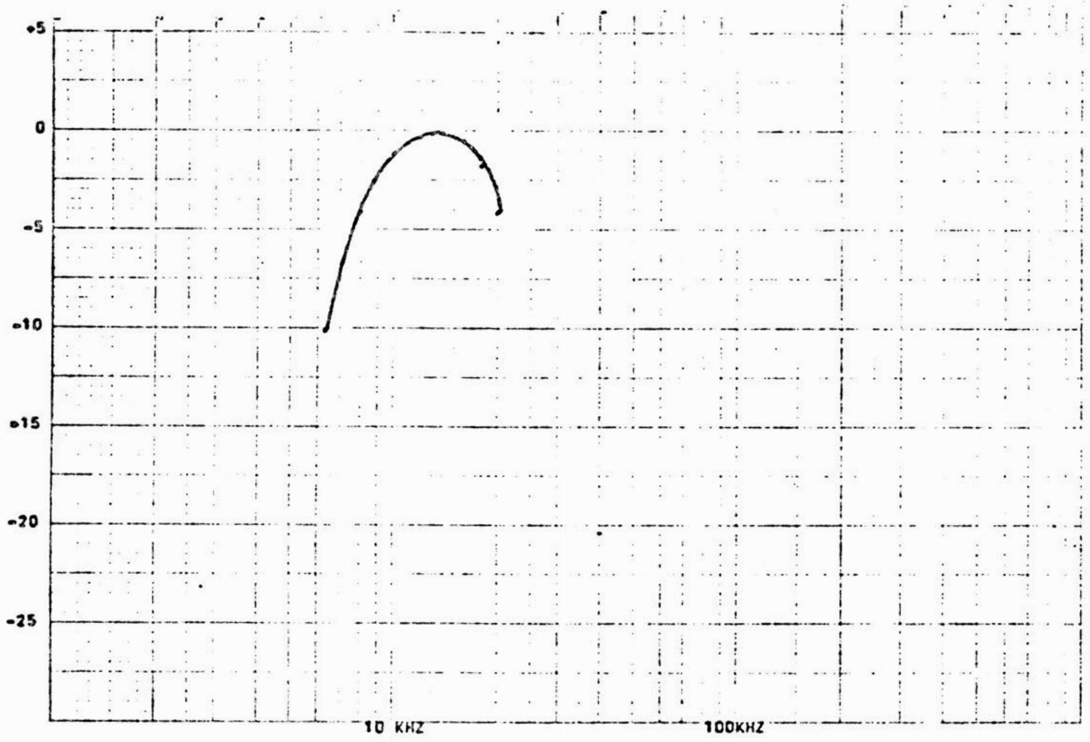
CHANNEL 24 LBP PHASE VERSUS FREQUENCY



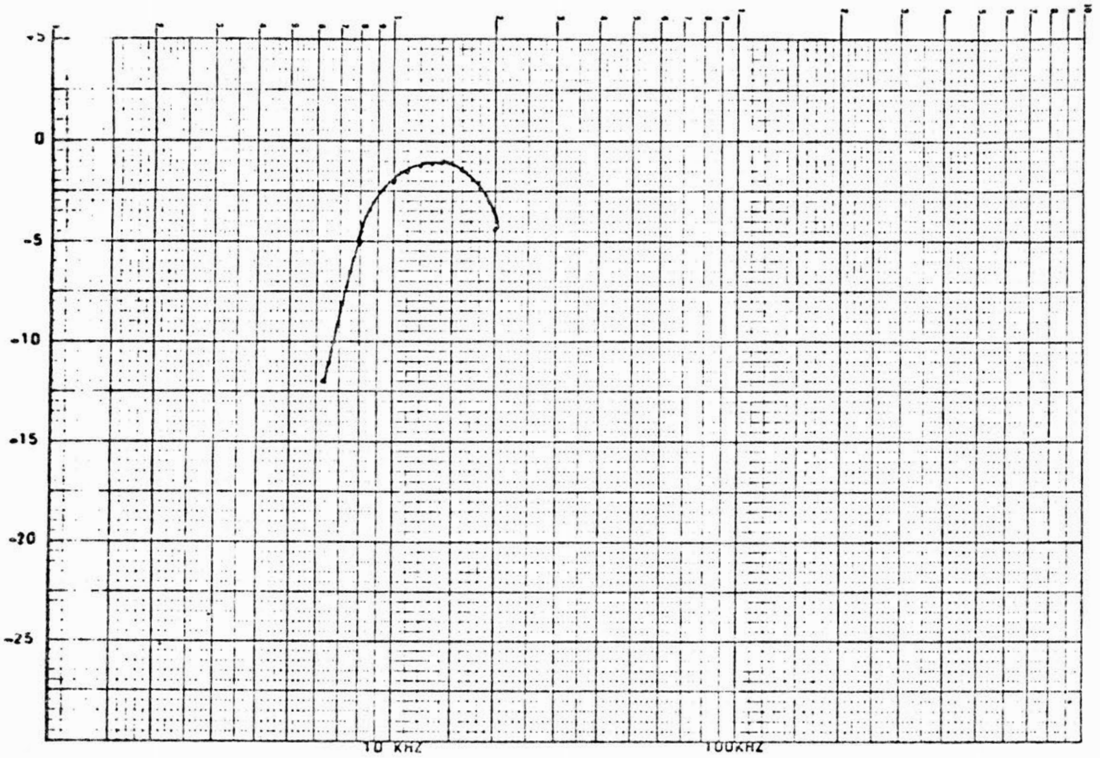
LBP MAXIMUM PHASE VARIATION BETWEEN UNITS



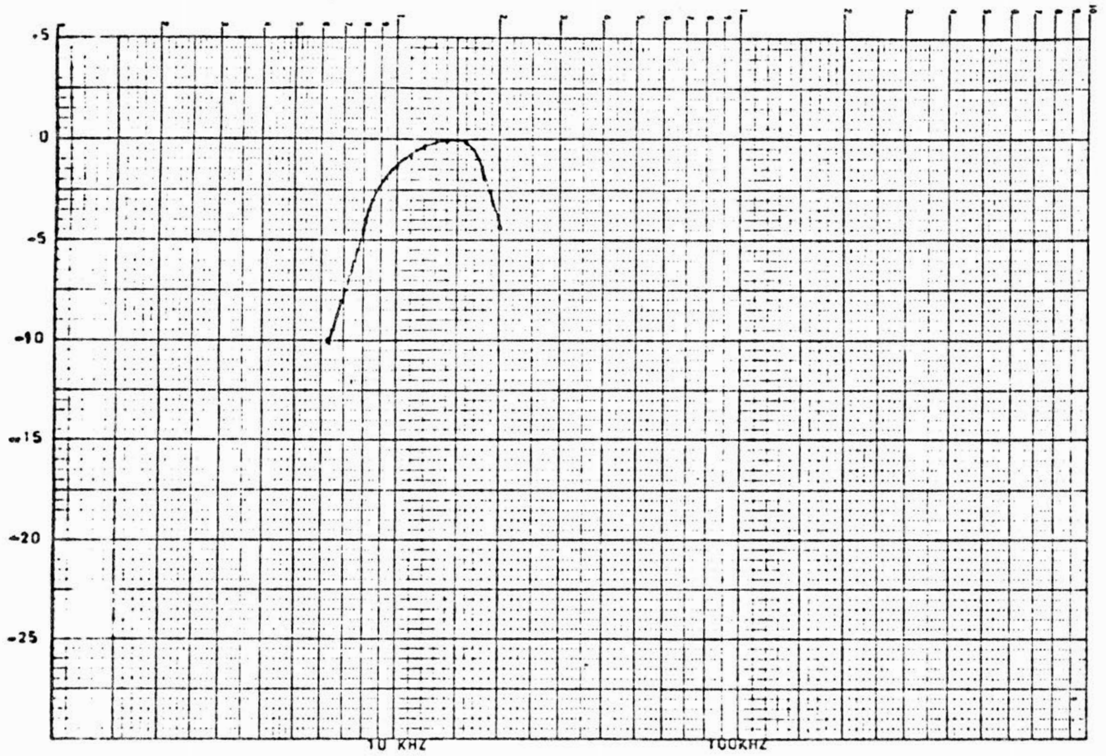
CHANNEL 21 M&P AMPLITUDE RESPONSE VERSUS FREQUENCY



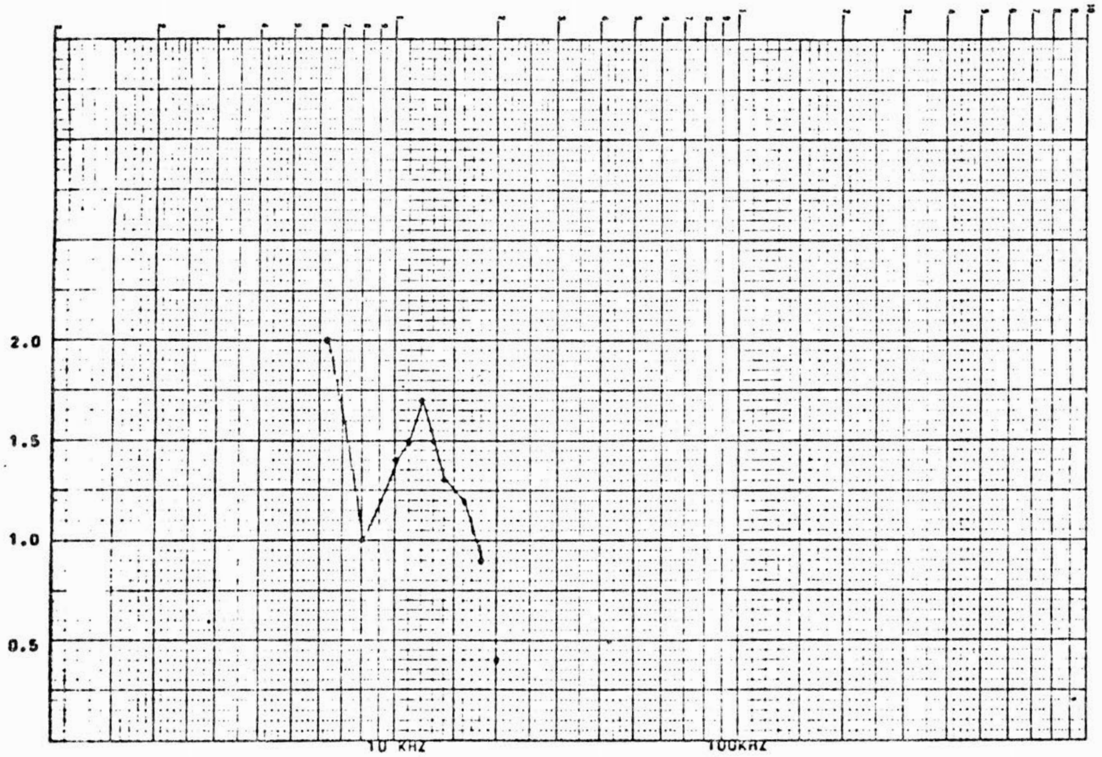
CHANNEL 22 MBP AMPLITUDE RESPONSE VERSUS FREQUENCY



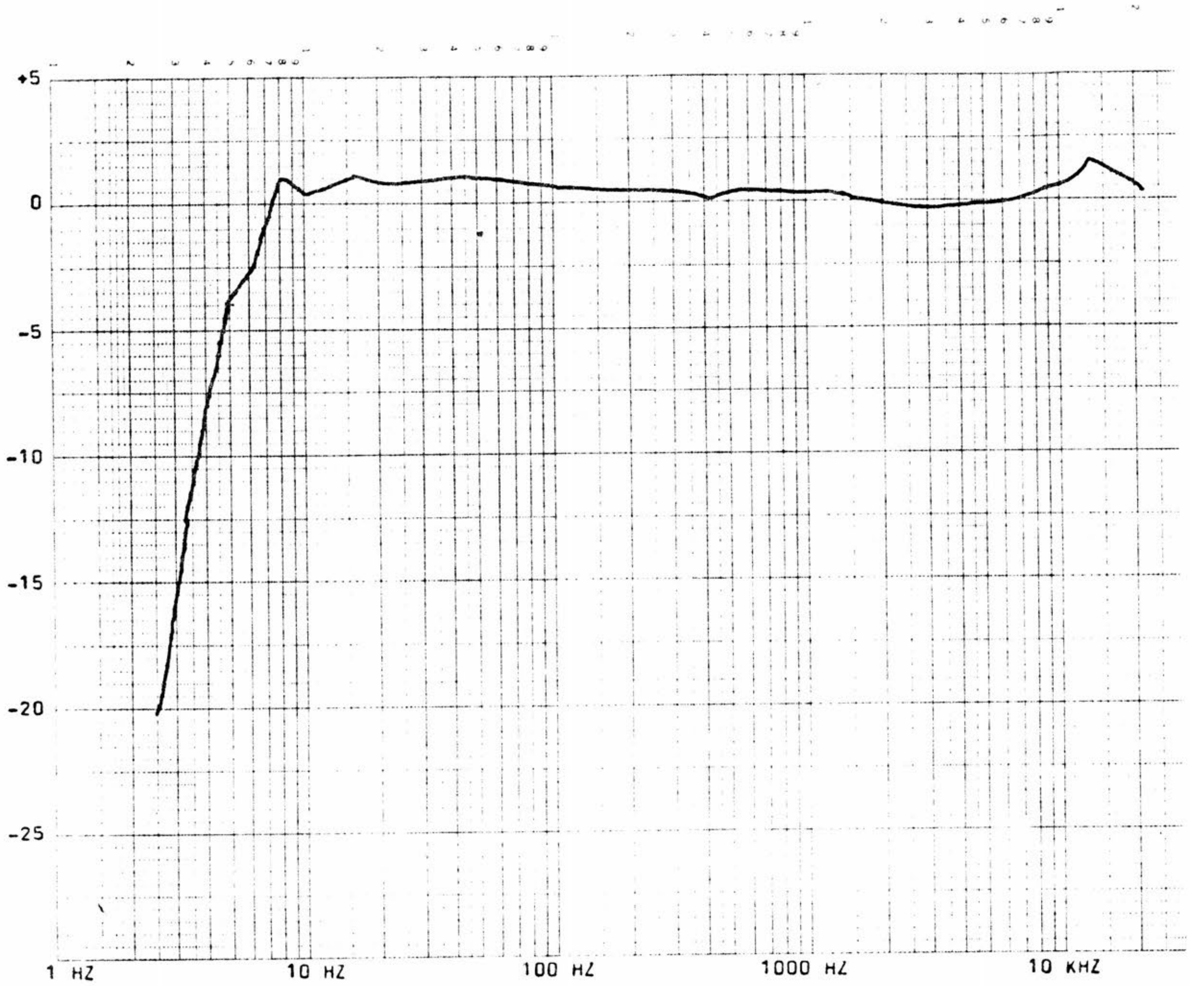
CHANNEL 23 MRP AMPLITUDE RESPONSE VERSUS FREQUENCY



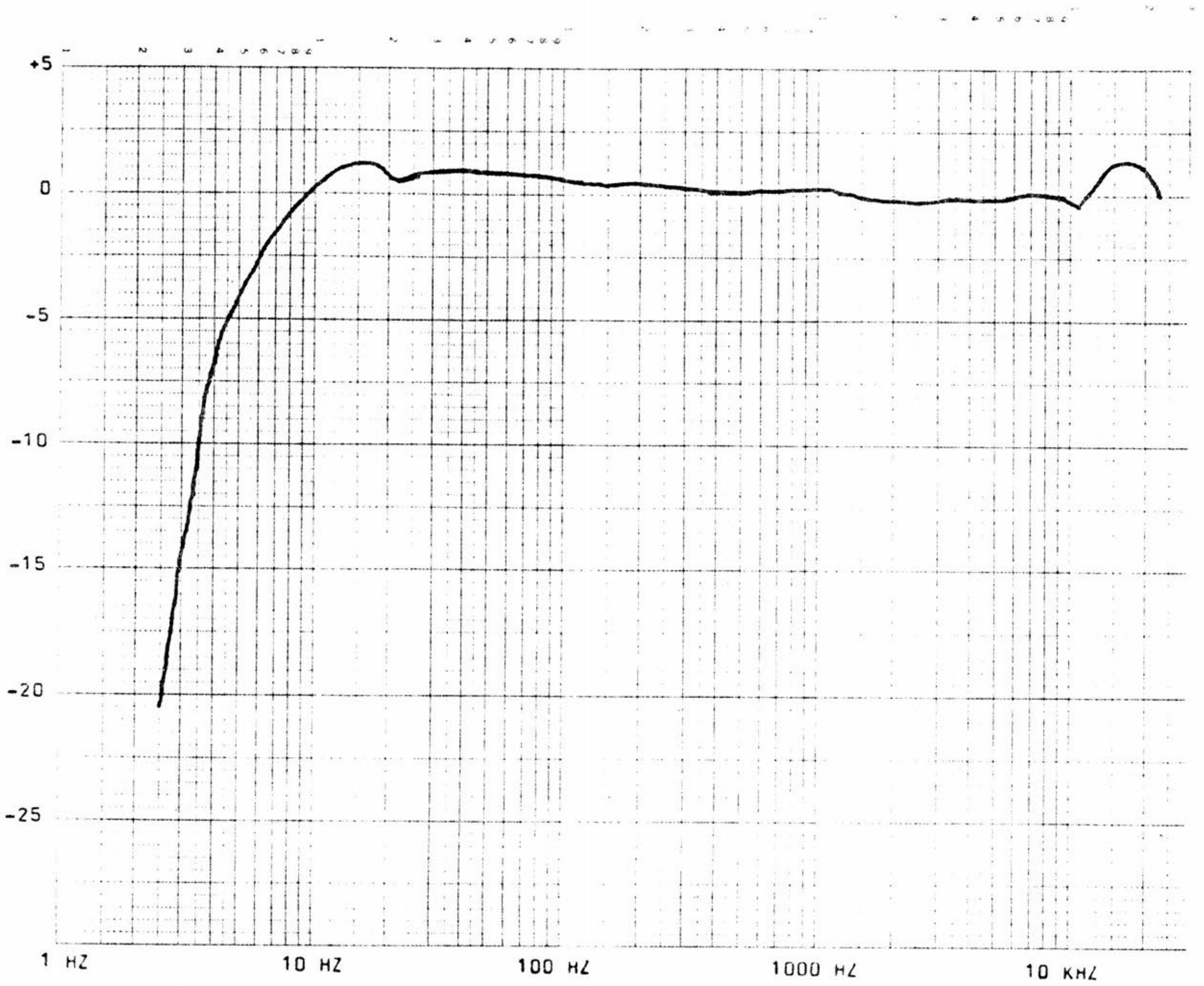
