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A TACTILE PAGING SYSTEM FOR DEAF-BLIND PEOPLE PHASE II

By:

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CONTENTS

ILLUSTRATIONS

SUMMARY

This report describes the work accomplished during Phase II of a three-phase project. The purpose of the project is to develop a breadboard model of a radio frequency paging system with vibrotactile outputs for use by deaf-blind people at the Helen Keller National Center for Deaf-Blind Youths and Adults. During Phase II we concentrated on the control logic and the on-body radio transmitter. We improved the control logic capability and studied methods for implementing the on-body portion of the logic in a small package. A small, low power, on-body transmitter was designed, developed, and tested with a wrist-strap antenna to extend the one-way communication system developed during Phase I to a two-way communication system.

ACKNOWLEDGMENT

The accomplishments of Phase II of the project, like Phase I, result from the diligent effort of many individuals. Expertise in several engineering disciplines is needed in a project of this type in spite of the fact that the total level of effort is modest. Significant progress has been achieved only because of the cooperative efforts of the individuals involved, especially Thomas J. Drewek, James C. Gaddie, Russell T. Wolfram, and John M. Yarborough. Mr. Yarborough, a former SRI staff member who is now employed by Signetics Corporation, was responsible for the control logic design during Phase I and continues to contribute to the project as an SRI consultant.

In addition to the above SRI personnel, the active participation of Frederick M. Kruger, the Helen Keller National Center for Deaf-Blind Youths and Adults, and James L. Jones, NASA Ames Research Center, has contributed significantly to the success of this project.

I INTRODUCTION

The work described in this report relates to the breadboard-model development of a radio-frequency paging communication system that has coded vibrotactile outputs suitable for use by deaf-blind people. The concept of this sytem was proposed by Dr. Frederick M. Kruger, Director of Research, Helen Keller National Center for Deaf-Blind Youths and Adults (the National Center), Sands Point (Long Island), New York. Dr. Kruger did initial breadboard development work and as an advisor to NASA is an active participant in this current effort. The project is funded by NASA through its Office of Technology Utilization, and the work is based in part on SRI's earlier tactile perception studies under NASA contract.

The paging system is intended to provide a means for communicating with deaf-blind people in an institutional environment, specifically, the National Center. During training and rehabilitation of clients at the Center, communication with selected groups and selected individuals is required on a routine basis and during emergency conditions. For example, in the event of a fire alarm, all clients must be quickly alerted, and during routine classroom training sessions a signal is needed to indicate the beginning and end of each session. Messages to individuals--such as notification of the arriv ' of a visitor--need to be communicated on a selected individual basis. During Phase I of the project, a breadboard model of a system having the above features was developed.

The Phase I model had one-way transmission capability and consisted of (1) a base station--an FM (frequency modulated) transmitter and its control logic; and (2) an on-body unit--an FM receiver, control logic, and a vibrotactile transducer output. Figure 1, taken from the Phase I report,* shows the components that comprise the one-way transmission system. The large box in the background labeled "Wrist-Com Control" houses the control logic and modulator for the base station transmitter, which is the Motorola unit on the right. ("Wrist-Com" is the name Dr. Kruger has given to the system and is derived from the fact that the on-body portion of the system in its final form will be small enough to wear on the wrist.) The three items in the left foreground are the battery pack, the receiver, and the control logic for the on-body unit--they are carried in the leather case shown in the background. The remaining item shown in the center foreground of the photograph as well as Figure 2, is the wrist-worn stimulator assembly.

The alert stimulator transfers time-sequential coded signals without any overt action required by the wearer; this stimulator consumes a relatively high amount of power from the battery. Fire alarm and time signals use this stimulator; the other coded signals are transferred by the low power message stimulator after an identifying code (Message Ready) has been signaled by the alert stimulator. To use the message stimulator, in what is called the Single Character Morse mode, the wearer places a finger on the tactile pin to sense a repeated Morse code character. Various characters will be assigned meaning by the Center. For clients with advanced capability, the message stimulator can be used to transfer any Morse code character, and provision is made at the base station for sending this information manually (Manual Morse mode).

Phase II of the project, to which this report is addressed, has been a modest effort that was interim in nature. Phase II augmented and

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*J. A. Baer, "A Tactile Paging System for Deaf-Blind People--Phase I," Contract NAS2-8711, SRI Project 3980, Stanford Research Institute, Menlo Park, California (February 1976).

