

DIRECT

Operational Field Test Evaluation Technical Performance and Cost



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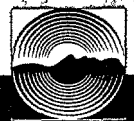


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SUMMARY

The Driver Information Radio using Experimental Communication Technologies (DIRECT) Operational Field Test (OFT) aims to increase the number of drivers who are aware of traffic incidents on their route by offering affordable route-specific automatic alerting. Both broadcast and roadside localcast delivery methods were tested on a 15-mile segment of I-75 in the Detroit area. Recruited drivers who used the segment on their commute route drove vehicles equipped with one of the delivery methods. Traffic information was provided by a professional announcer located at the Michigan Intelligent Transportation Systems Center (MITSC). The broadcast method used the Radio Data System (RDS) digital subcarrier of WDTR's FM signal to control the RDS entertainment radio; the analog traffic information was on another subcarrier. Four roadside localcast transmitter sites in the segment implemented a localized Low Power HAR and an Automatic HAR. While all three radio methods proved capable of providing clear, understandable messages, the perceived quality was highest for the FM subcarrier technique. However, the subcarrier messages did suffer unobjectionable multipath "pops" in the downtown area. The control reliability, for automatic interrupt, was the greatest for the RDS subcarrier. The AHAR control reliability was poor, missing interrupts about 25% of the time; the "alerting" for LPHAR used flashing lights, which operated poorly due to use of batteries for power. The broadcast technique was considerably less costly than either of the roadside techniques. In considering metro-wide deployment it is concluded that limited-distance segmented coverage, as in LPHAR and AHAR offers an advantage only if diversion information is included. With no diversion information all drivers approaching an incident should receive the same message; hence a wide-area broadcast approach is as effective as a segmented one. However, a normal power HAR deployment with flashing signs also remains a candidate. We believe the most cost-beneficial improvement over current all-incident spaced traffic reports on AM or FM stations would be a route specific service based on using the RDS subcarrier (only) of the FM stations along with in-vehicle paper maps.

TECHNICAL PERFORMANCE OF DIRECT'S TRAVELER INFORMATION SYSTEMS

1. GOALS OF THE OFT

The Driver Information Radio using Experimental Communications Technologies (DIRECT) Operational Field Test (OFT) pursued alternative ways to increase the number of drivers aware of traffic incidents on their route, and to provide earlier awareness of such incidents. Such awareness will then increase the driver's chances of avoiding becoming trapped in a segment of blocked or impeded expressway, and will contribute to both individual and aggregate reduction in travel times. A further goal of the OFT was to assess the reaction of "natural use" drivers to the traffic messages.

2. DIRECT'S APPROACH

The traffic information for DIRECT originated at the Michigan Department of Transportation (MDOT) ITS center in downtown Detroit-Michigan Intelligent Transportation Systems Center (MITSC). The MITSC infrastructure, composed of connected buried loops as well as camera coverage of portions of the instrumented section, was combined with incident detection data from other sources (helicopters, State Police reports, Michigan Emergency Patrol, etc.). A professional announcer employed by Metro Networks provided the audio reports.

The DIRECT project (1)pursued delivery methods for the traffic messages that are low-cost to the driver, so as to attract the largest number of users. This led to the use of one-way radio, either broadcast or localcast. The broadcast method used two subcarriers of an FM station; one roadside localcast method used a Low Power Highway Advisory Radio (LPHAR) and another used a custom method of automatically interrupting a special radio in the vehicle-called Automatic Highway Advisory Radio (AHAR). In addition, for purposes of comparison, a cellular-call-in method was tested. A message communications and control computer located at MITSC was used to send the traffic messages to the different transmitter sites.

In addition to minimizing cost to the driver, a second aspect of DIRECT's approach was the automatic interrupt or alerting for the radio methods.

MDOT leased 27 Chevrolet Lumina test vehicles and equipped them with one of the delivery system receivers and a tracking system. Five cars had RDS/SCA receivers; five had AHAR receivers; five had cellular phones; and five had only tracking, since LPHAR uses the standard AM band. Two test vehicles were equipped with all four receivers and served as spares; these are the vehicles used for taking our technical performance data. The technical performance did not include an evaluation of the tracking system.

3. SYSTEM DESCRIPTION

Before describing technical performance it is necessary to review the implementation of the communication technologies used in the DIRECT project. This includes the message communications and control computer used to send the traffic messages to the different sites and the feedback system used to acknowledge reception of traffic messages.

3.1. OVERVIEW OF THE FOUR DELIVERY METHODS

Figure 1 is extracted from Ref.(2) and shows an overview of the different DIRECT system delivery methods and how they are connected. A message computer at MITSC feeds all four delivery methods with message content and also controls access to the transmitters by sequentially dialing the specific communication link. A telephone line connects the message computer to the FM station, the cellular call server, and the LPHAR digital recorder. An 800 MHz trunked radio is used to connect the message computer to the AHAR digital recorders.

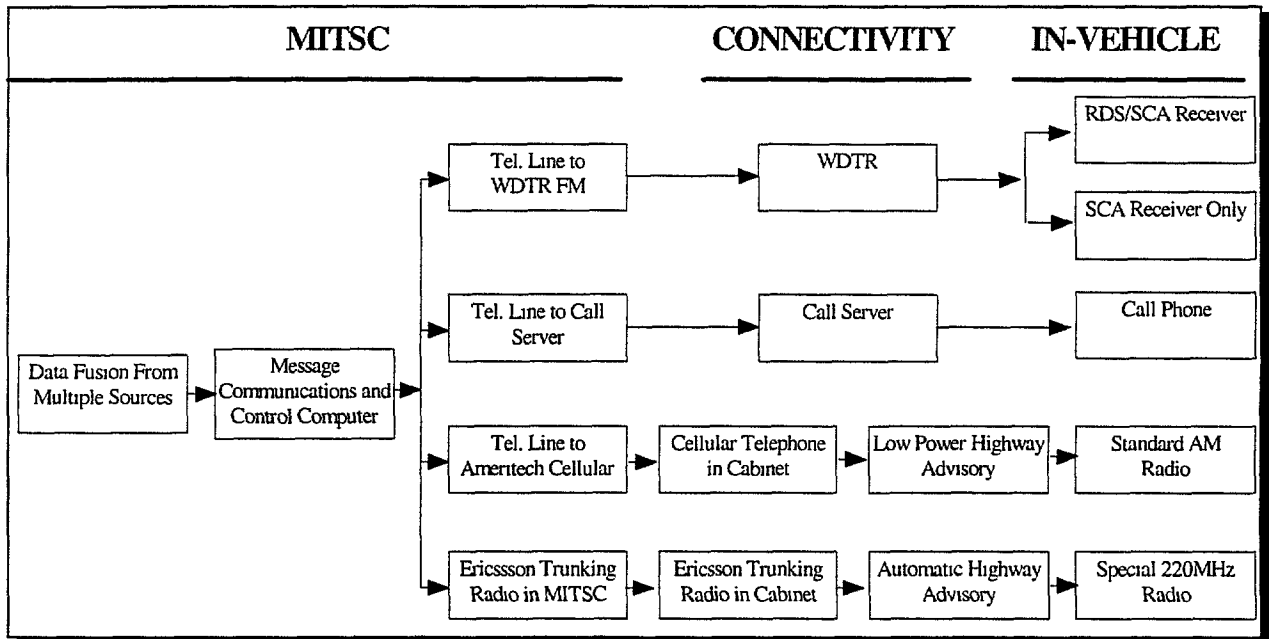


Figure 1 Overview of the four delivery methods.

3.2 MESSAGE COMMUNICATIONS AND CONTROL COMPUTER

This system is responsible for sending the traffic messages to all the delivery methods. An announcer speaks the traffic messages through a microphone. The message is then digitized and stored in the computer and sent to the different transmitter sites. Figure 2 shows the different components of the message communications and control computer.

The traffic messages, which are usually about 20 seconds in length, are sampled at 11 kHz; each sample is converted to an 8 bit word and the corresponding digitized message is about 220 kbytes. The digitized message is saved as a file with .wav extension in a directory that contains all broadcast messages. A Visual Basic application enables the user to select the sites where a particular traffic message is to be sent to. The message is then sequentially transmitted to these sites. When an operator becomes aware of an incident, we found, during a timed test, that it took about 1 minute for that message to be received by the RDS receiver; however it takes 12 minutes till all the sites have received the message. This is dependent on the following factors:

1. The application software was designed to deal with the different systems in a sequential manner with RDS being the first method that the software application communicates with.

