Hoist Radio System for Deep Shafts

Prepared for

UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF MINES

by

Collins Commercial Telecommunications Division
Circuit Switching Systems Operation
Cedar Rapids, Iowa 52406

Rockwell International

FINAL REPORT

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16. Abstract

The inductive communication system was developed under this contract for use in the hoist of deep mines. This program was a four phase program with experimental dual frequency equipment resulting from Phase I, emergency single frequency equipment developed under Phase II, and equipment documentation required under Phase III. An additional emergency system was provided under Phase IV.

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FOREWORD

This report was prepared by Collins Commercial Telecommunications Division, Rockwell International, Cedar Rapids, Iowa under USBM Contract Number H0230034. The contract was initiated under the Coal Mine Health and Safety Research Program. It was administered under the technical direction of PM&SRC with Dr. H. Ken Sacks acting as the Technical Project Officer. Mr. Frank Pavlich was the contract administrator for the Bureau of Mines.

This is a summary of the work completed as part of this contract during the period June 1973 to June 1976.

This report was submitted by the author on 30 June 1976.

List of Illustrations

1. INTRODUCTION

An inductive communication system was developed for the United States Bureau of Mines under Contract H0230034. This program was originally a 3-phase program with experimental equipment resulting from Phase I, emergency equipment for rescue work developed under Phase II, and equipment documentation required in Phase III. A fourth phase was added to provide an additional emergency hoist system.

The inductive communication system is designed to provide reliable voice communications between the hoist operator and the hoist cage at all levels down to 10,000 feet. Dual frequency, FM transceivers, operating at 35 and 52 kHz were developed as experimental units under Phase I. The two signals are transmitted simultaneously and received by the dual frequency receiver which has decision circuitry to select the strongest signal. The communication system consists of two sets of transceivers, power supplies, station controls, and rope couplers, with one set used in the cage and the other in the hoist room.

Evaluation of the experimental units by the Bureau of Mines resulted in changes that are incorporated into the Phase II emergency system. These transceivers provide communications with a rescue capsule in emergency situations. The transceivers are self-contained units and include the sealed lead acid battery and handset, and operate at 52 kHz. An auxiliary speaker assembly provides additional volume when required. Improved circuit efficiency allows dry cell operation for emergency use. A battery charger, two rope couplers, and a carrying case completes the Phase II system.

Phase III includes incorporation of design changes resulting from the Phase II evaluation. A complete documentation package for fabricating all portions of the system was supplied during this program phase.

An additional emergency hoist communication system was supplied under Phase IV.

2. PHASE I (JUNE 1973 – JUNE 1974)

2.1 MEASUREMENT PROGRAM

2.1.1 Signal Strength and Noise Levels

A field trip to a deep hoist metal mine was made to perform impedance and propagation measurements to verify the proposed diversity approach to hoist communications.

A visit was made to the Hecla Mining Company in Wallace, Idaho, on August 24 and 25, 1973. The trip was coordinated with National Bureau of Standards personnel who conducted noise measurements at the same time. The Lucky Friday Mine was chosen because its hoist system is located on the surface and was deemed a typical metal mine. The equipment was installed and the measurements completed on a Saturday when the mine was nonoperational.

The measuring equipment included two ferrite toroids designed to obtain a measure of the characteristic impedance of the mine shaft and to measure signal strength as a function of depth. (See figure 1.) The toroid designed for use at the surface was capable of being tuned
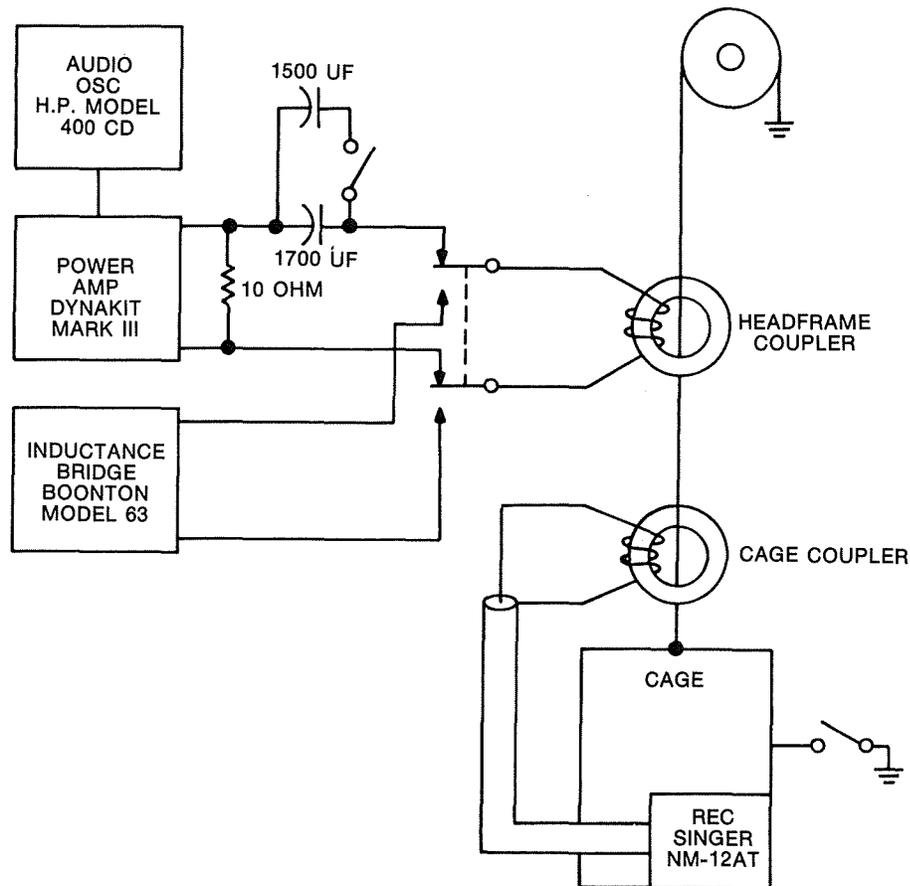

Figure 1. Signal Measurements Diagram, Lucky Friday Mine.

and untuned. It was series tuned at 36 kHz and 50 kHz for the signal strength transmissions and was left untuned for the input impedance readings as the secondary (hoist cable system) termination was changed. The toroid at the cage had a low impedance, untuned winding designed to operate into a 50-ohm load for picking up the two transmitted signals.

The surface toroid was placed around the cable just below the sheave wheel at the top of the 60-foot supporting structure. The other toroid was placed around the cable about 6 feet above the cage. Coaxial cable connected it to the receiver in the cage.

Input impedance measurements were taken with the cage shorted and unshorted at 36, 50, and 80 kHz for 6 depths: 0, 1450, 2000, 3050, 3650, and 4050 feet. Signal strength and noise measurements were taken at 36 and 50 kHz with the cage shorted and unshorted at the same depths.

The rf voltage across the termination of the power amplifier at the surface was kept constant at 10 volts. The power into the toroid was measured at 1.0 watt at 36 kHz and 0.7 watt at 50 kHz. Two types of measurements were made at each frequency. The signal strength at the cage was measured with the cage left floating (ungrounded), the normal arrangement, and with the cage shorted to ground conduit or metal framing at the stations. The residual noise level with no signal input was also measured under the two conditions. The results of these measurements were submitted in a report* to the TPO and are also summarized here.

An opportunity to obtain additional noise measurements in an operational mine occurred when a second trip to the Lucky Mine on 8 February 1974, to resolve mechanical mounting considerations, coincided with a trip by the National Bureau of Standards personnel for noise recordings at the mine. The same cage coupler used before was mounted above the cage and used to obtain noise at 35, 52, 75, and 100 kHz. The results of this trip were submitted in a report** to the TPO.

2.1.2 Signal Strength and Noise Level Results

The signal strength data from the first trip are plotted in figures 2 and 3. Figure 2 shows that the signal strength at 36 kHz for the unshorted (floating) cage continues to increase with depth from 2 millivolts at the 0 level to 8.5 millivolts at the 4050-foot level. Figure 3 shows that the 50-kHz signal for the unshorted cage increases from 3.2 millivolts at 0 level to a maximum of 11 millivolts at 3050 feet and then drops to 7 millivolts. These two plots indicate the existence of standing waves in the hoist shaft.

The shorted cage signal strengths are plotted on the same graphs and show an inverse characteristic with the signal strongest at the 0 level. Since the shorted cage condition will rarely, if ever, occur, it is of academic interest only.

The noise measurements taken in the nonoperating and operating mine for an unshorted cage are plotted in figures 4 and 5. The noise levels are converted to the proposed receiver 12-kHz bandwidth and indicate that during normal mine operations the levels are greater, which is to be expected. The input signal-to-noise ratio can be determined from the graphs and show that a minimum of 43 dB S/N can be expected at 35 kHz and 50 dB S/N at 52 kHz. These are

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*Report on the Lucky Friday Mine Measurements for the Deep Hoist Project, 11 January 1974.

**Noise Measurement at Hecla's Lucky Friday Mine for the Hoist Radio System for Deep Shaft, 12 February 1974.
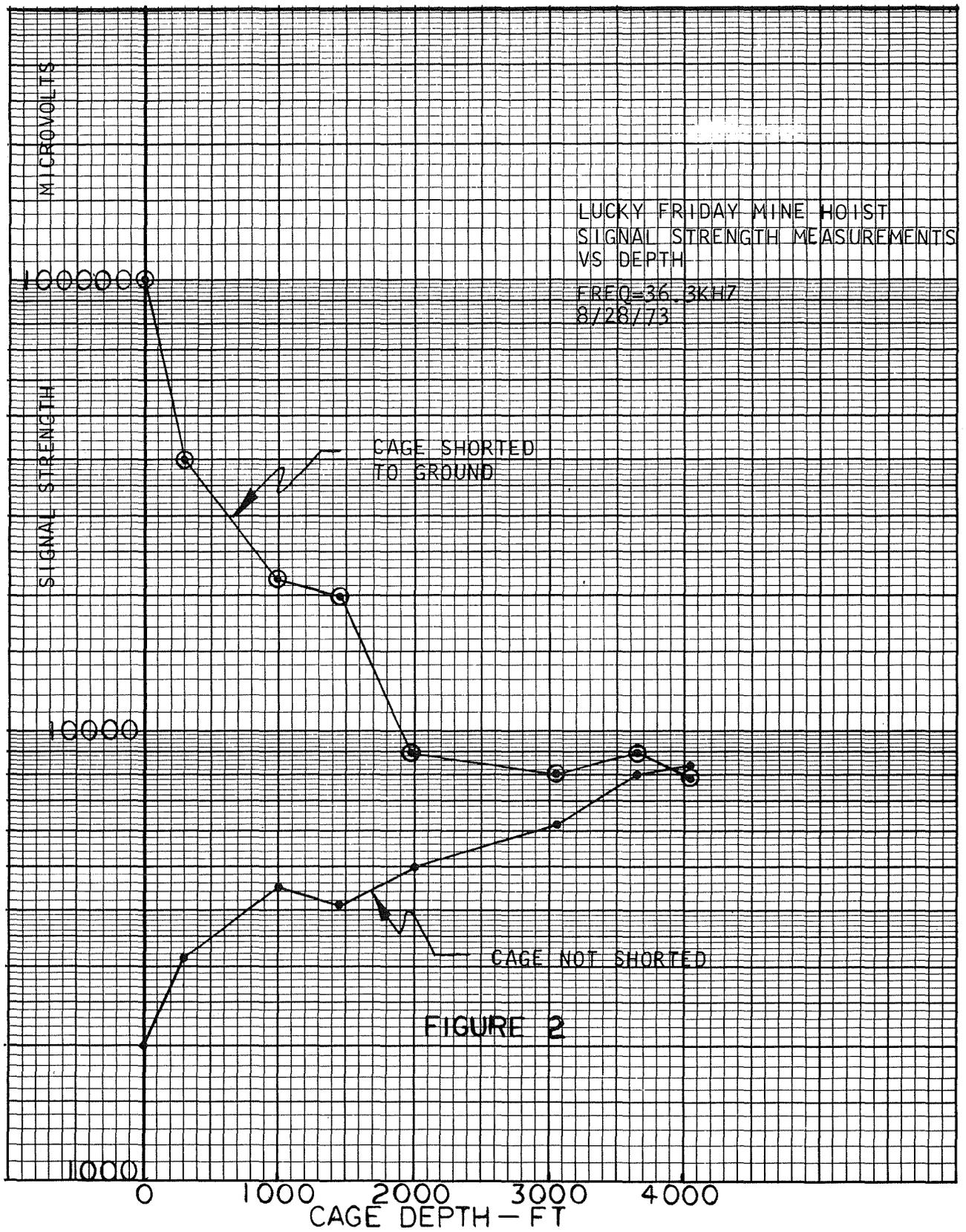
Figure 2.   Lucky Friday Mine Hoist, Signal Strength Measurements Vs Depth, Freq 36.3 kHz.

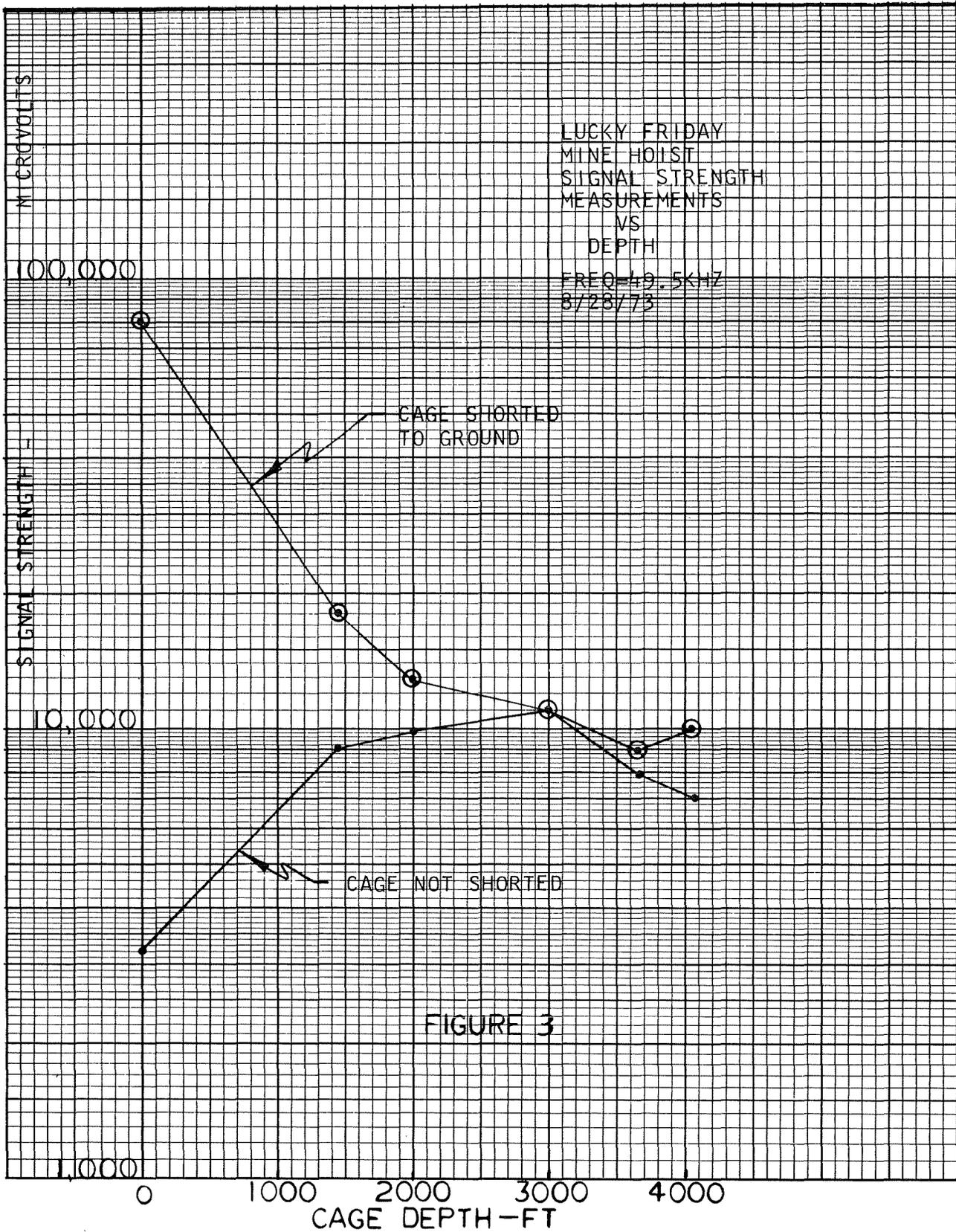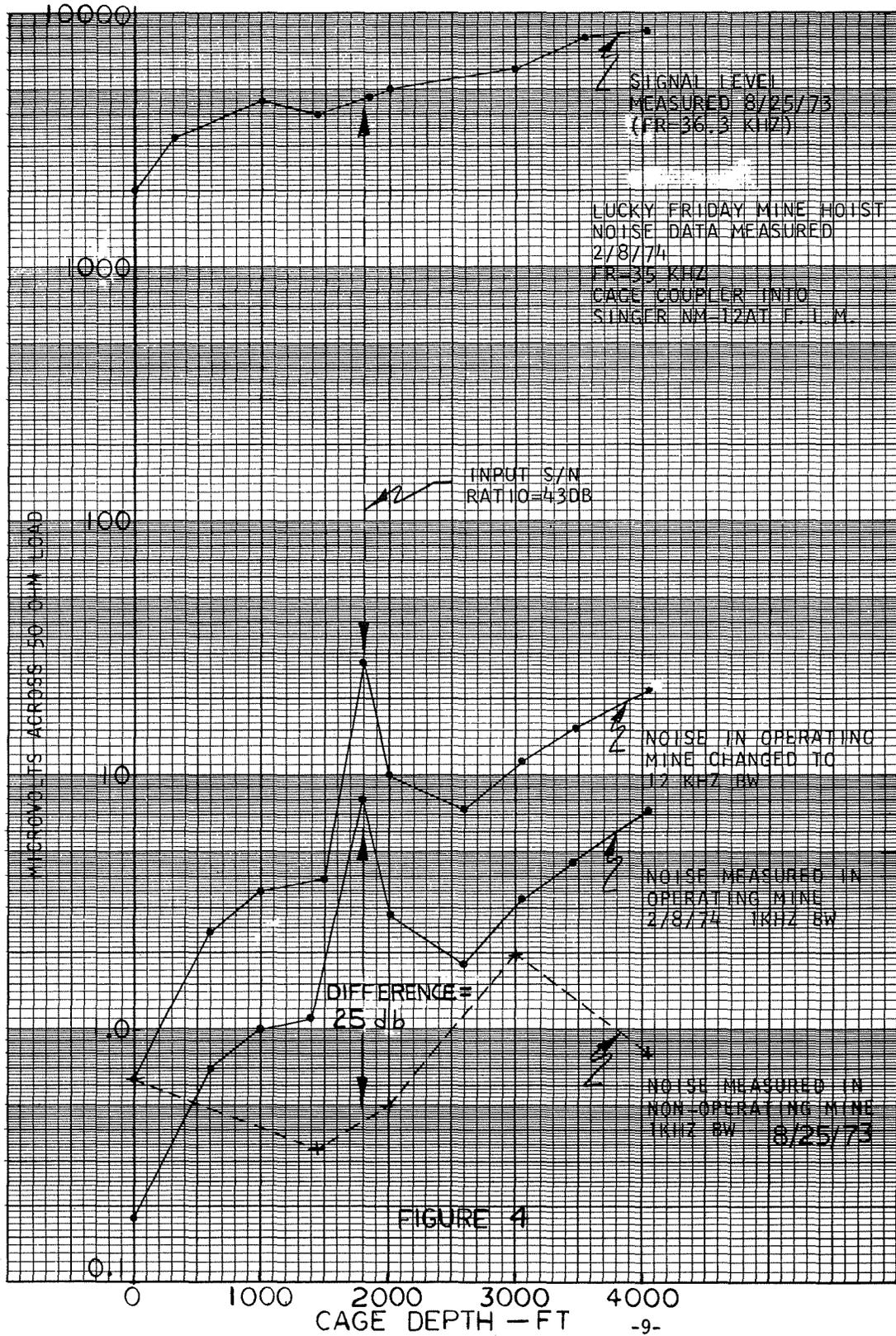Figure 3. Lucky Friday Mine Hoist, Signal Strength Measurements Vs Depth,
    Freq 52 kHz.