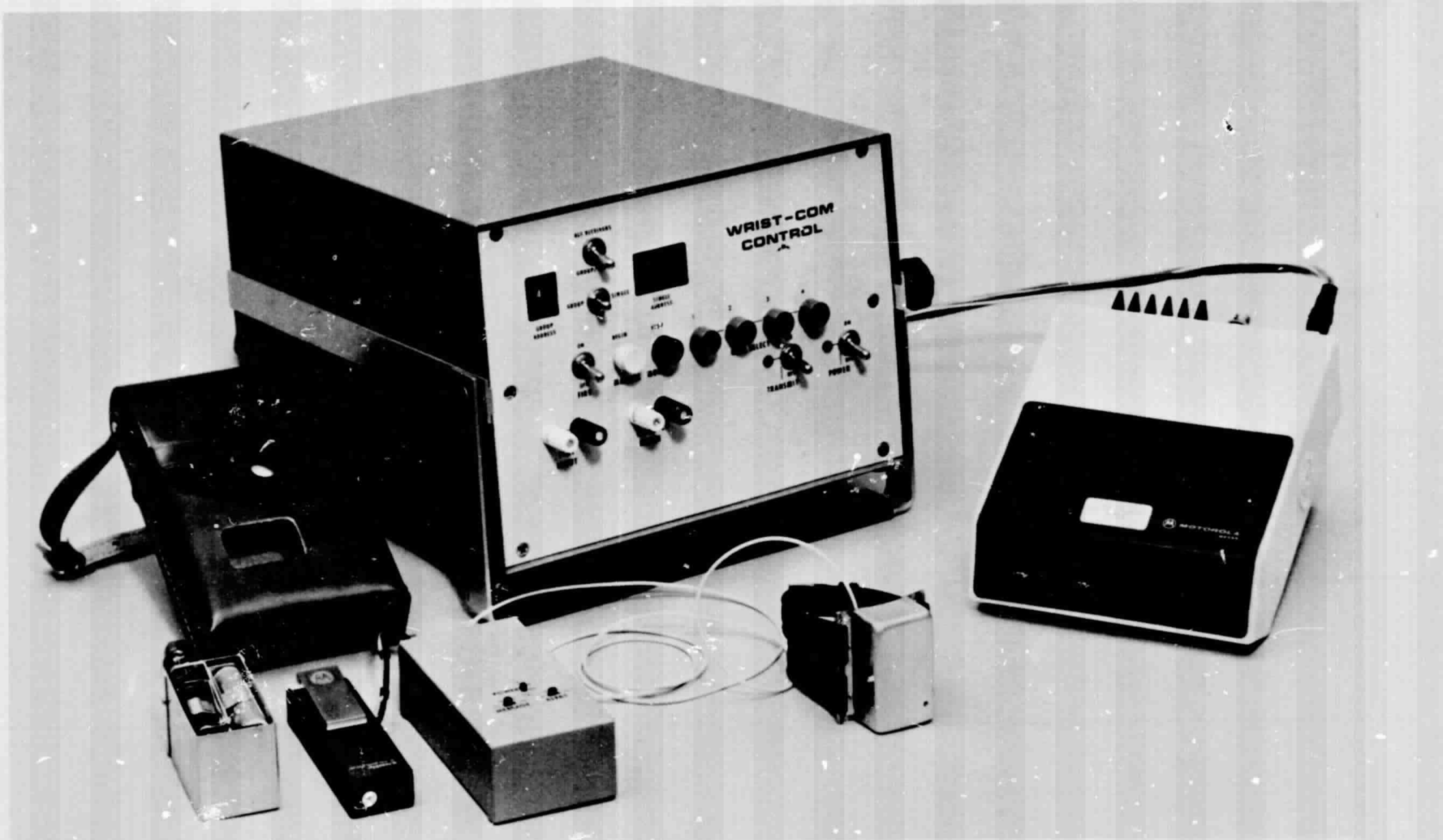

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FIGURE 1 BREADBOARD MODEL OF PAGING SYSTEM