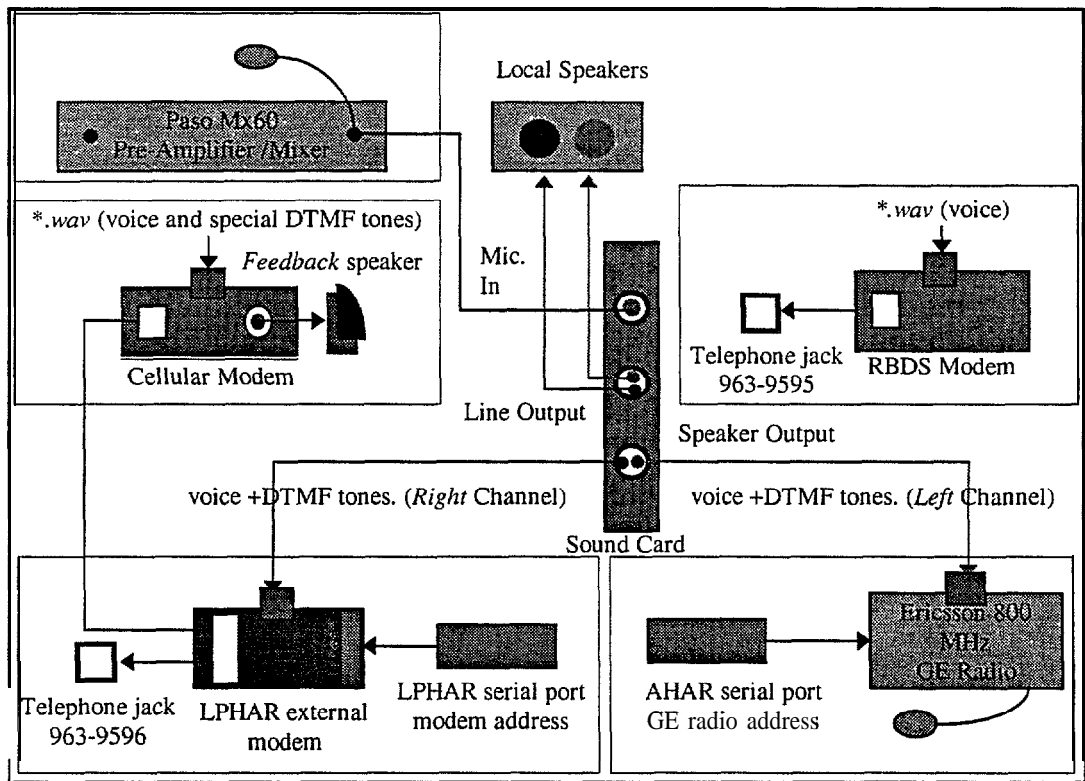


Figure 2 Message communications and control computer.

2. The impossibility of having the LPHAR modem and the Cellular modem on at the same time as they are connected to the same telephone line (Figure 2).
3. The 4 LPHAR transmitter sites are addressed by only one modem which also forces the sequential nature of addressing one site at a time.

In any operational system there would only be one or two delivery methods involved, which will cut the delay time if sequential connectivity were used; this aspect did not significantly limit the performance goals of this OFT. In addition it is essential to develop a robust software application.

We will describe briefly the hardware implementation of the different messaging mechanisms:

Cellular: An internal modem dials up the cellular server and sends the digitized message file. A speaker is connected to the modem voice output that plays the out-going message as well as the interrogation with the cellular server. Proper reception of the message is confirmed by dialing the cellular server and listening to the message under option 75 which corresponds to highway 175.

RDS/SCA: An internal modem dials up the FM station computer and sends the digitized message file.

LPHAR: An external voice modem is addressed by a serial port. It receives the voice message from the right speaker output of the sound card and dials up the cellular pager of the selected transmitter site. The DTMF tones control the digital recorder announcer operation, these tones select the memory bin where the message is stored, erase old messages, and update or insert new messages. In addition the modem also dials up the battery powered road-side beacons pager. The batteries are kept charged via solar cells. Messages sent to the closest transmitter may be heard via an AM receiver tuned to 1610 kHz and located at MITSC.

AHAR: A serial port addresses a GE radio which is capable of receiving voice and DTMF tones via the left channel of the sound card.

System Refinement: During the first few months of system operation commuters noted that some systems voice quality is acceptable while others are not. The system operator used to adjust the input sound volume till the sound quality of the impaired system becomes acceptable; however any adjustment made was sure to impair other working delivery systems. The reason is that each system has its own input signal dynamic range, hence no single volume position was satisfactory to all the dynamic ranges of all the systems. The problem was further complicated by the fact that some systems messages are preceded by DTMF tones used for control purposes; consequently these tones levels have to be adjusted too. To remedy this problem a deeper understanding of the whole system was necessary. Ghassan Shahine reconstructed the MITSC control room systems interconnections as shown in Figures 2 and Appendix A, studied the Visual Basic application code, and devised a successful plan to tune the system. The fundamental rule

in the plan was to calibrate the systems with the least degrees of freedom first and so on. The plan is summarized as follows:

1. Reduce the sound level at the input to the sound card to 15%. This would limit the room noise level entering the system.
2. Adjust the amplifier mixer (Figure 1) volume level to satisfy a good message on both RDS and cellular. This is an iterative process and needed few trials to have both systems perform adequately.
3. As the Master volume was reduced the DTMF tone used for the AHAR system was increased ten times using the creative studio application supporting the sound card.
4. The LPHAR and the AHAR systems are fed via the speaker output of the sound card. It was sufficient to use the balance adjustment of the speaker output to achieve a good quality of voice reception on both systems.

Since then the DIRECT project sound quality on all systems was acceptable.

3.3 MESSAGE DELIVERY FEEDBACK MECHANISM

This mechanism is composed of a variety of receivers available at MITSC that are accessible by the traffic messages operator (Figure 2) . These receivers enable the operator to confirm that the different messages have been received properly soon after they were sent by the message computer. In addition these receivers help in diagnosing some system malfunctions.

Following is a description of the feedback reception of the different technologies:

- RDS/SCA traffic message reception is confirmed via an SCA demodulator connected to an FM receiver tuned to 90.9 MHz. However this arrangement does not confirm that the TA bit is toggling the receiver in the vehicle dash (Figure 4).
- LPHAR message reception from the Canfield transmitter is confirmed by a Kenwood receiver tuned to 1610 kHz. However this system does not acknowledge reception of messages sent to the LPHAR sites at Westminster, Margaret, and Gardenia due to power output control at these sites.
- LPHAR beacons reception is confirmed by MITSC cameras installed on the highway and viewed by TV screens in the MITSC control room.
- AHAR reception at Canfield is confirmed by the SEA/ESP-520 receiver, however when a message is available at the Westminster and no message is available at the Canfield transmitter then the receiver scanner locks to the Westminster's transmitter frequency and hence the traffic message at Westminster reception would be confirmed.
- Cellular message reception is confirmed by dialing the cellular server directly.

3.4 RADIO DATA SYSTEM (RDS) AND SUBSIDIARY COMMUNICATION AUTHORITY (SCA)

This broadcast method (3) used digital subcarrier to control switching the audio of an RDS entertainment receiver to another Subsidiary Communications Authority (SCA) analog subcarrier on which the traffic message appeared. If this system were deployed the RDS receivers would have to contain an analog subcarrier decoder in addition to having a switching capability. The two subcarrier signals were added to the main channel signal of WDTR, Detroit's Public School FM station (at 90.9 MHz). This is a method for using a broadcast signal to automatically interrupt the driver's radio whenever a traffic incident on the specified route occurs, but requires that the driver's radio is tuned to the FM station delivering the subcarrier signals. Traffic messages sent from the message communications and controls computer at MITSC are handled first by another computer at the FM station that performs the following.

- Sets up both the RDS and SCA Encoders.
- Sends a prompting tone at the start of an updated or new traffic message to the SCA encoder, followed by a continuous transmission of the new or updated message with few seconds delay Between the end of one message and the beginning of the next one.