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Figure 4. Lucky Friday Mine Hoist, Noise Data Measured 2/8/74, Freq 35 kHz.

Figure 5. Lucky Friday Mine Hoist, Noise Data Measured 2/8/74, Freq 52 kHz.

more than adequate for good communications. This information was summarized for the TPO in a letter report*.

Figure 6 illustrates the received noise levels measured at 35, 52, 75, and 100 kHz as a function of depth in an operating mine and taken with the cage coupler. The worst case noise occurs near the 1000-foot level at 100 kHz. In addition to this steady-state noise, the National Bureau of Standards measured impulse noise (not shown) that occurred approximately 1 percent of the time, which would momentarily reduce the received S/N ratio.

2.1.3 Shaft Impedance Measurements

The hoist impedance measurements results were at variance with theoretical results. By determining the coupler equivalent T-circuit components values from open and short circuit measurements in the lab, the shaft impedance values could be calculated from the toroid input impedance measurements taken at the mine. These shaft impedances were then plotted on Smith charts for the various depths. The locus of points provides a means of determining the characteristic impedance of the shaft.

The chart values of characteristic impedance averaged 8 $\angle{-10°}$ ohms at 35 kHz and 20 $\angle{-50°}$ ohms at 50 kHz. Calculated characteristic impedances are in the order of 300 $\angle{0°}$ ohms based on the geometry of the shaft. This discrepancy was partly due to the lab reassembly of the toroid, which required considerable effort to reproduce the calibrated reading at the mine and raised doubt about the calibration procedure used.

At the time these measurements were being made, it was noted that the second cage alongside the one being measured (same shaft) was being used by the Bureau of Standards people and was at the bottom of the shaft during part of the day. Later in the day, it was in motion which affected the input impedance measurements to some unknown degree.

2.1.4 Measurements Program Conclusions

Signal strength measurements at the Lucky Friday Mine indicated the beginning of a standing wave pattern on the mine hoist system. This is to be expected, since any transmission line not terminated in its characteristic impedance will have standing waves. The termination of this line was the ungrounded cage, which represents a capacitive load to ground. Although the exact value of the characteristic impedance of the line remains doubtful, any attempt to terminate the line in its characteristic impedance would require cancellation of this cage capacity by coupling considerable inductance into the line. This would require an extremely large toroid. Furthermore, the cage capacity can vary, since at times, it was noted at the Lucky Friday Mine, an additional cage is attached or removed which could change the capacity by a factor or two. This would also vary from one mine to another. Any cancellation would hold at one frequency and for one capacity. Consequently, terminating the line in its characteristic impedance is impractical.

A better approach is to accept the hoist system as a line terminated in a varying capacity and to overcome the standing wave-null problem for very deep shafts with frequency diversity. It was shown at the mine that coupling into such a line can be accomplished simply, and that strong signal levels of 2 to 10 millivolts can be developed with a low power input of approximately 1 watt.

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*Letter Report to Dr. H. K. Sacks, dated 12 March 1974.
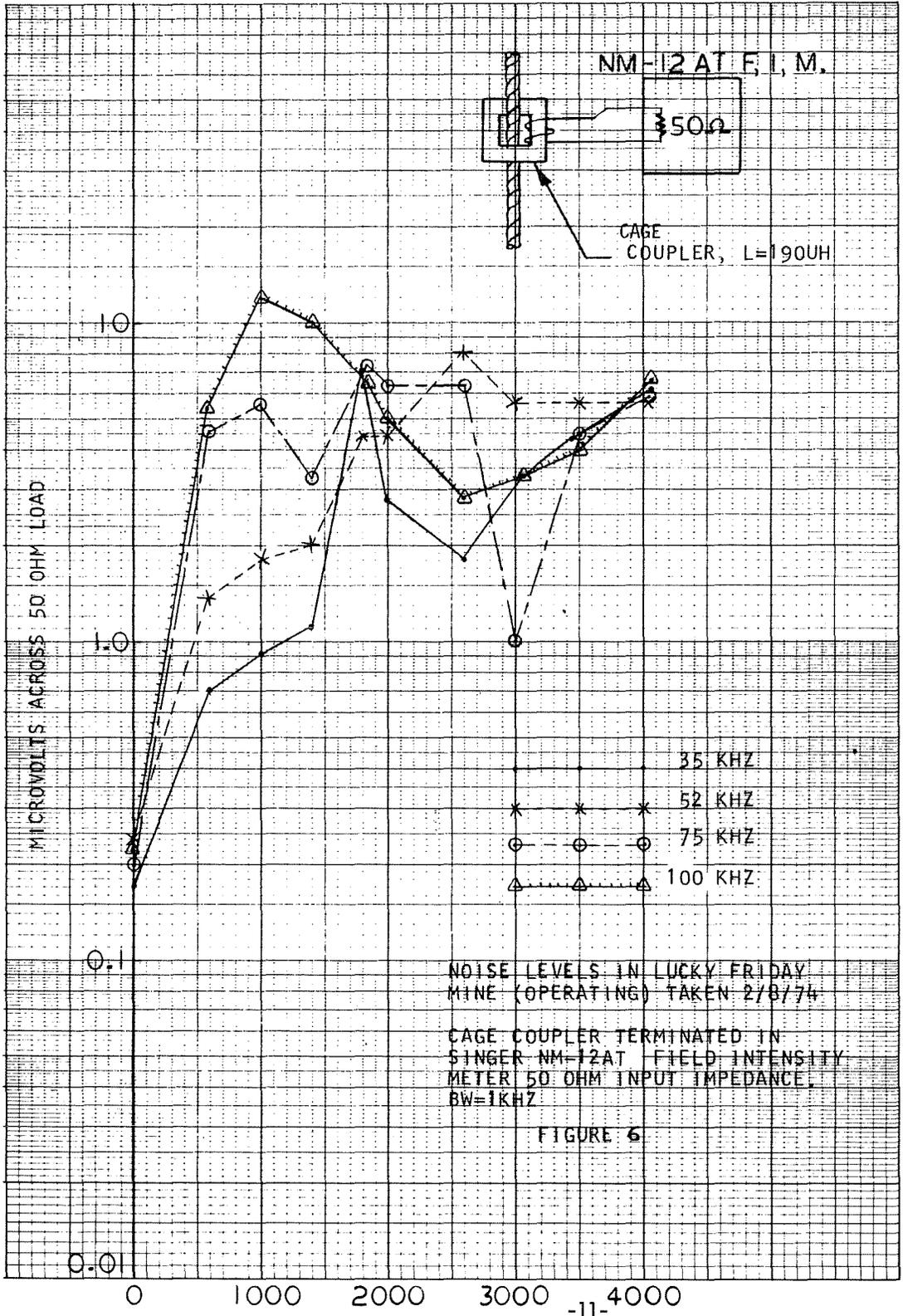
Figure 6. Noise Levels in Lucky Friday Mine (Operating) Taken 2/8/74.

2.2 PHASE I SYSTEM DESIGN

A possible loss of communications due to standing waves in the hoist shaft can be eliminated by transmitting two signals at different frequencies and receiving the strongest of the two signals. If the two frequencies are in the ratio of 1.5 to 1, a hoist cage position at a null for one frequency will be near the peak of the other frequency. The receiver selects the strongest of the two signals and gates it to the output speaker.

From an analysis of the cage characteristics, the received noise, and the received signal obtained from the Lucky Friday Mine measurement program, the frequencies of 35 kHz and 52 kHz were selected for the transceiver. This choice of frequencies eliminates harmonic interference problems when both signals are transmitted and received simultaneously. In addition, these frequencies avoid various military and government vlf stations that could cause interference such as Omega, New York; Omega, North Dakota; NAA, WWVL, etc.

The Phase I HCS-101 Hoist Communications System is composed of a hoist room station and a cage system. The hoist room station is shown in figure 7 and consists of a station control, upper left; transceiver, lower left; power supply/charger including battery, upper right; and the surface (headframe) coupler, lower right.

The station control speaker is normally squelched. When a transmission occurs from the cage, the squelch is broken and the cage operator is heard. The hoist operator picks up the handset, which disconnects the speaker, and communicates over the handset using the push-to-talk button.
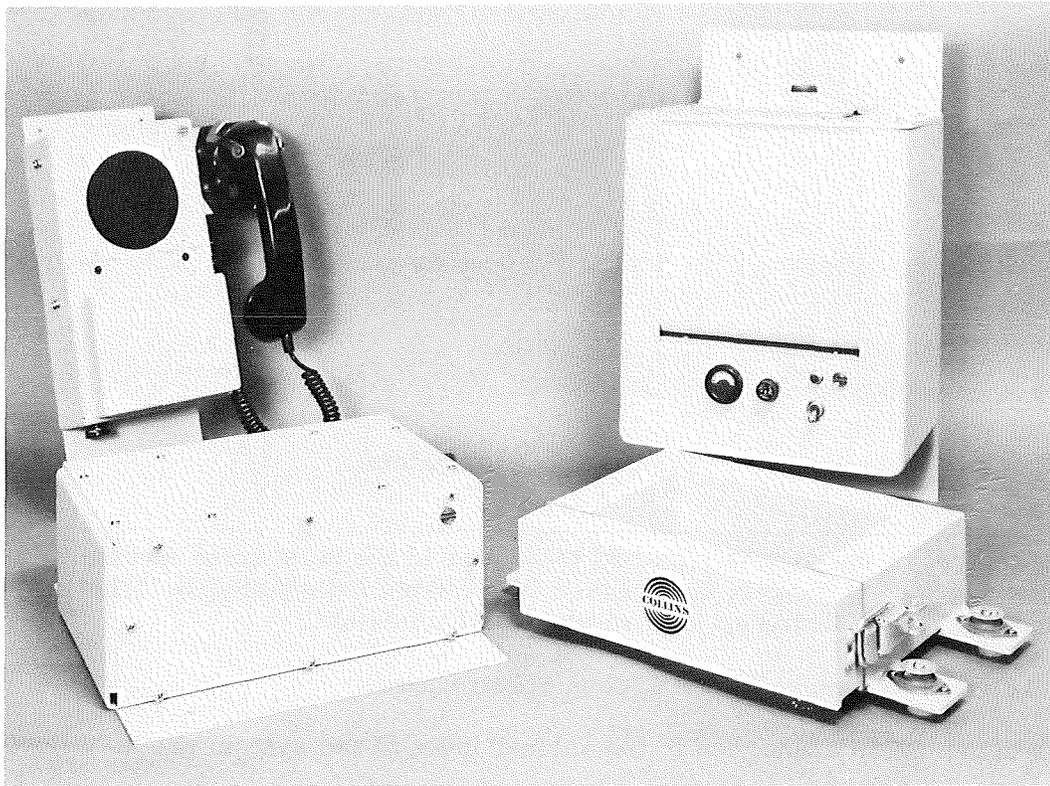
Figure 7. HCS-101 Hoist Room Station.

The battery sets in its holder above the power supply and is charged by the power supply/charger. After reaching full charge, the battery floats across the power supply under normal operation.

The cage system is shown in figure 8 and consists of the station control, upper right; the cage coupler, upper left; and the transceiver, lower right, mounted on a plate with the battery supply, lower left. In a typical installation, the station control is mounted inside the cage on the wall at a convenient height. The battery and transceiver can be mounted elsewhere in the cage or below it on a shelf. The battery must be readily accessible for replacement. The cage coupler is fastened to the rope above the cage with a built-in clamp.
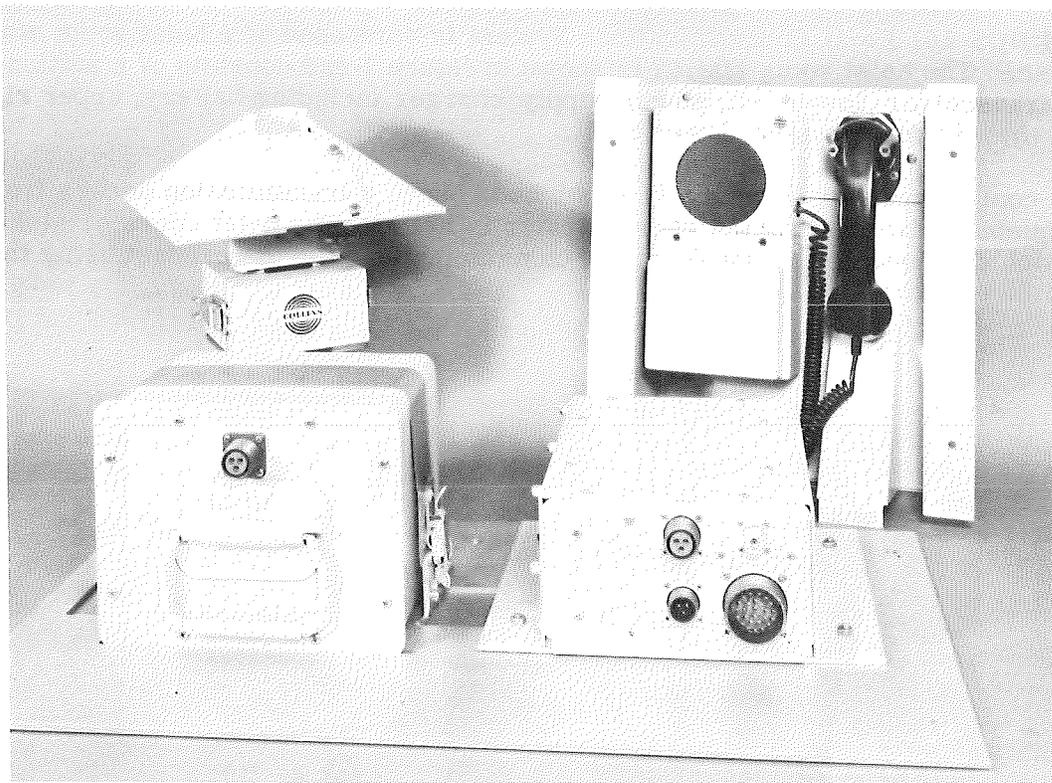
Figure 8. Cage System.

The station control in the cage is identical to the one in the hoist room and operation is identical. With the handset on hanger, the speaker is activated but squelched. When a transmission is heard, the handset is picked up for two-way communication.

2.2.1 HCS-101 Hoist Communication System Specifications

The Collins nomenclature assigned to the various units of the system are as follows:

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2.2.1.1 Hoist Room System (Figure 7)

a.   719L-1 Transceiver (lower left in picture)
b.   412X-1 Battery (part of upper right, shown in battery charger mount)
c.   962A-1 Power Supply/Battery Charger (part of upper right assembly)
d.   377H-1 Station Control (upper left)
e.   444E-1 Headframe Coupler, and Mounting Plate (lower right, plate not shown)
f.   Interconnect Cables consisting of control cable, power cable, and coupler coaxial cable (not shown)

2.2.1.2 Cage System (Figure 8)

a.   719L-1 Transceiver (lower right in picture)
b.   412X-1 Battery (lower left)
c.   377H-1 Station Control, mounted in cage bracket (upper right)
d.   444E-2 Cage Coupler (upper left)
e.   Interconnect cables consisting of control cable, power cable, and coupler coaxial cable (not shown)
f.   Mounting plate for transceiver and battery (bottom of picture)

The electrical and mechanical specifications of the HCS-101 are listed below:

General:

Frequency:	Dual diversity system, 35 kHz and 52 kHz.
Modulation:	Narrow-band FM (12F3), ±3-kHz deviation.
Supply voltage:	Battery operated (25 AH). Nominal 12.0 V dc. Power supply/charger, 115 V ac, 60 Hz, single-phase capable of operating radio and charging battery.
Temperature range:	-20 °F to 120 °F (-30 °C to +50 °C).

