Reflecting tomorrow's highways today

RF backscatter reflection in AVI systems

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Charting the development of RF-based AVI systems for ITS applications, the authors examine California's forward thinking approach to the development of 'smart highways'. The RF-based system described is now being installed for three major highway applications in California, with a new contract in northeastern USA recently awarded

California, the land of plenty – plenty of congestion, that is. Small wonder then that this state should be one of the first to develop a law that also sets the momentum for a *de facto* national standard. In 1992, the California Legislature passed into law Department of Transportation (CalTrans) Title 21, a mandate to regulate electronic toll equipment used in that state.

With California's monstrous population and love affair with the automobile, state lawmakers could not wait for the rest of the country to settle standardiza-

Multi-lane freeflow tolling in action

tion issues. Building tomorrow's highway today was the only expedient course for controlling and maintaining California's highways. To do that, California established Title 21 to set in motion *smart highway* projects in the state.

OBSTACLES TO COMMERCIALIZATION

One major obstacle to commercializing technology is the *crowding-at-the-gate* phenomenon. Many vendors converge at the gate to promote their solutions. Materials, construction techniques, and circuit designs are totally interdependent. Without practical experience, choosing the right vendor and right solution – that is, making the right choice that will prevail in the market place – beleaguers many an administrator. And it forces many to acquire psychic-like powers or at least conduct rigorous studies before committing funds. With Title 21, California took the initiative and staked out its future by choosing the direction of technology development.

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Certainly, Title 21 has influenced the emergence of radio frequency backscatter as the technology of choice in toll road automatic vehicle identification (AVI) systems. "The State of California has established a leadership position that will define the next generation of highway transportation for the country's infrastructure," said Kevin Moersch, president and chief executive officer for MFS Network Technologies.

RFID BACKSCATTER

The concept behind backscatter is simple, while applying the technique is fairly challenging. In the backscatter approach, a radio frequency signal is transmitted in a pencil-thin beam to a transponder attached to the windshield. The signal triggers RF emissions. The transponder holds 256 bits of data that are then reflected – or 'scattered' back – to the sending system. In other words, the

transponder data wait for the right wave to pick them up so that the data can 'surf' effortlessly to the reader. Transponder data includes information about the transaction record type, the transponder ID number, the reader ID number, the transaction status code, and the error detection code. Further, unique customer data can be specified.

A basic RFID backscatter system includes:

- A reader, which is the source of the signal, usually broadcast from a location that can read one reflector (tag) at a time;
- An antenna that directs the beam to the expected reflector, much like you would direct a flashlight beam. It also receives the reflected emission;
- A reflector, which is the transponder tag mounted on the vehicle that contains the identifying data. As the transponder does nothing except wait for the signal to trigger release of data, it uses very little battery life. That means it is more reliable, requires less maintenance, and is less costly than a transponder that actively transmits its own signal;
- A receiver, which is a conventional receiver that can separate the reflector emission from the static emission from all other sources;
- A controller that controls the data protocol of the reader.

BACKSCATTER ADVANTAGES

Compared to active technology, backscatter has definite advantages. Backscatter technology:

- Consumes less power, so the battery life is much longer;

Concept drawing of the SR-91 Express Lanes, California

- Defines a more precise read zone because of the physics of the reflection process. The system more accurately discriminates valid users from violators and it provides accurate readings despite close adjacent lanes;
- Communicates accurately with vehicles maintaining high speed on a limited-access open highway. From an 18-wheeler to a motorcycle, the size or type of vehicle does not prohibit the system from getting information from the tag;
- Reads more capably multiple tags in the interrogation field;
- Works effectively in environments with excessive dirt, dust, moisture, and poor visibility;
- Requires less expensive electronics;
- Allows the smallest possible bandwidth yielding the highest robustness against surrounding RF noise.

THEORETICAL UNDERPINNINGS

While Title 21 was based on an experimental system developed at the Lawrence Livermore Laboratories, funding did not provide for rugged field testing. Many specifications were developed solely from a theoretical standpoint; many of the practical problems of dealing with the environment were not discovered until actual implementation.

Title 21 identified the 902-928MHz band for AVI systems because it was thought that this was a relatively uncrowded band. Also, electronic components available for use in this range were considered to be plentiful and inexpensive. While this is still true to a certain extent, the explosion in the use of cellular phones (which use the 870-890MHz bandwidth) and pagers (930-932MHz) was not anticipated when planners were initially drawing up the specifications for Title 21 in the late 1980s. Nor did anyone predict the incredible surge in vehicle location and tracking systems that has developed in the last few years, thus confusing the standards-setting process.

THEORY VS REALITY

The impact of this encroachment on AVI systems is that they now must be even more powerful and even more focused than originally required in the Title 21 specifications. While this does not literally force AVI system design engineers back to the drawing board, it does require more retrofitting at the site during installation.

To cope with real-life situations, Texas Instruments implemented extensions to Title 21 that actually improved on the specifications. Some of these extensions resulted in the following features:

- Lane separation to prevent double-reads and cross-reads between two adjacent lanes;
- Extended message modes (larger size data block exchange) as well as multiple tag data blocks accessible by the reader;
- Encryption of data exchanged by reader and reflector (tag);
- Read/write capabilities that allow the reader to store and retrieve data from the reflector, for example, a

transaction timestamp and record of the point where the vehicle entered the tollroad;
- Unique agency code issued to the tag for administrative purposes;
- An acoustic signal telling the driver that a transaction took place.

