FIELD TESTING OF PROPOSED DIGITAL AUDIO RADIO SYSTEMS
PART I: MOBILE DATA COLLECTION SYSTEM

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ABSTRACT

This technical paper describes application of the mobile data collection system that was used to evaluate proponent Digital Audio Radio (DAR) systems in the San Francisco Bay Area in 1996, for a program sponsored by the Consumer Electronics Manufacturers Association (CEMA). To complete the task, the project required development of field test routes, refinement of test procedures, and FCC authorization for construction of transmitting facilities at a multi-user communications site. In addition to the engineering tasks, the hiring and training of personnel to act as real-time observers were required.

The test van included a computer data gathering system developed and constructed by the CEMA laboratory at the NASA/Lewis Research Center in Cleveland, Ohio. That system was used to gather data related to vehicle speed and position, observer reports of system performance, and RF signal levels encountered throughout the test routes. Recordings of the proponent DAR system recovered audio were made, along with video recordings of the vehicle path and spectrum analyzer images related to system performance.

INTRODUCTION

The beginning of 1996 brought with it the first on-site activities related to the CEMA DAR field testing program in San Francisco. In the prior year, eight proponent systems had been exhaustively tested in CEMA laboratory space at NASA/Lewis Research Center. The results of those laboratory tests were presented at a meeting in Monterey, California, in August 1995. [1] After completing some retesting activities requested by individual proponents, final planning of the field testing project phase began, including final selection of a transmitting site and construction of a suitable "mobile laboratory" that would be used to gather field data.

During several committee meetings related to the DAR testing process, the San Francisco Bay Area had been mentioned often as a potential location for conducting field tests of DAR systems, because of the desire to prove seamless mobile reception in an environment that included widely varying terrain and, consequently, varying radio wave propagation conditions. As many radio broadcast engineers know, the San Francisco Bay Area can offer no single transmission site that provides line-of-sight transmission to all populated areas. Three popular sites in the Bay Area host most of these transmitting facilities. The first site, containing the majority of FM stations, is situated atop San Bruno Mountain, just south of San Francisco. The second site is Sutro Tower, located within San Francisco, and the third site is known as Mt. Beacon, located just north of the Golden Gate Bridge in Marin County. While all three of these sites arguably serve San Francisco proper, they are all shielded by intervening terrain to many growing communities in the East Bay. Additionally, some North Bay communities also are shielded by terrain from all three sites. Therefore, in developing a plan for field testing, the San Francisco Bay Area was chosen because it was believed to be at least as challenging to radio wave propagation as any other location within the United States.

While it is beyond the scope of this technical paper to cover the characteristics of proponent DAR systems, some discussion is warranted to better describe the challenges faced in designing field tests. Of the nine system variants tested in the laboratory, all were originally designated for field testing. Four of the systems are designed to operate terrestrially within the FM broadcast band using a host FM station; those systems were called in-band on-channel, abbreviated as "IBOC." Two other FM broadcast band systems operated on adjacent channels (in-band adjacent-channel, or "IBAC"), and in place of an FM station, in an incompatible mode (in-band reserved-channel, or "IBRC"), respectively. Another IBOC system operated within the AM broadcast band, and it was designated "IBOC-AM." The remaining proponents consisted of the Eureka 147 terrestrial system, operating within the L-band (1,468 MHz) and the Voice of America/Jet Propulsion Laboratory ("VOA/JPL") satellite delivered system, operating within the S-band (2,030 and 2,050 MHz). A detailed technical description of each proponent system is provided in Reference [1].

For various reasons, all of the IBOC systems and the IBRC system eventually were withdrawn from field testing, leaving only the AT&T/Lucent IBAC, Eureka 147, and VOA/JPL systems. Operation of the IBAC system required construction of a terrestrial transmission system that used a conventional FM broadcast antenna but employed a transmitter specifically tailored to support the proponent RF signal. The Eureka 147 system required construction of a custom L-band transmission facility. Being satellite-based, testing of the VOA/JPL system required no construction of transmitting facilities aside from the existing uplink facility, which was located in New Mexico. A custom audio compact disc was produced by the National Radio Systems Committee, Digital Audio Broadcasting Field Test Task Group, containing one hour of programming and station identification, which was used for testing of all systems. Receivers for each tested system were installed within the mobile test van, as described later.