Figure 3 shows the different components necessary to send a message

The use of the RDS/SCA concept was to interrupt the driver via the RDS broadcast traffic advisory bit whenever a traffic message is transmitted. An RDS radio tuned to WDTR and stored in the vehicle trunk will have the TA bit enabled when a traffic alert message is broadcast. Also there is an SCA demodulator there that will retrieve the message information at the FM subcarrier. The TA bit is used as control input to the RDS radio located in the dash and will

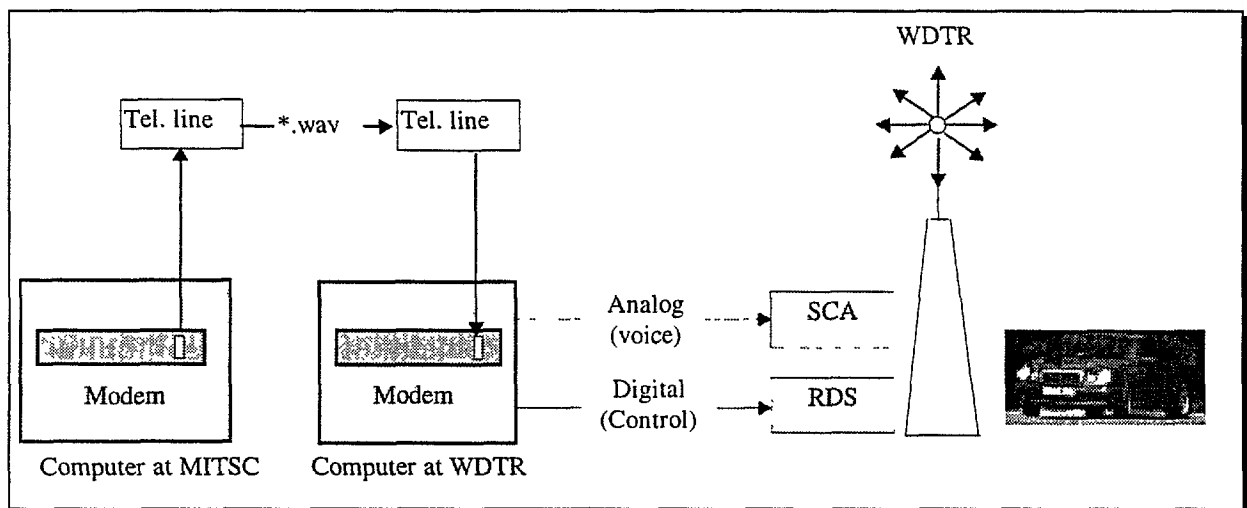


Figure 3 RDS transmission setup.

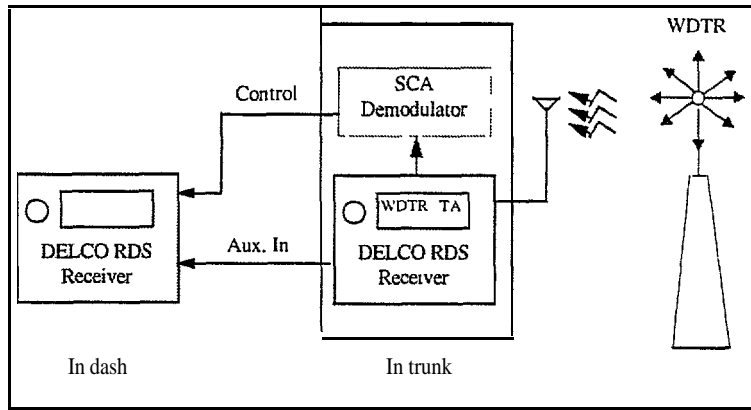


Figure 4: RDS/SCA in-vehicle two receiver implementation.

interrupt the radio on any channel AM or FM. The SCA message will be fed to its auxiliary input. Figure 4 illustrates the two receiver method of implementation. A switch is supplied that will disable the TA bit reception in order to allow the user to stop receiving the same traffic message.

3.5 LOW POWER HIGHWAY ADVISORY RADIO (LPHAR)

The LPHAR localcast method uses flashing signs placed both one-half mile ahead of and nearby the roadside transmitter to indicate to the drivers when the radio should be tuned to the LPHAR frequency of 1610 kHz to hear the traffic message. Note that this implements “automatic alerting” as compared to automatic interrupting.

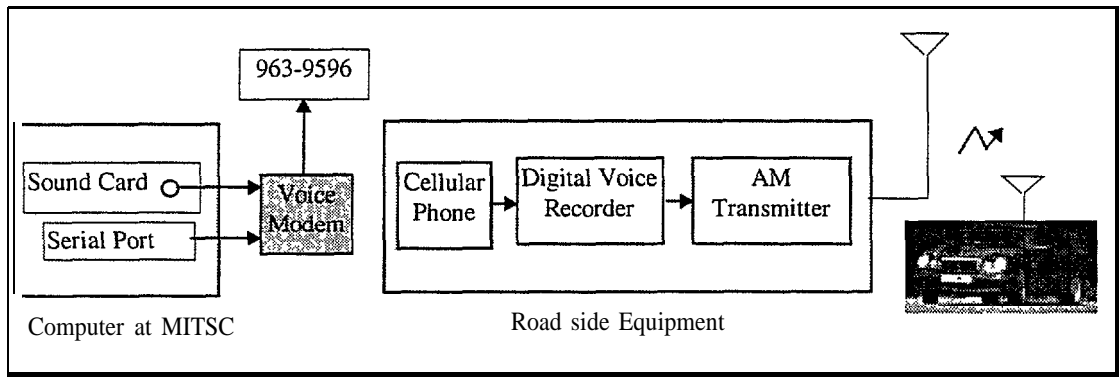


Figure 5 LPHAR transmission implementation.

Figure 5 shows the physical implementation of LPHAR transmission. The transmitters used are off the shelf transmitters tuned at 1610 kHz. There is no special equipment needed in vehicle to receive traffic messages other than the AM radio. The driver has to pay attention to the flashing lights once he/she is passing by their locations and tune the radio to 1610 if they are flashing. In the case that two contiguous transmitters are sending traffic messages, interference would occur around the middle of the road segment. Transmitter power output adjustment is necessary to create a dead zone within the segment if interference reception is objectionable.

Figure 6 shows the LPHAR implementation of the flashing lights. These lights are controlled by the message communication and control computer too. Whenever a traffic message is sent to one of the LPHAR site transmitters cellular phone, another call is made to a paging service and a pseudo coded telephone number that addresses the specific flashing light is sent to turn it on or off. These lights are powered by 12 volt, 900 cold cranking amps (CCA) batteries. The batteries also supply power to the paging units. The batteries themselves are supposed to maintain their charge via solar panels. The Michigan weather proved to be quite a challenge for these panels to adequately charge the batteries.

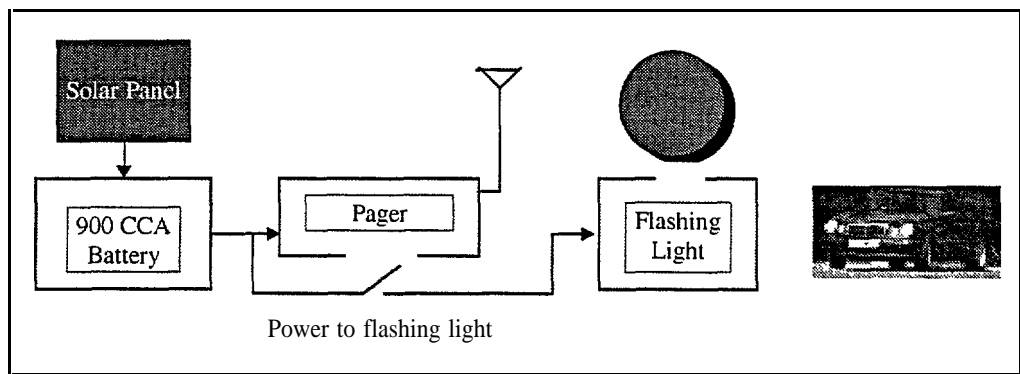


Figure 6 Roadside flashing light implementation for LPHAR.

3.6 AUTOMATIC HIGHWAY ADVISORY RADIO (AHAR)

The AHAR roadside (localcast) system is shown in Figure 7. This method automatically interrupted the driver's radio using a scanner to detect carriers at 220.116 or 220.118 MHz. This method uses one of the FCC's recent allocations of 5 kHz wide channels, and uses new modulation techniques (4) which permit operation in such a narrow bandwidth. A GE/Ericsson 800 MHz radio is used for MITSC to roadside communication, a digital voice recorder is used to store the most recent traffic message and continually feed it to an SEA/ESP-220 MHz transceiver for roadside to vehicle communication. Two channels were alternately used on the 4 transmitters sites, this is used in order to increase the distance between transmitters operating at the same frequency hence reduce interference at the radio. The in-vehicle transceiver is switched to the scan mode controlled by a combination of squelch and DTMF tone pair to indicate the start of a valid message. For a message to be received in the vehicle the signal has to be strong enough to

break squelch and provide the DTMF tones 1 and 4 as shown in Figure 7. Afterwards the in-vehicle radio will be preempted and the message is heard by the driver. Decoding of the “1” followed by the “4” tones is done by a special circuit. This technique works well as long as the transmitters are far apart till the receiver get out of lock of the current station and go into the scan mode. This has been a challenge for the Westminster site as it is sandwiched between the Canfield and Margaret transmitters sites, the received signal from these sites was usually strong and disallowed the receiver from going into the scan mode. Consequently messages at the Westminster site were not heard although they were successfully transmitted. This problem was discovered after the deployment of the system. One may learn from this is that the switching circuitry need to be able to switch based on signals with the higher signal to noise ratio or one has to spread the transmitters site enough to have adequate switching then fix the site. In a future AHAR implementation one may use a modem at the traffic center and a cellular phone at the roadside (similar to the LPHAR implementation) rather than the radio communication as implemented here.

