Automatic Vehicle and Container Identification Using Radio Frequency Technology

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Automatic vehicle identification (AVI) systems that use radio frequency (RF) technology in the 900 mHz to 4.0 gHz range have applications to a variety of intermodal transportation modes, including the railroad, trucking, and maritime industries. Past and present AVI technologies are reviewed and the different types of radio frequency equipment on the market, how the equipment can be used to improve terminal operations, management information systems, vehicle usage, service efficiency, traffic volume, and customer convenience are discussed.

An engineering and operational perspective is presented on the current state of computerized vehicle and container identification and what it can do for the intermodal industry now and in the future. No attempt has been made in this paper to propose a specific automatic vehicle identification (AVI) system; however, the concepts are presented in a manner designed to benefit both new and existing intermodal facilities.

The current state-of-the-art, electronic vehicle identification equipment has evolved rapidly from its infancy to commercialized, off-the-shelf products. State and federal governments, private industry, and the military are currently evaluating and installing pilot projects in anticipation of near-term full AVI implementation.

However, the intricate complexities of intermodalism and its far-ranging impact on rail, truck, air, and marine applications on both the national and the international levels demand careful planning and implementation for a coordinated worldwide AVI system to be successful. This will take time, but, in the same way that the United States helped set the standard in containerization, a standard for AVI may also be accomplished.

The nature and scope of this study have been restricted to exclude all AVI technologies and systems that could not meet the following intermodal requirements:

1. Variable speed ranges from 0 to 80 mph,
2. Varying tag reading distances from 1 to 20 ft, and
3. Vehicle location accuracy of ±5 ft.

In addition, need, intended use, application, and operational conditions (described later) served to further narrow the focus of the study.

TECHNOLOGICAL APPROACHES TO AVI

Automatic vehicle identification is a term that had its roots in the late 1960s and early 1970s and was used to describe any system that had the ability to determine individual equipment identifications in an automated manner. The early systems were of two different types, reflective and inductive. These two types of systems, which are still in limited harsh environmental use today, are briefly described here.

Inductive Systems

As the name implies, inductive coupling is used as the communications medium. Two coils, one mounted on the vehicle and the other fixed to the wayside, form an air core transformer through which data are transmitted. In some cases, the vehicle signal was induced directly to the running rails. Variable-frequency operation and multifrequency detection systems provided a method to uniquely identify a limited number of vehicles. Identification capability is expanded by employing vehicle-carried equipment to modulate a carrier frequency that is decoded by wayside equipment.

In general, systems of this type operate at carrier frequencies below 200 kHz, which limits their data rate and, thus, the maximum allowable vehicle speed. Due to the low coupling efficiency in these systems, the vehicle and wayside coils are relatively large, the spacing between them is somewhat critical, and their usefulness in side, top, and bottom reading locations is restricted.

Reflective Systems

Optical

A color or light-dark pattern on a label can be detected by a light-sensitive device as a particular code, usually referred to as a bar code. The use of technology such as laser scanning has made bar code reading a commercial reality for short-distance, clean environment applications such as warehouse operations or supermarket checkout scanning, where product costs are automatically determined by a bar code on the product label interacting with a computer.

Video

Television cameras placed to the side of the vehicle capture a stenciled vehicle number and transmit the signal to a remote monitoring station where a videotape recording is made for later playback. Initially, these systems were limited by the necessity of a source of illumination at the location and were subject to blurring at speeds greater than 24 k/hr. Advances have been made to minimize these problems and several systems are commercially available. Research in the field of automatic pattern recognition is under way in the hope of providing a fully automated system that does not require a human interface. As they do for bar codes, dirt, contamination, ice, and snow limit usefulness in a harsh environment.

Radio Frequency Systems

A third system that employs radio frequency (RF) technology is the state of the art in vehicle identification technology. It appears to overcome the environmental influences such as mud, ice, snow, darkness, and inclement weather that have plagued other systems (1,2).