TEST SITE CONSTRUCTION

As a result of related committee activities, use of the Mt. Beacon transmitting site was secured for the DAR field test program. As described above, Mt. Beacon is located just north of San Francisco; it hosts four FCC-grandfathered super-power Class B FM stations, two FM translators, and numerous other communications facilities. Thus, a challenging atmosphere was added to the test situation, in that the proponent equipment was required to operate in the presence of other strong RF signals without adverse effects to its own transmitted signal or to the transmitted signals of other stations.

Site Modifications

To construct the IBAC and Eureka 147 transmitting facilities, a few site modifications were required. First, a new 200-ampere three-phase electrical service was installed, which proved to be a somewhat difficult task in that the electrical service to the site was already near its capacity. After a number of discussions with the power provider, a method to accommodate the new service was devised. Second, an air conditioning system had to be installed in the test room. While the Mt. Beacon climate is usually quite mild during most of the year, the testing process began during the summer months, in the midst of an ongoing "heat wave" in the area. Temperatures in the test room rose to over 90 degrees Fahrenheit, which proved to be too high for proper operation of the prototype proponent equipment. Third, tower space was located for the proponent test antennas. Initially, the Eureka 147 transmitting panel antenna was side-mounted on a tower adjacent to the transmitter building, and the four-bay IBAC antenna was mounted on a nearby shorter tower. After initial propagation tests by the AT&T/Lucent engineers, the IBAC antenna was rebuilt into a three-bay, half-wave-spaced design, and it was remounted in the same position as the Eureka 147 antenna, once testing of the Eureka 147 system was completed.

FCC Authorizations and Site Management

FCC experimental authorizations were required for operation of both the IBAC and Eureka 147 systems. The IBAC system was proposed at 5 kilowatts effective radiated power on 96.9 MHz, which was second-adjacent to two San Francisco stations and co-channel to stations in Sacramento and Monterey, California, those being adjacent markets to the San Francisco Bay Area. The FCC granted use of the proposed frequency only after appropriate interference studies were submitted by others and agreements were received from all of the potentially affected stations. Securing an FCC authorization for the Eureka 147 system proved to be more difficult, in that the desired L-band frequencies are assigned only for military and government use in the United States. CEMA negotiated with the FCC, the National Telecommunications and Information Administration, and various other government and military agencies for over one year before final permission was secured to operate the test station. The agreement required real-time contact with a military frequency coordinating agency, as well as the establishment of an independent monitoring station on the grounds of NASA/Ames Research Center, in Sunnyvale, California, located about 35 miles south of the Mt. Beacon test site.

As a part of the FCC authorization documentation, surveys for the presence of non-ionizing RF radiation in excess of FCC/ANSI occupational limits were performed for each system installation. Fortunately, measured RF radiation levels of the Eureka 147 and redesigned IBAC transmitting antenna installations were found to be well under applicable limits. During transmitting antenna installation and removal, significant power cutbacks were required of the other site users to ensure that the tower riggers would not be exposed to excessive fields while climbing or working on the towers. While the associated coordination process was challenging at times, other site users were cooperative in agreeing to reduce power during nighttime antenna work.

During construction, adjustment, and operation of the transmitting facilities, strict supervision of on-site proponent activities was required to certify that no inadvertent or intentional proponent modifications had been made to encoders or modulators, which was the same equipment previously evaluated at the test laboratory. Additionally, site supervision was required at all times when transmitters were in operation. Not unexpectedly, the proponents spent many hours setting up and troubleshooting installation and equipment operation problems, many of which were related to the high RF field characteristics present at the site.