3.7 CELLULAR CALL SERVER

The Cellular Call Server is implemented with a TIE/Communications System 4002, four line voice mail system. One line is reserved for programming by the message communications and control computer. The remaining three lines form a rotary hunt, that is three lines could be active at one time, so if one of the lines is busy the server automatically connects through an inactive line. This limitation on the maximum number of lines to 3 lines may not be adequate in a deployable system. In addition another shortcoming of this server is its inability to have default messages automatically loaded as “There are no known incidents or delays at this time”. Also if an incident occurs the default message has to be removed to load the incident message and once the incident clears the operator has to erase it and then insert the default message again. The above limitations lead to the conclusion that a specially built computer controlled traffic advisory system that allows many active lines and a flexible messaging system would be appropriate for a wide scale deployment.

A final aspect of DIRECT’s approach was to pursue route-specific traffic information. Offering information which is specific to the driver’s route should attract the attention of more drivers and also provide earlier awareness in many cases. Any radio roadside method, including Changeable Message Signs, is inherently specific to that road and to intersecting roads ahead. The FM subcarrier method tested here can be made route specific by programming the RDS radio receiver for pre-planned segments of expressway or arterials. Although DIRECT involved only one segment of one expressway, the DIRECT OFT was consistent with route specific service since only drivers who used the instrumented route were recruited for the test vehicles.

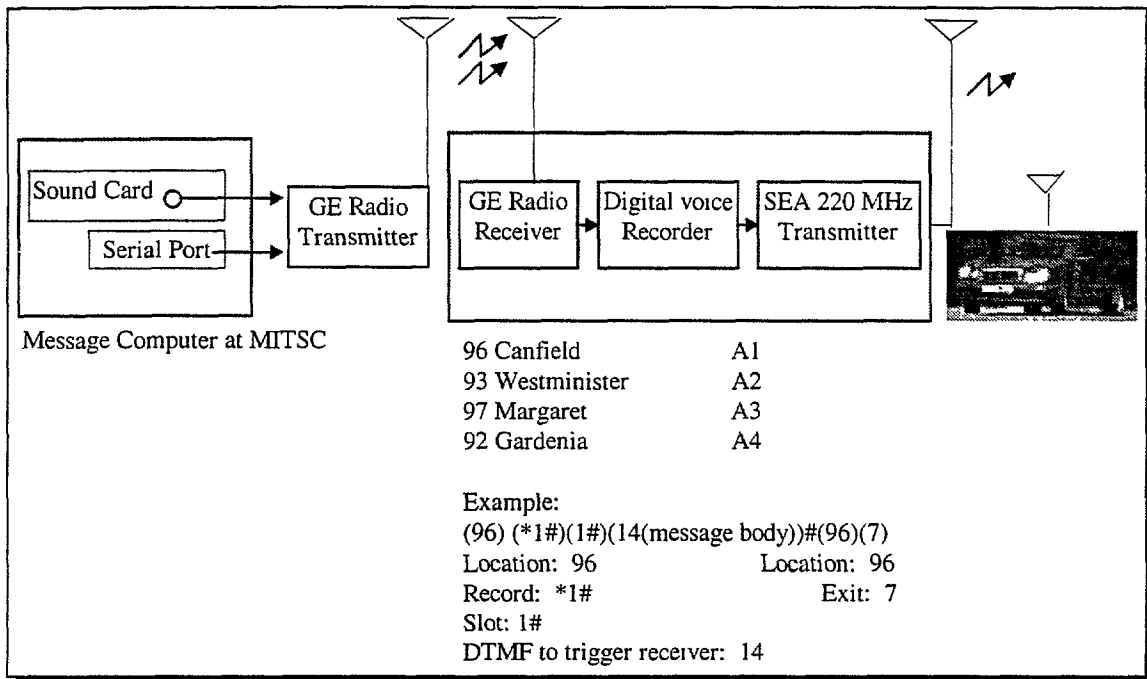


Figure 7 AHAR transmission implementation

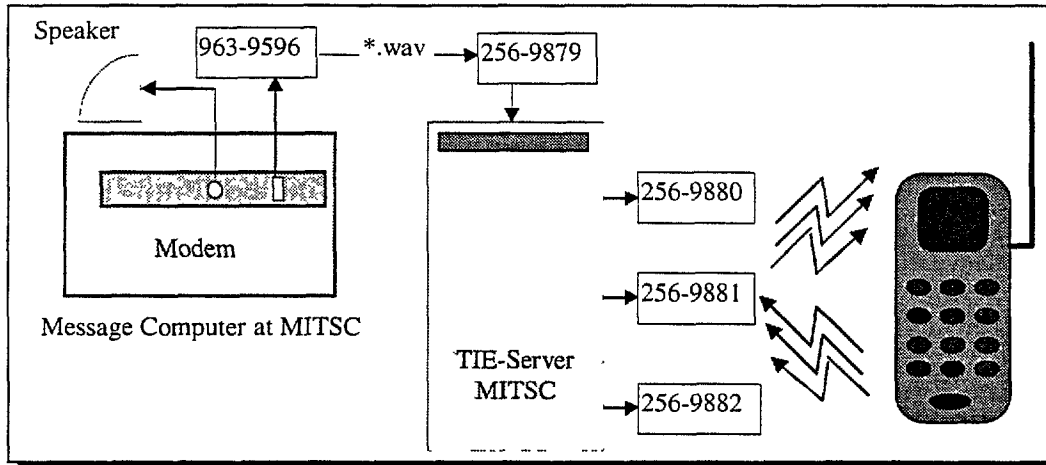


Figure 8 CELLULAR transmission implementation

4. PHYSICAL DEPLOYMENT OF TRANSMITTERS

A 15 mile segment of I-75, from downtown Detroit to the 14-mile road area, was covered by this OFT. Five vehicles were assigned to each of the four delivery method's (LPHAR uses the current entertainment radio), and drivers who use the I-75 segment on their commute trip were recruited (1). Figure 9 depicts the major components and configuration of this OFT.

The FM station covered the entire area, plus much more; four roadside installations, each one containing both an LPHAR and an AHAR transmitter, were spaced along the segment (2). The concept, for both the LPHAR and the AHAR, was to be able to put different messages on the same frequency at adjoining transmitters along an expressway. The original rationale for this “localization” was to permit different diversion messages to be deliverable at different sites along the corridor, without interfering with each other.

Subsequent developments revealed that a “deep pockets” organization, such as a State or municipal DOT, is not willing to assume the risks associated with giving diversion advice due to the possibility of a lawsuit (even though current all-incident reports on the AM or FM stations do sometimes include such advice). Furthermore, there is no infrastructure to inform of the status of diversion roads, to support any diversion advice. This means that the rationale for having localized sources of information no longer exists; any delivery system should simply aim to warn any approaching drivers (or drivers contemplating that route) of the incident on that route. This also means that a wide-area broadcast method is as effective as the more localized and segmented roadside delivery methods.

5. QUALITY OF RECEPTION PERFORMANCE

Comparing the received quality of the four tested delivery methods was an important objective of the technical performance plan. Speech quality measurements have a long history in the telecommunications and wireless fields. Our plan followed the general advice and principles in two tutorial quality measurement articles (5, 6). We concluded that the cognitive measurement goals here could be met, within the project budget constraints, by using the Mean Opinion Scoring (MOS) technique. This is a traditional widely used method, and achieves subjective ratings based on human listener tests. The “jurors” rank the samples into one of five categories ranging from excellent to unacceptable (see later).

Authentic ratings required that the speech samples be judged in an environment that includes the type of ambient noise expected to be present in the real listener environment. Here the major noise contributors are road-noise (from tires and bump-reverberations) and engine noise from large trucks. We wanted about 100 different message samples and about 50 jurors. The only feasible approach was to record message samples while we drove a test car through the instrumented corridor, followed by playing the randomly arranged samples to the jurors in the laboratory. We recorded messages samples from each of the four delivery methods during each of three test days, spaced over 9 months. Each of the recording days had normal weather, with no rain or snow. Appendix B lists the instructions and the questionnaire that were given to the jury in order to report their responses during the listening sessions.