Nominal current (12 V dc).

Transmit:

High power:	(10 W/channel) -4.2 A.
Medium power:	(5 W/channel) -2.7 A.
Low power:	(2 W/channel) -2.1 A.

Receive:

Squelched:	250 mA.
Speaker output:	650 mA.

Receiver:

Diversity:	Receives on 35 kHz and 52 kHz simultaneously.
Audio switching:	Voting logic allows strongest signal to provide audio output.

Sensitivity:	10 microvolts for 20 dB quieting, each channel.
Squelch:	Operates at 10 microvolts with minimum of 40 dB of quieting range.
Input impedance:	50 ohms.
Bandwidth:	14 kHz at 6-dB points.
Selectivity:	60 dB at ±20 kHz.
Frequency stability:	±0.25 percent.
Audio output:	5 watts into 8-ohm speaker; 0 dBm into 600-ohm handset earpiece.
Audio distortion:	5 percent distortion at 5 watts output.
Spurious and image rejection:	60 dB down; 80 dB down at 88, 100, 115, and 145 kHz

Transmitter:

Diversity:	Two frequencies, 35 kHz and 52 kHz, transmitted simultaneously.
Power output:	10 watts per channel.
Output impedance:	50 ohms.
Audio input impedance:	150 ohms.
Audio input level:	250 millivolts to 2.5 volts.
Audio response:	+1 dB to -3 dB from 300 to 3,000 Hz.
Frequency stability:	±0.25 percent.
Spurious and Harmonic emission:	-35 dB from carrier; frequencies at 88 and 100 kHz: 60 dB down.
Alarm capability:	Audio tone automatically transmitted.

Mechanical:

719L-1 Transceiver

Size:	4.5 x 11 x 7.8 inches.
Weight:	14 pounds.

962A-1 Power Supply/Battery Charger

    Size: 8.5 x 9.4 x 16.5 inches.

    Weight: 41 pounds.

412X-1 Battery (25AH)

    Size: 7.3 x 9.3 x 7.3 inches.

    Weight: 26 pounds.

377H-1 Station Control

    Size: 13 x 5.5 x 4.1.

    Weight: 5 pounds.

444E-1 Headframe Coupler

    Size: 8 x 12 x 3 inches.

    Weight: 10.5 pounds.

444E-2 Cage Coupler

    Size: 10.1 x 10.1 x 9 inches.

    Weight: 9.5 pounds.

2.2.2 Transceiver, Type 719L-1

The transceiver contains two receivers and two transmitters, operating at 35 kHz and 52 kHz. Figure 9 is a block diagram of the receiver. The receiver rf input from the coupler feeds through a bandpass filter into a common rf amplifier stage. The 35-kHz signal is fed into a balanced mixer and is mixed with a 420-kHz crystal injection. The resulting 455 kHz is amplified and filtered by a 12-kHz bandwidth mechanical filter. After additional amplification, the signal is demodulated and the resulting audio amplified to a 5-watt output level. The 52-kHz signal is fed to an identical strip for mixing, amplification, and detection. The noise from the detectors is passed through high-pass filters, rectified, and compared in a comparator circuit. The channel with the strongest signal-to-noise ratio is switched to the audio amplifiers. This circuit also acts as a squelch until a 20-dB signal-to-noise is obtained in either channel.

The transmitter block diagram is shown in figure 10. The microphone audio is fed to a compressor stage, which accommodates a wide range of input levels. The audio is then clipped and passed through a low-pass filter into the oscillator stages. The audio frequency modulates the three crystal oscillators using variable-capacitance diodes to pull the crystals the desired 3-kHz deviation. The 10-MHz injection is mixed with the 10.035 kHz input to provide the difference frequency of 35 kHz. It is also used to mix with the 10.052-kHz signal to produce the 52-kHz signal. Each resulting frequency is then amplified by a driver and PA stage. A combiner network feeds each signal into a common load without interaction and provides attenuation to the harmonic frequencies.
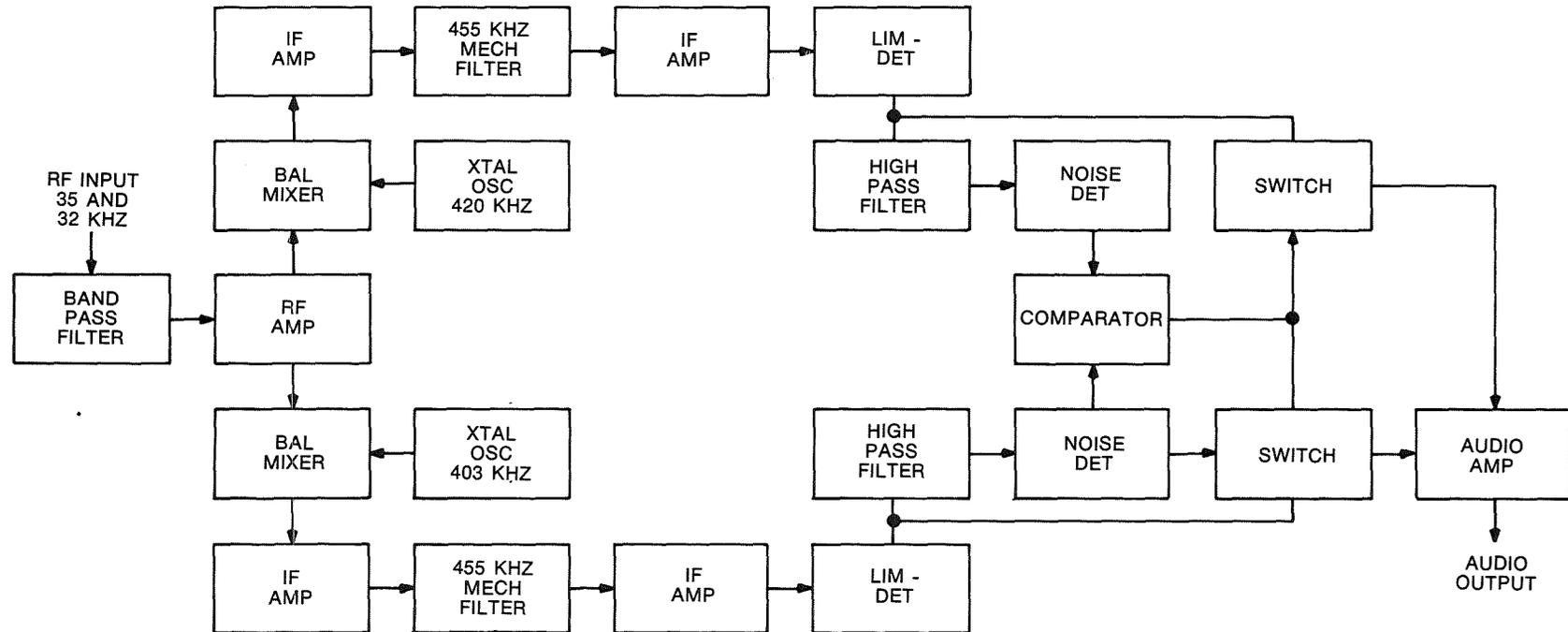
Figure 9. Phase I Hoist Receiver, Block Diagram.
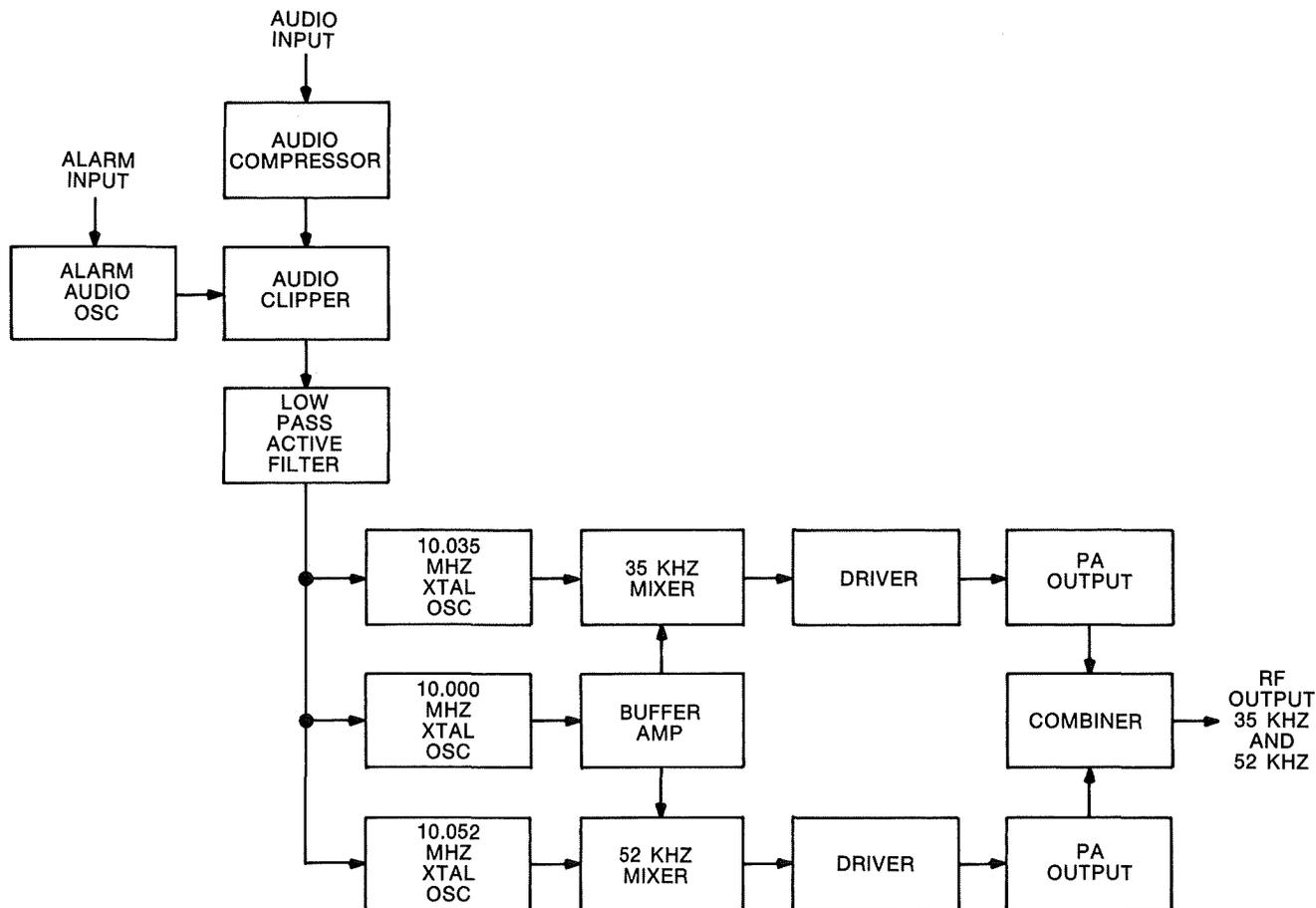
Figure 10. Phase I Hoist Transmitter, Block Diagram.

2.2.3 Station Control, Type 377H-1

The station control block diagram is shown in figure 11. The power on and low voltage
indicators are visible above the cover plate. When the 12-volt battery voltage drops to 10
volts, the low-voltage indicator lights as a warning to change batteries. A hinged cover allows
access to the on-off switch and special controls/indicators that are either set once or else
are used for Phase I test purposes. The set-once controls include volume controls for the
speaker and the handset. A self-test button allows the receiver to be turned on while trans-
mitting, allowing the operator to hear himself, thereby providing a quick test to show that
both the receiver and transmitter are in operating condition. Other test functions include
squelch override switches, channel indicators, channel select switch and a transmit power
level switch. These are used primarily for troubleshooting the radio. Two connectors are
available for a remote speaker or a remote handset. When the low-voltage light indicates a
battery change, the cage battery is removed and switched with the battery in the hoist room
power supply.

2.2.4 Power Supply/Battery Charger, Type 962A-1

The power supply/charger block diagram is shown in figure 12. A full wave rectifier operates from a 115 V ac, 60-Hz power source. The voltage is regulated to provide a constant voltage charging source. As the battery voltage rises, the current decreases to a trickle charge.

2.2.5 Battery, Type 412X-1

The sealed lead-acid rechargeable battery is contained inside a case provided with a connector. The battery consists of six 2.0-V dc 25 AH cells connected in series to produce 12.0 V dc. A thermal breaker limits the short-circuit current to a few amperes before opening and will cycle until the short is removed. The cells are sealed and will never require liquid addition.

2.2.6 Headframe Coupler, Type 444E-1

Toroids that encircled the rope were used to couple the rf signal from the transceiver to the hoist rope at the surface and at the cage. The coupling system was approached as two transformers coupled together with a single-turn link using coupling coefficient and mutual inductance concepts. The single-turn link contains an impedance that represents depth variations. The toroidal transformers were designed as parallel tuned circuits with a loaded Q of one. This low Q is at an impedance level of 50 ohms, which permits the use of 50-ohm coax without further transformation. Impedance matching is desirable since long transmission lines are involved between the surface transformer and the hoist room. For example, lengths of 400 feet or more may be required. If this line is properly terminated, then its insertion loss would be small, approximately 0.7 dB for 400 feet at 50 kilohertz. This low Q approach also allows a match at both 36 and 52 MHz, since the 3-dB bandwidth includes these frequencies.

The rectangular headframe coupler is composed of 8 bars of ferrite, Ceramag 5N material, clamped together at their adjacent corners into a U-shaped configuration onto which the coil is wound. This 3-sided coil is then installed in an aluminum cover made up of three sections of 5/32-inch aluminum extrusion, mitered and fusion welded at the corners. In the finished assembly, the coil is encapsulated in rigid foam for vibration damping and environmental integrity.

The fourth side of the core is the removable section and is a flat ferrite bar supported by rubber inside a single section of extrusion. Quick release latches, aided by guide pins for locators, are used to facilitate the assembly of the fourth side to the 3-sided coil. As the latches are closed, the ferrite bar places the silastic in compression, resulting in a highly
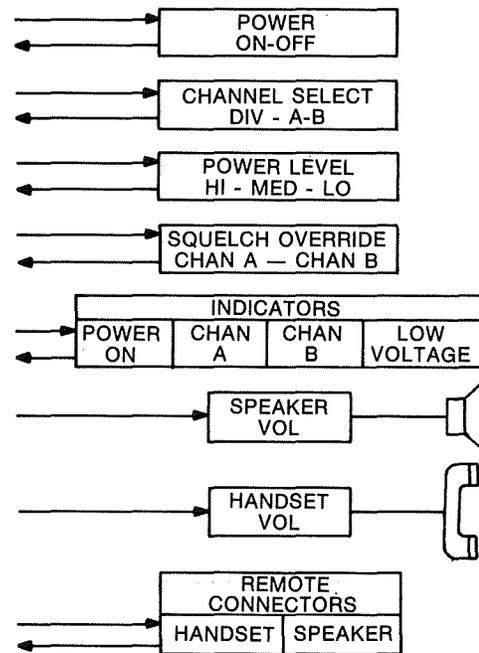
Figure 11. Phase I Station Control, Block Diagram.
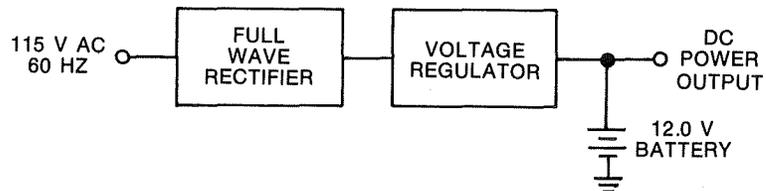
Figure 12. Phase I Power Supply/Battery Charger, Block Diagram.

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reliable contact between sections of the core. A flat neoprene gasket provides the environmental seal between the two sections of the coupler cover.

2.2.7 Cage Coupler, Type 444E-2

The cage coupler is identical to the headframe coupler except for size and the addition of a hood for protection from falling rocks. Quick release latches are used to allow the fourth side to be removed to allow positioning around the cable. A hinged bar with a thumb nut arrangement clamps the coupler to the cable. The hood also has a hinged plate to allow cable placement. Coaxial connectors Type N are used to connect the couplers to the transceiver antenna coax cable.

2.3 PHASE I SYSTEM DELIVERY

The HCS-101 Hoist Communication System was shipped to the Bureau of Mines TPO late June, 1974, as field testable units. An instruction manual was sent with the equipment and includes instructions on installation, operation, principles, service, and specifications. A set of schematics are also included.

Acceptance test data taken on the equipment was submitted to the TPO. This data included temperature and humidity tests.

The transceivers were returned in late August for postcoating and circuit modification prior to installation in the Lucky Friday Mine. The transceiver circuit cards were coated with an epoxy material, Dennis 1169, for additional protection against a humid environment. In addition, the slack rope alarm circuit was modified to allow a 1-second on, 5-second off duty cycle so that voice communication between the cage and the hoist room could be maintained during the alarm period.

The hoist communication system was installed in the Lucky Friday Mine near Wallace, Idaho, by the Bureau of Mines in September 1974.