Eureka 147 system installation. The Eureka 147 DAR system consisted of one primary encoder/modulator equipment rack, which was installed in the test room, along with a 200-watt power amplifier that was installed in a penthouse room at the site. A length of low-loss coaxial cable interconnected the power amplifier, through a filter network, to the panel antenna, which was mounted about 15 meters above ground. Complicating the project were additional installations at two other sites, which allowed the system to be tested in a “network” mode in addition to a single transmitter mode. The second installation was constructed at San Bruno Mountain, south of San Francisco, while the third site was constructed atop Round Top Mountain, in the East Bay hills near Oakland, California. The San Bruno Mountain site was interconnected to Mt. Beacon by way of a baseband RF signal carried on a common carrier microwave link. The Round Top Mountain site was constructed as an on-channel booster, with receiving and retransmitting antennas located at different levels on the same tower. All construction activities at the San Bruno and Round Top Mountain sites were handled by the proponent. Supervision was not necessary because no special modifications to the system encoder or modulator were required.

AT&T/Lucent IBAC system installation. The IBAC system consisted of an encoder/modulator equipment rack, an intermediate power amplifier rack, and a large final power amplifier. Both rack units were installed in the test room, while the final power amplifier, because of its large size, was placed in a temporary container located just outside the transmitter building. Two large notch filter assemblies also were installed within the outdoor container. A length of pressurized air dielectric coaxial cable was used to interconnect the filter output to the transmitting antenna. As mentioned above, the IBAC transmitting antenna was installed in the same location as the Eureka 147 antenna, after the conclusion of Eureka 147 field tests.

VOA/JPL system installation. The VOA/JPL S-band satellite system was uplinked from the JPL laboratory near White Sands, New Mexico, to a NASA Tracking and Data Relay Satellite in geosynchronous orbit over the Pacific Ocean. The VOA/JPL encoding equipment, taken from the CEMA laboratory in Cleveland, was installed at the uplink facility by a CEMA engineer. Initial tests were conducted to verify proper operation of the receiver, which was already installed in the DAR field test vehicle.

MOBILE DATA COLLECTION SYSTEM

CEMA and its related committees had determined the types of data that would be gathered during the field testing phase of the project to complement the laboratory data. Of key interest were the RF level, audio availability, and decoded audio quality of each proponent’s system, linked to real-time vehicle location and speed data. Real-time recordings of the RF spectrum adjacent to the proponent system’s signal and examples of comparable analog FM reception were also deemed potentially useful for subsequent analysis of the data.

Test Vehicle Configuration

With the objectives stated above in mind, along with the goal of automating as much of the data gathering process as possible, the CEMA crew at the NASA/Lewis Research Center designed a recording system that simultaneously collected audio, video, and computer data on each proponent system under test, linked together using SMPTE timecode. Audio information, consisting of the decoded stereo audio of the proponent system along with the output of two independent stereo analog FM receivers and the output of microphones located in the cockpit of the test vehicle, was recorded using a Tascam DA-88 8-track digital audio recorder. Two color video cameras were mounted above the driver in the test vehicle and were positioned in such a way as to provide a nearly 180° view of the test route in front and to the sides of the vehicle. The output of these cameras was combined with the video output of two spectrum analyzers (one displaying the RF environment around the proponent system signal and the other displaying the instantaneous RF level of the signal in zero-span mode) using a quad mixer, similar to those used in surveillance and security applications, and was recorded using a Super-VHS VCR with insert recording capability.