CHANNEL 24 MEP AMPLITUDE RESPONSE VERSUS FREQUENCY



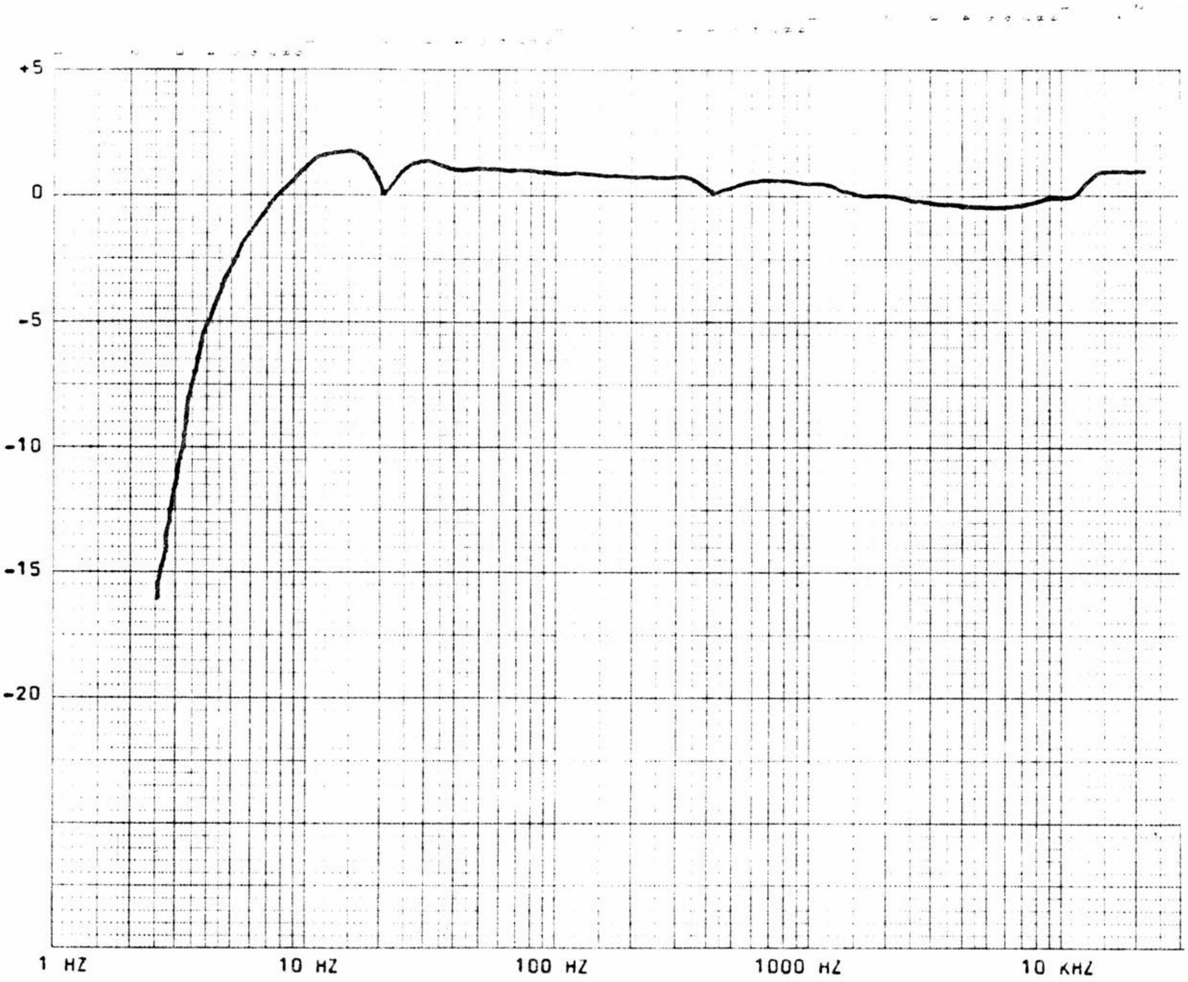
MBP MAXIMUM AMPLITUDE VARIATION BETWEEN UNITS



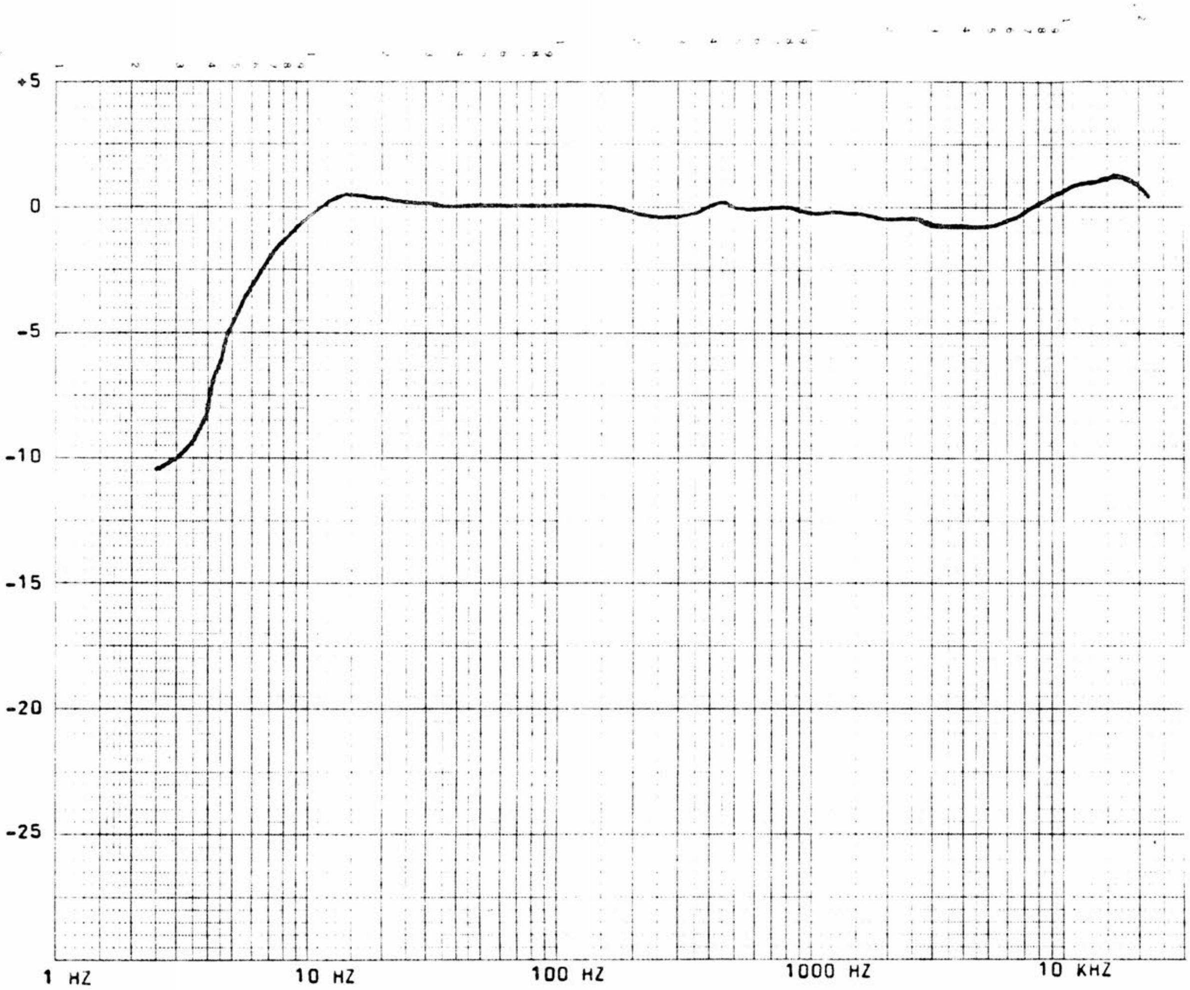
CHANNEL 21 ABP AMPLITUDE RESPONSE VERSUS FREQUENCY



CHANNEL 22 ABP AMPLITUDE RESPONSE VERSUS FREQUENCY

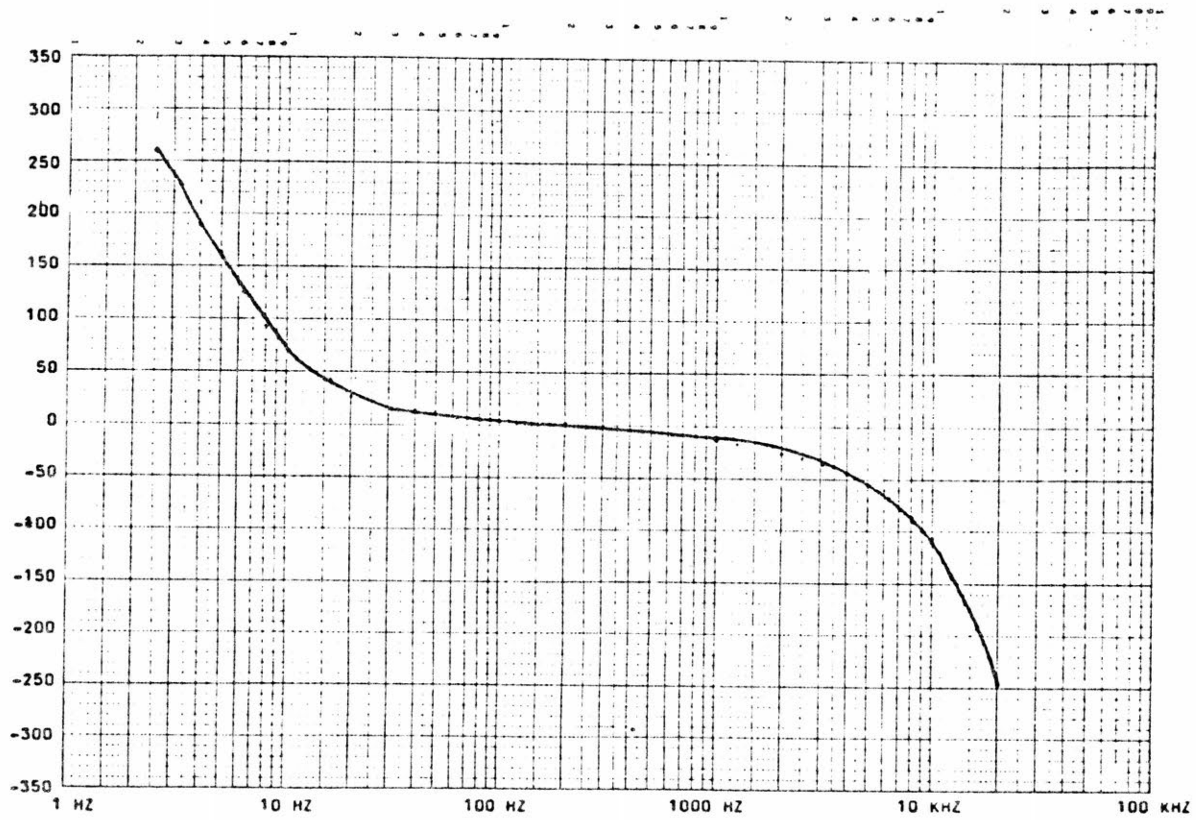


CHANNEL 23 ABP AMPLITUDE RESPONSE VERSUS FREQUENCY

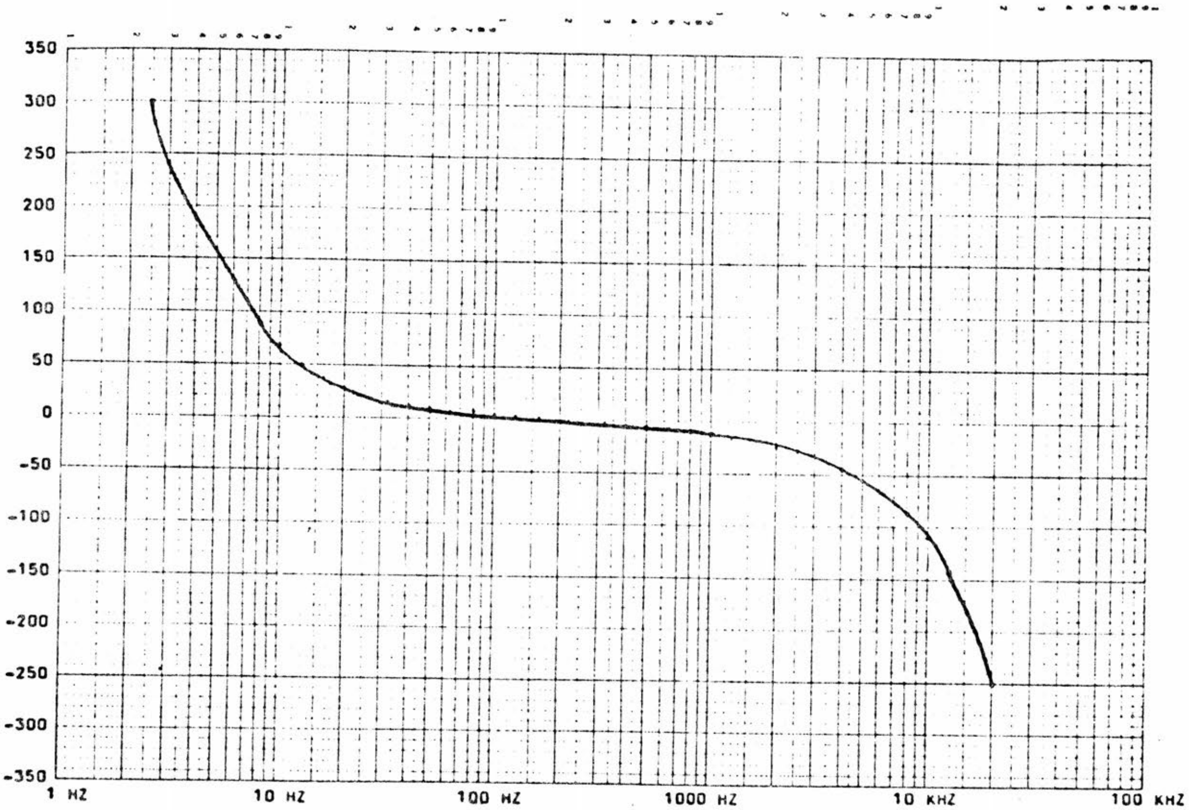


CHANNEL 24 ABP AMPLITUDE RESPONSE VERSUS FREQUENCY