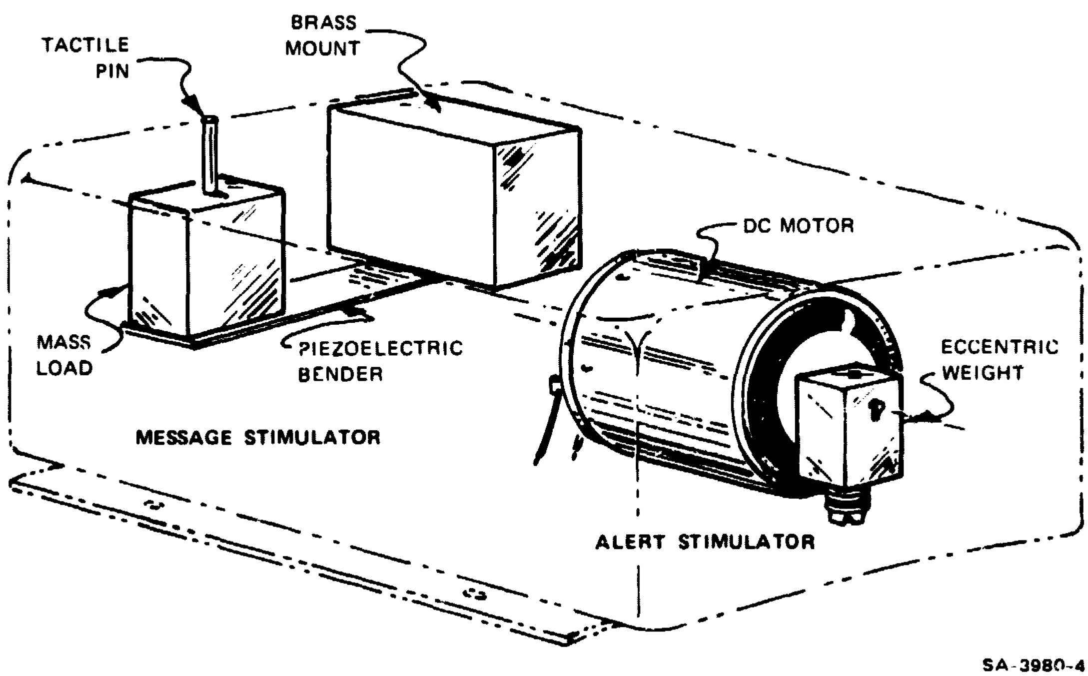

FIGURE 2 TACTILE STIMULATOR ASSEMBLY

improved the functions of the breadboard system developed in Phase I. A third phase is anticipated that will result in equipment that will be the basis for making additional units for use by clients at the National Center. During Phase II, the breadboard system was modified as follows:

- Certain aspects of the control logic for the base station and the on-body unit were improved, and some temporary modifications were added to the on-body unit to facilitate testing at the Center. These changes are described in Section II of this report.

- An on-body FM transmitter was developed to provide a a significant new function to the system, namely, two-way communication. This transmitter is a small low power, battery-powered unit, and it is the basis for a transmitter that will be included in a wrist-worn package to be developed during Phase III.

- The problems of miniaturizing the on-body control logic to make it suitable for inclusion in a wrist-worn package, which has been a significant problem since the outset of the project, have been addressed, and a proposed course of action is discussed in Section III.

The following components of the system were not modified:

- The stimulator assembly was not changed because of budgetary constraints, although some improvements would be beneficial.

- The radio frequency (RF) portions of the system associated with the one-way transmission feature were not changed. The present model operates satisfactorily at a frequency of 170.4 MHz--a government frequency assignment obtained by NASA for system development purposes.

II NEW FEATURES

A. General

The features added to the breadboard hardware during Phase II of the program are of two types: features, most of which will be included in the final version of the system, and features that were included temporarily to facilitate the specifying of vibrotactile signaling parameters. The parameters are mainly timing intervals of time-sequential codes for the alert and message stimulators. The Phase II features that will be included in the final version of the system are: an on-body radio transmitter, a base station demodulator, and certain additions to the control logic in the base station and the on-body unit. The on-body transmitter which is discussed in Part B, is the most significant feature from an overall system point of view. The control logic modifications, although time consuming and essential to the system, are somewhat difficult to appreciate without a detailed step-by-step description that would not be appropriate for this report. The temporary logic modifications and those for the final version are discussed in Part C of this section.

B. Two-Way Communication

One-way communication, from the base station to an on-body unit, was implemented in Phase I. To extend the operation to two-way communication requires an on-body transmitter and antenna, a base station demodulator, and control logic additions for these circuits. The description that follows relates primarily to the on-body transmitter.

The transmitter is to be used to request aid in the event of an emergency, and to acknowledge that a message addressed to a specific individual has been received and understood. The transmitter consists of a crystal-controlled two-stage VHF radio frequency generator, which is frequency-modulated by an audio tone oscillator and coupled to a wrist-strap antenna.

In the RF generator, the first stage is a single transistor crystal oscillator operating at 85 MHz with a third-overtone quartz crystal. The oscillator output drives the second stage, a two transistor frequency doubler, which produces a 20 mW output signal at 170 MHz. This output is coupled through a 3 dB attenuator to the wrist-strap antenna. The attenuator reduces antenna mismatch effects on the doubler operation. The tone oscillator uses two micropower operational amplifiers in a clipper-filter arrangement that requires no additional circuitry for amplitude stabilization. The sine wave output signal drives the tuning diode in the crystal oscillator to produce a frequenty deviation of ±1.5 kHz. This is doubled in the second RF stage to produce an output deviation of ±3 kHz. The total power consumption of the circuitry using a 5-volt power source is 50 mW.