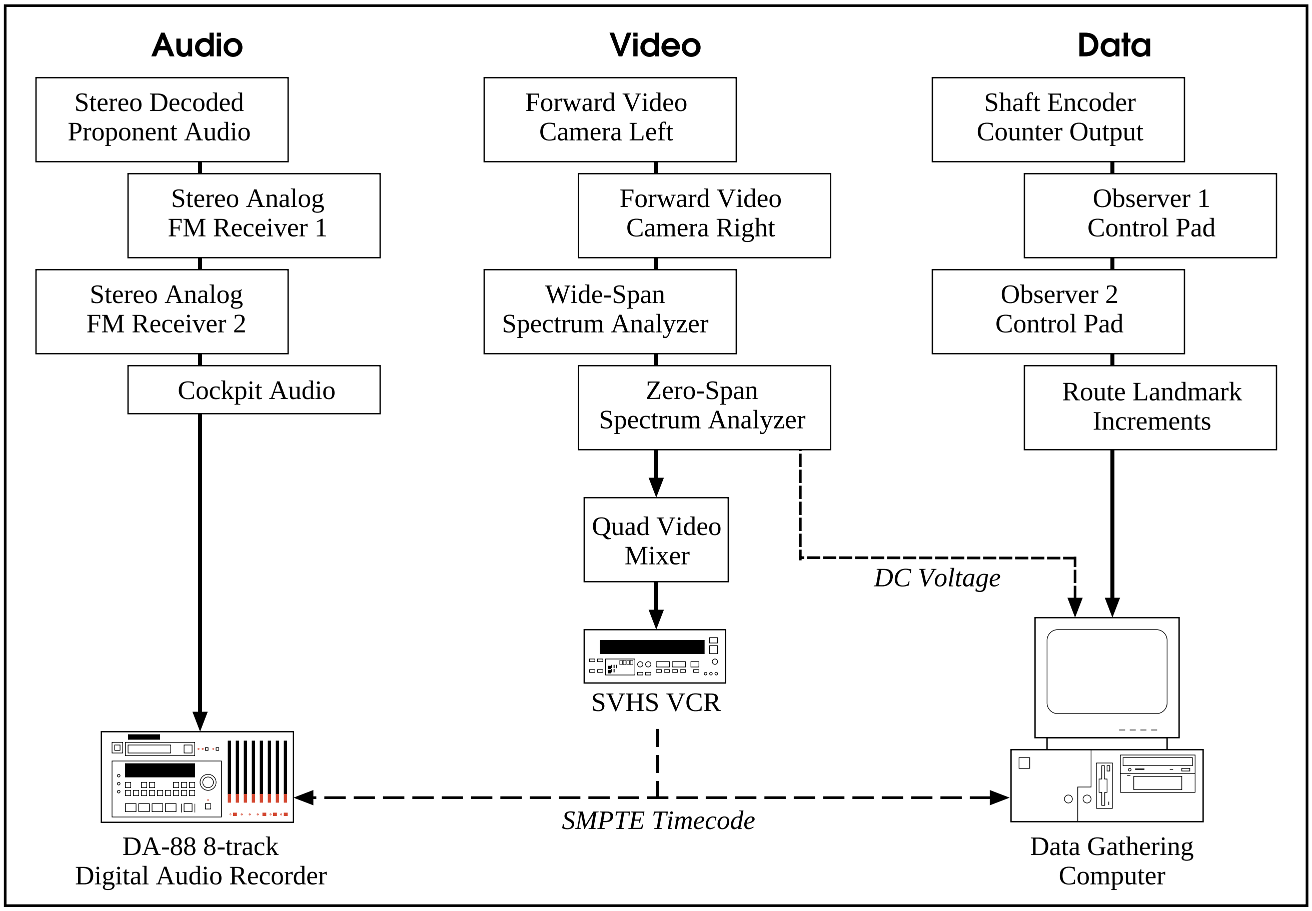

Figure 1. Simplified block diagram of test vehicle data collection system.

A PC-compatible computer running custom data collection software was the heart of the system, continuously recording the instantaneous RF level of the system under test via the DC output port of the zero-span spectrum analyzer, along with indications of audio dropouts and defects made by two human observers pressing buttons on standard PC game controllers. The software also recorded vehicle position data, consisting of continuous distance measurement determined by an optical shaft encoder mounted to the vehicle's rear wheel and discrete position landmarks along each test route that were manually incremented by the test system operator. To ensure data integrity and to protect against device failure, a spare DA-88 and VCR were incorporated into the system to provide real-time backup of the audio and video data. A simplified diagram of the field test system is shown in Figure 1.

Test Vehicle Outfitting

The entire system was preassembled at NASA/Lewis prior to installation into the test vehicle, a 1986 24-foot "Honey" motorhome, shown in Figure 2. To accommodate the weight and power requirements of the test system and of the proponent systems' receiving equipment, the vehicle required substantial modifications, performed by the NASA/Lewis crew. The interior of the vehicle was gutted, the rear suspension was raised and strengthened, and additional bracing was added to the walls and ceiling. New plywood flooring was installed, three captain's chairs were mounted for observers and the system operator, four large equipment racks were mounted along the side of the vehicle, and an AC power system consisting of paired rear-slung generators and interior uninterruptable power supply units was installed. To support the various antennas required by the proponent systems, a platform was constructed at the front of the roof of the vehicle and fitted with an aluminum ground plane, with a roof catwalk and rear-mounted steel ladder installed to facilitate access. This area is shown in Figure 3. The mounting of the optical shaft encoder used for distance measurement is shown in Figure 4.