Radio frequency technology employs a small integrated circuit with an electronic memory, commonly called a vehicle tag, and a reader-antenna system. The reader functions like the decoder in an optical bar-coding installation, the antenna like a scanner, and the tag like a bar code label; but that is where the similarity ends. The RF tag electronically stores data that are read by the antenna unit attached to the reader. A radio signal from the reader-antenna actuates a coded response from the tag when there is a direct path (although not necessarily a line of sight) between them. The electronic identification tag can contain a fixed identifier or it may be programmable, depending on the type of system used (3,4).

INTERMODALISM

Intermodal services are an infant and expanding industry. To reach its potential and at the same time enjoy profitability, it needs improved control or information processing, or both, for many facets of its operations. Research has determined that the principal goals of both control systems and information processing systems that may be sensibly applied to intermodal terminals are to increase the flow rate of containers and trailers through the terminal (by both increasing volume and reducing handling time) and to increase productivity of both personnel and plant (5). The opportunities for automatic vehicle identification equipment to participate in and help achieve these goals is vital to profitable operations.

Improved control and information processing are prerequisites to handling the expected dramatic increases in intermodal traffic, while decreasing unit handling costs by a significant factor. For intermodal terminals, the goals of the improved control and information systems are to allow an increase in the traffic throughput with little or no increase in staff and only the most prudent additional capital investment.

Some gains in productivity of staff, equipment, and investments are being achieved today through better training, enhanced working conditions, improved terminal design, and more efficient equipment use. These gains are impressive, but, if the heart of the productivity and control problems is not reached, costly bottlenecks will remain.

At medium to large terminals, technological innovations offer the possibility of an almost automated flow of rail cars, trailers, containers, chassis, and truck tractors through the terminal. For large terminals that have been historically saddled by land unavailability, budget constraints, and an unwieldy layout, a tracking system that uses AVI can increase overall throughput by improving the flow of information throughout the system. Individually coded tags on the tractors, trailers, containers, and chassis, with monitoring readers located on hostler (yard) vehicles, at key geographic locations inside the terminal, on gantry cranes and other lifting equipment, and at the entrances and exits to the facility will increase the speed and accuracy of identifying and locating equipment.

AVI REQUIREMENTS

Several different technologies have been applied in AVI systems; some are successful, others not. The reasons are clear (6). Research has shown that there are basic requirements for any AVI system and they can be summarized as

1. AVI must maintain an extremely low rate of undetected errors.
   - Signal transmission between the tag and the reader must not be influenced by environmental conditions such as rain, snow, dirt, and darkness or by electromagnetic interference.
   - The system must be insensitive to mechanical stress.
   - It must be able to work in a temperature environment of -40°C to +70°C. It must be able to survive greater extremes outside of this temperature range and still function properly when it returns to the proper temperature.
2. A high data rate is required to allow the capture of several frames of information at the highest expected vehicle speed. These multiple frames of information must be compared to confirm a correct tag reading.
3. The system should be adaptable to all potential installations, and it should be as maintenance free as possible. Extremely compact and rugged construction free from parts subject to wear and tear is required. It is especially important for the tag to be passive and highly reliable. Maintenance such as cleaning or readjustment should not be required.
4. The digital output of the reader's tag data should be in a suitable format for transmission to the host computer over a suitable transmission medium, (i.e., direct wire, radio, microwave, or telephone lines). The communications output of the reader should allow for both polled and unpolled operation, with bidirectional message transmission. Varying transmission rates of from 300 to 9600 baud (speed of data communication between computers) with a simple logging or computer interface protocol should be available so the system can be easily integrated into today's computerized society.
5. The overall system installation must be able to accurately pinpoint the location of equipment. Tag transmission distances have intentionally been restricted to less than 30 ft from the reader-antenna to pinpoint the location of the vehicle and to reduce interference from other AVI-equipped vehicles in a nearby area.