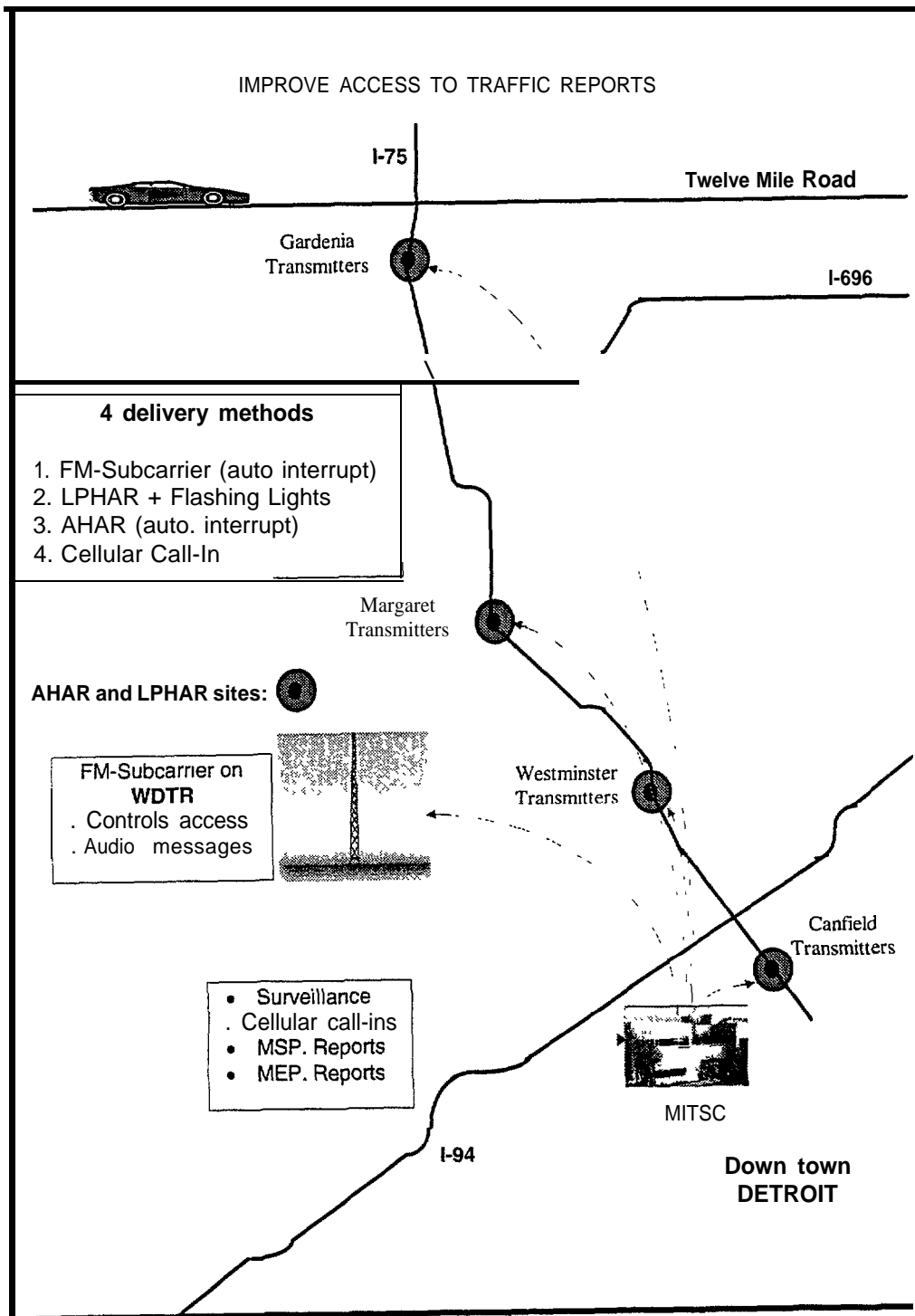


Figure 9 DIRECT system diagram

A “binaural head” (7, Appendix C) and an associated special digital recorder was used for recording the messages samples as we drove the test car through the corridor. The binaural head, supplied by Sonic Perceptions Inc., of Brighton, MI is a specially constructed recording arrangement, with a torso of a human shape, and microphones placed in the earlobes of the dummy’s head. The reason for using the binaural head rather than an ordinary tape recorder is the fact that the outer ear is a directional filter; hence the direction of the incoming message to the ear is important. In addition the direction of the incident wave is affected by the body shape, and that is why the dummy has a sort of average human face and upper body. Any messages recorded in this fashion permits replicating to any listeners the actual conditions equivalent to their being in the vehicle during the test run.

The messages here similar to any reception in a moving vehicle, were subject to the following effects:

1. The effect of the range of the moving vehicle to the roadside or FM transmitters
2. The interference effects caused when the vehicles is between two transmitters (for LPHAR only).
3. The effect of road noise, passing vehicles (especially trucks), bridges, high buildings, wind, rain, sleet, driving pattern, etc.
4. Variations in received message intelligibility amongst the different systems due to bandwidth and modulation differences.

A total of 40 different fictitious incident traffic messages, each about 15 seconds long, were pre-recorded by the operator in the Traffic Message Center (Terry Brown of Metro Networks). Messages from this set of 40 were sent over the three radio (and one cellular) delivery systems during the three recording days. Since the LPHAR test messages could conceivably be received by any driver tuned to 1610 kHz, and the other delivery system messages by one of the 27 natural use vehicles equipped with either AHAR, RDS/SCA or cellular receivers, the phrase “this is a test message; please ignore its contents” appeared both before and after the fictitious incident message. A large number of test messages were recorded during each run since the recorder was run continuously as the test vehicle traversed the corridor. The LPHAR messages had about 45 seconds of dead time between messages; the AHAR messages had about one minute between messages so as to minimize the area of two transmitter coverage; and the RDS messages interrupted about every two minutes. The cellular messages were recorded sporadically during the trips, During each run we adjusted the volume to a level that yielded easy understanding, assuming that is what a typical driver would do; nevertheless, the volume did differ somewhat between different delivery methods.

The recorded traffic messages were edited using Sonic Perception’s LIBRA editing system (8). The preceding and trailing warnings were removed, and ninety six traffic message samples were selected. For both LPHAR and AHAR only samples that occurred within the design coverage area were retained. No such screening was needed for the RDS/SCA since the coverage extended over the total span (actually the entire metro area). The “jury tape” of 96 messages contained some messages which repeated 2 or 3 times since there were only 40 base

messages, but the samples all had different road noise, etc. The four delivery methods occurred randomly on the jury tape.

We recruited a total of 48 jurors from among staff and faculty at the University of Michigan and from our personal network. The range of ages went from early 20s to 75, and were about equal between male and female. The sessions lasted about one hour and fifteen minutes. The set of 96 messages samples was then played to this panel of 48 jurors in 9 separate sessions. Each of the message samples came from one of the four delivery methods and they were arranged randomly, as noted. High quality headphones from Sonic Perceptions were used by the jurors.. Before listening to the samples, jurors were briefed using the document in Appendix B and oriented to road-noise listening by viewing a prepared video tape of driving the expressway while an AM radio station was in the background.

The jurors rated the quality according to an objective scale. We used the Mean Opinion Score as the quantifier of subjectively rated transmission performance. The scale used was: 5-excellent; 4-good; 3-fair; 2-poor; and 1 -unacceptable, using the recommended criteria:

1. **Unacceptable--The** number of words and names that are not understood is sufficient to render the message unusable. Some repetition might help, but it is doubtful.
2. **Poor--**A few words or names not understandable, and would require a repetition to understand, caused by breakups and or tears.
3. **Fair--Most** all words still understandable. The breakups and scratches are noticeably annoying.
4. **Good--**All words still clear Some “breakups” or scratches, which did not prevent understanding.
5. **Excellent--**All words and names were clear Free of distracting “tears” or breakups.

The jurors were given the scenario: During this test you are asked to assume that you are driving along some expressway somewhere in the country, and that your radio is programmed to interrupt you with information about any incident that is on your route, and which will affect your trip. Hence the message is a serious, business-like communication, and should not be compared to entertainment or advertising. The important issue is to clearly understand the message and the words/names. There will be the usual background road noise associated with tire noise, wind noise, and the reverberations resulting from road irregularities. Furthermore there will be variations in volume. Do not judge the message sample on the basis of volume or accompanying road noise, which vary from sample to sample. Concentrate on the message itself, noting any distortion and difficulty in understanding words and names.

The average and standard deviation for the 48 jurors listening to 90 message samples was:

Table 1. Judged Quality Results

	Average	Standard Deviation
RDS/SCA	4.345	.64
LPHAR	4.22	.44
Cellular	3.87	.51
AHAR	3.09	.69

The quality of the SCA FM subcarrier, with access controlled by the RDS subcarrier, was the highest. The SCA quality was exceptionally good for all areas except downtown; there the multipath produced “pops” that were definitely distracting. There were two messages in our sample that had particularly bad multipath, and can be viewed as “outliers “. If these are removed the SCA average is 4.437 with a 0.45 standard deviation. After many monitoring trips, the authors are convinced that the SCA quality is appreciably better than that of the other methods. This superior quality can be attributed to the fact that the analog SCA subcarrier is embedded in the wideband FM signal, which provides the recognized noise-resistant benefit of the 200 kHz bandwidth. The bandwidth of the subcarrier itself is only about 10 kHz, and uses double-sideband amplitude modulation. As noted, the SCA subcarrier signal does experience “pops” due to multipath when near many tall buildings (downtown), but in most cases this does not appear to distract from the clear and pleasant nature of the reception.