Once these modifications to the vehicle were complete, the testing system and proponent receiving equipment were installed and connected. Digital and analog audio

Figure 2. The CEMA DAR field test vehicle.

Figure 3. Antenna mounting plane and catwalk.

Figure 4. Optical shaft encoder installation.

were routed through patch bays to facilitate quick system changes. A video monitor, powered audio speakers, and headphone distribution amplifiers were installed for monitoring of the test data being collected. A portion of the equipment installation is shown in Figure 5. After all systems were installed and checked at NASA/Lewis, the test vehicle was shipped to San Francisco.

Test Route Selection

To ensure that all proponent systems were tested under a range of propagation conditions, the CEMA committees determined that six "long path" routes, averaging about one hour in length each, would be driven for each of the proponent systems. The routes were selected to be representative of the challenging propagation characteristics for which the San Francisco Bay Area was chosen as a field test site, including terrain shielding, urban shielding, heavy foliage, long over-water paths, and dense multipath environments. A map of the routes selected is shown in Figure 6. That figure also shows the locations of the Mt. Beacon, San Bruno Mountain, and Round Top Mountain test sites. As previously discussed, the Mt. Beacon site was employed for both Eureka 147 and AT&T/Lucent testing, while the San Bruno and Round Top sites were used only for Eureka 147 testing.

Field Activities

To serve as a base of operations for all field activities, a staging area was constructed in Mill Valley, about five kilometers (three miles) north of the Mt. Beacon transmission site. A large garage bay was selected at a storage facility with convenient access to U.S. Highway 101, the main north-south route on the western side of San Francisco Bay. The facility was also adjacent to a well-stocked hardware store and service station, both of which proved to be invaluable resources throughout the preparation and testing phases. The garage bay itself was large enough to accommodate the test vehicle as well as a heavy-duty workbench and storage cabinet for blank data tapes, proponent equipment, cables, and spare parts. A temporary electrical system was installed prior to the test vehicle's arrival to provide overhead lighting and a shore power connection for the vehicle's power subsystem.

Test vehicle staffing. During normal field testing operations, the test vehicle was staffed by a crew of four: a driver, a test equipment operator, and two observers. The observers were trained prior to the commencement of testing to identify signal dropouts and audio defects, and to mark each event by pressing the appropriate buttons on their game controllers. The test equipment operator oversaw the operation of the entire system, controlled the software, supervised the observers' indication of signal events, assisted the driver with navigation, and incremented landmarks along each route.

Timecode synchronization. SMPTE timecode was used to synchronize all of the data recording devices, with the video subsystem serving as the timecode source for the other two recording subsystems. The audio and video tapes were "prestriped" with timecode prior to