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3. PHASE II (January 1975 - July 1975)

3.1 BUREAU OF MINES PHASE I EVALUATION MEETING

The Bureau of Mines conducted an evaluation of the field testable HCS-101 Hoist Communication System, delivered under Phase I of the contract. As a result of this evaluation, certain modifications appeared desirable. Consequently, a joint meeting with personnel from Collins and Arthur D. Little, Inc. was held at the Pittsburgh Mining and Safety Research Center, Pittsburgh, Pennsylvania, on 7 November 1974, concerning the Phase II objectives. The results of the meeting are summarized as follows:

a. The hoist system must be designed primarily for use with an emergency rescue capsule with general hoist-cage communication secondary. Consequently, portability, self-containment, and battery life are paramount objectives. Handset operation for a period of 8 to 12 hours with a 50-percent duty cycle is desired, using 12 V dc dry cells for power.
b. Since rescue operation with the capsule goes down to 2,000 feet and today's deepest mine shaft is 5,000 feet, diversity operation is not necessary. A frequency of 300 kHz was considered as a possible hoist frequency. This higher frequency could increase rope signal strength but noise pickup might be increased by a greater level resulting in a lower received signal-to-noise ratio. The first null would occur around 1,600 feet. Since 35 and 52 kHz has been demonstrated to work and circuitry is designed, it was agreed to remain with the higher of the two frequencies, 52 kHz.
c. Coupler efficiency should be increased, if possible, to reduce the transmit power thereby increasing battery life.
d. Antenna connections should be spring loaded type terminals instead of N-type connectors.
e. The power source should be standard lantern type dry cell batteries that can be easily obtained anywhere.
f. Labeled terminal strips should be provided behind a removable panel in case of connector breakage.
g. A handset should be used with the transceiver eliminating the speaker.
h. Connectors to be used are: Deutsh Type DM9702-197S for handset and type DM9601-197P for transceiver.
i. A method of hanging the transceiver and battery package between the slings of a rescue capsule and on a standard hoist cage should be provided.
j. The 250 mA of standby current should be reduced if feasible.
k. Two complete units are required including fiber-glass packing cases and a maintenance plan.

It was agreed that Collins would provide a Phase II design plan embodying the modifications requested by MESA and discussed at the meeting.

3.2 PHASE II DESIGN PLAN

The Phase II Design Plan for Hoist Radio System for Deep Shafts, dated 10 December 1974, was submitted to the Bureau of Mines. The plan proposed a transceiver designed for emergency use with a rescue capsule. The 52-kHz transceiver would be in a single package containing the batteries and handset with optional speaker operation.

It was recommended that sealed lead acid storage batteries be used as the primary power source and that dry cells be used as an emergency backup only because dry cells have extremely low A-H capability at low temperatures. Dry cells will provide 9.8 hours of use on a 50-50 duty cycle at +70 °F but only 36 minutes at -20 °F. In comparison, 5 A-H storage batteries will provide 35 hours at +70 °F and 19.3 hours at -20 °F.

Developmental efforts would be concentrated on minimizing current drain in both receive and transmit by redesigning the various stages.

The objective would be to reduce the receive current to approximately 35 mA and the transmit current to approximately 250 mA. This transmit power is expected to produce a coupler current comparable to that presently obtained at the 10-watt level in Phase I. Considerable effort would be directed toward this power amplifier-coupler interface where maximum induced rope voltage with the minimum amount of dissipation is desired. This would require an investigation into different coupler ferrite permeabilities and shape factor in order to improve the coupler efficiency over the Phase I type.

Major mechanical design changes include a different mechanical package with a new card cage and three printed circuit boards replacing the Phase I metal circuit boards.

The design plan was reviewed by the Bureau of Mines. It was requested that the following modifications be implemented into the design plan.

a. That PC boards be wired into cabling rather than use PC connections because of poor reliability of edge-on type connectors.
b. Address problem of squelch break of Phase I receiver.
c. Use of a special terminal strip that would provide access to the antenna, mike, and external speaker without exposing circuitry.
d. The antenna, speaker, and handset connectors should be placed on a removable plate so that they may be changed if desired.
e. An eye-bolt or other strain relief be provided for antenna wire.
f. Provide a charger and charging jack for the rechargeable battery.
g. Boards should be coated and system must be rainproof.
h. Environmental testing should include rapid temperature cycling.

These changes were agreed upon and the development of the Phase II Hoist Communication System proceeded.

3.3 PHASE II SYSTEM DESIGN

Evaluation of the Phase I experimental units resulted in changes that were incorporated into the Phase II emergency units. These transceivers provide communications with a rescue capsule in emergency situations. The transceivers are self-contained units that include the sealed lead-acid battery and handset, and operate at 52 kHz in the FM mode. An auxiliary speaker assembly provides additional volume at the surface unit when required. High circuit efficiency allows dry cell operation for emergency use. A battery charger, two rope couplers, and a carrying case completes the Phase II system.

The Phase II HCS-102 Hoist Communications System is composed of seven units as shown in figure 13. The two transceivers are shown in front of the carrying case and are identical. The speaker assembly is shown between the transceivers. At the bottom left is the battery charger for the rechargeable batteries inside the transceivers. The large surface coupler is located in the foreground with the small circular capsule coupler at the bottom right. An elliptical type coupler was developed later for use around double-backed rope arrangements.

In a typical emergency capsule situation, the small coupler would be fastened to the rope above the sling of a capsule. The transceiver would be tied within the sling, just above the top of the capsule. Holes and handles in the transceiver would allow a tie-down, probably upside down to protect the connectors. A special cable would connect the handset connector to the connector existing on the top of the capsule. The handset would then be the only item inside

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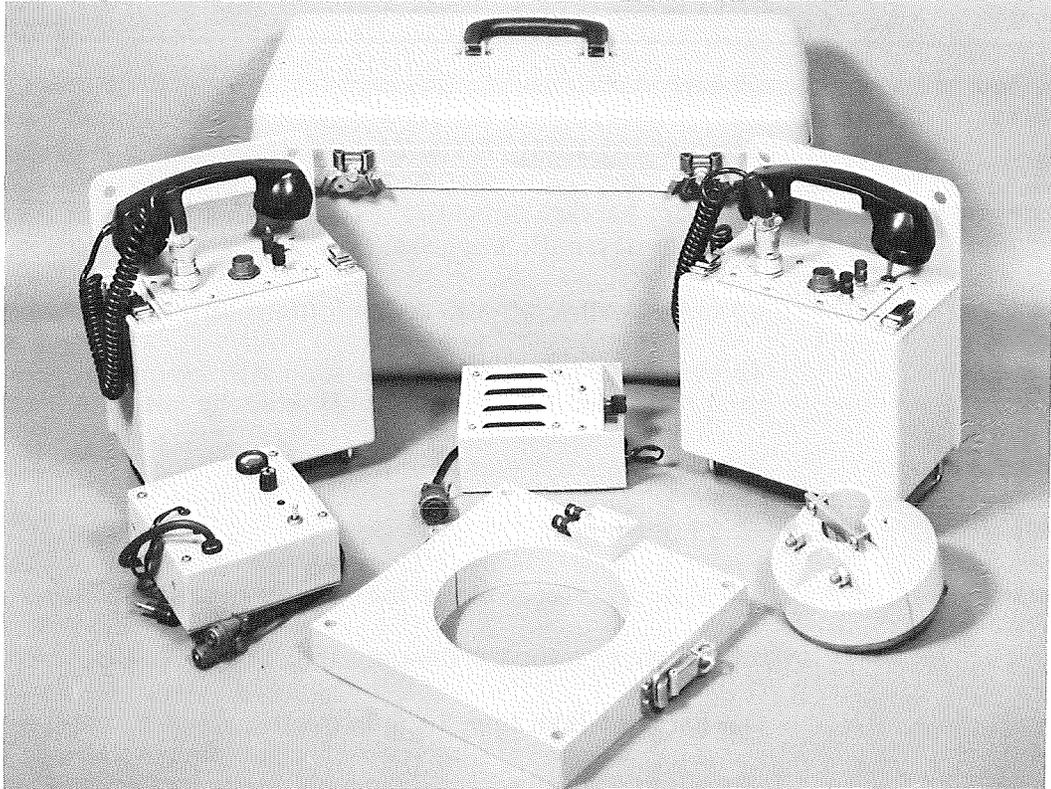
Figure 13. HCS-102 Hoist Communication System.

the capsule with the operator. With the unit on continuously, the operator would maintain constant communications with the surface using his push-to-talk handset.

On the surface, the large coupler is mounted above the shaft and around the rope in a manner dependent upon circumstances. Holes in each corner allow the use of a rope tie-down, depending upon the condition of the shaft at the time of the emergency. The transceiver can rest on the ground with the operator in constant contact with the capsule using the handset. The external speaker can be attached if additional people wish to hear both sides of the conversation.

3.3.1 HCS-102 Hoist Communication System (Emergency) Specifications

The Collins nomenclature assigned to the various units of the HCS-102 Hoist Communication System are as follows:

a. 719L-3 Transceiver
b. 962A-2 Battery Charger
c. 959L-1 Speaker
d. 444E-3 Headframe Coupler
e. 444E-4 Cage Coupler
f. 28N-2 Carrying Case

The electrical and mechanical specifications of the HCS-102 are listed below:

Electrical

Frequency:	52 kHz
Modulation:	Narrow-band FM (12F3) ±3-kHz deviation.
Supply voltage:	12 V dc, battery operated. 5 AH sealed lead acid battery or 12-V dc dry cell, Burgess Type TW2 or equivalent.
Current drain:	35 mA standby; 35 mA receive (handset); and 210 mA transmit.
Operating time:	42 hours (50% RX, 50% TX, with 5 AH battery). 95 hours (10% RX, 10% TX, 50% standby with 5 AH battery).
Transmit power output:	0.5 watt into 4.7-ohm resistive load.
Frequency stability:	±0.25 percent.
Coupler output:	1.0 V ac induced voltage into 1 turn link secondary.
Sensitivity:	10 microvolts for 20-dB quieting.
Squelch:	Operates at less than 10 microvolts.
Selectivity:	-60 dB at ±20 kHz.
Audio output:	0 dBm into handset, 2 watts into 8-ohm speaker.

Mechanical

	Size (in)	Weight (lb)
719L-3 Transceiver:	12.6 x 9.4 x 5.8	13.2
962A-2 Battery Charger:	6.0 x 6.0 x 2.4	3.6
959L-1 Speaker:	6.5 x 4.5 x 2.6	3.4
444E-3 Headframe Coupler:	11.0 x 11.0 x 1.5	16.4
444E-4 Cage Coupler:	3.4 x 6.0 dia	12.5
28N-2 Carrying Case:	23 x 13 x 10	10.7

3.3.2 719L-3 Transceiver Design

The Hoist Communication System is an inductive radio system operating at 52 kHz in the FM mode at ±3-kHz deviation. Figure 14 is a block diagram of the transceiver.

The rf current in the rope induces a voltage in the coupler resonant circuit which is applied to the receiver rf amplifier. This 52-kHz signal is fed into a balanced mixer and is mixed with a 403-kHz crystal injection. The resulting 455 kHz is amplified by an if stage and filtered by a 12-kHz mechanical filter. After additional amplification, the signal is demodulated and the resulting audio is amplified to a 0-dBm level for the earpiece and to a 2-watt level for the speaker.
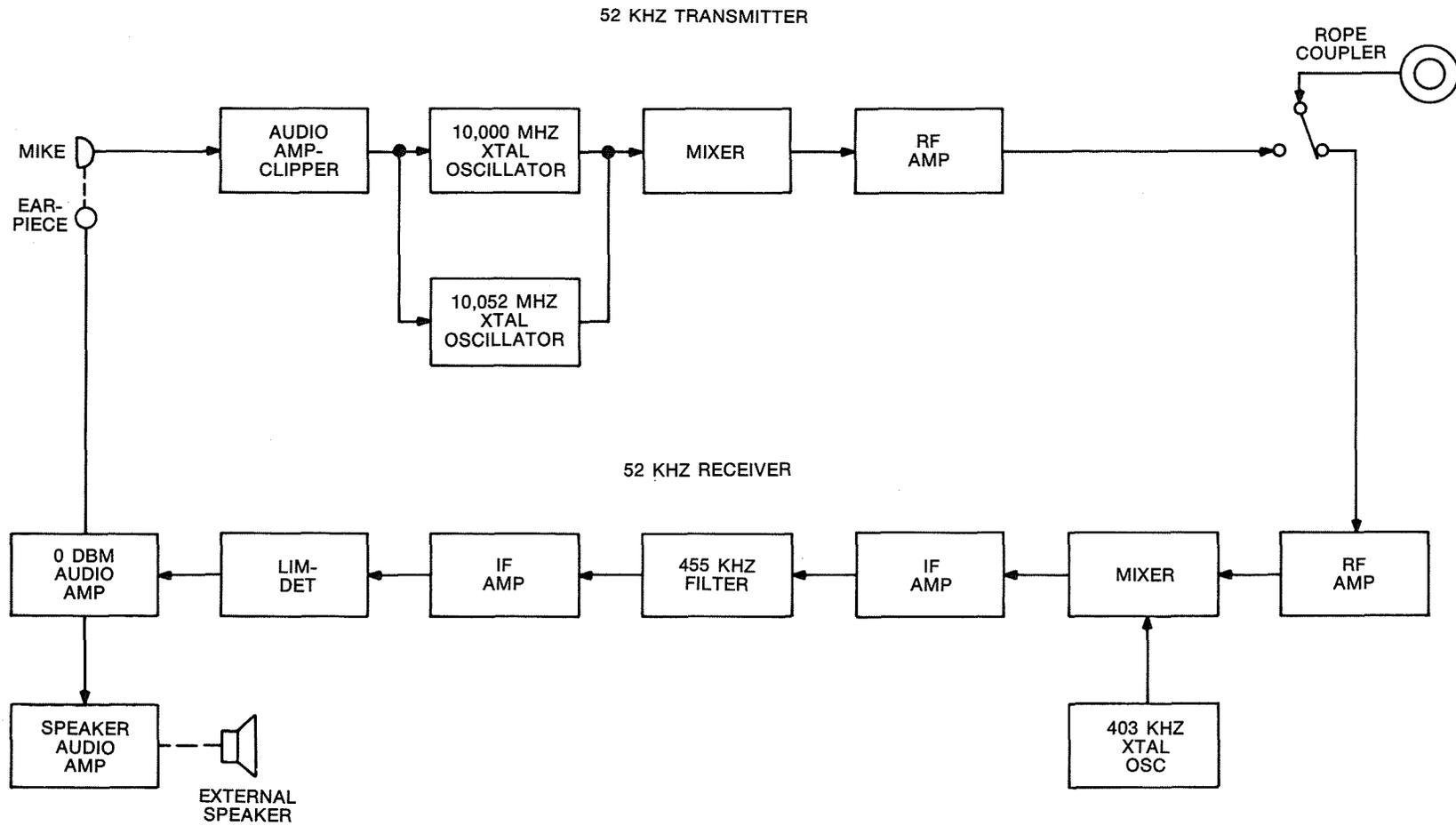
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Figure 14. Phase II Block Diagram For Hoist Transceiver.

In the transmit mode, the carbon mike audio is fed to an audio amplifier-clipper stage. The clipped audio modulates the two crystal oscillators, using variable capacitance diodes to pull the crystals the desired 3 kHz. The two injections are mixed together to produce the 52-kHz difference frequency. After additional amplification, the signal is fed to the coupler series tuned circuit that couples the rf energy to the hoist rope.

3.3.2.1 Receiver Design

The basic frequency mixing technique from the Phase I radio was retained. The primary objective was to lower the receiver current from the 250 mA of Phase I to 35 mA by making design changes to various circuit stages. This was accomplished in part by replacing the MC1590 opamps with transistors. By making the audio power amplifier optional and utilizing handset reception, additional current reduction was obtained in the operate mode. Eliminating the dc to dc converter used in Phase I to provide a negative voltage for the opamps produced further current savings.

Transistor type 2N2222A's were chosen for the rf and if amplifiers. These transistors have a low noise figure (4 dB), a substantial current gain (50 min) and are low cost ($0.20). It was noted that when transistors are used with low collector current (1 mA or less), then the parameter r_e, the small signal impedance of the emitter-base function becomes a factor that cannot be neglected. Its value is inversely proportional to the emitter current, and in order to stabilize the stage with voltage supply variations, (which varies r_e and gain), a large value of unbypassed emitter resistance is required to override this resistance. However, when low impedance loads are used, the gain per stage is thereby limited since the stage gain is approximately the load resistance divided by the unbypassed emitter resistance. Consequently, the following circuit, figure 15, was used to provide the desired gain into a low impedance and still maintain a low stage current of 2 mA.

The emitter follower, Q2, is direct connected to the amplifier, Q1, and provides the impedance transformation to the low impedance load. The resistor, R3, is chosen to provide the desired gain of about 25 dB. This circuit was used for the rf amplifier and the two if amplifiers.

In the rf amplifier application, tuned circuits were used in the base circuit and in the collector circuit to obtain selectivity. Diodes were added across these circuits to clamp the input signal to prevent an overload condition at high signal inputs. Levels from 5 microvolts to 3.0 volts can be handled without output degradation.

Figure 15. RF Stage
Circuit Diagram.

The MC1596 balanced modulator linear IC was used as the first mixer. Since the injection frequency 403 kHz is close to the if frequency 455 kHz, good injection oscillator suppression is necessary to prevent the oscillator feedthrough from overloading the if stages. The MC1596 provides 6 dB of conversion gain while maintaining the injection feedthrough (after balancing) at 3 millivolts. Current drain of the mixer is 7 mA.