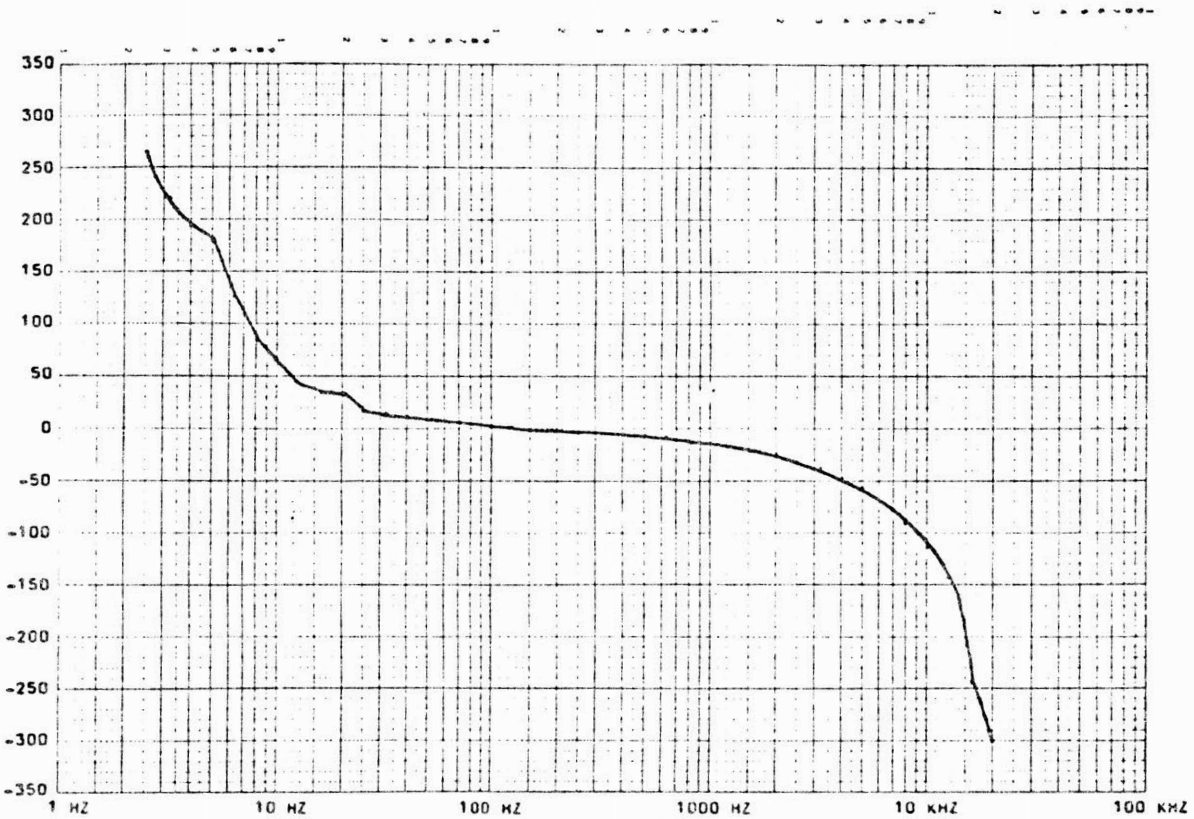
ABP MAXIMUM AMPLITUDE VARIATION BETWEEN UNITS



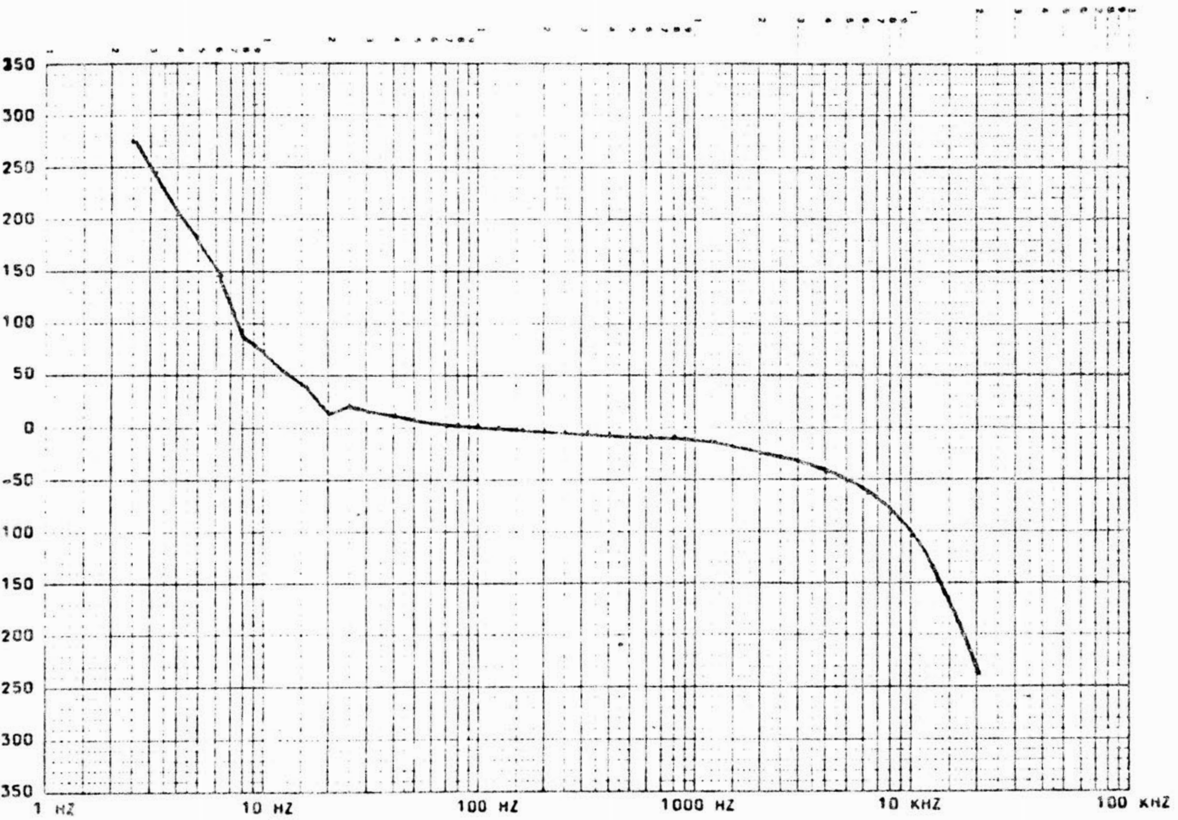
CHANNEL 21 ABP PHASE VERSUS FREQUENCY



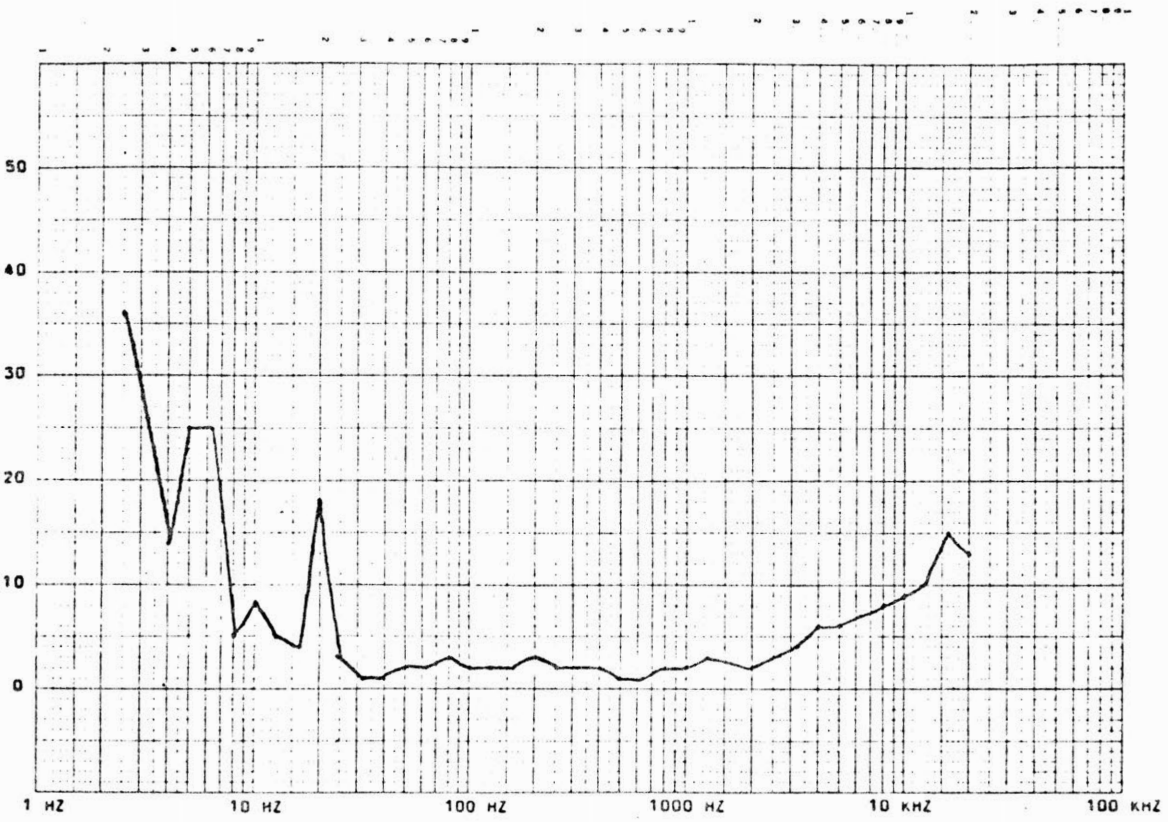
CHANNEL 22 ABP PHASE VERSUS FREQUENCY



CHANNEL 23 ABP PHASE VERSUS FREQUENCY



CHANNEL 24 ABP PHASE VERSUS FREQUENCY



ABP MAXIMUM PHASE VARIATION BETWEEN UNITS

LOW BAND PASS AMPLITUDES

FREQUENCY (hertz)	CHAN 21	CHAN 22	CHAN 23	CHAN 24
