Communications Architecture for Early Implementation of Intelligent Vehicle Highway Systems

D. J. CHADWICK, V. M. PATEL, AND L. G. SAXTON

Communications—wireless communications in particular—is a critical component of intelligent vehicle highway systems (IVHS). It is costly when viewed from two different angles: first, its dependence on using the scarce natural resources called radio frequency (RF) spectrum, and second, the actual cost of implementing the necessary infrastructure and the required (in-vehicle) user equipment. On the other hand, it is imperative, for the success of the national IVHS program, to plan a near-term IVHS architectural implementation to show positive first-user benefits. Bearing in mind the above constraints, it is natural to think of designing an IVHS communications architecture that makes use of existing infrastructures for other communications services. This strategy enables more efficient use of the RF spectrum while it reduces the total cost of services by sharing the communications infrastructure and end-user equipment. A communications architecture is proposed for IVHS called the Subsidiary Communications Authority Traffic Information Channel (STIC), based on the widely available FM radio broadcast services' infrastructures by making use of FM subcarrier technology. This preliminary design also shows that STIC has a higher data transmission capacity than any other existing FM subcarrier broadcast system and that it has the potential to meet the one-way outbound (broadcast) data transmission capacity needs of IVHS for the next few years. In addition, STIC architecture is capable of being scaled up in the future.

The intelligent vehicle highway system (IVHS) program is broadly described as applying modern communication and control technology to the needs of highway transportation. In this regard, IVHS is yet another part of society that is increasingly interwoven with and dependent on modern communications technology. At home, at the business place, or in transit, currently available communications provides an additional dimension of information exchange to enhance one's business and personal life.

The success and viability of IVHS is dependent on several factors; however, perhaps none will be more central and fundamental than efficient, reliable, and affordable communications. Although some IVHS functions will be serviced by "hard-wire"-type communications, the more advanced system concepts generally involve communication with a moving vehicle and thus require some form of wireless approach. At issue here is the substantial growing demand for RF spectrum to support various perceived and developing markets such as high-definition television and advanced personal communications. Given these spectrum constraints, there is a real incentive to overlay IVHS communication functions on existing services where possible. Two examples that have been discussed are digital cellular and FM subcarrier.

IVHS is not a single system but rather a broad set of applications with functions and technology that intersect in various situations. IVHS also has a range of technology and system availability spanning products that are available today to concepts not expected to be marketed until after the turn of the century. This range of both product types and market timing poses a dilemma to IVHS. For the most efficient system and effective use of spectrum there is the need to establish an overall efficient architecture for IVHS. Efforts to make this analysis and to postulate the most preferred architecture are now being initiated but will require at least 2 to 3 years. However, there is an immediate need to bring to market and thus realize the benefits of many IVHS applications that are near-term implementation candidates. A primary example is the desire to market motorist information and route guidance-type systems. Thus, this early market need results in the necessity to establish communication resources and standards now for these current applications without benefit of knowing the form of the final IVHS architecture. The practical compromise is to attempt to establish a communication design to service these near-term needs that is easily available, minimizes any Federal Communication Commission (FCC) rulemaking needs, is economical, and is adaptable to future architecture designs (*1*).

Given these objectives and constraints, FHWA has been considering various communications approaches to service motorist information and route guidance-type applications. These systems do not necessarily have a single or homogeneous set of communication needs as there is a strong need to provide both low-cost, basic performance systems and higher-cost, high-performance systems. Low cost can be characterized as radio data system (RDS)-traffic management system (TMS) type systems, whereas the higher-performance systems are of the TravTek type.

The use of the subcarrier part of each FM station's frequency assignment has some particular advantages—especially for the low-end systems (*2*). However, there also appears to be the opportunity to reconfigure the subcarrier in a manner in which the FM subcarrier could also service high-end systems. This potential has been the focus of recent efforts, and this paper is part of an effort to share this promising communications approach with the IVHS community. If further analysis and preliminary field testing support the value

D. J. Chadwick and V. M. Patel, The MITRE Corporation, 600 Maryland Ave., S.W., Washington, D.C. 20024. L. G. Saxton, FHWA, Turner Fairbank Highway Research Center, McLean, Va. 22101.

of this approach the objective would be to work it into early operational tests.