The dominant AVI system today uses a radio frequency (RF) transmission medium in the frequency range of 900 mHz to 4.2 gHz. (A block diagram of a typical RF system is shown in Figure 1.) Tag operation in these frequencies provides several advantages over the older systems: The signal transmis-

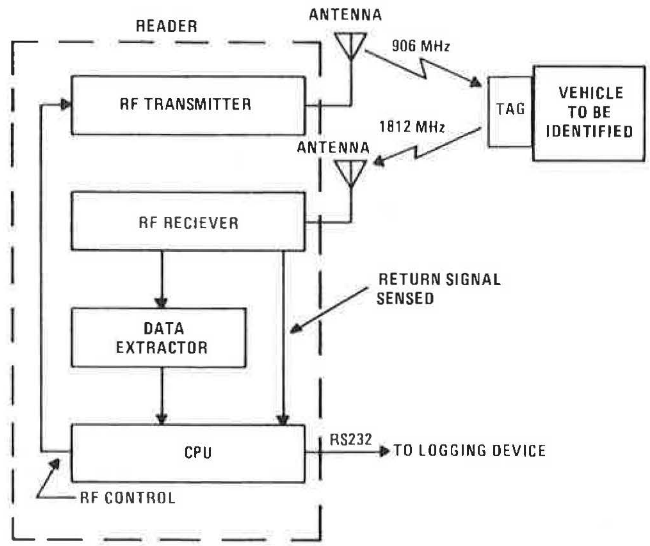

FIGURE 1 Typical RF system.

sion can penetrate nonmetallic objects such as ice, snow, wood, asphalt, and dirt. The shorter wavelength also allows the antennas to be small, resulting in a compact and rugged unit. Tags in this frequency range vary in size from 2 in. x 4 in. x 3/8 in. to 4 in. x 8 1/2 in. x 2 in.

Currently, there are two different types of tags available: fixed code and variable (read-write) code. The amount of data stored inside the tag can vary: The fixed code tags have between 18 and 128 bits (8 to 20 digits, numeric or alphanumeric combinations). The variable code tags (read-write) have between 1K and 4K bits available. Some portions of the read-write tag data can be software "fixed" for permanent unit identity and are nonchangeable by the field readers.

There does not appear to be any compatibility between products from the different manufacturers. There are three basic groups of readers: passive tag-transmit and receive, receive only, and active tag-transmit and receive.

What is needed or desired by users? In discussions with individuals representing the different modes of transportation, there has been a sharp division of thought about the use of a read-only or a read-write type of tag.

Read-Write Tag

The active tag-transmit and receive is a battery-powered device that can store up to four thousand bits of data received from the reader for later transmission back to another reader. This tag is used where more or varying information is required from the tag than just the identification digits. With a read-write tag system, pertinent information concerning the vehicle (e.g., type, empty or loaded weight, hazardous loads, destination, routing, waybill data, maintenance dates) can be kept with the vehicle and not in a computer data base. This has the benefit of reducing computer data base size, processing time, and the required information exchange between computers as the load moves through the overall intermodal system. Another advantage is that the tags require lower RF power levels from the reader to operate. In addition, control process instructions can be received from the tag instead of from the main computer.

A disadvantage is that tag interrogation time can increase from 25 milliseconds to more than 1 sec, depending on the amount of data being read or written into the tag and the number of verification check cycles used. In addition, the distance the tag can be written to is decreased by 25 to 50 percent over the read distance. (This is significant in several AVI systems where tag operation is possible at under 5 mph and less than 6 ft from the reader antenna.) Another concern expressed is that, when the information contained inside the tag is no longer required, the tag must be run by a reader and purged of its old information. If this is not done, the vehicle could accidentally be rerouted on the basis of the old information. Also, data transmission time from the host processor to a specific reader may be increased to provide for the additional error checks that are necessary to verify the data that are written into or read from the higher capacity read-write tags.

The lithium battery used inside the read-write tag normally has a useful life of from 5 to 7 years that is heavily dependent on how many read-write operations are performed. When the tag battery falls below a predetermined level, a bit in the tag memory is changed from a one to a zero. This battery status bit is then transmitted to the reader along with the remaining data to indicate that the tag or battery must be replaced. This occasional maintenance requirement must be considered when comparing the benefits of a read-write tag system to a non-battery-powered read-only system.