The wrist-strap antenna provides a novel means for the transmission of radio signals by on-body devices such as this wrist-worn transmitter. The antenna itself is the human arm. A wrist-strap device is used to couple radio energy to the arm antenna. This coupler consists of two rectangular strips of copper foil enclosed in an insulating wristband. One strip is connected to the transmitter RF output terminal. The other strip is connected to the transmitter's metal enclosure, which is connected internally to the ground or common side of the circuitry. The RF energy is capacitively coupled from the copper strips to the arm. The impedance looking into the wrist-strap coupler varies somewhat from person to person but is usually in the range from 40 to 60 ohms, with only a small reactive component. It is thus a good match to the 50 ohm output impedance of the transmitter RF circuitry.

A test version of the transmitter was fabricated using miniature electronic components mounted in a small metal enclosure. This test transmitter is shown in Figure 3; the white wristband contains the copper foil strips for the antenna. Field tests were made at the SRI building complex using the test transmitter, wrist-strap antenna, and a base receiver with a ground plane monopole antenna 30 feet high. Very good outside coverage was obtained to at least 1200 feet separation. Coverage inside buildings varied from very good to poor depending upon the type of building construction and the location within the building. The miniaturized version of the on-body unit discussed in Section III will include this transmitter in a repackaged module, and the following characteristics and protocol have been established for two-way communication:

<u>General</u>

- A single frequency assignment will be shared by the base station and wrist transmitters, 170.4 MHz. All signals from on-body transmitters to the base station will have the same characteristic, namely, a carrier with a single frequency tone that is frequency modulated onto the carrier.
- To acknowledge receipt of a message the user will depress a switch button once.
- To request aid at any time the user will depress a switch button three or more times in succession (the same button as for the acknowledge).
- Periodically and automatically the base station will test the operational status of the on-body unit(s) by requesting a transmission from the on-body transmitter. This action will be transparent to the user.*

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*See footnote on page 12.