A crystal-controlled oscillator operating at 403 kHz is used as the injection source. A Pierce oscillator circuit is used with the crystal operating in an antiresonance mode. The crystal has a stability of ±0.015 percent over the temperature range. The injection level to the mixer is 0.1 V ac. Current drain is 0.7 mA.
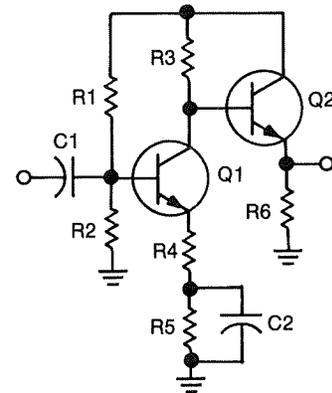
The if amplifiers are used to provide an impedance match to the mechanical filter with enough gain to override the filter loss. The transistor stage circuit is identical to figure 15. The low output impedance of the stage is used to drive the 500-ohm input to the filter. Two stages are used to overcome the 20-dB loss of the filter and to provide a net gain of 30 dB.

A CA3075 linear integrated circuit is used for additional if amplification, limiting, detection, and audio amplification. The IC contains a 3-stage if amplifier with 60 dB of gain with good limiting characteristics. The detector section utilizes a differential-peak-detection circuit that requires a single external coil in the detector circuit. An audio preamplifier provides 20-dB voltage gain with low impedance output for driving additional audio stages. Current drain is 15 mA.

A single 2N2222-type transistor is used to provide a 0 dBm output across the 600-ohm handset earpiece. The circuit board also includes a balanced complementary transistor quad that provides a 2-watt output for the speaker. An opamp type LM224 is used as a driver. This entire circuit is energized only if the speaker connector is connected to the transceiver.

Three types of squelch circuits were considered: an input signal-to-noise, an audio output signal-to-noise, and a carrier squelch. A tone squelch was also briefly examined, but due to its apparent complexity, was not carried to the breadboard stage.

An input signal-to-noise squelch practically identical to the Phase I type was decided upon. This squelch is actually a noise-quieting type where an input rf signal quiets the detector output. The squelch trip point is somewhat adjustable and presently is set for an input signal-to-noise ratio of 15 dB.

This squelch is insensitive to input noise levels. A General Radio Noise Meter providing random noise was used to produce input noise levels up to 1.0 volt. A signal 15 dB above the noise level broke squelch regardless of actual noise level input. For the cases where spurious frequencies near or actually on frequency become troublesome, an adjustable pad on the receiver input is provided to give a maximum of 40 dB of insertion loss. This pad will be of benefit only if the desired signal is greater than the spurious, which should be the case most of the time. Previously reported cases of squelch breaking in Phase I radios could not have occurred from excessive noise, but more likely from a spurious signal close in or on frequency. Here, the pad would be of benefit if squelch breaking became a problem.

In the Phase I radio, a squelch override transistor circuit could also have been a cause of squelch breaking. Long leads ran between the circuit and the station control. Any induced signal on this lead could possibly trip the squelch. This circuit is not being used in the Phase II configuration.

The audio output signal-to-noise squelch possessed time constant problems. A long time constant was required to prevent the squelch from dropping out between syllables and would cause a long noise burst after transmission. It also had the disadvantage of not opening on carrier, which is highly desirable for test purposes, and this approach was not pursued further.

A carrier squelch was also breadboarded. Although it worked well with carrier, it was susceptible to noise. Noise levels of the same magnitude as the signal would operate it also. Because of this undesirable characteristic, this approach was set aside.

The total receive current drain is 35 mA in both the squelched and unsquelched mode using handset operation. The current drain remains unchanged because the squelch circuit current increases by the amount the 0 dBm stage decreases when it is turned off.

The 2-watt amplifier uses another 4 mA when turned on. When driven by audio, the current drain can get to 200 mA, depending upon the nature of the voice modulation.

3.3.2.2 Transmitter Design

The basic frequency mixing scheme of the Phase I transmitter was retained in the Phase II radio, except that the 35-kHz channel was omitted. The audio processor was designed for an input level of 0 dBm from a carbon mike. The processor uses two sections of an LM224 operational amplifier. The first stage is a limiter type amplifier with 30 dB of gain providing hard limiting starting at about 100 millivolts. An RC network is used to provide a 6 dB per octave preemphasis, starting at about 700 Hz. The second stage is an amplifier-filter that provides some filtering of the clipped waveform as well as the correct voltage level to provide the proper frequency deviation in the reactance modulator.

Two crystal-controlled, reactance modulated oscillators are used. One operates at 10.000 MHz, and the other is displaced by 52 kHz and operates at 10.052 MHz. Each crystal is reactance modulated by a varactor diode circuit to produce a ±1.5 kHz deviation at the crystal frequency. By frequency modulating the oscillators 180 degrees out of phase with each other, a total deviation of ±3 kHz is obtained at the 10-MHz frequency. The two injections are mixed together in a transistor mixer stage to produce the difference frequency of 52 kHz, with the ±3 kHz deviation remaining unchanged.

Matched crystals are used to provide identical frequency versus temperature characteristics over a wide temperature range so that the differential change remains well within the ±0.25-percent stability specification.

The mixer is followed by an rf amplifier stage that is temperature compensated to provide power output stability over temperature. This stage compensates the output stage within ±1.5 dB of its nominal output at room temperature. A thermistor temperature sensing circuit causes additional drive below 0 °C. The circuit is inactive at temperatures higher than 0 °C.

It was determined (see paragraph 3.3.3) that a reactive input power of 7 volt-amps is required for the 3 x 5 x 1 coupler to obtain a V_o of approximately 1.7 volts. The circuit to deliver this power should do so with a minimum of dc power.

Tuning the coupler circuit to resonance was decided upon for the following reasons: (1) the circuit Q would help provide harmonic attenuation; (2) a resistive load would be presented to the PA stage; and (3) the voltage across the coupler coil is multiplied by the Q.

The choice of circuit Q is dependent upon several factors. A high Q (50) would provide the desired VI with little power. However, an upper limit of Q is established by the bandwidth required to pass the voice frequencies. With 3-kHz deviation and a 300- to 3000-Hz audio response, this bandwidth is equal to twice the deviation or 6 kHz. This is the narrowest bandwidth that could be used and does produce detectable speech quality degradation. This represents a Q (f/$\triangle$f) or 8.7.

A Q of 8.7 is too high because the tolerable u (and inductance) variation would be 12 percent for the tuned circuit to remain within the 3-dB points. This results in a gap tolerance of about ±0.001 inch instead of the proposed ±0.002 value. A better compromise would be a Q of 5. This Q would allow a u variation of 20 percent for a 3-dB tuned circuit variation. In addition, the wider bandwidth improves the voice quality considerably.

Once the VI and Q have been chosen for the series tuned circuit, the power consumed by the circuit is a constant and is independent of the number of turns on the coupler. The following circuit and figure 16 shows this (see columns 1 through 5). The VI and the Q is a constant for various values of inductive reactance. The power dissipated in R is a constant.

Although a wide range of reactances appear usable, such is not the case in practice. A limited range occurs with a low impedance source consisting of a complementary Class B stage. This circuit is shown in figure 16 also.

Referring back to the table under circuit measurements, the 12-volt dc current is seen to decrease as the inductive reactance increases. A limit is reached between X=50 and 100 ohms.
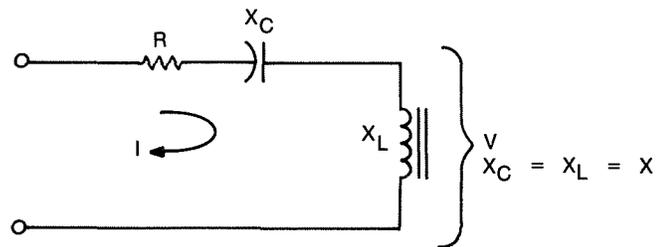
1	2	3	4	5			
VI = 7		Q = 5		POWER IN R	CIRCUIT MEASUREMENT		
I	V	X	R	I^2R	E	IDC	PC POWER IDC X 12V
2.64A	2.65V	1Ω	0.2Ω	1.39W	-	-	
1.87	3.74	2	0.4	1.40	-	-	
1.32	5.29	4	0.8	1.39	-	-	
0.84	8.37	10	2.0	1.41	1.25	0.281	3.37W
0.53	13.2	25	5.0	1.41	1.95	0.219	2.63
0.37	18.7	50	10.0	1.37	3.50	0.180	2.15
0.26	26.5	100	20.0	1.35	3.8	-	
0.12	59.2	500	100.0	1.44	-	-	

$$X_C = X_L = X$$

NOTE:
R1 ADJUSTED TO PROVIDE A Q OF 5

Figure 16. Power Measurements.

The source voltage E flattens at 3.8 due to the 12-volt power source, producing only 13 volts for V instead of the 16.5 volts desired. Measurements below X = 10 ohms couldn't be taken because the stage source impedance prevented overall circuit Q's of 5.

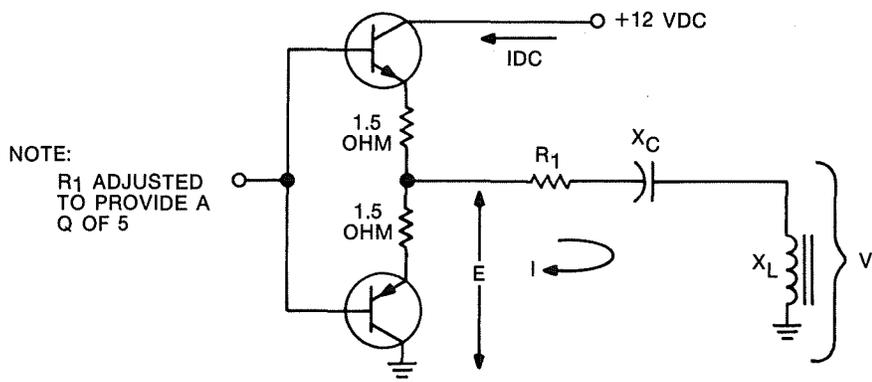The table (in figure 16) shows that a high inductive reactance (large number of turns) is desirable to reduce the 12 V dc power, and is also desirable in receive to increase the signal transfer. The measurements also show that the practical limit for this circuit is a reactance of 50 ohms, which requires a source voltage E = 3.5, produces a VI of 7, a 12-V dc current of 0.180 ampere, and a stage dissipation of 2.15 watts.

These levels are comparable with those originally proposed in the Phase II Design Plan for the Hoist Radio System for Deep Shafts, where it was proposed to accomplish this with 200 mA or less of dc current drain.

A further reduction in dc current drain for the PA stage occurs when the series tuned circuit is capacity shunted as shown in figure 17. The current decreases from 180 mA to approximately 150 mA using the input capacity addition. A theoretical analysis* shows that the addition of the shunt capacitor changes the network impedance relation so that the real power delivered to the coupler peaks about 2.5 kHz above the power peak supplied from the voltage source. Consequently, the total dc current is decreasing when the coupler power is peaking.

This circuit was incorporated to further reduce the current drain in transmit. The total current drain of the transmitter circuit, including the PA stage, measures 210 mA at 12 V dc while providing 18 V dc across the coupler coil impedance.

Complete schematics of the units of the radio are included in the Phase III documentation package.

3.3.3 Coupler Design (Type 444E-3/4/5)

A broad look at the PA coupler problem indicated that the PA design and power requirements are dependent directly upon the coupler characteristics and design.

Figure 17. Capacity Shunted Series Tuned Circuit.

The following analysis leading to the present PA coupler configuration is detailed in the following paragraphs and applies to the cage coupler, since it is the most critical element due to its small size and short air gap.

It was the intent of this program phase to develop the same induced rope voltage that exists at the Phase I 10-watt power level, and to accomplish this with a minimum of dc power. To determine the rope output voltage existing in the Phase I system, the following equation** is used which relates the rope output voltage to the input power:

$$V_o^2 = \frac{8\pi^2 \text{ uf VIAX} 10^{-9}}{L}$$

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*Letter Report to Dr. H. K. Sacks dated 27 August 1975, Hoist Coupler Circuit Analysis.
**Arthur D. Little, Inc., Minutes of Hoist Phone Meeting, dated 18 November 1974, page 4.

where V = voltage across primary, volts

I = current in primary, amperes

u = permeability

f = frequency, Hz

L = mean path length, cm

A = core cross section, cm^2

V_o = open circuit voltage in 1 turn secondary

The output voltage V_o of the Phase I cage coupler is calculated as 1.7 V for the 10-watt power level using the following parameters:

V = 22.5 volts

I = 0.45 amperes

u = 400

f = 52 kHz

L = 36.6 cm

A = 6.45 cm^2

Rearranging the equation in terms of VI gives:

$$VI = \frac{V_o^2 L\ 10^9}{8\pi^2 ufA}$$

The coupler parameters can then be chosen to minimize the input reaction power for a given output voltage V_o.

Tape wound cores made of supermalloy were chosen as a material for the couplers. A stock size toroid was used with dimensions of 3-inch id, 5-inch od, and 1-inch high. This size allows the core to be cased mechanically and still fit around a 1-3/4-inch rope. Thus L and A are determined in the equation.

The permeability of this core is about 10,000 to 30,000 at 50 kHz. However, once the toroid is cut, the u is reduced by a factor of 1/2 to 1/4, depending upon the condition of the junction when rejoined. The u is extremely sensitive to small air gaps; one thousandth of an inch reduces the u by 1/2. Consequently, it is impractical to control the u under the conditions of repeated assembly and disassembly unless a sizable controlled air gap is introduced, especially in a tuned circuit application.

The air gap required for a u of 1000 was calculated. The permeability and air gap are related by the following equation:

$$\frac{1}{U_e} = \frac{1}{U_a} + \frac{L_g}{L}$$

where U_e = u with air gap

U_a = u without air gap

L_g = length of air gap

L = mean path length

To reduce a u of 10,000 to 1000 requires an air gap of 0.0113 inch for the 3 x 5 x 1 toroid. Since two air gaps exist, each is required to be 0.0056 inch. Additional calculations indicate that these gaps should be held within ±0.001 to maintain a u (and inductance) variation less than 20 percent for the tuned circuit application that was explained in earlier paragraphs. These mechanical dimensions and tolerances are impractical to maintain with normal field handling practices.

Consequently, it was decided to reduce the u to 500. This requires a total air gap of 0.024 inch of 0.012 for each gap. The tolerance becomes ±0.002 for 20-percent u variation. This gap distance, although still small, is more practical to accomplish and maintain.

Since L, A and u have been determined, the VI input required for the new coupler to produce the same Phase I output voltage can now be calculated using the following parameters:

V_o = 1.7 volts

L = 31.9 cm

u = 500

f = 52000 Hz

A = 6.45 cm^2

$$VI = \frac{V_o^2 L\ 10^9}{8\pi^2\, ufA} = 6.96$$

This input reactive power of 6.96 is about 30 percent less than that required for the Phase I coupler.

The coupler figure of merit F*, which equals V_o^2/VI, is a means of comparing coupler electrical performance. The calculation F of this coupler at 52 kHz for the nonresonant case is:

$$F = \frac{V_o^2}{VI} = \frac{(1.7)^2}{6.96} = 0.415$$

The F of the Phase I coupler is calculated as 0.252, indicating a predicted improvement ratio of about 1.7.

Actual measurements of the coupler produced a V_o of 1.45 volts for a VI of 7.2. Although the secondary voltage is only down about 1.5 dB from the calculated value, the figure of merit drops to 0.290, which is still somewhat greater than the Phase I coupler figure of merit of 0.252.

The surface coupler of Phase I proved to be large enough in diameter to pass the rope sway that exists near the sheave at the top of the headframe. This required a round toroid that has an 8-inch inside diameter and an outside diameter of 10 inches with a 1-inch height. Ferrites of this size are extremely expensive in addition to being brittle and difficult to handle without breakage. Iron cores were investigated and have the desired characteristics of high permeability, low loss, rugged construction, and availability. Tape wound cores were recommended as being the easiest to manufacture in the 8-inch size. A nickel-iron alloy called supermalloy was chosen for the material for both the cage and surface coupler.

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*Arthur D. Little, Inc., Working Memorandum #E-2 dated 3 March 1975, entitled Analysis and Comparison of Hoist Rope Couplers for Hoist Shaft Communications Systems.

The surface coupler required a total air gap of 0.040 inch to provide an effective permeability of 500 for the 8 x 10 x 1 size toroid. Since the output voltage V_O is inversely proportional to the mean path length, a lower V_O occurs because of the longer mean path of the larger coupler. Consequently, the figure of merit is also reduced. Measured values of V_O equal 1.1 for a VI of 6.8. The figure of merit equals 0.180.

An elliptical cage coupler was also developed as an addition to this contract. This shape allowed its use around the double-back section of the hoist rope and also around larger diameter ropes up to 2-5/8 inches. The same material and construction was employed in this coupler as was used in the others. A total air gap of 0.034 inch was used. Measured values of V_O equal 1.26 volts for a VI of 6.9. The figure of merit equals 0.230.

3.3.4 Power Source

Dry cells have severe limitations in capacity at low temperatures and are not completely adequate for this application. It was recommended that sealed lead acid storage batteries be used as the primary power source and that the dry cells be used as an emergency backup. The transceiver enclosure is designed to enclose two 12-V dry cells for the emergency application. Dry cells will provide 9.8 hours of use on a 50-50 duty cycle at +70 °F but only 36 minutes at -20 °F. In comparison, 5 AH storage battery will provide 35 hours at +70 °F and 19.3 hours at -20 °F. Detailed information concerning this problem is presented in the following paragraphs. The information about ampere-hour capability and capacity versus temperature is obtained from the Eveready Battery Application Engineering Data book dated 1971.

Dry batteries are ordinarily tested on circuits of constant resistance and results are usually expressed as the time of discharge rather than as the capacity in ampere hours. The ampere hours can be calculated, however, by determining the average value of the current.

The voltage characteristics of various makes and brands of dry cells differ and, therefore, the average current delivered by a particular cell can be regarded as only an approximation of the performance of other cells and batteries under comparable conditions.