	(in db referenced to .155 volts rms)			
2.5	-21.0	-19.0	-18.0	-13.8
3.2	-15.0	-13.0	-11.0	-15.0
4.0	-9.0	-8.0	-6.0	-9.0
5.0	-4.8	-4.4	-2.8	-5.0
6.3	-3.3	-3.0	-1.3	-3.3
8.0	-2.0	-1.3	0.1	-1.7
10.0	-0.5	0.3	0.7	-0.3
12.5	-0.1	0.1	1.0	0.0
16.0	0.4	0.7	0.9	0.4
20.0	1.0	1.0	0.8	1.2
25.0	0.1	0.2	0.7	-0.1
32.0	0.3	0.3	0.8	-0.1
40.0	0.3	0.3	0.7	-0.1
50.0	0.3	0.3	0.0	-0.2
63.0	0.2	0.1	0.4	-0.3
80.0	0.1	0.0	0.4	-0.4
100.0	0.0	-0.1	0.3	-0.4
125.0	-0.1	-0.1	0.3	-0.4
160.0	-0.1	-0.2	0.3	-0.5
200.0	-0.1	-0.2	0.3	-0.5

250.0	-0.1	-0.2	0.3	-0.5
320.0	0.0	-0.1	0.4	-0.4
400.0	0.3	0.0	0.0	0.0
500.0	-0.8	0.0	-0.7	-0.5
630.0	-3.6	-3.3	-4.5	-4.0
800.0	-10.5	-9.9	-11.0	-10.8
1000.0	-17.3	-16.6	-18.0	-6.4

HIGH BAND PASS (MBP)

6300.0	-10.2	-10.1	-12.0	-10.0
8000.0	-4.0	-4.1	-5.0	-4.5
10000.0	-0.6	-1.2	-2.0	-1.4
11000.0	0.0	-0.6	-1.5	-0.8
12000.0	0.4	-0.4	-1.3	-0.4
13000.0	0.4	-0.2	-1.1	-0.2
14000.0	0.3	-0.1	-1.0	-0.2
16000.0	-0.1	-0.5	-1.3	-0.2
18000.0	-1.5	-1.8	-2.4	-1.7
20000.0	-4.0	-4.1	-4.4	-4.3