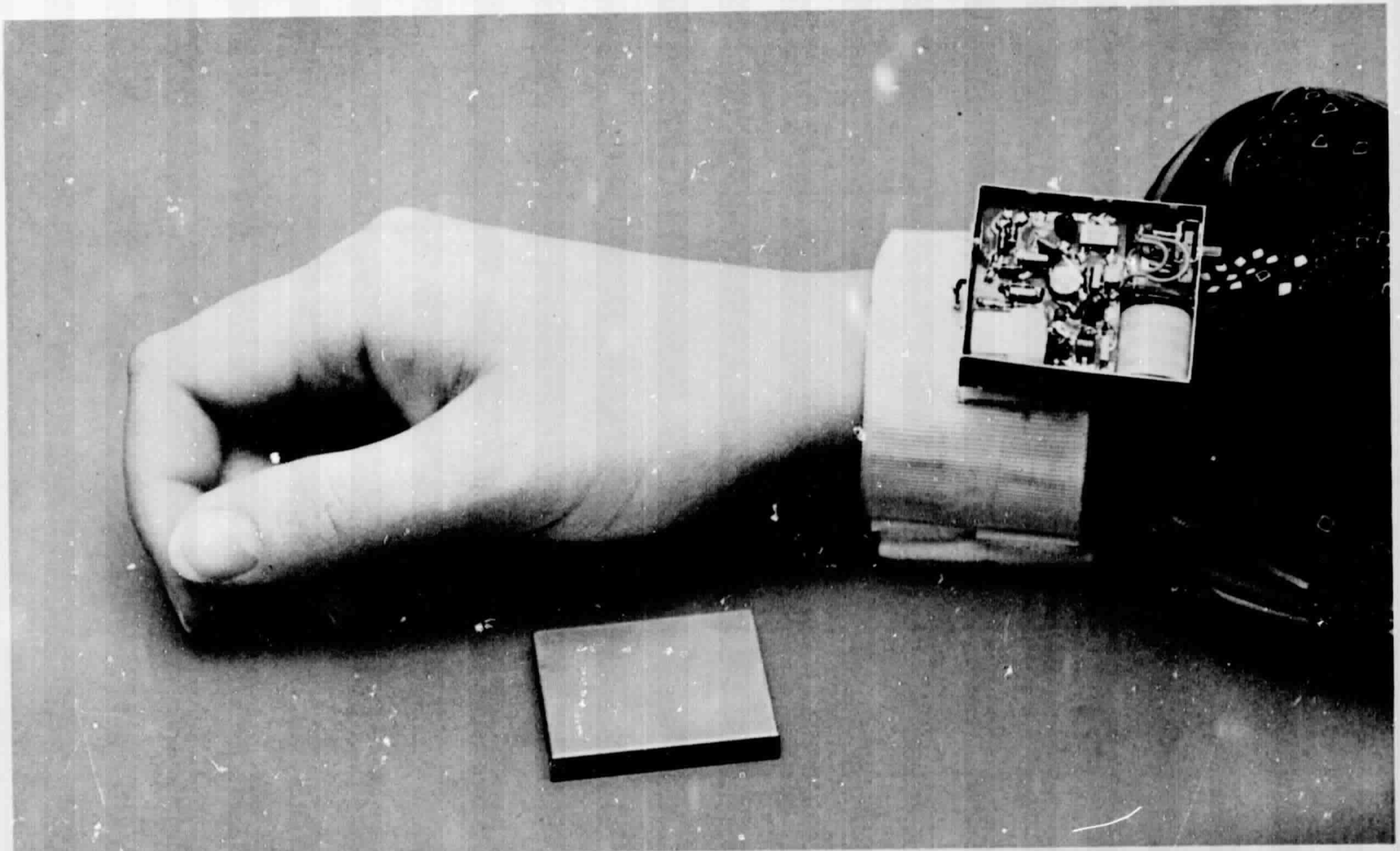

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FIGURE 3 WRIST-WORN TEST TRANSMITTER

Acknowledge Sequence

- After the base station sends a Single Character Morse code message to a selected individual, the base station will automatically interrogate the addressed receiver and request an Acknowledge signal (Acknowledge Interrogation mode).
- When the user understands the message and depresses the switch button, a status flag is set (the Acknowledge status flag).
- Upon receipt of an interrogation code from the base station the on-body unit automatically tests its status flag. If the flag is set, the on-body transmitter will be turned on to indicate the message has been received, that is, message acknowledged.
- Upon receipt of the signal from the on-body unit, the base station responds with a coded signal that resets the Acknowledge status flag.
- If the switch button is depressed while the alert stimulator is sending vibrotactile code (Message Ready only), the alert stimulator is turned off and the message stimulator is turned on.
- If the button is depressed indicating receipt of message while the message stimulator is still presenting the vibrotactile code, the stimulator is turned off in addition to the setting of the status flag.

Aid Request Sequence

- When the base station is not sending a message under the control of an operator or the time clock, and it is not in the Acknowledge Interrogation mode, the base station control logic will automatically switch to the polling mode. (Under certain circumstances the Acknowledge Interrogation mode and the polling mode will operate in a time-sharing manner.)*

- When an individual requests aid (by depressing the button three or more times) an on-body status flag is set (the Aid Request status flag).
- To detect the fact that an Aid Request has been made, the base station in its polling mode sends a coded signal successively to each group of users to ascertain the binary state of the Air Request status flag.*
- In response to the coded signal, each on-body unit in the addressed group tests the state of its own status flag, and if in the set state it sends a signal to the base station.*
- When the base station receives a signal from any member of the group addressed, it switches out of the group polling mode and sends a coded signal to the individual on-body units within the appropriate group. (As before, receipt of the base station's coded signal causes the on-body unit to test its Aid Request status flag.)*
- When the base station addresses individually the on-body unit whose status flag is set, that on-body unit transmits a signal to the base station, and this identifies the requestor.
- Upon receipt of the signal from an individually addressed on-body unit, the base station responds with an "assurance message" to the message stimulator (or perhaps the alert

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*See footnote on page 12.

stimulator) and also resets the on-body Aid Request status flag. flag.

- Simultaneous with sending the assurance message the base station control module indicates the existence of an emergency condition to the operator by a suitable alarm (panel lamp and audible alarm), and the panel indicates the address of the requestor.*

At this writing the breadboard system, including a slightly modified version of the test transmitter, is being prepared for shipment to the National Center for RF coverage and two-way communication testing. The base station receiver is a Motorola unit that is included in the same enclosure as the base transmitter--the piece of equipment shown in Figure 1 is actually a transceiver. An SRI designed demodulator has been added to the receiver and is also included within the enclosure. Plans call for testing the system in two modes. One is an automatic-response mode in which the base station operator will send a message to the on-body unit which will then automatically respond with a transmission from the on-body transmitter. (This is accomplished by turning the on-body transmitter on and off in lieu of or simultaneous with the alert stimulator.) An indicator at the base station will show when the transmission from the on-body unit has been received by the base station, thus completing the communication cycle. In the other testing mode, deaf-blind people and people with normal sight and hearing will wear the on-body unit and be a link in the communication cycle. Upon command from the base station via the message stimulator, the wearer will depress a switch button to turn the transmitter on and then release the switch to turn it off. A subsequent message

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*Full implementation of these features will not be included in the next breadboard version because of anticipated budget constraints and the fact that there will be only a single on-body unit.

from the base station operator will indicate to the wearer whether or not a satisfactory response transmission was received at the base station.