COMMUNICATIONS OUTLETS FOR EARLY IMPLEMENTATION

Public policy analysts generally agree that new systems such as IVHS must provide their first increment of user services or public benefits within about 5 years of the inception of the project. Further, the initial offerings to the public have to be "winners"; that is, they have to be perceived as providing the benefits that they promised at their inception, at a cost commensurate with those benefits. The Interstate highway system is a good example of this incremental implementation strategy. In this case, the new highways were opened to traffic after the completion of segments only a few miles long, thus delivering their promised benefits (safer, higher-capacity, higher-speed roadways) quickly and in ever-increasing measure.

For IVHS to operate in the same way, it is essential that initial implementations not depend on the design, development, and installation of large infrastructures. This is especially true in the case of communications systems because they have to be in place before any other subsystems can even be tested effectively. This drives the conclusion that early IVHS projects will have to make use of existing communication outlets to the maximum possible extent.

Several available communications technologies are available for early IVHS projects. Each will be discussed in turn, elaborating on issues such as capacity, coverage, and cost.

RDS

RDS is widely used in Europe for a variety of services including traffic information (*3*). Broadcast stations in the United States plan to install the system as well, but its applications may well degenerate to the single function of program type identification (classical, rock, sports, news, etc.) because the system's capacity and hence level of detail for route guidance data transmission are very low. RDS uses an AM subcarrier on the FM broadcast station that is located at 57 kHz on the FM baseband. The total baseband bandwidth that RDS occupies is about 7 kHz or from just above the stereo L-R spectrum limit at 53 kHz to 60 kHz. The gross data rate for the channel is set at 1,187.5 bps, almost half of which is used for error correction. After extracting the capacity used by fixed RDS functions, the data rate remaining for "additional" services is under 300 bps. That rate will not begin to support IVHS data requirements for traffic link time updates, for example. RDS is, however, a robust system. Its cost is also relatively low. FM broadcast stations in the United States plan to adopt the system, if only to support a program-type function.

Highway Advisory Radio and Advanced Highway Advisory Radio

Highway advisory radio (HAR) and advanced highway advisory radio (AHAR) systems are widely used in the United States for broadcasting information to travelers in a limited area. Services include traffic information, parking availability at airports and national parks, scenic view alerts, and so forth. The systems use AM broadcast-band equipment, operating at low power levels. Until recently, the transmitters were operated on fixed frequencies (530 and 1610 kHz), within the frequency range available to standard car radios. In the future, HAR and AHAR stations will be assigned anywhere in the AM broadcast band that is available, considering the assignments to local commercial stations. Because they operate in a band in which the maximum modulating frequency is 5 kHz, the capacity of the systems to handle data is limited and is meant to be a voice announcement medium. Because of their limited range, HAR stations would have to be installed to support IVHS services in nearly all cases, which goes against the strategy of limiting infrastructure installation initially.

FM/Subsidiary Communications Authorization

As part of its license, every FM broadcast station is granted the authority to broadcast other program material on subcarriers that cannot be detected by standard receivers (see Figure 1). These subsidiary communications authorization (SCA) subcarriers are already used by some stations as sources of extra revenue and carry program material that ranges from sports programs and paging data to background music and stock quotes. Many stations do not currently use their SCA subcarriers. FM broadcast stations provide a high grade of service to well over 90 percent of the area of the United States and to 100 percent of the area where early IVHS experiments are likely to be conducted. The equipment needed to enable the SCA signal is inexpensive, and no modification to the station is required. Likewise, SCA receivers are available at low cost. The capacity of the SCA channel, given suitable