FULL BAND OUTPUT (ABP)

2.5	-20.0	-20.4	-16.0	-10.3
3.2	-14.0	-12.7	-9.8	-10.0
4.0	-8.0	-6.9	-5.0	-8.0

5.0	-4.0	-3.8	-2.5	-4.8
6.3	-2.7	-2.4	-1.1	-3.0
8.0	0.9	-0.7	0.3	-1.3
10.0	0.3	0.3	1.3	-0.3
12.5	0.5	0.8	1.5	0.3
16.0	0.9	1.0	1.5	0.4
20.0	0.6	0.5	-0.1	0.3
25.0	0.7	0.7	1.1	0.2
32.0	0.7	0.8	1.1	0.1
40.0	0.8	0.8	1.0	0.0
50.0	0.8	0.7	1.0	0.0
63.0	0.7	0.6	0.8	0.0
80.0	0.6	0.6	0.8	-0.1
100.0	0.5	0.4	0.7	-0.1
125.0	0.4	0.4	0.7	-0.1
160.0	0.3	0.3	0.6	-0.1
200.0	0.3	0.3	0.6	-0.4
250.0	0.3	0.2	0.6	-0.5
320.0	0.2	0.1	0.6	-0.4
400.0	0.0	0.0	0.0	0.0
500.0	0.3	0.0	0.4	-0.2
630.0	0.3	0.0	0.5	-0.2
800.0	0.2	0.0	0.4	-0.2
1000.0	0.1	0.0	0.4	-0.3
1250.0	0.1	-0.1	0.2	-0.3
2000.0	-0.3	-0.4	-0.1	-0.6

2500.0	-0.4	-0.4	-0.3	-0.7
3200.0	-0.4	-0.3	-0.4	-0.8
4000.0	-0.3	-0.3	-0.5	-0.8
5000.0	-0.3	-0.3	-0.5	-0.8
6300.0	0.0	-0.1	-0.5	-0.5
8000.0	0.3	-0.2	-0.2	0.1
10000.0	0.9	0.6	-0.2	0.7
12500.0	1.4	0.9	0.8	0.8
16000.0	0.7	1.1	0.8	1.0
20000.0	0.1	-0.1	0.8	0.3