C. <u>Control Logic Additions</u>

New control logic features have been added during Phase II to both the base station and the on-body unit. Changes in the on-body logic have required a considerably greater effort to implement than those for the base station because of packaging restraints (that is, the small size of the on-body unit). In order for the entire Wrist-Com system to be successful in its final version it is necessary that the on-body portion be small enough to be conveniently worn on the wrist, and require low operating power. Throughout the project the control logic has been an important factor in establishing goals and determining the amount of effort required to pursue these goals. This was true for Phases I and II and is expected to be true for Phase III. During Phase I it took a considerable effort to provide the necessary on-body control functions using a small number of logic packages (thirty 14- and 16-pin dual in-line packages). This resulted in a sophisticated logic design that is very effective, although somewhat complicated from a design and understanding point of view. In keeping with this effort to minimize package count, the volume necessary for the wiring of the logic packages was also held to minimum. This was achieved by using magnet wire (#36 double coated film insulation) and wire wrapping directly onto the pins of the packages. This method of fabrication, however, does not lend itself to making retrofit changes in the logic, such as those required during Phase II of the work.

The logic design and packaging efforts of Phase I made it possible to house the on-body control logic in the metal enclosure shown in Figure 1. The logic required two densely packed boards that were mounted in the enclosure. The enclosure is actually somewhat larger than was necessary for the two boards; it was sized to fit into the leather carrying case. Because of this, the package additions required for the Phase II version were mounted on a third board that was also put into the enclosure. The logic changes in the base station and the on-body unit required a substantial effort to implement, in part a result of hardware retrofitting. A detailed description of the logic itself is not included here; instead, a list follows citing the modifications for both the base station and the on-body unit. The modifications fall broadly into three categories; simplification of the base station operator procedures, simplification of the interpretation required by the user of the tactile output under specific circumstances, and improvement in functional reliability:

- Addition of a clear-to-send indicator for Manual Morse code mode.
- Addition of base station switch-opening control of the vibration period for the Time Period Indicator.
- Addition of automatic turn on and turn off of the base transmitter under logic control.
- Addition of automatic Fire Stop signal to all receivers.
- Addition of repetitive Fire Alarm turn on.
- Removal of the spurious vibration of the message stimulator that precedes the alert stimulator Message Ready code when in Manual Morse code mode.
- Removal of the overlapping vibration periods of the alert and message stimulators.

All of the above modifications were intended to be improvements that would be included in, or at least evaluated for, the final version of the system. The additional space required for the logic packages in the on-body unit for some of the functions may be hard to justify in a hard-wired random logic implementation (see Section III). In addition to the above listing, four temporary modifications were made in the on-body logic to facilitate testing at the National Center with the aid of deaf-blind people. These modifications permit field adjustment of certain timing intervals as follows:

- Addition of a variable control of the code rate for the Fire Alarm--alert stimulator.
- Addition of variable control of the code rate for the Message Ready signal--alert stimulator.
- Addition of variable control of the code rate for the Single Character Morse code mode--message stimulator.
- Addition of variable control of the number of repeats of the Message Ready signal--alert stimulator.

The three code rates and the number of repeated signals are adjustable by potentiometers included in the control logic enclosure and accessible from outside the leather case.

Figure 4 shows the rates (determined at the Center) for the Message Ready and Fire Alarm signals from the alert stimulator, and the approximate tactile sensation. The code assigned to Message Ready is: on for one unit of time, off for one unit of time, on for one unit of time, off for five units of time. Tests determined that this sequence should be repeated once. One unit of time was set to equal approximately 0.4 seconds, as measured electrically using an oscilloscope. However, because of the buildup and decay time of the motor in the alert stimulator, there is no abrupt transition between the on and off condition when sensed tactually. The minimum effective vibration period is approximately 0.8 seconds--the motor does not come to a complete stop during the 0.4-sec off time.