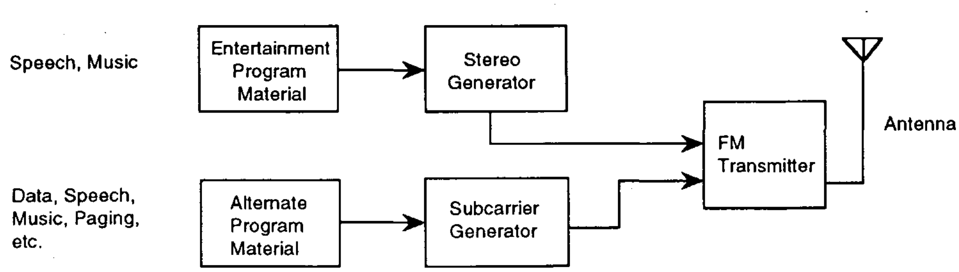

FIGURE 1 FM broadcasts with SCA.

modulation and coding approaches, can be more than 16 kbps, as is discussed later in this paper. Thus, an installed infrastructure of high-capacity, wide-area communications exists to support IVHS needs for communications from the highway to vehicles.

Television Data Channels: Vertical Blanking Interval and Aural Subcarriers

Broadcast TV channels offer two different outlets that will support data communications for IVHS. The first system, called vertical blanking interval (VBI), modulates the first 20 picture lines of each frame, which cannot be "seen" on the screen because they occur during the interval (blanking) when the picture is "off." VBI already is used extensively to provide closed captioning for the aurally handicapped. This service is supported on a single VBI line (Line 4). The technology exists to chain from 2 to all 20 lines into a single virtual data channel, with a resultant capacity of about 56 kbps, although it is somewhat complex. Receivers to use the VBI channel are basically full TV visual implementations because the signals have to be recovered from the composite video baseband. At present the only VBI receivers that are in production are limited to the closed caption service and would not support general data communications.

A TV station is really two "associated" broadcast stations with separate transmitters for the visual and aural signals (Figure 2). The TV aural transmitter is actually just an FM station with somewhat different technical characteristics. As such, subcarriers can be supported as with conventional FM. One of the standard TV aural subcarriers is called the secondary audio program (SAP). It is infrequently used for some of the same services as FM SCA and occasionally to broadcast a running commentary of the main TV program for the visually handicapped. The SAP channel has a much wider bandwidth than the SCA subcarriers, although the basic technology is identical. SAP receivers are available only as a separate device (i.e., not built into a TV set) from one manufacturer at present. Since the bandwidth available on a TV aural signal is large, more than one wideband subcarrier can be accommodated. Even in those cases in which a TV station is using SAP, another subcarrier can be added for traffic data.

Because there are fewer TV stations than FM stations in most areas, and because their coverage area is typically smaller, the TV data channels may be less desirable in some situations. However, in major metropolitan areas where needs warrant, these outlets could provide an extra measure of capacity.

Land Mobile Frequencies in the Range of 220 to 222 MHz

Although it is certain that all IVHS communications requirements cannot be met by any single system, there are a few basic critical functions for which the desirability of continent-wide common frequencies is obvious. To accommodate fundamental services in the safety and warning area, which should be available to all "classes" of users, these messages should be carried on frequencies that are the same everywhere so that the simplest possible radio design can be supported. The National Telecommunications and Information Administration and FCC recently opened a new land mobile band between 220 and 222 MHz. The band plan allots frequencies to several kinds of users over a set of 200 channel pairs, each 5 kHz wide. Besides being divided between government and nongovernment users, the frequencies are allotted to national and regional applications. Within the nongovernment set, users in both commercial and noncommercial classes are accommodated. The FCC has received applications from about 80,000 individuals for nongovernment licenses in the band, but the principal interest by these people is in the commercial frequency pairs.