PHASE OF OUTPUTS

(Degrees versus Frequency)

LOW BAND PASS (LBP)

2.5	292.0	335.0	321.0	271.0
3.2	254.0	243.0	244.0	243.0
4.0	209.0	201.0	199.0	201.0
5.0	168.0	163.0	163.0	163.0
6.3	135.0	130.0	126.0	135.0
8.0	101.0	96.0	91.0	95.0
10.0	75.0	71.0	68.0	73.0
12.5	58.0	54.0	50.0	52.0
16.0	42.0	39.0	36.0	38.0
20.0	32.0	31.0	21.0	34.0
25.0	21.0	18.0	16.0	18.0
32.0	12.0	10.0	9.0	10.0
40.0	6.0	6.0	4.1	5.0
50.0	1.2	0.0	-1.0	-0.1
63.0	-4.0	-5.0	-6.0	-6.0
80.0	-10.0	-10.0	-12.0	-12.0
100.0	-16.0	-16.0	-18.0	-17.0
125.0	-23.0	-24.0	-25.0	-24.0
160.0	-32.0	-32.0	-34.0	-33.0
200.0	-42.0	-42.0	-44.0	-42.0
250.0	-54.0	-53.0	-55.0	-54.0

320.0	-70.0	-70.0	-72.0	-72.0
400.0	-93.0	-92.0	-101.0	-95.0
500.0	-126.0	-126.0	-135.0	-130.0
630.0	-190.0	-188.0	-182.0	-176.0
800.0	-211.0	-209.0	-214.0	-211.0
1000.0	-233.0	-231.0	-235.0	-243.0

HIGH BAND PASS (MBP)

6300.0	84.0	88.0	81.0	81.0
8000.0	23.0	16.0	9.0	21.0
10000.0	-53.0	-59.0	-67.0	-56.0
11000.0	-90.0	-93.0	-100.0	-90.0
12000.0	-121.0	-120.0	-130.0	-120.0
13000.0	-148.0	-151.0	-156.0	-146.0
14000.0	-183.0	-181.0	-192.0	-180.0
16000.0	-244.0	-241.0	-250.0	-239.0
18000.0	-305.0	-299.0	-307.0	-298.0
20000.0	-361.0	-355.0	-354.0	-352.0

FULL RANGE OUTPUT (ABP)

2.5	260.0	300.0	264.0	275.0
3.2	229.0	223.0	220.0	246.0
4.0	190.0	188.0	191.0	202.0
5.0	161.0	157.0	180.0	182.0

6.3	125.0	122.0	125.0	147.0
8.0	91.0	89.0	86.0	89.0
10.0	70.0	68.0	65.0	73.0
12.5	52.0	50.0	47.0	52.0
16.0	40.0	38.0	36.0	39.0
20.0	26.0	29.0	33.0	15.0
25.0	22.0	20.0	19.0	22.0
32.0	16.0	15.0	15.0	16.0
40.0	13.0	12.0	12.0	12.2
50.0	11.0	10.0	9.0	9.8
63.0	8.0	8.0	7.0	6.5
80.0	6.0	8.0	5.0	4.6
100.0	4.0	4.0	3.0	2.5
125.0	2.5	2.0	1.3	0.8
160.0	1.3	0.6	-0.8	-0.7
200.0	1.3	-1.3	-2.0	-2.1
250.0	-1.1	-1.3	-2.7	-2.5
320.0	-2.1	-1.1	-3.4	-2.7
400.0	-4.3	-2.8	-4.7	-4.0
500.0	-5.0	-5.0	-6.1	-5.0
630.0	-8.0	-7.5	-8.0	-7.5
800.0	-10.0	-10.0	-11.0	-9.4
1000.0	-13.0	-13.0	-14.0	-12.0
1250.0	-18.0	-16.0	-17.0	-15.0
2000.0	-25.0	-24.0	-26.0	-24.0
2500.0	-30.0	-29.0	-32.0	-29.0

3200.0	-36.0	-36.0	-39.0	-35.0
4000.0	-44.0	-44.0	-49.0	-43.0
5000.0	-54.0	-54.0	-57.0	-51.0
6300.0	-68.0	-68.0	-71.0	-64.0
8000.0	-86.0	-87.0	-90.0	-82.0
10000.0	-109.0	-110.0	-113.0	-104.0
12500.0	-145.0	-142.0	-143.0	-135.0
16000.0	-193.0	-191.0	-195.0	-180.0
20000.0	-249.0	-250.0	-250.0	-237.0

MAXIMUM AMPLITUDE AND PHASE VARIATION BETWEEN UNITS

LOW BAND PASS (LBP)

FREQUENCY	MAXIMUM VARIATION	
	AMPLITUDE	PHASE
2.5	7.2	64
3.2	4.0	11
4.0	3.0	10
5.0	2.2	5
6.3	2.0	9
8.0	2.1	10
10.0	1.2	7
12.5	1.1	8
16.0	0.5	6
20.0	0.4	13
25.0	0.8	5
32.0	0.9	3
40.0	0.8	2
50.0	0.5	2
63.0	0.7	2
80.0	0.8	2
100.0	0.7	2
125.0	0.7	2
160.0	0.8	2
200.0	0.8	2

250.0	0.8	2
320.0	0.8	2
400.0	0.3	9
500.0	0.8	9
630.0	1.2	14
800.0	1.1	5
1000.0	11.6	12

HIGH BAND PASS (MBP)

6300.0	2.0	7
8000.0	1.0	14
10000.0	1.4	14
11000.0	1.5	10
12000.0	1.7	10
13000.0	1.5	10
14000.0	1.3	12
16000.0	1.2	11
18000.0	0.9	9
20000.0	0.4	9

FULL BAND PASS (ABP)

2.5	10.1	36
3.2	4.2	26
4.0	3.0	14

5.0	2.3	25
6.3	1.9	25
8.0	2.2	5
10.0	1.6	8
12.5	1.2	5
16.0	1.1	4
20.0	0.7	18
25.0	0.9	3
32.0	1.0	1
40.0	1.0	1
50.0	1.0	2
63.0	0.8	2
80.0	0.9	3
100.0	0.8	2
125.0	0.8	2
160.0	0.7	2
200.0	1.0	3
250.0	1.1	2
320.0	1.0	2
400.0	0.0	2
500.0	0.6	1
630.0	0.7	1
800.0	0.6	2
1000.0	0.7	2
1250.0	0.5	3
2000.0	0.5	2

2500.0	0.4	3
3200.0	0.5	4
4000.0	0.5	6
5000.0	0.5	6
6300.0	0.5	7
8000.0	0.5	8
10000.0	1.1	9
12500.0	0.6	10
16000.0	0.3	15
20000.0	0.9	13