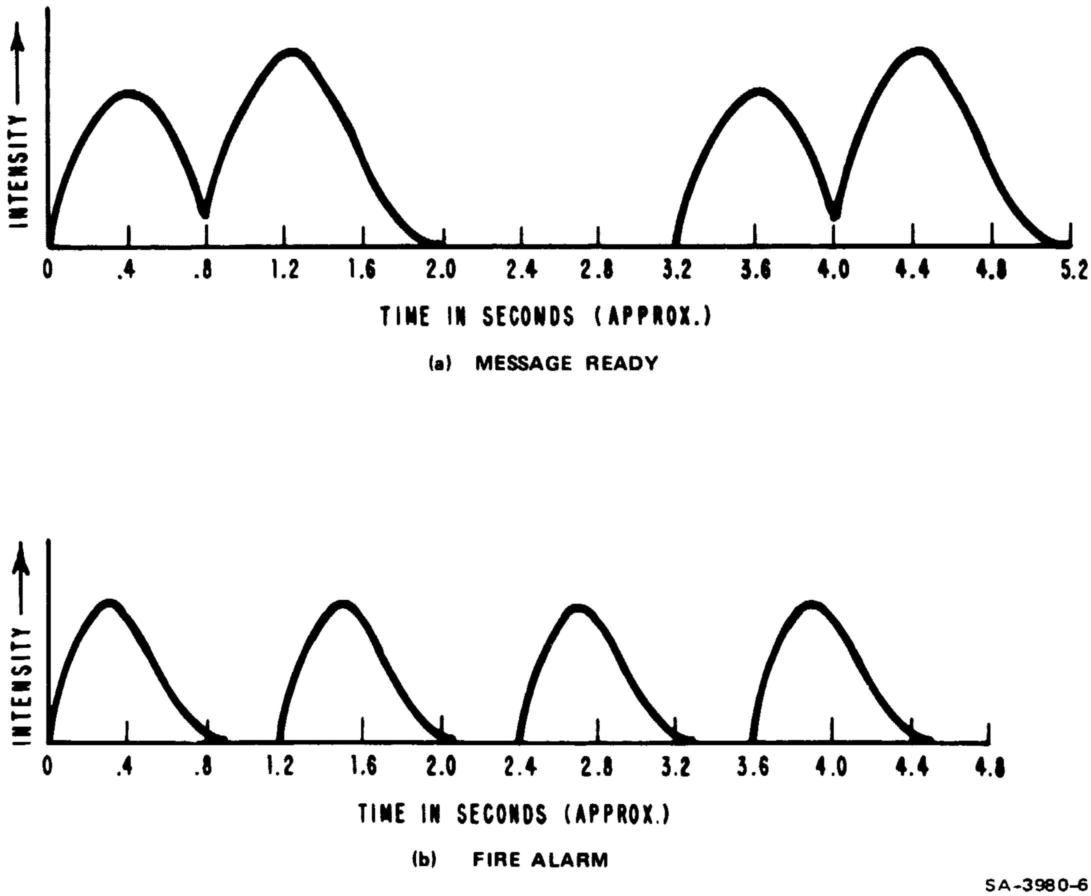

FIGURE 4 ALERT STIMULATOR SENSATION

The code for the Fire Alarm is: on for one unit of time, off for three units of time, repeat for an undefined period of time. (This cycle is briefly interrupted by periodic retransmission of the RF Fire Alarm bit-stream from the base station.) One unit of time was set to equal approximately 0.3 seconds. However, as for the Message Ready signal, the buildup and decay time of the motor influences the tactile sensation. The stimulation intensity for the Fire Alarm is somewhat less than it is for the Message Ready signal because the time allowed for motor acceleration is 0.3 seconds rather than 0.4 seconds. These tests confirmed that the intensity level established for the alert stimulator during Phase I is satisfactory. The two-position intensity switch was set in the low position for the tests at the National Center and the conditions illustrated in Figure 4. In the next version of the system, plans call for two intensity levels that are strap-selectable. Similarly, the rate of the Single Character Morse code from the message stimulator will be strap-selectable.

For the Single Character Morse code mode (message stimulator), the vibrotactile stimulus representing a dot has a duration of one unit of time and the vibrotactile stimulus representing a dash has a duration of three units of time. One unit of time was set at the National Center to equal 0.26 seconds, which means a dot has a duration of 0.26 seconds and a dash, following the usual convention, has a duration three times greater--0.78 seconds. The off interval (no vibration) within a character has a duration of 0.26 seconds, and the off interval between repeated characters has a duration of 0.78 seconds. For example, one of the Morse code characters used--message number 1--is the letter "O" (dash, dash, dash), and requires 3.64 seconds, including the 0.78-sec off interval between characters.

It is interesting to note that the minimum timing element for the alert stimulator is approximately three times the value of the timing element for the message stimulator; namely, three fourths of a second as compared to one-fourth second. The alert stimulator is not capable of operating at a faster rate because of the buildup and decay time of the motor and its eccentric load. The message stimulator, a piezo-electric flexure-mode vibrator, has no tactually discernible buildup or decay time. This speed limitation of the alert stimulator is an additional reason, along with saving battery power, for using two types of stimulators in the on-body unit.