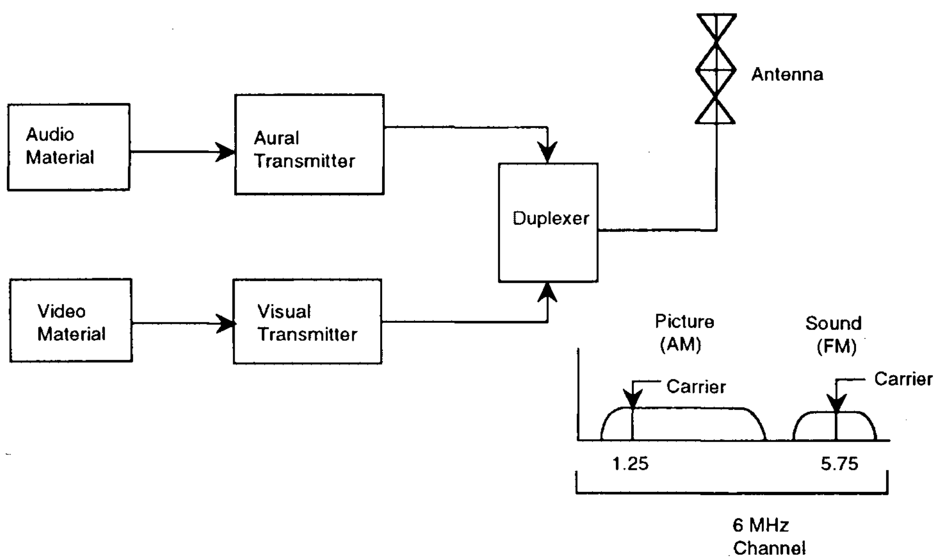

FIGURE 2 Television broadcasting.

Besides the safety and warning services mentioned above, the use of continent-wide frequencies in this band would enable a "hailing" function, wherein the other frequencies in use for other services in a given area can be broadcast and used to automatically tune the in-vehicle receivers. This approach unencumbers the design and frequency acquisition of systems from the absolute need to be exactly the same across the continent.

DESIGN FEATURES OF AN SCA-BASED TRAFFIC INFORMATION CHANNEL

Within the FCC regulations for FM radio broadcast services, the SCA subcarrier can be placed anywhere in the range from 60 to 99 kHz on the baseband (*4*). Figure 3 shows the baseband spectrum of a commercial FM broadcast system with such an arrangement. The subcarrier at 76 kHz can be modulated by the digital traffic data stream and then used to frequency modulate the main carrier to a level corresponding to a modulation index of 10 to 20 percent. Although the FCC limits the injection level of the subcarrier modulation on the main FM carrier to 10 percent when the subcarrier is placed at 76 kHz, the FCC should not object to using an injection level of 10 to 20 percent for STIC. Placing the subcarrier at 76 kHz improves reception and simplifies design because 76 is a fourth harmonic of the pilot tone at 19 kHz. Eventually, this feature reflects as a cost-reducing factor for the mobile receiver.

To reduce the synchronization and timing requirements on the receiver circuitry that demodulates and extracts the SCA traffic information, the digital traffic data rate of the basic modulating signal of the SCA channel is derived via a "binary division" of the subcarrier frequency (76 kHz) itself. A division by eight of the subcarrier frequency would give a base SCA channel baud rate of 9.5 kbps. Using a quadrature phase shift keying (QPSK) modulation scheme for the subcarrier modulation will give a data rate of about 19 kbps (twice the baud rate).

As shown in Figure 3 for the FM/STIC baseband spectrum as well as in Figure 4, which shows the channel structure for