This two-way communication becomes more demanding when there are numerous readers and only one host computer. Questions have been asked such as: Will one reader or all readers be sent the updated information in advance of the tag's arrival or will it take place when the tag arrives? These communication problems have been discussed and evaluated in small, highly concentrated systems only. To this author's knowledge, no large, multiple-location, multiple-reader, real-time operations have been tested and evaluated to allow the read-write tag problems to be realistically assessed.

Read-Only Tag

Some readers use passive tags, transmit a keying-on signal to power up the tag, and wait for a coded response from the tag at the same or double frequency. Others sweep a frequency spectrum and look for a response. A second group of readers is receive-only and uses an active (battery-powered) tag that is continually transmitting. These systems are similar in operation and do not require separate discussions.

Basically, the read-only tag systems employ a fixed identifier code of between 6 and 20 numeric or alphanumeric digits. The tag's identifying code can be one-time programmed by the factory or, for some systems, in the field with a special programming unit. When programmed, the tag identifier cannot be changed.

The readers transmit a radio frequency signal toward the tag. This initial signal turns the tag on and sends a signal back to the reader indicating the tag's presence. When the reader detects this return signal, the reader's transmitter turns fully on, repeatedly requesting the tag's full identifier for a number of successive readings. The difference between a passive tag transmit-receive and an active (battery) tag transmit-receive is in the RF power levels used by the reader to power up the tag. Passive tags require reader power levels of up to 8 watts whereas battery tags may require only milliwatts.

In a read-only tag system, the vehicle data must be kept in a host processor. The benefits include the small amount of data transfer between the reader and the host processor when a tag is read, the ability to alter the vehicle data base immediately without waiting for the tag to pass a reader station, and a physically smaller tag due to fewer components. Also, inclusion of the AVI tag ID number only in the existing computer reporting systems is viewed as minimal, and greater vehicle (tag) reading speed and distance are maintained.

The disadvantages are that the tag data are limited to only the identifier digits. All other data concerning the vehicle type, load, routing, and so forth must be kept in a host computer and exchanged between computers as the vehicle moves through the intermodal system. Also the passive tags require higher levels of RF power from the reader to operate. [Note: All of the RF systems reviewed met or bettered American National Standards Institute (ANSI) and Occupational, Safety and Health Association (OSHA) standards.] A typical AVI system, and its theory of operation, is shown in Figure 2.

MIS AND TERMINAL CONTROL

No one can talk about one facet of a system without discussing the other areas that are affected. The largest area of impact is in the computerized management information systems (MIS) and local terminal operations and control systems.

IMIS

Nominally, Intermodal Management Information System (IMIS) keeps track of the location of trailers and calculates service charges to customers. Beyond that, IMIS stores an audit trail to help deal with trailers that go astray and customer assertions about damage or charges and can provide operational performance data for terminal managers and system analysts. IMIS is concerned with systemwide operations data and other data that relate to contractual matters (5).

Except for overall performance statistics, IMIS is not generally concerned with local operations. For example, IMIS knows that a trailer is in a given terminal, is on a particular train or ship, or is on the street in the care of a particular drayage firm; it is not aware of the lot and row within a terminal where the trailer is parked or what rail car or ship it is on.

Some terminal operation and control functions are appropriately served by a systemwide IMIS. These include accounting for and analysis of terminal operations costs and prediction of the arrival of trailers and containers. Terminal operating personnel must generate certain data needed by the systemwide IMIS, including waybill data, train or ship identification, and the time of occurrence of key events for use in calculating customer charges and in establishing the required audit trail. The more sophisticated MIS designs also provide a few management aids for use by terminal managers.

At the IMIS level the job of tracking and accounting for units shipped and their current approximate locations is fairly well defined. The IMIS computer support systems are sophisticated and have a high degree of accuracy but are dependent on the correct and timely entry of data. Implementation of AVI can help reduce or eliminate manual data entry errors at the origination point, at intermediary transfer points, and at the termination point.