Factors that affect the ampere-hour capacity of dry cells are (1) temperature, (2) the cut-off voltage – the capacity delivered is greater as the cut-off voltage is lower, (3) the relative time of discharge and recuperation – the performance is normally better when the discharge is intermittent, (4) the rate of discharge – the capacity is greater as the discharge current is less, down to a certain point beyond which the service efficiency decreases because the spontaneous reactions within the cells become an increasingly important factor.

Graph figure 18 shows the ampere-hour capacity of F cells that are the type used in the popular 6-V lantern batteries and the larger 12-V dc batteries, Eveready Type 732, used for spot lights. The curve indicates that the F cell (1.5 V) has a 7 AH rating at 10 mA but only 0.66 AH at 150 mA of continuous current. The battery terminal voltage drops from 12 V dc to 9.0 V dc, which is considered the cut-off voltage. In contract, a lead acid storage battery of 12 V dc rated at 5.0 AH would have a 5 AH capability at a 150 mA current drain.

The effect of temperature on the output may be expressed as a ratio or percentage based on normal output. The graph, figure 19, shows the relative capacity at various temperatures of a 22-1/2-volt battery unit containing F cells discharging through 1250 ohms (0.018 ampere) to a cut-off voltage of 15 volts. This is the only information available and gives an indication of what may be expected when dry cells are operated at low temperatures.
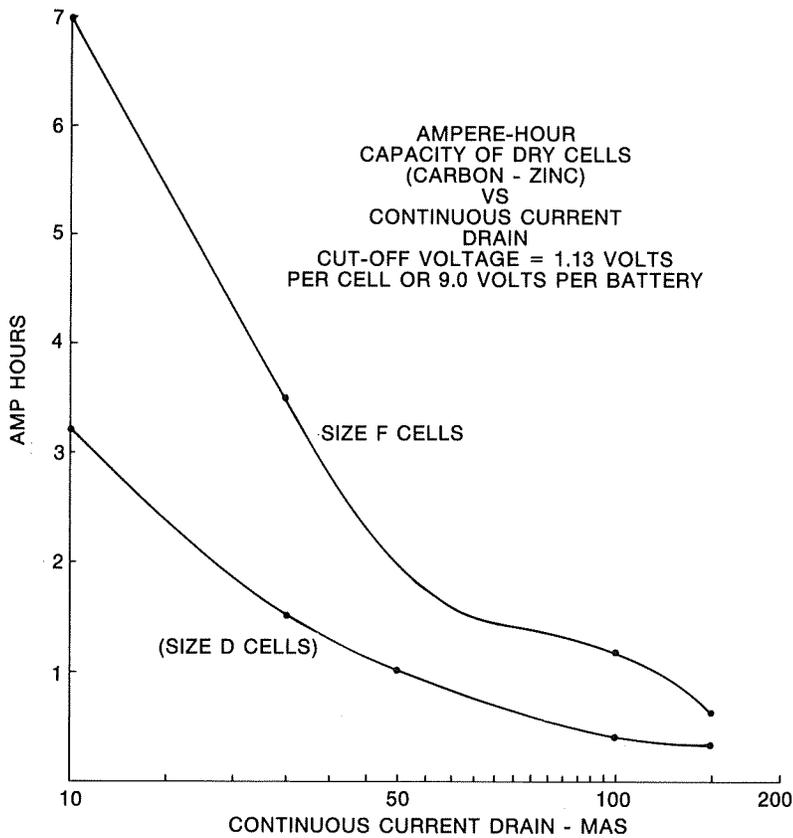
Figure 18. Ampere-Hour Capacity of Dry Cells Vs
Continuous Current Drain.

In comparison, the change in capacity for a sealed lead acid 12-V battery is also shown. The discharge rate is C/10 or 0.5 ampere for a 5.0 AH battery.

The current drain for the receiver (0 dBm output) is estimated at 35 mA and a maximum of 250 mA for the transmitter providing a 0.5-watt rf output. There will be very little difference between standby and receive because of the low audio output. Assuming a 50-percent duty cycle for transmit with the receiver on 50 percent of the time, the total hours of operation can be calculated:

$$\text{Total AH} = (0.50)\ (A_T)\ (H) + (0.50)\ (A_R)\ (H)$$

Since the average current will be $\dfrac{0.250 + 0.035}{2} = 0.143$ A, the battery AH is obtained from figure 18 as 0.7 AH:

Total AH = 0.7

A_T = 0.250 A (transmit)

A_R = 0.035 A (receive)

$0.7 = (0.5)\ (0.25)\ (H) + (0.5)\ (0.035)\ (H)$

H = 4.9 hours

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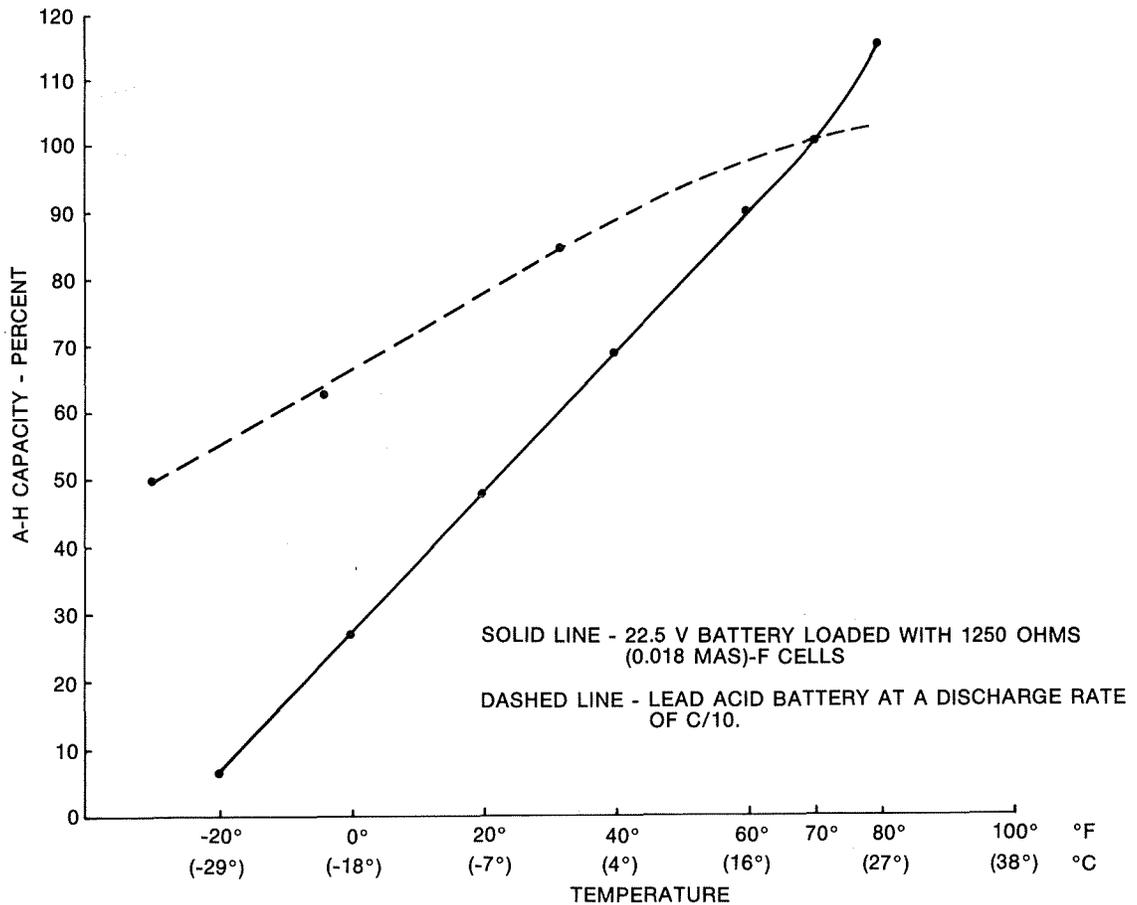
Figure 19. A-H Capacity Vs Temperature.

Two batteries will provide approximately 9.8 hours of operation at room temperature.

At -20 °F, the dry cells have a capacity of 6 percent of the capacity at +70 °C according to figure 19. Consequently, at this temperature, the capacity will be 6 percent of 9.8 hours or 0.6, or 36 minutes.

In comparison, a 5 AH sealed lead acid battery would have an operating time of 35 hours at +70 °C and 55 percent of 35 hours or 19.3 hours at -20 °F.

The shortcomings of dry cells at low temperature is apparent. This characteristic must be reckoned with during the winter months if dry cells are used in the emergency application.

3.3.4.1 Battery Tests

Life test measurements were conducted on 12-volt dry cell batteries. A Burgess Lantern Battery #TW2 (replaces #732) was placed on a 50/50 duty cycle with 2 minutes of transmit at 250 mA and 2 minutes of receive at 35 mA resulting in an average current of 143 mA. With this average current drain, the 12-V battery lasted 22.4 hours, using a cut-off voltage of 9

volts. This is in contrast to the 4.9 hours calculated previously that was based on ampere hour ratings of Eveready dry cells. This is a 17.5-hour difference between the two manufacturers for the same current drain.

Another Burgess 12-V battery was tested at -20 °F under a constant resistive load to provide a 150-mA discharge at 12 V. This single 12-V battery lasted 4.86 hours, using 9.0 V as the cut-off voltage. The predicted value based on Eveready data was 36 minutes or 0.6 hour, a difference of 4.26 hours. The intended use of two 12-V dry cells would provide 9.7 hours of operation at the -20 °F (-30 °C) temperature using the Burgess batteries. Although these measurements show that present day dry cell batteries are much better than expected (based on 1971 Eveready data), it is still advantageous to use a lead acid battery, especially for the surface transceiver. The use of a speaker on this unit could run the average receive current at about 200 mA for a 2-watt output with certain voice types. Consequently, the recommendation was followed where the supplied battery is a sealed lead acid with space available for two 12-V dry cell batteries for emergency use.

3.3.5 Battery Charger Design (Type 962A-2)

The battery charger is required to charge the sealed lead acid batteries inside the transceivers. A connector is made accessible by opening up the front cover of the transceiver for connection to the charger.

Constant voltage charging is used because it is the most efficient and the fastest method of charging this type of battery. A charging voltage of 14.1 volts and a 1.5-A capability allows an 80-percent discharged battery to be recharged in about 2-1/2 hours. At this voltage, the battery can also be left on charge for long periods of time without any damage to the cells.

A regulated dc power supply was purchased and used as a charger. A charging meter was added to indicate the degree of charging. Two outputs are provided so that both batteries (two transceivers) can be charged simultaneously at a lower rate of charge. The charger is short circuit protected.

The charging characteristics of a very deeply discharged sealed lead acid battery is different from most batteries. The initial charge acceptance of the battery is very low for a number of hours, then begins to take a much higher rate, and finally tapers off like a normal battery. After the current has increased and then tapered off, the cell is in a fully charged condition.

3.3.6 Speaker Design (Type 959L-1)

The speaker unit provides additional volume for either transceiver. A pendant cable connector connects to the transceiver, which enables the 2-watt amplifier in the receiver. A volume control with a minimum position to prevent complete cutoff is used to set volume. A transformer provides a two-to-one impedance transformation to match the 8-ohm speaker to the 4-ohm amplifier output.

3.4 PHASE II SYSTEM DELIVERY

The hoist communication system was shipped to the Bureau of Mines TPO on 21 August 1975. Five instruction manuals were also submitted that include instructions on installation, operation, servicing, and specifications.

Acceptance test data was taken on the equipment and the results are shown in the appendix. The following tests were conducted on the equipment:

a. Receiver sensitivity
b. Receiver squelch
c. Selectivity, spurious, and image rejection
d. Audio output and distortion
e. Receive frequency stability
f. Audio response
g. Transmit frequency stability
h. Transmit power output
i. Transmit spurious and harmonic emissions
j. Transmit deviation
k. Voltage variation test
l. Temperature test: -50 °C to +70 °C including frost formation and melting
m. Humidity test: 7-day test with temperature at +70 °C (severe humidity)
n. Thermal shock: Rapid temperature cycling in accordance with MIL-STD-220D Method 107C, test condition A-1, except step 1 shall be -50 °C and step 3 shall be +70 °C
o. Battery life test

4. PHASE III (JANUARY 1976 – JUNE 1976)

4.1 BUREAU OF MINES EVALUATION

An evaluation of the Phase II radio showed noise bursts occurring at threshold signal levels in the transceiver. Tests on the breadboards and on the receiver boards indicated that the problem was probably being caused by the interconnect wiring of the transceiver. During the Phase IV construction of an additional hoist system, test measurements revealed that the interconnect wiring grounds were causing the problem. Floating the negative side of the circuitry cured the problem. Additional minor component and wiring changes on the receiver board eliminated noticeable squelch chatter at threshold levels.

These changes were incorporated into the design drawings.

4.2 DOCUMENTATION

Five copies of the design drawings were submitted 8 June 1976. These drawings consist of fabrication drawings, assembly drawings, and a list of materials including schematics.

Five copies of a revised and expanded instruction manual were also submitted. The manual includes a maintenance section which consists of field tests, bench tests, and voltage measurements.

45/46

5. PHASE IV (JANUARY 1976 – JUNE 1976)

An additional hoist communication system identical to that supplied under Phase II with the optional elliptical coupler in place of the round cage coupler was constructed and bench tested. This system was used to fix the noise bursts noted in the Phase II radio. It also provided an opportunity to check and correct the design drawings.

6. CONCLUSIONS AND RECOMMENDATIONS

This Hoist Radio System program resulted in a hoist communication system for use with a rescue capsule in an emergency situation. The transceivers are self-contained units operating from internal batteries to provide reliable two-way voice communications between the surface and the capsule.

Reviewing the concluded program brings out two potential improvements in the system: (1) the carrying case, and (2) the coupler.

Currently, one large case is used for the two transceivers, battery charger, speaker, and one coupler. The other coupler is in another smaller case. The system would be easier to handle if two equal size cases were used to provide more equal weight distribution.

Although the small round coupler and the elliptical coupler provide efficient rope signal coupling, they are heavy and expensive. A more desirable arrangement would be to consider a proximity coupler that would not encircle the rope but would lay against it. Such a coupler would be less efficient but simpler and lower in cost. However, an investigation would be required to determine allowable signal loss that such a coupler would produce.

For additional detailed information on hoist signalling theory, refer to Arthur D. Little, Inc., report "Propagation of Radio Waves in Coal Mines, Task F, H0346045."

APPENDIX

TEST DATA

ON

HOIST COMMUNICATION

SYSTEM HC-102

AUGUST 15, 1975

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Hoist Communication System

Acceptance Test Procedures

1.0   Scope

This test procedure contains test instructions to perform a demonstration test for the Hoist Communications System, HCS-102.

1.1   Equipment Definition

The HCS-102 CPN 622 2908 001 consists of· the following equipments:

Qty.	CPN	Type
2	622-2902-001	Radio Receiver - Transmitter, Type 719L-3
1	622-2903-001	Battery Charger, Type 962A-2
1	622-2904-001	Headframe Coupler, Type 444E-3
1	622-2905-001	Cage Coupler, Type 444E-4
1	622-2906-001	Speaker, Type 959L-1
1	622-2907-001	Carrying Case, Type 28N2

2.0   Reference Information

2.1   Specifications

The following document is applicable to this procedure:

1. Bureau of Mines Contract No. H0230034, Phase II.

2.2   Publications

Instruction Manual for Hoist Communication System, HCS-102.

3.0   Test Equipment Required

The following equipments or their equivalents are required:

1. Test Oscillator, HP 651B
2. Audio VTVM, HP 400D
3. Counter, HP 5243
4. Audio Oscillator, HP 200CD
5. Distortion Analyzer, HP 330B
6. RF VTVM, Boonton Type 91
7. Audio load, special
8. Wave Analyzer, HP - 310A
9. VTVM, HP 410B
10. D.C. Power Supply, H.P. 6267B
11. Deviation Meter, Marconi Type TF-791D
12. FM Sig Gen HP 8640B
13. Mixer, HP 10514A
14. SIG Gen HP 606B
15. Synchronizer HP8708A
16. Timer
17. Chart Recorder

4.0   Test Conditions

4.1   Atmospheric Conditions

The tests shall be conducted under prevailing laboratory ambient conditions of temperature, pressure and humidity; unless otherwise indicated.

4.2   Input Power

The transceivers are operated from internal rechargeable batteries. For test purposes, use 12 VDC power supply with 0.5A capability.

4.3   Warm-Up Time

None.

4.4   Duty Cycle

The duty cycle shall be continuous in recieve or transmit as required to perform the tests.

4.5   Audio Termination

Receiver output measurements shall be made into a special load consisting of transformer and a 8 ohm load. A 600 ohm load is required for 0 DBM measurements.

4.6   Transmitter RF Load

The RF output load shall be the coupler.

4.7   Receive RF Input

The RF input to the receiver shall be through a 50 ohm cable from a signal generator having an effective source impedance of 50 ohms. The input signal measurements shall be in terms of the voltage across the input terminals of the receiver.

5.0   Test Requirements

5.1   Receive Sensitivity

    a. Conditions

        Set up equipment as shown in Figure 1.

    b. Measurements

1. Set HP606B - synchronizer to 1.000 MHZ and the Marconi to 1.052 MHZ to obtain 52 KHZ out of HP mixer. Set modulation to 1KHZ and deviation to 3KHZ.

2. Feed signal into antenna terminals, J3 and J4 of transceiver at about a 10 millivolt level.

3. Use 8 ohm special load connected to J2 and 600 ohm connected to J1 of transceiver and measure audio output and distortion.

5.5 Receive Frequency Stability

a. Conditions

Set up equipment as shown in Figure 1.

b. Measurements

1. Pull out PC boards to obtain access to receiver injection oscillator test point, TP7.

2. Connect counter to TP7 and record data.

5.6 Audio Response

a. Conditions

Set up equipment as shown in Figure 2.

b. Measurements

1. Set HP606B - synchronizer to 1.000 MHZ and the Marconi to 1.052 MHZ to obtain 52 KHZ out of HP mixer. Set modulation to 1KHZ and deviation to 3KHZ.