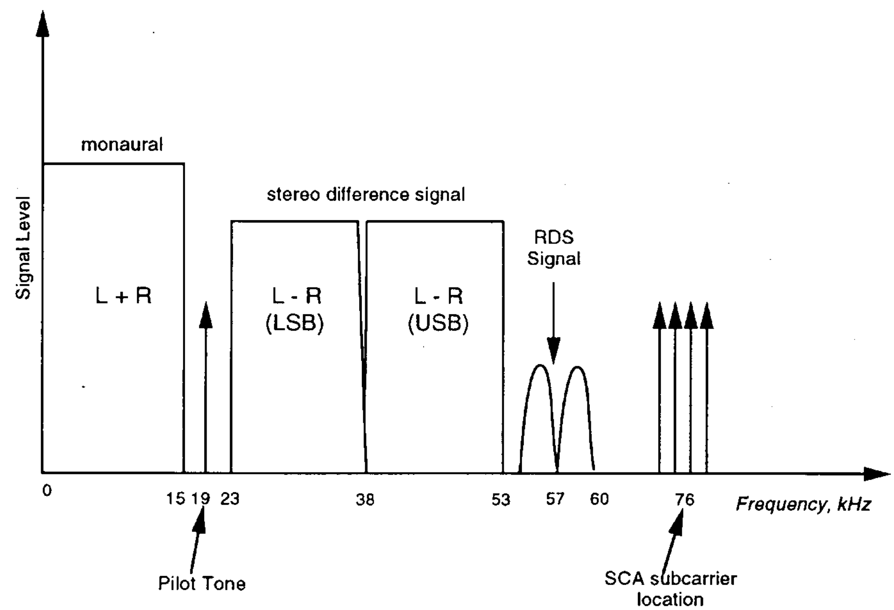

FIGURE 3 FM baseband format under the STIC system.

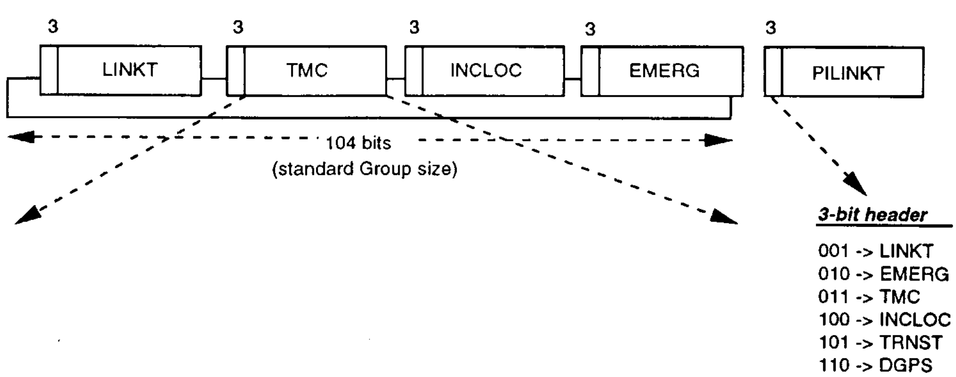

FIGURE 4 SCA STIC structure.

STIC system, the RDS data structure was subsumed as far as possible. The size of the data blocks ("groups" in RDS terminology) is maintained at 104 bits long, as in the European RDS. In addition, a three-bit header is added in front of each data block to signify what type of data block follows. Presently, the following types of data blocks are defined:

1. LINKT data groups will provide the updates for the link times to the vehicles as necessary. They also will be used for periodic refreshing of the basic link-time data base resident in the vehicles (e.g., with a periodicity of once every 5 min). The group structure is shown in Figure 5. This type of message is essentially for use with the high-end family of IVHS services and will be ignored on reception by the in-vehicle STIC system equipment for the low-end services users.
2. EMERG group will broadcast emergency-related data when the situation demands. A severe accident involving toxic chemical spill is a good illustration. Although this data group may be broadcast infrequently, it will be assigned the highest priority and may preempt transmission of any other data group. This group is applicable to both the high- and low-end services users.
3. TMC group is the European RDS-TMC data group (*5*). It is planned to adopt the ALERT "C" protocol, with modifications to suit the U.S. requirements, containing most features as proposed in ALERT "C." This data group again is for both high- and low-end services users.
4. INCLOC: Whenever a TMC group transmits incident-related information that has associated location information to be broadcast, it is sent out via one or more INCLOC blocks. Figure 6 shows the details of the structure of this group. This message group is applicable to both the high- and low-end services users.

The TRNST block conveys desirable schedules of, and connections to, the public transit system (both surface and subsurface systems). The DGPS block may be used to broadcast the correctional (time and location) parameters computed by the differential GPS station for the area.