For example, a trailer or container can be placed on the wrong rail car or ship, or the rail car can be switched into the wrong train, or the rail car can be misrouted at the receiving terminal. With the strategic placement of AVI readers, these occurrences would be electronically noted and immediate corrective action could be taken before the trailer or container was lost, the contents were damaged due to spoilage, it was subjected to vandalism or theft, or penalty charges for late delivery could be assessed to the carrier. In the case in which a rail car is set out due to an equipment failure and the trailer or container is between terminals, AVI

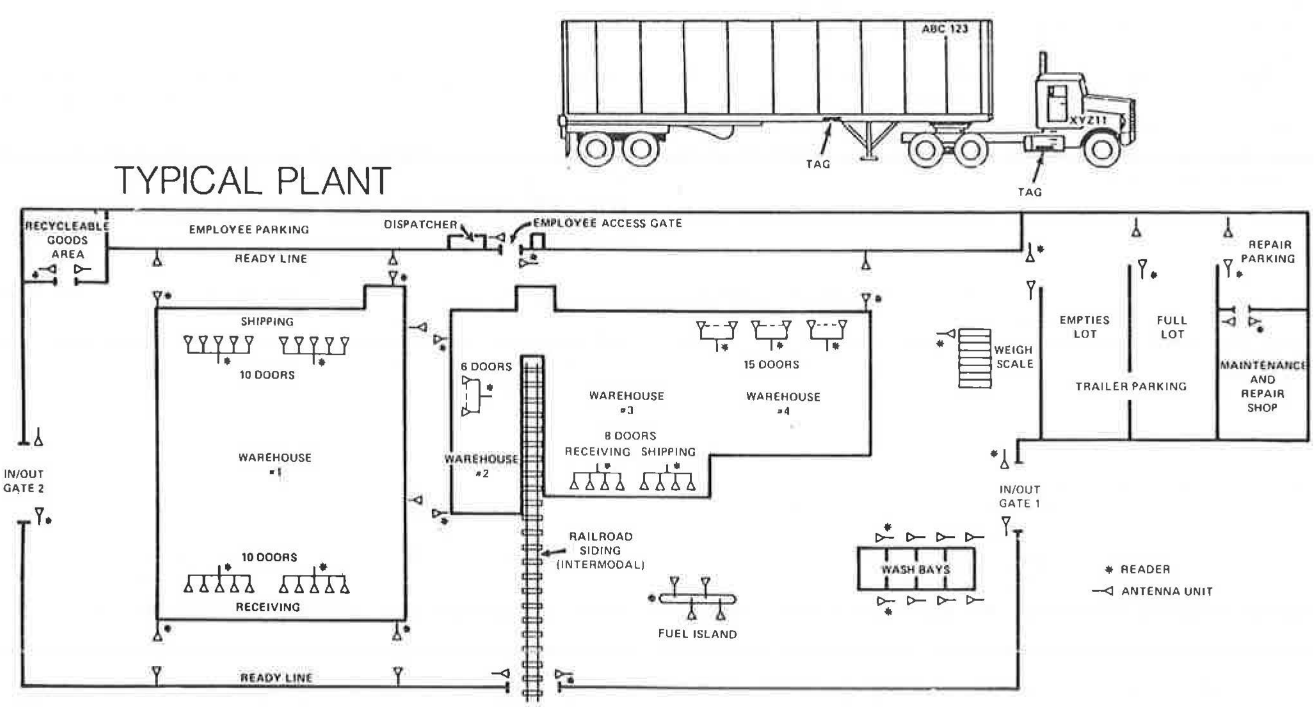

FIGURE 2 Warehouse application showing different possible locations where AVI can be used within a terminal.

readers would help narrow the search area. The same reasoning can be applied at truck terminals, marine ports, and large drayage companies. The "occasional" misrouted or lost shipment can be quite costly to the shipper and the carrier alike.

Terminal Control

The effects of AVI on terminal control can be seen in numerous areas. At the terminal gate, entry and exit times can be reduced significantly. With data links to freight forwarders and consolidators, larger trucking firms, and railroad or marine terminals, waybill information can be electronically transferred in advance, permitting the trailers or containers to bypass normal paper-intensive gate operations and be identified electronically without stopping. Operators can be directed by changeable message signboards to the correct parking or pickup area, eliminating the time and costs associated with stopping at the gate to be checked in and directed. For late arriving shipments, terminal operators can react faster and be more responsive to the situation through increased automation. Weigh scales can be unmanned with vehicle identity automatically obtained and combined with the scale weight and input into the terminal control system without the usual paperwork or manual data entry delays or errors.