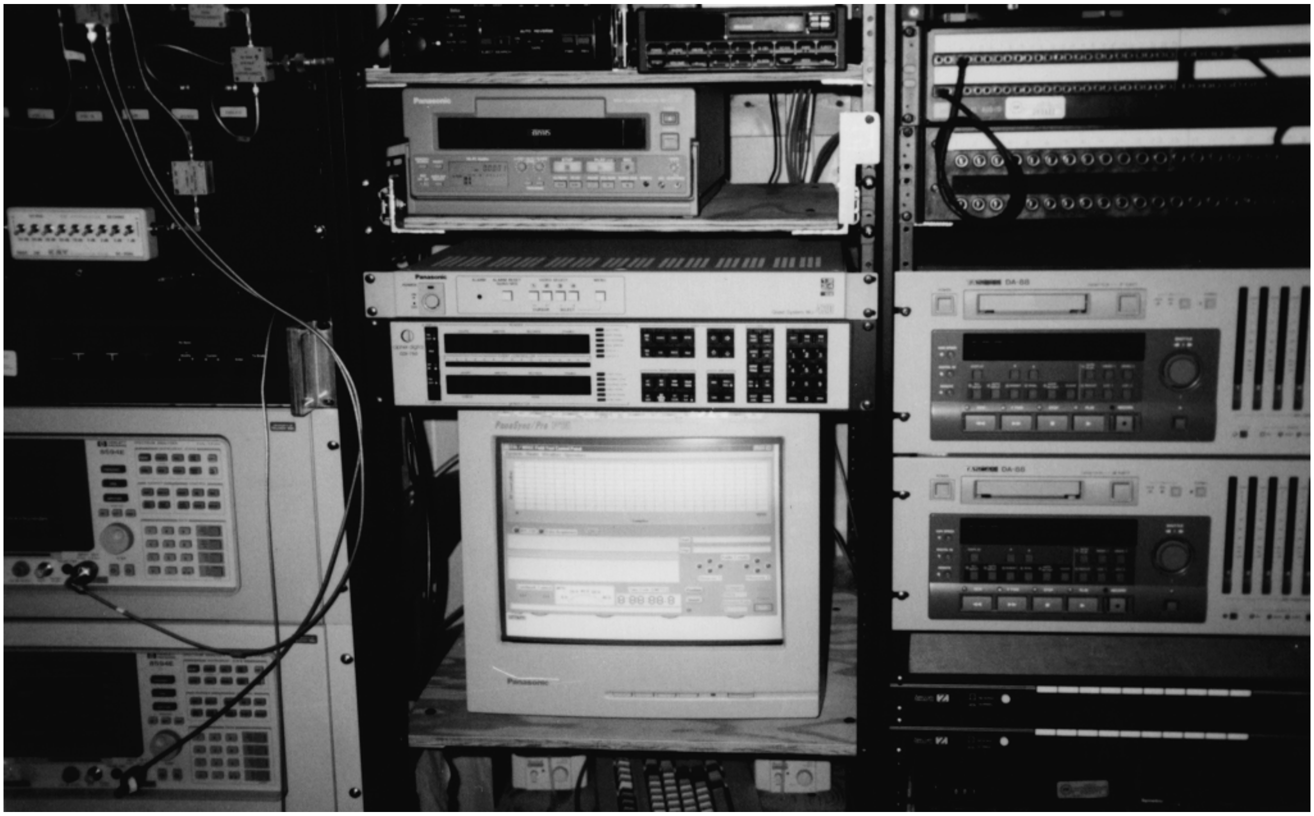

Figure 5. Test vehicle data gathering equipment.

each test run. With the VCR in video insert mode, the prerecorded timecode contained in the linear audio track would be sent to the other recording devices while the output of the quad video mixer was being recorded onto the videotape.

Software operation. The data collection software was designed to record copious amounts of information about each system. With each pulse of the wheel-mounted optical shaft encoder, the software stored a record containing the digitized instantaneous RF level of the system under test, with every few records containing current SMPTE timecode, current landmark, observed audio events, and weather information. At 200 pulses per revolution of the shaft encoder, this resulted in a data record being written for each 1.17 cm (0.461 in) the test vehicle traveled, or more than 85,000 records per kilometer (137,000 records per mile). If the vehicle was stopped for any length of time, the software would automatically write complete records to the data file every 5 seconds.

As well as serving as a recording system for computer data, the software provided a central control point for much of the test system's other hardware. At the beginning of each test run, after the test system was configured for the proponent system under test, and after all tapes had been loaded into the recording devices, the test software was started and basic information about the test run to be conducted (system identification, test route, and current weather conditions) was entered by selecting appropriate options from a series of menus. With this information, the software automatically downloaded the proper settings to the two spectrum analyzers and loaded a file containing landmark descriptions for the specified route. The software also was used to activate the insert record mode on the VCR, which sent timecode to the slaved DA-88 audio recorders and back to the computer.