Both the LPHAR and the Cellular had a reception quality rated high, but not as high as the SCA subcarrier. LPHAR is more vulnerable to noise since it uses an amplitude-modulation that is vulnerable to noise, both distant (from thunderstorms) and local (from near-by trucks). Further, the LPHAR was working with lower power than the normal HAR to permit having close transmitters on the same frequency.

The cellular records here were not as good as they should be due to our inability to properly interface the cellular handset and binaural head ear-piece. For this reason the cellular volume was lower than for the other methods which caused many jurors to lower their quality judgment. Also, the jurors reacted to the fact that the cellular sample was always monaural whereas all the other samples were heard binaurally. There is extensive literature on the design quality of cellular systems (9,10). The cellular design standard is to achieve “a signal to noise ratio of 18 dB or more over 90 percent of the area covered by the system”. It has been reported that in some cities the heavy usage has resulted in ratios less than 18 dB during peak times, but the system here appeared to meet the high quality criteria.

The AHAR was judged to have an appreciably lower quality than the other three, which corresponds to the authors’ experience during hundreds of receptions. While AHAR signal was often crisp and clear, it has a narrower bandwidth (3 kHz) than the SCA subcarrier, consequently message intelligibility was somewhat impaired especially with voice fricatives as f, s, z and stops as t, k which have high frequency bands above 2000 Hz. So a t may sound like a p. when the high frequency components are eliminated; also the third voice format is typically around 2500

Hz, so if an announcer has a higher third format, the announcer's voice may not be recognized. A tendency for AHAR to deliver some slurred words was noted.

6. AUTOMATIC INTERRUPT (OR ALERTING) PERFORMANCE

A major goal of DIRECT was to provide either route specific automatic interrupts (RDS/SCA, AHAR) or automatic alerts (flashing signs for LPHAR). Thus an important measure of technical performance was the interrupt or alerting record. While DIRECT actually started operation in April, 1996, it was not until October, 1996 that some volume setting problems at the message control center were corrected. Starting in November, 1996 we began a once-weekly run of the expressway span to monitor and check the status of all four delivery systems. This was done on Monday mornings, to take advantage of the fact that the natural use drivers were given a test message each Monday morning; if they heard nothing, or had reception problems, they were to call in. We used these same test messages for our "delivery system check" on most Monday mornings between November 1996 and December, 1997. With this technique we accumulated a set of 48 "delivery system checks". This represents a sampled record of the interrupt/alert performance and is an indication of the reliability of that function. The data is sketched in Figure 10; the dashed intervals are the times when the vehicles were returned pending the next set of drivers.

The interrupt record of the RDS subcarrier from the WDTR FM station would have been perfect over the test period were it not for an unusual "station down" problem that lasted for two weeks (FM stations are not typically down for such a long time). With this event included, the radio toggling record for the RDS subcarrier was 94%. Further, when operating it interrupted reliably and perfectly throughout the range of the FM station (about 50-mile diameter circle), based on sample tests. The RDS subcarrier is a rugged, reliable data link, and the in-vehicle instrumentation (2) used in DIRECT provided excellent performance.

The interrupt record of the AHAR, shown in the third row of Figure 10, was lower. Here it is impossible to separate "interrupt" performance from simply "up" performance. The transmitter may be on, but the scanner may not interrupt the radio. The weekly sampled data indicates that interrupts at all four sites occurred only 21% of the time. Interrupts by 3 or 4 of the sites occurred 69% of the time. Two or more of the sites interrupting occurred 96% of the time, and one or more occurred 98% of the time.

This less-than-perfect record is due mainly to the experimental nature of the AHAR system implementation here. It was constructed with the least cost, and there was insufficient time to "prove out" the system. In addition to working with a transceiver that was fairly new (4), the control method used a scanner looking for the presence of either of two frequencies. Canfield and Margaret sites transmitted at 220.116 MHz while Westminster and Gardenia sites transmitted at 220.118 MHz. Consequently consecutive transmitters alternated between the two frequencies in order to avoid interference at the receiver. Nevertheless, the scanner operation introduced a source of malfunction. The in-vehicle scanner locks-on when receiving a powerful enough signal at either frequency. Many times a higher-than-necessary power from one of the

transmitters kept the in-vehicle receiver-scanner locked to that transmitter and prevented it from locking on to the neighboring transmitter. Hence timely interrupts were not initiated at the proper locations and even sometimes a given transmitter was never heard. It is clear that, given sufficient time and engineering, a reliable interrupt mechanism could be devised for a radio in the 220 MHz band.

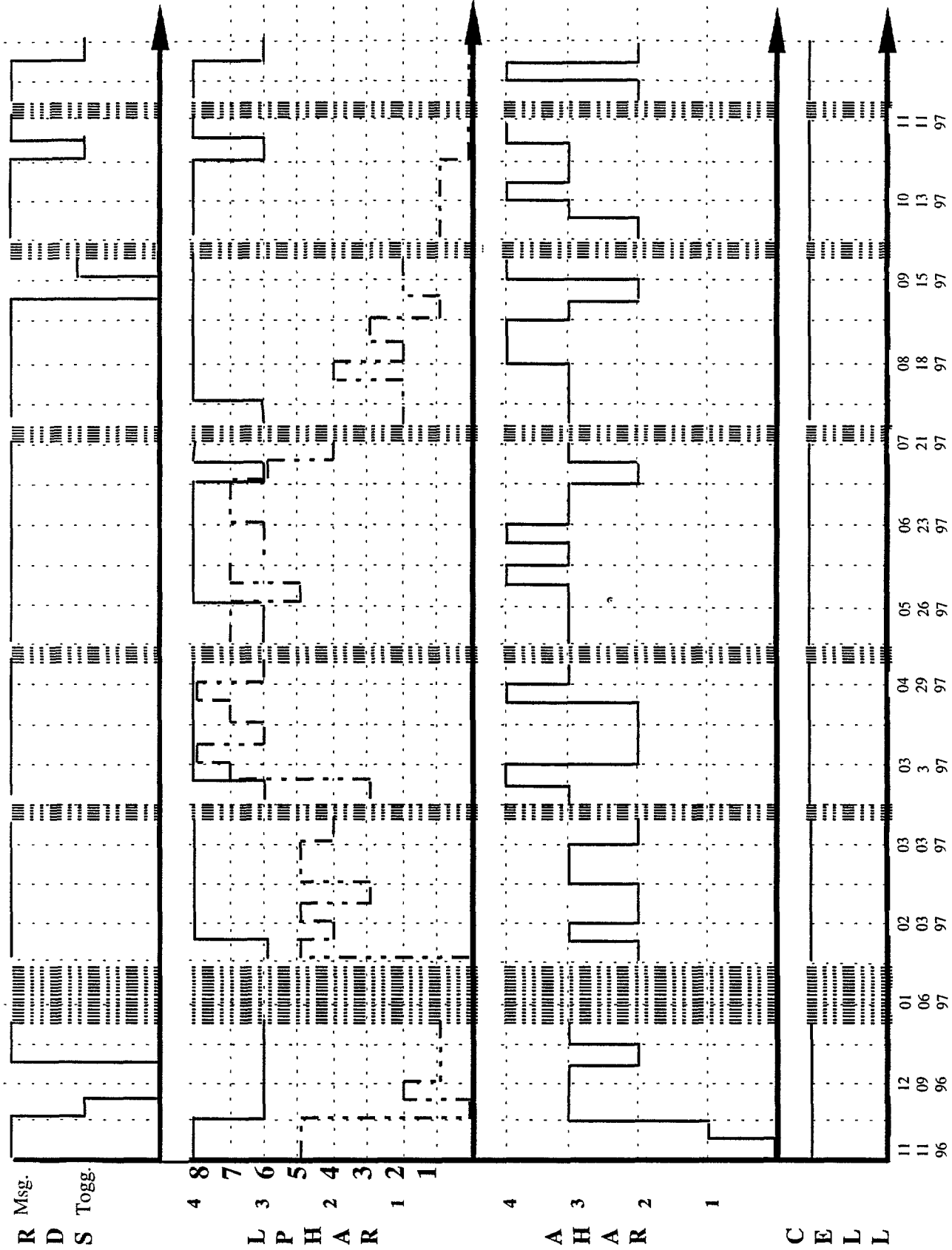
“Alerting” to the presence of an incident ahead was provided by the roadside flashing lights for the LPHAR delivery system. The flashing light performance experienced during DIRECT, as exhibited by the 48 system checks, is shown by the dotted-line in the second row of Figure (10). Without doubt the performance of the flashing lights was the poorest performer of all the components of DIRECT. This was due entirely to the decision to power the lights, and the accompanying control pager, with automotive storage batteries refreshed by a solar panel. The solar panels simply did not keep the batteries up in the cloudy Michigan weather, and attempts to replace the batteries in a timely manner when needed was not up to the task. We monitored only the Southbound lights, since there was a software block to turning on the northbound lights in the AM, when we were driving. Hence we used the Southbound lights as our test sample. During the 48 weekly samples, all 7 lights were on only 17% of the samples. Six or more were on 27% of the samples; five or more, 37% of the samples; four or more 46%; three or more 52%; two or more 65%, and one or more 81% of the samples. One saving grace is that there was redundancy in both the LPHAR and AHAR delivery methods since there were four sites spaced over about 12 miles. Hence missing an interrupt or alert from one of the sites could result in receiving a timely interrupt from one of the other sites. Nevertheless, one must conclude that the alerting performance implemented by the flashing lights was very poor during DIRECT.