STIC CAPACITY AND IVHS COMMUNICATIONS LOAD

It is estimated that even with full advanced traveler information system (ATIS)-advanced traffic management system (ATMS) implementation, a downlink gross data rate of about 19 kbps would be sufficient to handle required services, in-

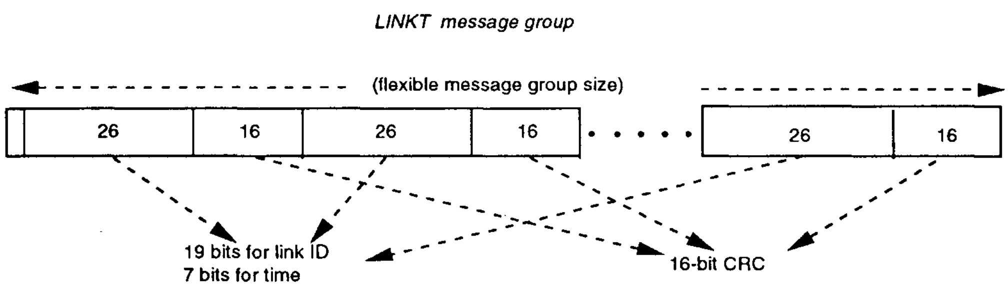

FIGURE 5 STIC group structures (LINKT).

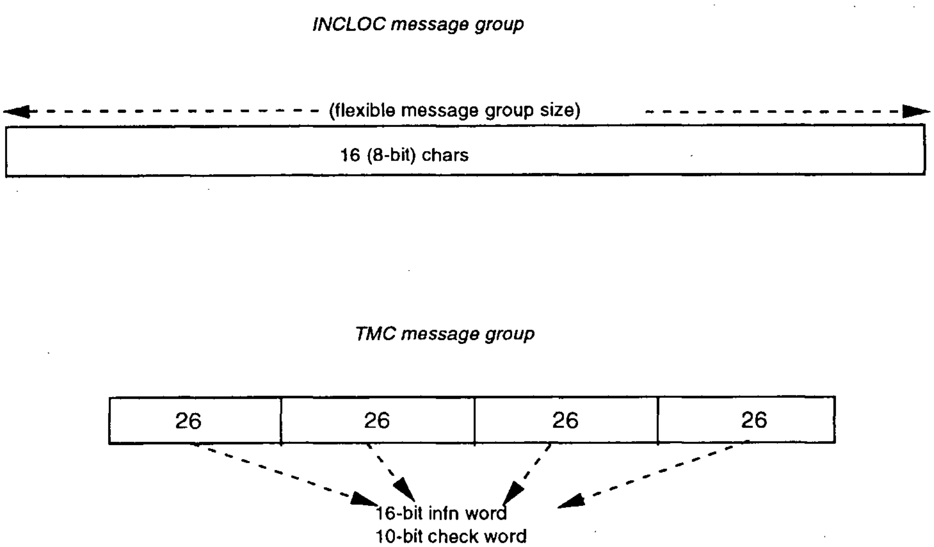

FIGURE 6 STIC group structures (INCLOC and TMC).

cluding updating the in-vehicle link-time data base with acceptable periodicity. Given below are the salient features of the communication downlink load for IVHS along with an example computation.