Data gathering. Once the recording systems were running and synchronized, the test route was driven while the observers listened to the decoded digital audio on headphones and marked audio defects and dropouts. The operator monitored the collection of RF data on a strip chart displayed by the data collection software, marked landmarks onto the computer record, and took notes of any odd occurrences or problems with the recording system. After the route was completed, the tapes were checked for data and proper playback synchronization. Finally, the computer data files were backed-up to tape at the end of each testing day, and blank

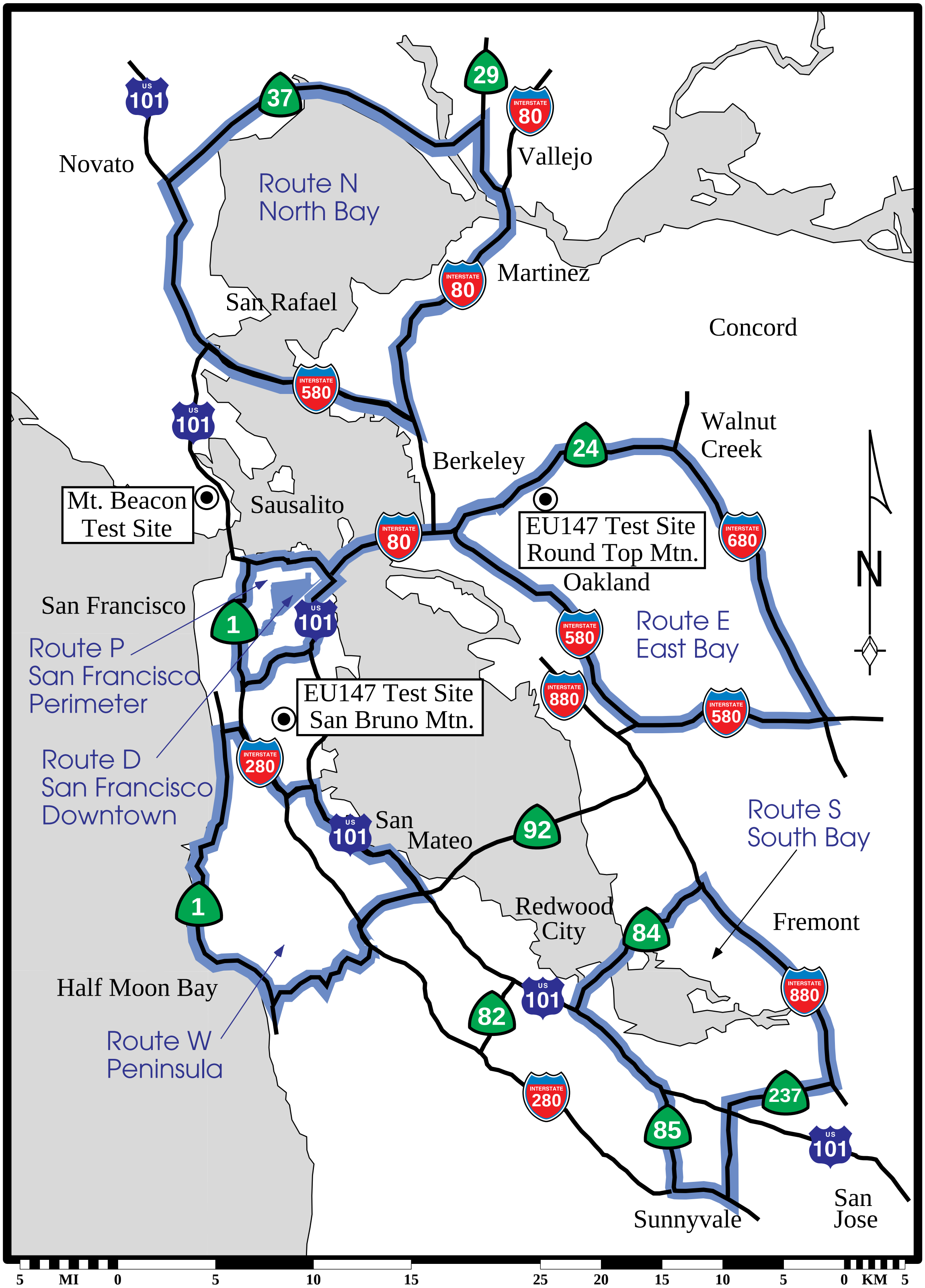

Figure 6. Selected test routes.

tapes were loaded for prestriping in preparation for the next day's testing activities.