Even when working, the drivers during this particular OFT might miss such lights because:

1. Vision obscured by large trucks.
2. Uncertainty about the signs location.
3. Dimmed light intensity caused by low battery or fog.
4. Momentary diverted attention while passing the flashing light location.

When considering use of flashing lights in an operational permanent situation, probably the best position is to embed the lights in the overhead signs that announce major interchanges.

Figure 10 Reliability report of DIRECT delivery system.



7. TRANSMITTER RELIABILITY PERFORMANCE

As noted in the previous section, the automatic interrupt and alerting performance could be caused by either transmitter down, failed communication to transmitter, or malfunction in the message control part at MITSC. Nevertheless we did develop data on the “transmitter down” cause during the weekly Monday morning runs.

During the April 1996 through Dec. 1997 period, the FM subcarrier method had the greatest reliability, marred only by the unusual “station down” period mentioned before. This is due to the single transmitter, with an always-present staff to monitor and quickly fix any problem that might arise (we are all aware of the near-perfect record of FM stations in general).

The next most reliable system was the series of LPHAR transmitters (of course the AM/FM receivers in the cars are reliable). These units were ordinary HAR transmitters with their power lowered. There is a substantial history of reliable HAR transmitters, which was evidenced here. However, roadside units involved also: 1) the need for communication between the TMC and roadside unit; and 2) the flashing signs to alert the driver to “tune in”. The reliability of the digital trunk radio used to communicate to the LPHARs was fairly good, but sometimes failed to function properly.

The AHAR transmitters proved to be fairly reliable; any inability to receive an AHAR transmitter was often due to the scanner being unable to lock-on to the stronger signal while the other frequency is still present. Also, there were some problems with the communications to the AHAR transmitters, using a trunked digital radio.

8. EVALUATION OF COST

Cost data was gathered from equipment sources and from contractors who are in the business of constructing delivery systems of the type being evaluated. The following cost estimates are aimed at those costs any agency would incur, not necessarily using items identical to those used in DIRECT OFT. The approximate acquisition cost for the three delivery systems approaches are:

FM Station Method:

- \$ 3395 for RDS encoder (SCA-100)/ FM station.
- \$2050 for SCA encoder SCA-300B)/ FM station
- \$ 1500 Computer and Modem/ Fm Station
- \$ 1000 Installation Cost
- \$ 100 extra per radio receiver, for RDS/SCA feature.
- Monthly dedicated telephone line cost.

AHAR Method:

- \$ 13000 for each roadside transmitter.

- \$ 5000 installation cost for each transmitter.
- \$ 3000 for communication and power facilities' to each site.
- \$ 1100 for special receiver in each vehicle (SEA ESP520)² .
- Monthly dedicated telephone line cost.

LPHAR Method:

- \$ 11990 for each roadside transmitter. This includes the price of the AM transmitter, digital voice recorder, cellular phone, panel box, and cabling inside the panel.
- \$5000 installation cost for each transmitter.
- \$3000 for communication and power facilities to each site
- \$5000 for each flashing light installation.
- Monthly telephone line charges for two lines, one for paging the flashing lights and one for addressing the digital voice recorder via a cellular phone.

Message Communications and Control Computer

This is a standard IBM compatible machine with a sound card and three modems. The market value of a high end unit is about \$2500.

In addition there is the cost of the software application at the message communications and control computer and the software application at the FM station.

These estimates, based on the OFT here, indicate that equipping an entire metro area with LPHAR or AHAR is prohibitive, relative to using one or a few FM stations.

The maintenance cost is practically the highest for LPHAR and AHAR as the number of transmitters needed is dependent on the size of the coverage network; in addition each transmitter site has many components that may be the cause of failure.

Table 2 shows a comparative summary of the cost data.

Table 2: Cost Comparison of the Different Technologies

	Infrastructure	In-Vehicle
RDS	Low	Low
LPHAR	High	Zero
AHAR	Hieh	Moderate
Cellular-Call-In	None	Monthly Fee (low)

¹ This is an approximate cost. The true cost is dependent on the proximity of the communications and power line feeders to the transmitter site.

² A mass produced receiver at 200 MHz should retail for \$200 to \$400.

9. CONCLUSIONS

The technical performance during the DIRECT OFT indicates that all three one-way radio methods, RDS/SCA FM subcarriers, LPHAR, and AHAR, can deliver clear, understandable traffic messages. The received signal quality of the SCA subcarrier was jury-judged to be the highest, with LPHAR behind that, and AHAR the lowest. Although the AHAR had the lowest judged quality during this particular OFT, there is no doubt in the authors' mind that an AHAR system using the components here can provide good quality messaging if adequate attention is given to power setting. The cellular call-in technique also provided high quality messaging.

The automatic interrupt performance was highest for the RDS subcarrier while the AHAR interrupt performance was considerably lower. The lowered interrupt performance of AHAR was due mainly to the Westminster site (#2); any overpowering at Canfield (#1) locked up the in-vehicle scanner so that site #2 was frequently not heard. The flashing light alerting for the LPHAR was adequate when the units had sufficient power, but this was the poorest performing aspect during this OFT.

There is no question that the DIRECT OFT was unusually ambitious in its implementation of four different delivery methods, including tracking instrumentation (not evaluated) for the 27 test cars, for the allocated budget. An overarching conclusion is that not enough time and manpower was devoted to bringing all the systems up to good working order, and then maintaining them in a "sense of urgency" fashion. The message control system was fairly reliable in function at the outset, but experienced surprise crashes. There was a perpetual sense of experimenting with and changing this system, and no exhaustive method of documenting the events and any changes was developed. The combination of the unreliable flashing lights, the problems with site #2 of AHAR, and the message control problems just treated, means that some of the natural use results will be constrained by "less than firm operational status". Nevertheless, persistent effort by dedicated MDOT personnel permitted reliable operation of the RDS/SCA method and enabled completion of major aspects of the OFT.

When considering metro-wide deployment the infrastructure cost of an FM station based system will be much lower than either an AHAR or an LPHAR system; the increased cost to the driver is modest (about \$40). Further, the system will be much easier to construct and maintain than either of the roadside techniques. However, use of FM stations requires the renting of the subcarriers, which is a market driven cost that is difficult to predict. It would be necessary for most FM stations to carry the information in order to be effective unless RDS radio manufacturers move to dual-tuner radios.

While either an LPHAR or an AHAR system would provide a reasonable quality delivery method, such a dispersed system would both be costly to build and to maintain, due to its distributed nature. There is no cost to the driver for the LPHAR system, since the receiver is the current entertainment radio.

We have already noted that limited distance segmentation as implemented by DIRECT's LPHAR and AHAR no longer appears necessary since diversion advice will not be delivered. In effect, all drivers approaching the incident should receive the same message. In the last few years a consensus has emerged for the use of normal power (10 watt) HAR in the U.S. Flashing lights are used on highways signs to alert drivers to tune to the normal 8 mile diameter range HAR transmitters. The transmitters, when located near major intersections, cover all the intersection roadways, as do the messages on the transmitters. The drivers are alerted to an incident on their route by the signs, but the transmitter may have more than one incident's message. This, along with the zero cost to the driver, makes HAR plus flashing signs a cost-beneficial candidate for route specific alerting, although the field installations of both the transmitters and the flashing signs result in a substantial acquisition and maintenance cost.

The minimum cost and high performance of using FM subcarriers, plus the ability to alert the driver "in the (pre-trip) driveway" cause us to conclude that use of RDS to form a route specific service is the most cost-beneficial technique. However, we no longer believe it is desirable to use the SCA subcarrier for the message content because:

- 1) its use would require substantial change to the on-the-market RDS receiver.
- 2) it would require renting two subcarriers from each participating FM station.