AVI readers located inside the terminal area can provide an audit trail of vehicle movements throughout the facility. On the basis of this information, equipment location in the terminal is continually updated, and operators are able to alter hostler yard assignments to meet changing needs. Queueing of AVI-equipped trailers or containers on the loading or storage aprons is improved if the actual vehicle type, size, and weight can be electronically matched with AVI-equipped rail cars, ship, or available chassis. When cranes and other lifting equipment are provided with AVI readers, the containers or trailers they move can be immediately identified and input into the system host computer. The crane or lift operator's job is enhanced as the number of decisions he has to make is reduced.

Other functions inside the terminal can benefit from AVI. Readers located at the maintenance shops can check vehicles in and out, providing operators with the instant status of the equipment (i.e., when it went in for repairs, how long it has been in, or when a piece of equipment last had maintenance performed). Wash bays, storage areas, loading docks, and other internal points can be monitored as shown in Figure 2.

AVI SYSTEM SPECIFICATIONS

The railroads, in their far-reaching but ill-fated attempt to institute a bar code AVI system some years ago, were successful in developing a set of guidelines and specifications that remain applicable today (7). The Automatic Car Identification (ACI) System Specification for American Railroads, dated January 31, 1977, by the Association of American Railroads (AAR), states the desired minimum acceptable user general and functional requirements for a railroad ACI (8). This document could be used as the basis for an intermodal standard because it addresses and sets minimum requirements for the following items:

- System reliability and accuracy;
- Accuracy and readability rates;
- Label information content and product markings;
- Speed and direction constraints;
- Environmental conditions;
- Mounting locations (railcar, TOFC/COFC);
- Workmanship and quality control;
- Safety;
- Temperature and humidity ratings;
- Electromagnetic interference and susceptibility;
- Physical characteristics;
- System maintainability;
- Enclosures; and
- System configuration.

It is apparent that this list covers an extensive and broad category of requirements that are demanded of an AVI system to meet the demands of the intermodal industry.

CURRENT USERS

There are a number of AVI systems operating in the railroad environment that can handle both rail and intermodal trains simultaneously (9). The current problem is in reading trailer-container-chassis-tractor sets in a road environment (i.e., entrance or exit to a terminal). In this application the lane width typically varies from 8 to 14 ft or more. In this situation there is a need for an in-pavement antenna that can be driven over without damage or an antenna that can read a tag located within an established critical range of view. Currently, there is only one AVI system using the in-pavement type of antenna. It is being evaluated by a large West Coast container terminal.

There is also a state- and federal-sponsored automatic vehicle identification and weighing-in-motion (AVI/WIM) program, or "Crescent States" project, that is evaluating a number of AVI systems for use as a heavy vehicle electronic license plate (HELP). This multistate program proposes to label tractors and trailers and electronically identify each vehicle while it is being weighed at highway speeds, to reduce the amount of time truckers spend at state-owned ports of entry and other weigh scales.

Toll bridge and toll road operators see AVI as a way to increase vehicle throughput, reduce personnel and equipment costs, and improve profitability. Some private and corporate trucking and automobile fleets have already invested in AVI systems for fleet management.

SUMMARY

When designing an AVI system, it is necessary to consider the large number of potential uses it can have. The wider the applications that can use the system, the lower the overall cost will be from the initial implementation phase through full system application.

In summary,

1. AVI equipment available today can be and is being successfully used in a number of different, yet related, applications.
2. AVI can improve control and information processing time on a local or systemwide basis.
3. AVI can significantly reduce manual data entry errors and increase productivity.
4. AVI systems can readily be incorporated into existing or new terminal designs and computer systems.
5. AVI does not need to be fully implemented on a systemwide basis before it becomes useful. Significant benefits and cost savings can be realized in almost any size installation.

6. Coordinated standardization efforts must be made to ensure equipment and system performance compatibility in the different modes of intermodalism, including international users, if unnecessary costs or other adverse impacts are to be avoided.