POTENTIAL IMPROVEMENTS

The organization and supervision of such a field testing project led to realization of several ways in which future projects of this type could be made more efficient. Areas for improvement were determined both at the test site and for the test van operation, as described below.

Test Site Improvements

While the cooperation of a site manager and reasonable lease rates are important aspects, selection of a test transmitting site should consider factors that will reduce the amount of time and expense that must be expended to make it suitable for field testing. A site should be selected that can offer enough room for all of the associated equipment to be set up in one place. Depending on the geographic area, air conditioning and/or other climate control methods should be present to allow the test area to be maintained at a nominal room temperature. Adequate AC power reserves should be available without the need to install a new service; some stations, for instance, have the capacity to operate both main and auxiliary transmitters simultaneously, and that excess capacity might be made available for use during testing operations.

The availability of tower space is also important. A proposed test transmission site should offer several "equivalent" locations on one or more towers at which antennas could be mounted, to minimize the time and effort that must be spent installing and removing transmitting antennas. Also, the antenna mounting locations should be selected such that other nearby facilities need not be required to shut down during antenna rigging operations to meet RF radiation protection requirements.

A site that would meet all of these "wish list" requirements is probably a rarity, but a site that has at least some of these desirable features would have helped in completing testing operations more quickly and efficiently than at the Mt. Beacon site.

Test Van Improvements

First and foremost, the need for a reliable test vehicle was identified early on during field test preparations. It was evident that the ten year-old motorhome selected to serve as a test vehicle had led a hard life, and the loss of test time due to its numerous breakdowns was excessive. Problems encountered during the testing process included brake system replacement, manifold and muffler system replacement, transmission adjustments, and oil leak repairs. Additionally, cracks and rotting areas in the camper shell were a concern if wet weather was ever encountered; luckily, the weather remained clear during testing, but leaks were found during the rainy weather that followed completion of the testing. Clearly, use of a new or newer vehicle would have avoided these problems.

Regarding parts of the van-mounted test system, the shaft encoder, used to measure distance traveled, was a continual problem area. Being mounted to the back wheel of the test van, it was open to damage by road debris and sudden shock, leading to the breakage of its metal shaft during data gathering operations. Eventually, an acceptable mounting configuration was determined, and a spare encoder was carried as a backup. The shaft encoder system allowed distance measurement in resolutions of less than 1.3 centimeters (about 0.5 inches), but clearly that level of precision was not needed for the long path routes over which data was gathered. A better system might have employed a Global Positioning System (GPS) receiver; GPS receivers are presently inexpensive and they offer position data output of sufficient accuracy that is easily interfaced with recording computers. [2]

Other problems encountered with the test van system included data gathering computer failures, camera misalignment, connector separations due to vibration, and failure of one of the audio recorders. The data gathering computer consisted of a consumer "Pentium clone" IBM compatible unit. It failed randomly numerous times, requiring that several portions of test routes be repeated after rebooting. A better choice would have been an industrial-rated computer, constructed to withstand the shocks of mobile operation. This is substantiated by the fact that two of the proponent receiver systems employed industrial computers that never experienced any failures.

The other vibration-related problems were addressed and corrected as required. A modified mount was devised for the video cameras, which cured the misalignment problem. Connectors were replaced and improved as necessary, and the presence of a backup audio recorder proved invaluable, in that the main recorder failed during the main part of testing operations. In a related area, the inclusion of analog and digital audio patch bays was an excellent idea on the part of the test van construction personnel, as it allowed for the audio rerouting required to use the backup audio recorder as a main without rewiring the cable harnesses and interconnections in inaccessible portions of the equipment racks.

CONCLUSION

Being a part of the CEMA DAR field tests was a rewarding experience. While experience was drawn from prior mobile data gathering projects, the complexity of coordinating the assembly of a test transmission site and the operation of a related mobile data gathering system provided enjoyable challenges. The project resulted in the generation of concise and fairly obtained data for all tested proponent systems. A complete report of the test results has been prepared, and it is available from CEMA. [3]

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