We therefore believe it is desirable to simplify the broadcast system so that all the information is offered over the single RDS subcarrier. Such an approach is described in (1 1,12). The route specific alerting service is formed by programming the driver's radio for pre-planned (frequent) routes. The driver's display would show the expressway number and direction, the escape exit ahead of the queue, a dynamic delay estimate, and the downstream re-entrance number. A paper map in the car would enable the driver to interpret the broadcast information.

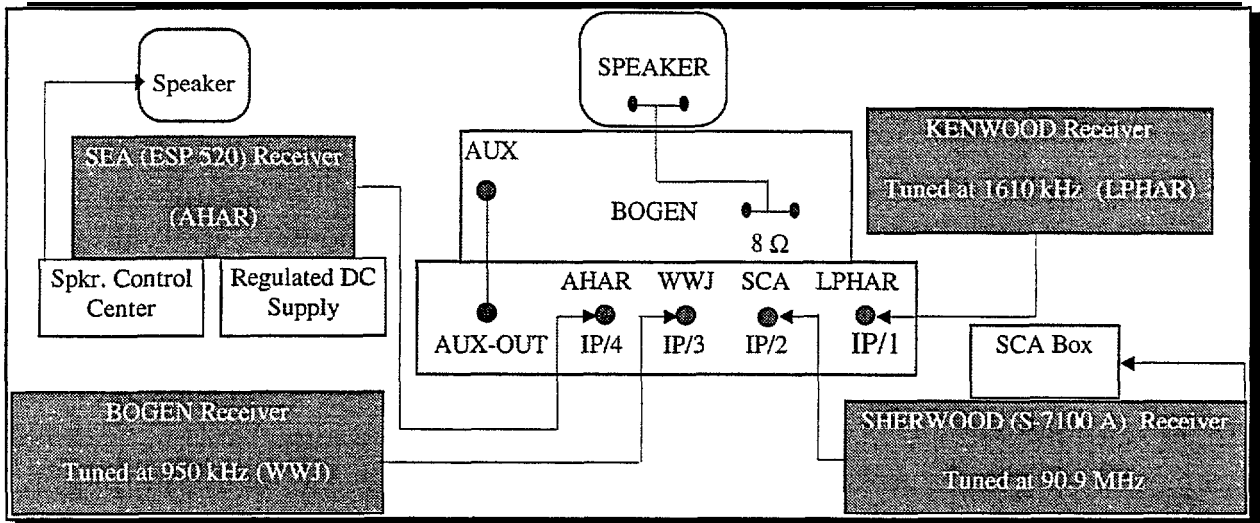
10. ACKNOWLEDGEMENTS

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APPENDIX A



TRAFFIC MESSAGES RECEPTION AT MITSC

APPENDIX B

JURORS HANDOUTS

- 1. EVALUATION OF FOUR DIFFERENT TRAFFIC MESSAGES DELIVERY SYSTEMS**
- 2. TRAFFIC MESSAGES QUALITY EVALUATION**

EVALUATION OF FOUR DIFFERENT TRAFFIC MESSAGE DELIVERY SYSTEMS

BACKGROUND: The Michigan Department of Transportation and the Federal Highway Administration have implemented four different experimental low-cost radio methods for relaying pertinent traffic messages to drivers. Samples of made-up traffic messages were recorded in a vehicle while driving at posted speed, using special equipment. These samples have been entered on a “jury tape” for judgment by volunteer listeners. Each of the message samples reached the vehicle via one of the four delivery methods, and they appear randomly on the recording you will hear.

SCENARIO: During this test you are asked to assume that you are driving along some expressway somewhere in the country, and that your radio is programmed to interrupt you with information about any incident that is on your route, and which will affect your trip. Hence the message is a serious, business-like communication, and should not be compared to entertainment or advertising. The important issue is to clearly understand the message and the words/names. There will be the usual background road noise associated with tire noise, wind noise, and the reverberations resulting from road irregularities. Furthermore there will be variations in volume.

LISTENER TASK: You are being asked to estimate the quality of the reception for each of the traffic message samples that you will hear. Seven blocks, each with seven messages, will occur over about 20 minutes, at which time you will take a break. A second set of 7-long blocks then follows. The total time to do this test, including this introduction, is about one hour and a half.

You will be hearing these messages at varying volumes in the presence of the road noise and unavoidable distortions and noise associated with many radio techniques. You are asked to concentrate on the message itself, noting any distortion and difficulty in understanding words and names. **IT IS ESPECIALLY IMPORTANT THAT YOU NOT JUDGE THE MESSAGE SAMPLE ON THE BASIS OF THE 1) VOLUME, 2) ACCOMPANYING ROAD NOISE, 3) MONO VERSUS STEREO, ALL OF WHICH VARIES FROM SAMPLE TO SAMPLE.**

After the sample has been played, 4 seconds of silence will occur during which you are to choose one of the following five categories:

1. **Excellent--All** words and names were clear Free of distracting “tears” or breakups.
2. **Good--All** words still clear Some “breakups” or scratches, which did not prevent understanding.
3. **Fair--Most** all words still understandable. The breakups and scratches are noticeably annoying.

4. **Poor--A** few words or names not understandable, and would require a repetition to understand, caused by breakups and or tears.
5. **Unacceptable--The** number of words and names that are not understood **is** sufficient to render the message unusable. Some repetition might help, but it is doubtful.

A short video, to orient you to simulating driving on an expressway, will now be played. A practice message block will then be played and discussed.

TRAFFIC MESSAGE QUALITY EVALUATION JUROR RESPONSES

Juror Category:

Age: _____

Gender: M F

Please ✓ your response

PRACTICE BLOCK

	Excellent	Good	Fair	Poor	Unacceptable
1.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

BLOCK 1

	Excellent	Good	Fair	Poor	Unacceptable
1.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

BLOCK 2.

	Excellent	Good	Fair	Poor	Unacceptable
1.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

BLOCK 3

	Excellent	Good	Fair	Poor	Unacceptable
1.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

6.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

BLOCK 4

	Excellent	Good	Fair	Poor	Unacceptable
1.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

BLOCK 5

	Excellent	Good	Fair	Poor	Unacceptable
1.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

BLOCK 6

	Excellent	Good	Fair	Poor	Unacceptable
1.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

BLOCK 7

	Excellent	Good	Fair	Poor	Unacceptable
1.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

BLOCK 1

	Excellent	Good	Fair	Poor	Unacceptable
1.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

5.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

BLOCK 2

	Excellent	Good	Fair	Poor	Unacceptable
1.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

BLOCK 3

	Excellent	Good	Fair	Poor	Unacceptable
1.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

BLOCK 4

	Excellent	Good	Fair	Poor	Unacceptable
1.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

BLOCK 5

	Excellent	Good	Fair	Poor	Unacceptable
1.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

BLOCK 6

	Excellent	Good	Fair	Poor	Unacceptable
1.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

4.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

BLOCK 7

	Excellent	Good	Fair	Poor	Unacceptable
1.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

HEAD acoustics GmbH

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D-521 34 HerzogenrathTelephone. +49 2407-577-0
Telefax +49 2407-577 99**HMS II.1 (Code 1210)**

HEAD Measurement System

Standard version of the Artificial Head Measurement System HMS II.
Independent of mains power



HMS II.1 features a patented mathematically-defined geometric simulation of a human head and shoulders. The measurement electronics are built into the torso. These electronics include the Measuring Amplifier SPM II and the HEAD Monitor Amplifier HMA II for connecting two electrostatic HEAD-phones. Compatibility to conventional recording methods is ensured by the availability of two independently selectable equalization modes. HMS II.1 is ready for use with the digital HEAD Data Recorder HDR IV. 1.

The digital equalization ADD 1, which is an option to the HEAD DATA Recording System HDR IV.1, allows exact and frequency-dependent calibration of HMS equalization modes, their individual adaption to user-defined requirements and the realization of special equalization for special sound fields.

The HEAD Measurement System HMS II.1 with its archive of measurement engineering: The remote controlled HEAD DATA Recorder HDRIV.1 is an approved complement and recommended option

FEATURES

- Portable, independent-of-mains system
- Modular design
- ID equalization
- FreeField equalization
- Digital equalization retrofit-table in conjunction with the option HDR IV. 1
- Minimal inherent noise
- High modulation
- Compatible with both human hearing and conventional measurement technology
- Calibratable
- User-friendly
- Award-winning design

APPLICATIONS

- Use in product development
- Measurements inside vehicles and at test stands
- Use in production and quality control
- Use in room acoustics
- Measurements at workplaces
- Special and standard measurements

OPTIONS

- **HDR IV.1 (Code 5410):**
Digital Data Recorder for HMS II
- **BHM III (Code 1263):**
Binourol HEAD Microphone
- **MMAII.1 (Code 1262):**
Adopter for impedance converter when operating with conventional measuring microphones (B&K socket)
- **MMA II.2 (Code 1265):**
Adopter for impedance converter when operating with conventional measuring microphones (LEMO socket)