- INCLOC capacity sample calculation: assuming eight alpha characters for a street and two streets to define an intersection: $8 \times 2 = 16$ characters for every intersection (abbreviated location information in text form), and no error detection or correction. Using the total STIC capacity of 19 kbps for INCLOC message blocks only, and with 16-character (or 131-bit) blocks, 19,000/131, or about 145 intersection-level location information sets, could be passed on to the motorists each second.
- STIC capacity sample calculation:
  - —Assuming the following set of traffic information load: one INCLOC group is necessary to be transmitted for every TMC group, and TMC groups consume 6 percent (1.2 kbps) of the total channel capacity (19 kbps). This means 1.2 kbps are consumed by TMC messages and 1.47 kbps by INCLOC messages. Thus, the STIC capacity available for LINKT groups alone is $19 - 2.67 = 16.33$ kbps.
  - —Optimally, having a flexible LINKT message group (say, 213 bits long), five link times could be broadcast via one group. Utilizing the total remaining capacity every second: $(16{,}330/213) \times 5$, or about 383 link times, could be broadcast along with about 11 TMC groups and 11 INCLOC groups. In other words, with about 16 kbps channel capacity allotment to LINKT blocks, more than 22,000 link times may be transmitted each minute—which is perhaps adequate, at least for the initial few years of IVHS deployment.
- QPSK subcarrier modulation will be used to provide double the data rate (19 kbps) from a baud rate of 9.5 kbps. A modulation efficiency of 1.5 bits/Hz is not very sophisticated by today's state-of-the-art modulation standards. Only a modest amount more in system cost could push the practical channel speed further upwards as requirements expand.
- To keep the end equipment relatively inexpensive, data compression is currently not incorporated. However, it may be a viable approach to increase the data rate in the future and should be evaluated.
- Service range: Although the modulation level of the main carrier allowed by the SCA signal is about half that of the main program signal, the SCA modulating signal would be digital in nature and, consequently, can tolerate a lower ratio of signal to noise (SNR) at the receiving end. Computations show that the geographical range of coverage for the STIC information signal would be almost the same as that for the standard FM entertainment signal.
- STIC is scalable to more sophisticated ATIS/ATMS deployment.

ESTIMATION OF SERVICE RANGE FOR STIC

An FM detector, called a discriminator, produces an output voltage that is proportional to the frequency deviation of the input signal. Thus for a given SNR, the range reduction for the SCA channel, with a modulation index of 0.2 (as compared with the main channel whose index is typically 0.35 if SCA is present) can be estimated from the relationship:

$$20\log_{10}(0.2/0.35) = 20\log_{10}(0.57) = 20(-0.24) = -4.9\text{dB} \quad (1)$$

This is the SCA channel output power as compared with that of the main entertainment channel(s).

From the free-space loss equation,

$$Lp = 20\log_{10}(d) + 20\log_{10}(f) + K \quad (2)$$

a 4.9-dB reduction in signal power corresponds to a range reduction of

$$4.9 \text{ dB} = 20\log_{10}(d) \quad (3)$$

That is, $\log_{10}(d) = 0.245$, or $d = 1.76$. Hence, the service range of the SCA channel is 1/1.76 or 57 percent that of the main program for the same SNR.

The effect of a reduction in required SNR associated with the SCA channel is a dB-for-dB change, which can be substituted into Step 3. Thus, reducing the required SNR on the SCA channel by only 5 dB, because of the more robust digital signal, will restore the SCA coverage to that of the main "entertainment" signal for the FM station.

MODULATION AND ERROR CORRECTION

SCA regulations allow freedom to choose any modulation scheme. In general, the more sophisticated the modulation technique employed the higher the bit rate yield of a given bandwidth, measured as bits per hertz. For example, a QPSK modulation will offer double the channel capacity compared with bipolar or 2-PSK. However, the engineering trade-off is the cost of higher requirements of power radiated, that is, better SNR at the receiver end to obtain the same BER. Nevertheless, keeping the same emitted power level or received SNR, the BER can still be maintained by incorporating appropriate error correction schemes into the system to obtain an ultimate channel capacity that is much better than that available with 2-PSK, although it may not be twice as much.

Out of a number of modulation schemes that exist, such as minimum-shift keying (MSK), multiamplitude MSK (MAMSK), offset PSK, $\pi/4$ shifted PSK, raised cosine PSK, quadrature amplitude modulation (QAM), nonlineraly filtered QAM, Gaussian filtered MSK (GMSK), and so on, one or more may have an optimal set of characteristics to make the best fit for STIC in combination with one or more error correction schemes. In a mobile environment with Raleigh fading and multipath in an urban surrounding, unacceptable negative impact on the received BER would occur without robust signal properties and conditioning. This calls for thorough analytical and, perhaps, simulation studies to analyze a variety of scenarios and arrive at the right choice of modulation and error correction schemes that would provide an acceptable error rate and highest possible data capacity, accompanied by a reasonable cost for user equipment. It is important to also bear in mind the fact that implementation of not all modulation (for example, "codulation" approach or modulation in combination with memory) techniques may be currently available in chip form, but because of the volume of motorists, if the services are found beneficial and marketable, the volume production itself has the potential of offering the user equipment at a much reduced price.