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APPENDIX

Typical AVI System

The AVI equipment presented here is of one type only and is described merely to illustrate the operation of a typical radio frequency-based AVI system (4).

Basic Reader

In operation, the reader continuously transmits a low-power radio frequency (RF) signal through the antenna system. This signal is a series of pulses of short duration, generally referred to as "sniff" pulses. The vehicle tag is passive and powers up only in the presence of the sniff pulses generated by the reader. When the tag has been powered up, it reports its fixed code via a return radio frequency signal.

The reader consists of an RF transmitter, an RF receiver, a data extractor, and a microprocessor controller. Under control of the microprocessor, the transmitter generates the RF signal used to power the tag. Maximum power out of this unit is adjustable, which will allow reading of tags at distances of up to 9 m. The tag doubles the receive frequency and transmits a signal back to the receiver. The RF receiver detects the modulated return signal from the tag and signals the central processor unit (CPU) that a return signal has been detected. When this occurs, the CPU instructs the transmitter to cease the sniff and to transmit instead at its maximum power level to provide a sustained source of energy to keep the tag powered up. The tag's coded return signal is passed through the receiver to the data extractor, which demodulates the signal and shapes it for use by the CPU. The CPU checks the received data for errors and passes the data on to a logging device or host computer under software control.

The basic reader is considered a data terminal equipment (DTE) device at its communications interface connector. The communication interface options include RS232, RS422, and a 20-milliampere current loop. Data transmitted between the reader and a host processor have the following characteristics:

1. Asynchronous serial data are transferred as 7-bit ASCII characters. Bit eight is either zero or set with respect to odd parity, depending on the option selected. All alphabetic characters transmitted to the reader are upper case letters.
2. Each character transmitted to and from the reader is bounded by one start bit and one stop bit, making each word transmitted a total of 10 bits in length.
3. The data transmission rate between the reader and a host processor is selectable between 300 and 9600 baud, depending on the options selected.

Data transmission error detection in the form of a two-byte (Mod 256) checksum can be optionally selected. The checksum is included at the end of each multicharacter message transmitted by the reader.

Reader Antennas

Several different antennas are available to suit individual application needs. These antennas are divided into short-range and long-range reading ability.

The long-range antenna consists of separate transmit and receive antennas mounted in fiberglass cases. The cases are suitable for outdoor service and are normally used for roadside installations where vehicle tags will be read across one or more highway lanes.

Long-range antennas are also used in applications in which the reader is mounted on board the vehicle and the wayside tags are some distance away, overhead for example.

There are three types of short-range antennas: rail, underground, and industrial. The short-range antenna is a single transmit and receive PC board housed in a protective enclosure for each different application. Because these antennas operate using RF signals, they may be imbedded in concrete, asphalt, wood, or other nonmetallic substances without operational degradation.

Vehicle Tags

Examination of the block diagram (Figure 3) of the passive vehicle tag will show that it consists of an

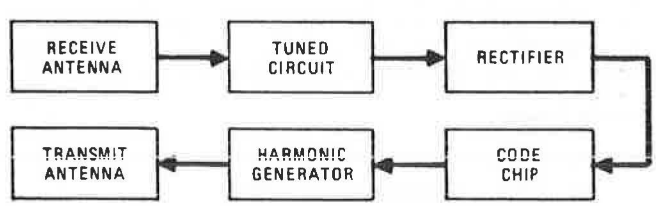

FIGURE 3 Passive reader tag.

antenna to receive the reader RF signal, a tuned circuit to block RF energy from other sources, a rectifier to power the unit, a generator, the programmable read-only memory (PROM) code chip, and an antenna to transmit the signal back to the reader. The vehicle tag can be programmed once in factory or field with up to 12 alphanumeric characters by means of a programmer that is intended to be used in a maintenance facility. The programmer provides the end-user with a means to program tags on site instead of having them factory programmed. The programming unit includes a simple keypad and display for ease of operation. The desired tag code is entered and verified. When verified, the code is permanently burned into the tag, which is then sealed and ready for installation.