III ON-BODY MINIATURIZATION

From the outset of this project (and in Dr. Kruger's planning before this project was initiated) a major factor has been the requirement that all the necessary functions of the final version of the on-body unit must be implemented in a small package suitable for wearing on the wrist. This puts stringent limitations on the power consumption, size, and weight of each subunit included in the on-body unit. The subunits are the power supply, control logic, receiver, transmitter, and stimulator assembly; each of these can be reduced in size, especially the control logic. Emphasis on the control logic is planned for Phase III of the project and has also been given consideration during Phase II. Several different approaches were studied, and we concluded that the best approach was to use microcomputer chips in a hybrid package. The possibility of the microcomputer approach was considered during Phase I, but, at that time, it would have been a higher risk approach than hard-wired logic, partly because of the state of development of CMOS microcomputer technology. The microcomputer to be used in the next version of the breadboard system will not result in either the smallest or the most economical implementation, but, all things considered, it seems the most reasonable solution.

The first possibility we investigated for miniaturizing the control logic was the use of a semicustom LSI (large scale integration) chip. A fully custom chip was not considered because of the high cost. It turned out that the semicustom chip was also too expensive--$32,550 to a semiconductor manufacturer plus associated SRI costs. Semicustom chips are made by selective masking for interconnection of transistors made on LSI chips in high quantity production. A manufacturer of these semicustom chips using CMOS technology (for low power) was contacted and a cost and size estimate obtained on the basis of the Phase I logic diagram. It was estimated that the entire logic could be put on a single chip measuring 7.2 by 7.3 mm (282 by 288 mils) and would cost $32,550 for the minimum quantity of fifteen chips. This chip has 1600 pairs of CMOS transistors.

The second approach considered was to obtain in chip form the approximately 30 MSI (medium scale integration) and SSI (small scale integration) circuits required to implement the logic, and package them using hybrid circuit techniques. A manufacturer of hybrid circuits estimated the price for this would be $8000 for a minimum quantity of ten sets, but the set required two hybrid packages each measuring 5 × 15 × 57 mm, plus an additional allowance for pinouts. This size was judged to be too large.

It is our conclusion that a microcomputer, assembled in a hybrid package, will be intermediate in price and size compared to the above two methods. In addition, it offers advantages in flexibility compared to the other methods. However, the microcomputer approach involves more risk than the other two methods because a proven hardware logic design is available as a basis for the LSI and all-hybrid implementations. This hardware design will also assist in the development of a microcomputer system, but not to the same extent, so there are more unknowns in following this course of action. We anticipate using RCA's 1802 CMOS microprocessor as the basis for the microcomputer. Three additional chips from RCA's COSMAC family will probably be required.

IV CONCLUSIONS

The modifications made in the control logic of the base station and the on-body unit proved to be generally satisfactory, and additional improvements are anticipated. Tests performed at the National Center resulted in setting the code rate so that the vibration period for the shortest code element is three-fourths of a second for the alert stimulator and one-fourth second for the message stimulator.

Tests for RF coverage were performed using the on-body transmitter and wrist-strap antenna in and around SRI's building complex. These tests indicate adequate coverage, assuming that multiple receivers will be used at strategic locations in the final installation.

In the on-body unit there are five modules: the power supply, the control logic, the transmitter/antenna, the receiver, and the stimulator assembly. Each of these could be reduced in size. The most significant reduction is possible in the control logic, and our miniaturization effort during Phase III will be concentrated on the control logic. Various options for implementing this logic were considered, and we reached the conclusion that the use of RCA's CMOS microcomputer chips packaged in hybrid circuit form is the best solution. The stimulator assembly for the next model will use the same types of vibrators, but in a more compact arrangement. The receiver, except for the demodulator, will be a module dissected from a commercial paging receiver. The power supply will use a single 5-volt battery with two dc-dc converters, 1.3 volts for the receiver and 30 volts for the message stimulator. The transmitter will be a smaller version of the transmitter developed during this phase.

The most important conclusion of Phase II is that the development of a Wrist-Com model having two-way communication capability and an on-body unit small enough to be worn on the wrist, appears feasible within the anticipated budget constraints of Phase III. Unfortunately, the wrist unit will be larger than desirable, and some functions will not be fully implemented. Nevertheless, in this form it should be possible to carry out a fairly exhaustive evaluation. It is our hope that the practicality of the entire concept will have been adequately demonstrated at the conclusion of Phase III and that subsequent work will develop the full potential of the concept.