2. Feed signal into antenna terminals, J3 and J4 of transceiver at about a 10 millivolt level.

3. Use 8 ohms special load connected to J2 and 600 ohm on J1 of transceiver and measure audio output.

4. Record data as shown on data sheet.

5.7   <u>Transmit Frequency Stability</u>

a. <u>Conditions</u>

Set up equipment as shown in Figure 3.

b. <u>Measurements</u>

1. Using loop through coupler, connect to counter.

2. Key radio with no modulation and record data.

5.8   <u>Transmit Power Output</u>

a. <u>Conditions</u>

Set up equipment as shown in Figure 3.

b. <u>Measurements</u>

1. Key radio and measure RF voltage across coupler inductor with the HP 410B VTVM. Use test point on coupler and 1T loop.

5.9   <u>Transmit Spurious and Harmonic Emissions</u>

a. <u>Conditions</u>

Set up equipment as shown in Figure 3.

b. <u>Measurements</u>

1. Connect HP Wave Analyzer to the loop in the coupler.

2. Key the radio and using the carrier as a reference, measure harmonics listed on the data sheet.

5.10   Transmit Deviation

    a. Conditions

        Set up equipment as shown in Figure 3.

    b. Measurements

        1. Connect deviation meter to TP-4 of the exciter card through a 400 pf capacitor.

        2. Record deviation on data sheet.

        3. Repeat with TP-5.

        4. Calculate total deviation.

5.11   Voltage Variation Test

    a. Conditions

        Set up equipment as shown in Figures 2 and 3.

    b. Measurements

        1. Connect transceiver to the external, variable power supply and adjust for 13 VDC.

        2. Key radio and measure power output versus DC voltage using procedure detailed in paragraph 5.8.

        3. Using procedure outlined in paragraph 5.4, check received audio output versus dc voltage.

5.12   Temperature Tests

    a. Conditions

        1. Set up equipment for transmit data as shown in Figure 3.

        2. Set up equipment for receive data as shown in Figure 2.

5.14   Thermal Shock

a. Conditions

Set up equipment as shown in Figure 1, 2, and 3 as appropriate.

b. Measurements

1. Take receive sensitivity in accordance with paragraph 5.1 and receive audio output in accordance with paragraph 5.4

2. Take transmit data in accordance with paragraph 5.8.

3. Place units into chamber.

4. The equipment shall be subject to a rapid temperature cycling test in accordance with MIL-STD-202D, method 107C, test condition A-1, except step 1 shall be -50°C and step 3 shall be +70°C.

5. After test is complete, repeat paragraph 1 and 2.

5.15   Battery Life

a. Measurements

Battery life is measured with resistive loads set up at 12VDC to provide 250 ma for transmit and 35 ma for receive. (48 ohm and 343 ohms).

Set up timer to provide a duty cycle of 50% transmit for 2 minutes and 50% receive for 2 minutes. Measure battery voltage versus time with a chart recorder.

Check battery life (12 V to 11 V) of the sealed lead acid battery at room temperature and at -30°C.

Repeat with two 12 v dry cell lantern batteries (Burgess #TW2) in parallel. Use 12 V to 9 V as battery life criterion.

TEST SET-UP 1

FIGURE 1

SIG GEN
HP 606B

SYNCHRONIZER

MIXER
HP
10514A

FM SIG GEN
HP 8640B

12 VDC
POWER
SUPPLY

TRANSCEIVER

J1   J2 J3

J4

600
OHM
LOAD

DIST.
ANALYZER
HP 300B

SPECIAL
8 ~ LOAD

AUDIO
VTVM

TEST SET-UP 2

FIGURE 2

6.0   Test Data: Refer to procedures for test methods.

6.1   <u>Receive Sensitivity</u> (5.1)

Record quieting for 10 microvolts input.

Transceiver	8 Load	600 Load
E1	*35* db	*32* db
E2	*34* db	*32* db

6.2   <u>Receive Squelch</u> (5.2)

Record audio output with radio squelched and unsquelched.

Transceiver	Unsquelched	Squelched	<u>DB</u>
E1	*3.0*	*0.01*	*49.5*
E2	*3.1*	*0.009*	*50.5*

6.3   <u>Selectivity, Spurious and Image Rejection</u> (5.3)

	Transceiver	
	<u>E1</u>	<u>E2</u>
Reference Output for 10 uv input	*0.01* v	*0.015* v
Spurious at +60 db	-- KHz	-- KHz
	--	--
	--	--
	--	--
Image Response 858 KHZ	--	--
Response at 80 db level:		
88 KHz	--	--
100 KHz	--	--
115 KHz	--	--
145 KHz	--	--

6.4   Audio Output and Distortion (5.4)

Record audio output voltage and distortion

Transceiver	Audio Output	Dist.	600~ Out	Dist.
E1	4.3 VAC	5.6 %	+1 DBM	5.1 %
E2	4.2	3.8	0 DBM	3.5

6.5   Receive Frequency Stability (5.5)

Transceiver	Frequency
E1	403.007 KHZ
E2	403.014

6.6   Audio Response (5.6)

Transceiver	Audio Frequency	600~ Load Response	8~ Load Response
E1	1 KHz (REF)	0 db	0 db
	300 Hz	+0.3	-1.0
	2 KHz	-1.8	-1.8
	2.5 KHz	-2.8	-3.0
	3 KHz	-3.9	-5.0
E2	1 KHz (REF)	0 db	0 db
	300 Hz	-0.2	-0.9
	2 KHz	-1.5	-1.4
	2.5 KHz	-2.5	-2.8
	3 KHz	-3.3	-4.3

6.7   Transmit Frequency Stability (5.7)

Transceiver	Frequency
E1	52.008 KHz
E2	52.006

6.8 <u>Transmit Power Output</u> (5.8)

				DC Current	
Transceiver	1 T Loop	Power Output		Transmitter	Receiver
E1	1.10 H.Coupler	18.0 VAC		225 MA	35 MA
E2	1.45 C.Coupler	18.5		230	36

6.9 <u>Transmit Spurious and Harmonic Emissions</u> (5.9)

Transceiver	Spurious	Level
E1		
	52 KHz (REF)	0 DB ~~VAC~~
	104 KHz (2nd Harm)	38 DB
	156 KHz (3rd Harm)	35
	(4th Harm)	48
E2	(5th Harm)	35
	52 KHz (REF)	0 ~~VAC~~ DB
	104 KHz (2nd Harm)	38 DB
	156 KHz (3rd Harm)	37
	(4th Harm)	45
	(5th Harm)	37

6.10 <u>Transmit Deviation</u> (5.10)

Transceiver	Frequency	Deviation
E1	10.052 MHz	1.700 KHz
	10.000 MHz	1.240
	Total	2.940 KHz
E2	10.052 MHz	1.40 KHz
	10.000 MHz	1.42
	Total	2.82

6.11 Voltage Variation Test (5.11)

Transceiver	Voltage	Audio Out 600 ~	8 ~	Power Output
E1	13.0	+0.8 DBM	4.5 VAC	21 VAC
	12.0	0	4.1	18
	11.0	−0.3	3.8	14
	10.0	−1.2	3.2	8
	9.0	−3.0	2.5	2.4
E2	13.0	+0.5 DBM	4.3 VAC	21 VAC
	12.0	0	4.0	18.5
	11.0	−0.1	3.6	14
	10.0	−1.0	3.1	9
	9.0	−2.0	2.5	4

6.12 Temperature Tests (5.12)

Transmit - E1

Temperature	Frequency Stability	Power Output
+25°C	52.014 KHz	19 VAC
−50°C	51.935	8.5
−30°C	51.963	14.5
+25°C	51.991	18.0
+50°C	52.030	19.0
+70°C	52.042	18.8

Receive - E1

Temperature	Audio Out 600~	8~	Sensitivity	Frequency Stability
+25°C	0 DBM 4.2	VAC	34 db	463.015 KHZ
-50°C	-2.0	2.5	36	402.976
-30°C	-1.0	3.3	37	402.990
+25°C	0	4.2	34	403.005
+50°C	-0.5	4.1	33	403.001
+70°C	-1.0	3.8	33	402.995

Transmit - E2

Temperature	Frequency Stability	Power Output
+25°C	52.003 KHz	18.5 VAC
-50°C	52.052	7.8
-30°C	52.090	12.0
+25°C	51.967	18.5
+50°C	51.996	18.5
+70°C	51.990	18.5

Receive - E2

Temperature	Audio Out 600~	8~	Sensitivity	Frequency Stability
+25°C	0.1 DBM 4.1	VAC	35 db	403.013 KHz
-50°C	0.2	3.0	35	402.974
-30°C	+1.2	3.6	36	402.993
+25°C	+0.2	4.1	37	403.013
+50°C	-1.0	3.7	35	403.010
+70°C	-1.8	3.3	36	403.011

6.13 Humidity Test

Before Humidity

Sensitivity	Audio Out	Power Output	Frequency Xmit	Rec
_32_ DB	_4.3_ VAC	_20_ VAC	52.021	403.014 KHZ
	_0_ DBM			

After Humidity

Sensitivity	Audio Out	Power Out	Frequency Xmit	Rec
_28_ DB	_4.2_ VAC	_19.5_ VAC	51.990	403.015 KHZ
	_0.2_ DBM			

6.14 Thermal Shock

Before

Sensitivity	Audio Out	Power Out	Frequency Xmit	Rec
_34_ DB	_4.2_ VAC	_19_ VAC	52.003	403.00?
	_0_ DBM			

After

Sensitivity	Audio Out	Power Out	Frequency Xmit	Rec
_34_ DB	_4.4_ VAC	_19.5_ VAC	52.001	403.006
	±0.1 DBM			

6.15 Battery Life Test

50/50 Cycle: 2 minutes transmit - 250 ma.

2 minutes receive - 35 ma.

Room Temperature (+25°C): Sealed Lead Acid Battery:

Measured (12 V to 11 V) - 31 hours (4.4 AH)

Calculated (12 V to 11 V) - 35 hours (5.0 AH)

Lantern Battery, Burgess #TW2

Measured (12 V to 9 V) - 86 hours (2 batteries in parallel)

Calculated (12 V to 9 V) - 19.6 hours (2 batteries in parallel)

Cold Temperature (-30°C): Sealed Lead Acid Battery:

Measured (12 V to 11 V) - 18.8 hours

<u>Calculated</u> (12 V to 11 V) - 19.3 hours

Lantern Battery, Burgess #TW2:

<u>Measured</u> (12 V to 9 V) - 13 hours (2 batteries in parallel)

<u>Calculated</u> (12 V to 9 V) - 0.6 hours (2 batteries in parallel)

TEST DATA

ON

HOIST COMMUNICATION

SYSTEM HC-102

AUGUST 15, 1975

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Hoist Communication System

Acceptance Test Procedures

1.0 **Scope**

This test procedure contains test instructions to perform a demonstration test for the Hoist Communications System, HCS-102.

1.1 **Equipment Definition**

The HCS-102 CPN 622 2908 001 consists of· the following equipments:

Qty.	CPN	Type
2	622-2902-001	Radio Receiver - Transmitter, Type 719L-3
1	622-2903-001	Battery Charger, Type 962A-2
1	622-2904-001	Headframe Coupler, Type 444E-3
1	622-2905-001	Cage Coupler, Type 444E-4
1	622-2906-001	Speaker, Type 959L-1
1	622-2907-001	Carrying Case, Type 28N2

2.0 **Reference Information**

2.1 **Specifications**

The following document is applicable to this procedure:

1. Bureau of Mines Contract No. H0230034, Phase II.

2.2 **Publications**

Instruction Manual for Hoist Communication System, HCS-102.

3.0 **Test Equipment Required**

The following equipments or their equivalents are required:

1. Test Oscillator, HP 651B
2. Audio VTVM, HP 400D
3. Counter, HP 5243
4. Audio Oscillator, HP 200CD
5. Distortion Analyzer, HP 330B
6. RF VTVM, Boonton Type 91
7. Audio load, special
8. Wave Analyzer, HP - 310A
9. VTVM, HP 410B
10. D.C. Power Supply, H.P. 6267B
11. Deviation Meter, Marconi Type TF-791D
12. FM Sig Gen HP 8640B
13. Mixer, HP 10514A
14. SIG Gen HP 606B
15. Synchronizer HP8708A
16. Timer
17. Chart Recorder

4.0   Test Conditions

4.1   Atmospheric Conditions

The tests shall be conducted under prevailing laboratory ambient
conditions of temperature, pressure and humidity; unless otherwise
indicated.

4.2   Input Power

The transceivers are operated from internal rechargeable batteries.
For test purposes, use 12 VDC power supply with 0.5A capability.

4.3   Warm-Up Time

None.

4.4   Duty Cycle

The duty cycle shall be continuous in recieve or transmit as required
to perform the tests.

4.5   Audio Termination

Receiver output measurements shall be made into a special load con-
sisting of transformer and a 8 ohm load. A 600 ohm load is required
for 0 DBM measurements.

4.6   Transmitter RF Load

The RF output load shall be the coupler.

4.7   Receive RF Input

The RF input to the receiver shall be through a 50 ohm cable from a
signal generator having an effective source impedance of 50 ohms. The
input signal measurements shall be in terms of the voltage across the
input terminals of the receiver.

5.0   Test Requirements

5.1   Receive Sensitivity

   a. Conditions

       Set up equipment as shown in Figure 1.

   b. Measurements

-2-

1. Connect special 8 ohm load to J2 of the transceiver.

2. Override squelch by grounding terminal 4 of TS-1. Use terminal 6 of TS-2 for ground. (Connector plate must be removed).

3. Connect HP 651B Test Oscillator to terminal 2 and 3 of TS-1 and record results for levels shown on data sheet.

5.2   Receiver Squelch

a. Conditions

Set up equipment as shown in Figure 1.

b. Measurements

1. Override squelch by grounding terminal 4 of TS-1 to TS-2, 6, to obtain a reference audio output voltage. (This will be noise but will be almost the same magnitude as an audio tone.)

2. Remove the ground to squelch the radio and record level.

5.3   Selectivity, Spurious and Image Rejection

a. Conditions

Set up equipment as shown in Figure 1.

b. Measurements

1. Use 8 ohm load into J2 of the transceiver.

2. Set HP 651B test oscillator for 10 microvolts at 52 KHZ and obtain an audio output reference.

3. Increase signal level 60 dB and sweep from 72 KHZ to 1,000 KHZ and from 32 KHZ down to 10 hertz. Note any frequencies that produce the reference voltage. Avoid subharmonics of the 52 KHZ.

4. Increase level to 80 dB and check response at frequencies listed.

5.4   Audio Output and Distortion

a. Conditions

Set up equipment as shown in Figure 2.

b. Measurements

-3-

1. Set HP606B - synchronizer to 1.000 MHZ and the Marconi to 1.052 MHZ to obtain 52 KHZ out of HP mixer. Set modulation to 1KHZ and deviation to 3KHZ.

2. Feed signal into antenna terminals, J3 and J4 of transceiver at about a 10 millivolt level.

3. Use 8 ohm special load connected to J2 and 600 ohm connected to J1 of transceiver and measure audio output and distortion.

5.5   Receive Frequency Stability

a.   Conditions

Set up equipment as shown in Figure 1.

b.   Measurements

1.   Pull out PC boards to obtain access to receiver injection oscillator test point, TP7.

2.   Connect counter to TP7 and record data.

5.6   Audio Response

a.   Conditions

Set up equipment as shown in Figure 2.

b.   Measurements

1.   Set HP606B - synchronizer to 1.000 MHZ and the Marconi to 1.052 MHZ to obtain 52 KHZ out of HP mixer. Set modulation to 1KHZ and deviation to 3KHZ.

2.   Feed signal into antenna terminals, J3 and J4 of transceiver at about a 10 millivolt level.

3. Use 8 ohms special load connected to J2 and 600 ohm on J1 of transceiver and measure audio output.

4. Record data as shown on data sheet.

5.7 <u>Transmit Frequency Stability</u>

a. <u>Conditions</u>

Set up equipment as shown in Figure 3..

b. <u>Measurements</u>

1. Using loop through coupler, connect to counter.

2. Key radio with no modulation and record data.

5.8 <u>Transmit Power Output</u>

a. <u>Conditions</u>

Set up equipment as shown in Figure 3.

b. <u>Measurements</u>

1. Key radio and measure RF voltage across coupler inductor with the HP 410B VTVM. Use test point on coupler and 1T loop.

5.9 <u>Transmit Spurious and Harmonic Emissions</u>

a. <u>Conditions</u>

Set up equipment as shown in Figure 3.

b. <u>Measurements</u>

1. Connect HP Wave Analyzer to the loop in the coupler.

2. Key the radio and using the carrier as a reference, measure harmonics listed on the data sheet.

5.10   Transmit Deviation

   a. Conditions

       Set up equipment as shown in Figure 3.

   b. Measurements

       1. Connect deviation meter to TP-4 of the exciter card through
           a 400 pf capacitor.

       2. Record deviation on data sheet.

       3. Repeat with TP-5.

       4. Calculate total deviation.

5.11   Voltage Variation Test

   a. Conditions

       Set up equipment as shown in Figures 2 and 3.

   b. Measurements

       1. Connect transceiver to the external, variable power supply
           and adjust for 13 VDC.

       2. Key radio and measure power output versus DC voltage using
           procedure detailed in paragraph 5.8.

       3. Using procedure outlined in paragraph 5.4, check received
           audio output versus dc voltage.

5.12   Temperature Tests

   a. Conditions

       1. Set up equipment for transmit data as shown in Figure 3.

       2. Set up equipment for receive data as shown in Figure 2.

b. Measurements

    1. Place transceiver into temperature box and take data at room temperature.

    2. Take receive data first. Measure sensitivity in accordance with paragraph 5.4, and frequency stability, paragraph 5.5.