BENEFITS OF THE STIC DESIGN

- It is available quickly for early field trials and initial operational systems.
- It has adequate capacity to handle IVHS growth for the foreseeable future.
- No additional RF spectrum is required (procurement processes for radio frequencies are long and cumbersome).
- It has very low infrastructure capital and OA&M costs and relatively inexpensive user equipment.
- The user of low-end (basic traffic information on congestion, incident, weather, and safety advisory) IVHS services, with relatively inexpensive in-vehicle hardware and without any elaborate data base capability, still has available location information, associated with traffic congestion or incident, with an intersection-level granularity, for display in abbreviated alphanumeric character form straight from the information broadcast source.
- It is easily integrated into long-term "full-up" IVHS architecture. The basic low-cost hardware in the vehicle is common to both the low- and high-end (navigation, route guidance, etc.) versions. This situation enables the user to scale up subscription from a low-end to high-end set of services when the latter is available and the user is ready to make use of it.
- On the other hand, motorists who normally utilize the high-end set of IVHS services in their hometowns may prefer to fall back on the low-end set of IVHS services while traveling to (or on a long-distance trip passing through) some other town temporarily, instead of buying the detailed (CD) data base relevant to the particular city of travel. For the high-end family of IVHS services, one would require additional equipment—for example, processors and data bases, and so on.
- Many other types of services could be subsumed within the STIC system, for example, for transit information and correction information for differential global positioning system. The SCA channel capacity is expected to have enough capacity for quite a few years in the future. Furthermore, if the need for greater capacity arises later, there are comparatively simple ways of updating the STIC system. First, more sophisticated and efficient modulation and coding schemes are already being conceived, developed, standardized, and implemented on chips. Second, one will have the option of arranging for additional FM broadcast stations for transmission of traffic information while incorporating regionalization into the data to be broadcast.
- A major advantage of the STIC system is its flexibility to simultaneously accommodate the users of both the low- and high-end IVHS services; in other words, both types of motorists will be able to coexist. Consequently, there is assurance for soft transition no matter how the user population changes: (a) only low-end user penetration changes, (b) only high-end user penetration changes, or (c) any combination in any proportion of the above two changes.

CONCLUSIONS

STIC can provide a large-bandwidth data communications link between the highway infrastructure and vehicles. This link could be implemented very quickly to support IVHS field operational trials and would integrate well into an end-state IVHS architecture.

REFERENCES

1. J. Chadwick, V. Patel, and G. Beronio. The Relationship Between System Architecture and Radio Frequency Requirements for Intelligent Vehicle Highway Systems (IVHS). *Proc., 1992 Annual Meeting of IVHS AMERICA*, Newport Beach, Calif., 1992.
2. M. P. Ristenbatt. *A Communications Architecture Concept for ATIS.* Communications and Signal Processing Laboratory, Electrical and Computer Science Department, University of Michigan, Ann Arbor, 1991.
3. *Mobile Information Systems.* (J. Walker, ed.) Artech House Publishers, Boston, Mass., Oct. 1990.
4. J. Chadwick and V. Patel. A Communications Architecture Concept for Intelligent Vehicle Highway Systems (IVHS). *Proc., Intelligent Vehicles 1992*, Detroit, Mich., July 1992.
5. P. Davies and G. Klein. Field Trials and Evaluations of the Radio Data System Traffic Message Channel. In *Transportation Research Record 1324*, TRB, National Research Council, Washington, D.C., 1991.

Publication of this paper sponsored by Committee on Communications.