    3. Take transmit data next. Note: Make certain antenna coax from transceiver is disconnected from test oscillator before beginning.

    4. Take transmit frequency stability, paragraph 5.7, and power output paragraph 5.8.

    5. Repeat data at the various temperatures listed on data sheet. When transceiver is brought from $-30^{o}C$ to $+25^{o}C$, open box and make certain frost forms and melts on unit. Operate radio while frost forms and melts before unit stabilizes at $+25^{o}C$.

5.13 Humidity Tests

a. Conditions

Set up equipment as shown in Figure 1, 2, and 3 as appropriate.

b. Measurements

    1. Take receive sensitivity in accordance with paragraph 5.1, receive audio output in accordance with paragraph 5.11 - C - 3 (at 12 VDC nominal voltage).

    2. Take transmit data in accordance with paragraph 5.8.

    3. Place units into humidity chamber.

4. Subject the equipment to an atmosphere in which the relative humidity is maintained in excess of 95 percent, unless stated otherwise in the following steps. Moisture shall be provided by steam or by evaporation of water having a pH value between 6.5 and 7.5 measured at 25°C. The velocity of air throughout the exposure area shall not exceed 150 feet per minute. The test chamber shall be vented to the atmosphere to prevent the build-up of pressure. Provisions shall be made to prevent water from dripping onto the equipment from above. The procedure shall be in accordance with the following steps:

Step 1. Over a two-hour period, raise the chamber temperature to 50 ± 3°C and increase the relative humidity to a value in excess of 95 percent.

Step 2. Maintain the chamber termperature at 50 ± 3°C with the relative humidity in excess of 95 percent for 6 hours.

Step 3. During the next 16-hour period, decrease the temperature gradually to 38°C, or lower. During this period, keep the relative humidity as high as possible and do not allow it to fall below 85 percent.

Step 4. Steps 1, 2, and 3 consititute a cycle. Repeat these steps until a total of 10 cycles (240 hours of exposure) have been completed.

Step 5. At the end of the exposure period, remove the equipment from the test chamber and drain off (do not wipe) any condensed moisture. Within one hour after the two cycles are completed, apply normal supply voltage and turn equipment on. Allow fifteen minutes following the application of primary power for the equipment to warm up. Immediately following the warm-up period, make such tests and measurements as are necessary to determine compliance with applicable equipment performance standards.

5.14   Thermal Shock

   a.   Conditions

        Set up equipment as shown in Figure 1, 2, and 3 as appropriate.

   b.   Measurements

        1.   Take receive sensitivity in accordance with paragraph 5.1

             and receive audio output in accordance with paragraph 5.4

        2.   Take transmit data in accordance with paragraph 5.8.

        3.   Place units into chamber.

        4.   The equipment shall be subject to a rapid temperature cycling

             test in accordance with MIL-STD-202D, method 107C, test

             condition A-1, except step 1 shall be -50°C and step 3 shall

             be +70°C.

        5.   After test is complete, repeat paragraph 1 and 2.

5.15   Battery Life

   a.   Measurements

        Battery life is measured with resistive loads set up at 12VDC

        to provide 250 ma for transmit and 35 ma for receive. (48 ohm

        and 343 ohms).

        Set up timer to provide a duty cycle of 50% transmit for 2 minutes

        and 50% receive for 2 minutes. Measure battery voltage versus

        time with a chart recorder.

        Check battery life (12 V to 11 V) of the sealed lead acid battery

        at room temperature and at -30°C.

        Repeat with two 12 v dry cell lantern batteries (Burgess #TW2)

        in parallel. Use 12 V to 9 V as battery life criterion.

TEST SET-UP 1

FIGURE 1

TEST SET-UP 2

FIGURE 2

TEST SET-UP 3
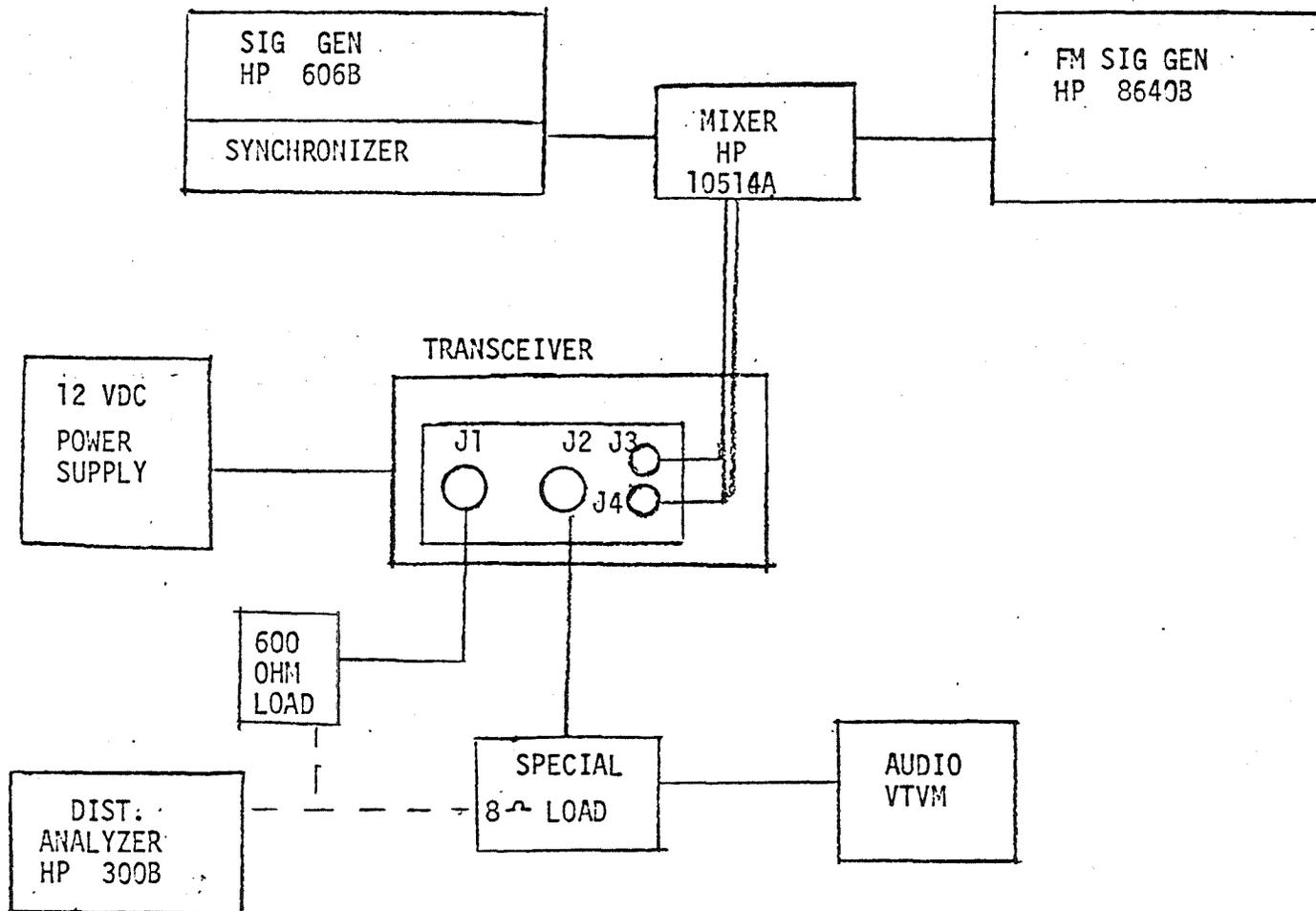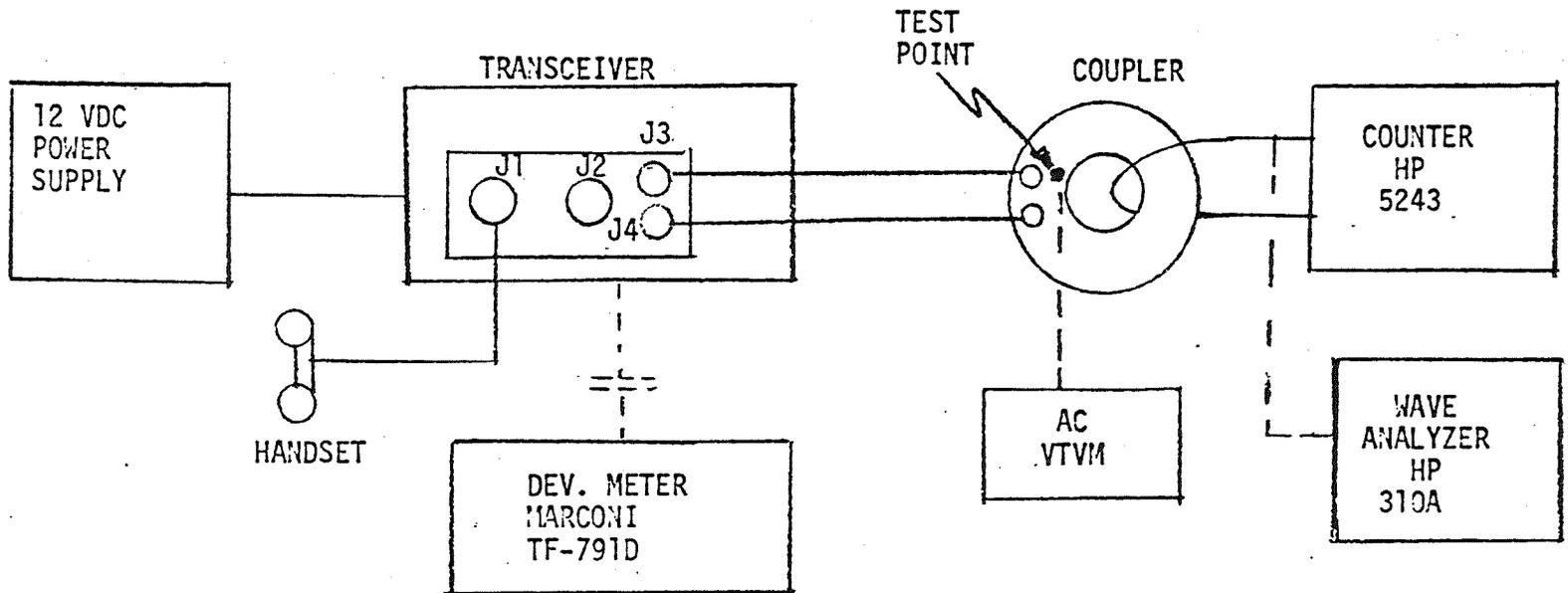
FIGURE 3

6.0   Test Data: Refer to procedures for test methods.

6.1   <u>Receive Sensitivity</u> (5.1)

Record quieting for 10 microvolts input.

Transceiver	8 ᐱ Load	600 ᐞ Load
E1	_3 5_ db	_32_ db
E2	_·3 4_ db	_3 2_ db

6.2   <u>Receive Squelch</u> (5.2)

Record audio output with radio squelched and unsquelched.

Transceiver	<u>Unsquelched</u>	<u>Squelched</u>	<u>DB</u>
E1	_3·0_	_0.01_	49.5
E2	_3·1_	_0.009_	50.5

6.3   <u>Selectivity, Spurious and Image Rejection</u> (5.3)

	Transceiver	
	<u>E1</u>	<u>E2</u>
Reference Output for 10 uv input	0.01 v	0.015 v
Spurious at +60 db	-- KHz	-- KHz
	--	--
	--	--
Image Response 858 KHZ	--	--
Response at 80 db level:		
88 KHz	--	--
100 KHz	--	--
115 KHz	--	--
145 KHz	--	--

6.4 Audio Output and Distortion (5.4)

Record audio output voltage and distortion

Transceiver	Audio Output	Dist.	600Ω Out	Dist.
E1	4.3 VAC	5.6 %	+1 DBM	5.1 %
E2	4.2	3.8	0 DBM	3.5

6.5 Receive Frequency Stability (5.5)

Transceiver	Frequency
E1	403.007 KHZ
E2	403.014

6.6 Audio Response (5.6)

Transceiver	Audio Frequency	600Ω Load Response	8Ω Load Response
E1	1 KHz (REF)	0 db	0 db
	300 Hz	+0.3	-1.0
	2 KHz	-1.8	-1.8
	2.5 KHz	-2.8	-3.0
	3 KHz	-3.9	-5.0
E2	1 KHz (REF)	0 db	0 db
	300 Hz	-0.2	-0.9
	2 KHz	-1.5	-1.4
	2.5 KHz	-2.5	-2.8
	3 KHz	-3.3	-4.3

6.7 Transmit Frequency Stability (5.7)

Transceiver	Frequency
E1	52.008 KHz
E2	52.006

6.8 <u>Transmit Power Output</u> (5.8)

Transceiver	1 T Loop	Power Output	DC Current Transmitter	Receiver
E1	1.10 —H.Coupler	18.0 VAC	225 MA	35 MA
E2	1.45 —C.Coupler	18.5	230	36

6.9 <u>Transmit Spurious and Harmonic Emissions</u> (5.9)

Transceiver	Spurious	Level
E1		
	52 KHz (REF)	0 DB VAC
	104 KHz (2nd Harm)	38 DB
	156 KHz (3rd Harm)	35
E2	(4th Harm)	48
	(5th Harm)	35
	52 KHz (REF)	0 VAC DB
	104 KHz (2nd Harm)	38 DB
	156 KHz (3rd Harm)	37
	(4th Harm)	45
	(5th Harm)	37

6.10 <u>Transmit Deviation</u> (5.10)

Transceiver	Frequency	Deviation
E1	10.052 MHz	1.700 KHz
	10.000 MHz	1.240
	Total	2.940 KHz
E2	10.052 MHz	1.40 KHz
	10.000 MHz	1.42
	Total	2.82

6.11 Voltage Variation Test (5.11)

Transceiver	Voltage	Audio Out 600 ∿	8 ∿	Power Output
E1	13.0	+0.8 DBM	4.5 VAC	21 VAC
	12.0	0	4.1	18
	11.0	−0.3	3.8	14
	10.0	−1.2	3.2	8
	9.0	−3.0	2.5	2.4
E2	13.0	+0.5 DBM	4.3 VAC	21 VAC
	12.0	0	4.0	18.5
	11.0	−0.1	3.6	14
	10.0	−1.0	3.1	9
	9.0	−2.0	2.5	4

6.12 Temperature Tests (5.12)

Transmit - E1

Temperature	Frequency Stability	Power Output
+25°C	52.014 KHz	19 VAC
−50°C	51.935	8.5
−30°C	51.963	14.5
+25°C	51.991	18.0
+50°C	52.030	19.0
+70°C	52.042	18.8

Receive - E1

Temperature	Audio Out 600 ~	8 ~	Sensitivity	Frequency Stability
+25°C	0 DBM	4.2 VAC	34 db	463.015 KHZ
-50°C	-2.0	2.5	36	402.976
-30°C	-1.0	3.3	37	402.990
+25°C	0	4.2	34	403.005
+50°C	-0.5	4.1	33	403.001
+70°C	-1.0	3.8	33	402.995

Transmit - E2

Temperature	Frequency Stability	Power Output
+25°C	52.003 KHz	18.5 VAC
-50°C	52.052	7.8
-30°C	52.090	12.0
+25°C	51.967	18.5
+50°C	51.996	18.5
+70°C	51.990	18.5

Receive - E2

Temperature	Audio Out 600 ~	8 ~	Sensitivity	Frequency Stability
+25°C	0.1 DBM	4.1 VAC	35 db	403.013 KHz
-50°C	0.2	3.0	35	402.974
-30°C	+1.2	3.6	36	402.993
+25°C	+0.2	4.1	37	403.013
+50°C	-1.0	3.7	35	403.010
+70°C	-1.8	3.3	26	403.011

6.13   Humidity Test

Before Humidity

| Sensitivity | Audio Out | Power Output | Frequency |
| | | | Xmit | Rec |

Sensitivity   Audio Out   Power Output   Frequency
                                            Xmit   Rec

__32__ DB   _4.3_ VAC   __20__ VAC   52.021 403.014 KHZ
               _0_ DBM

After Humidity

Sensitivity   Audio Out   Power Out   Frequency
                                         Xmit   Rec

__28__ DB   _4.2_ VAC   _19.5_ VAC   51.990 403.015 KHZ
               _0.2_ DBM

6.14   Thermal Shock

Before

Sensitivity   Audio Out   Power Out   Frequency
                                         Xmit   Rec

__34__ DB   _4.2_ VAC   __19__ VAC   52.003 403.00 ͢
               __0__ DBM

After

Sensitivity   Audio Out   Power Out   Frequency
                                         Xmit   Rec

__34__ DB   _4.4_ VAC   _19.5_ VAC   52.001 403.006
               ±0.1 DBM

6.15   Battery Life Test

50/50 Cycle: 2 minutes transmit - 250 ma.

               2 minutes receive - 35 ma.

Room Temperature (+25°C): Sealed Lead Acid Battery:

Measured (12 V to 11 V) - 31 hours (4.4 AH)

Calculated (12 V to 11 V) - 35 hours (5.0 AH)

Lantern Battery, Burgess #TW2

Measured (12 V to 9 V) - 86 hours (2 batteries in parallel)

Calculated (12 V to 9 V) - 19.6 hours (2 batteries in parallel)

Cold Temperature (-30°C): Sealed Lead Acid Battery:

Measured (12 V to 11 V) - 18.8 hours

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<u>Calculated</u> (12 V to 11 V) - 19.3 hours

Lantern Battery, Burgess #TW2:

<u>Measured</u> (12 V to 9 V) - 13 hours (2 batteries in parallel)

<u>Calculated</u> (12 V to 9 V) - 0.6 hours (2 batteries in parallel)