In implementing three significant Californian projects, Texas Instruments TIRIS Highway Systems and partner MFS Network Technologies Inc. are winning the battle between technology and the road environment. However, the partnership also is dealing with the concurrent problem of new industry growth pains.

For example, one problem that had not surfaced until the projects were well underway resulted from new FCC regulations that shrank the available ISM band spectrum. This forced Texas Instruments TIRIS to redesign the receiver – a painful process under normal circumstances, but excruciating under accelerated schedules. Short of relying on a crystal ball to see into the future, AVI system providers around the world are faced with similar unpredictable occurrences.

SR-91 CONGESTION RECORDS

Near Los Angeles, the SR-91 Express Lanes project is a 10-mile privately funded tollroad joining two urban counties, Orange and Riverside. With more than 255,000 vehicles using California's eight-lane Riverside Freeway (State Route 91 or SR-91) each day, SR-91 is one of the most heavily congested traffic corridors in the USA. Sometimes traffic is so heavy a driver can spend two to three hours traveling only 10 miles. The highway is a major contributor to the US$100 billion estimated to be lost annually in the USA from loss of productivity due to traffic congestion.

SR-91 AND THE AVI SYSTEM

The heart of the SR-91 system is Texas Instrument's TIRIS AVI system, which uses backscatter to automatically collect data from a pocket-sized transponder mounted inside on the windshield of each vehicle.

The SR-91 system also incorporates sophisticated technology with the following subsystems:
- Traffic management with in-road sensors to manage traffic flow;
- Video that constantly monitors the entire highway;
- Variable message signs to advise motorists of up-to-date road and traffic conditions as well as the toll rate;
- Variable toll rates depending on road congestion conditions;
- Fiber optic communications for high-speed transmission links between all the video, voice, and data systems;
- Violation enforcement with digitized video to capture vehicle and license plate images of violators;
- Mobile communications with the California Highway Patrol.

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An RFID transponder responds to a query from the SR-91 control system. The system asks for the transponder's identity, and the transponder replies by sending a code programmed in its memory. The system searches its database for that identity and grants privileges depending on the status of the ID. For example, the system can grant the tollway access to a paid-up toll customer.

REALITIES OF IMPLEMENTATION

Integrating the AVI system with these subsystems is another problem not addressed in the specifications. In fact, "experienced systems integrators can write their own ticket at most companies marketing AVI systems," according to Oliver Crosswhite, TIRIS Highway Systems manager and former vice president at MFS Network Technologies. System integration in this context deals with new, state-of-the-art technology designed and developed totally independently – not an easy task by any measure.

The ability to distinguish a single vehicle approaching the read area created by the antenna reader is dependent on the antenna orientation. Just like a flashlight beam, if the beam is dispersed on an object that is close, the intensity is greater than if shined on an object farther away. Pattern measurements become very dependent on reflections from any close object, including earth, roads, cars, metal windows – everything.

The speed of the car is also a factor. Uplinks from vehicles that are traveling under the antenna at high speed are obviously harder to capture than those vehicles moving slowly through a toll plaza. Altering the length of the antenna footprint provides the best results in adjusting between the open highway and toll plaza scenarios.

The system must be fast. To start with, the transmission rate is 300kbps requiring a 128-bit transmission in less than 0.5 milliseconds. Then, add in system protocols, which consume additional time. Then, meet the SR-91 specifications requiring 40 reads while the vehicle is in the antenna's footprint (or field of read) guaranteeing that the system will work with vehicles traveling as fast as 150mph. Some system. Repeat: it has to be fast.

Tests have shown that the SR-91 system can identify two vehicles traveling in separate lanes within one foot of each other, or two motorcycles traveling side by side in one lane, even when they are switching lanes. The system correctly identifies over 99 per cent of the vehicles it encounters. With over 40,000 transactions a week, the system used at SR-91 must be accurate and reliable 24 hours a day, seven days a week.

REPLACING TCA'S RFID TECHNOLOGY

Another project in Orange County is found on a five-mile stretch of road between Irvine and Laguna Hills. The Transportation Corridor Agencies' (TCA) Foothill Corridor project, called FasTrak, was an existing tollroad already using RFID technology. Motorists complained that poor battery life made the

tags extremely inconvenient.

Enter MFS and Texas Instruments to replace the existing system with a TIRIS AVI system. As a result, experts are calling The Foothill Corridor the most successful toll road launch in America to date. Ridership projections almost immediately passed estimates, and today AVI customer 'counts' nearly meet goals established for the Year 2000 – five years early. "Before the Foothill Corridor opened, I had my doubts about how much time I would save getting to work. Now I save 20 minutes each way, every day, and I've never had to sit in line at a toll booth – I love it!" said Pamela Watson, a resident of the area. Scott Baldwin, another resident, added, "It is simple. The less time I spend in the car, the more time I spend with my family. That is why I use FasTrak."

AVI ON ATCAS BRIDGES

In the third major California project, CalTrans operates nine state-owned bridges using the Advanced Toll Collection and Accounting System (ATCAS). Seven of the toll bridges are in northern California in the general vicinity of San Francisco. The other two are in southern California, one in Long Beach and the other in San Diego. Implementation is just underway on this project so it is too early to tell what kinds of problems will be encountered that have not yet been anticipated. Suffice it to say that waterway traffic near and under the bridges will add to the complexity of making any AVI system work.

MASSPIKE RISKTAKERS

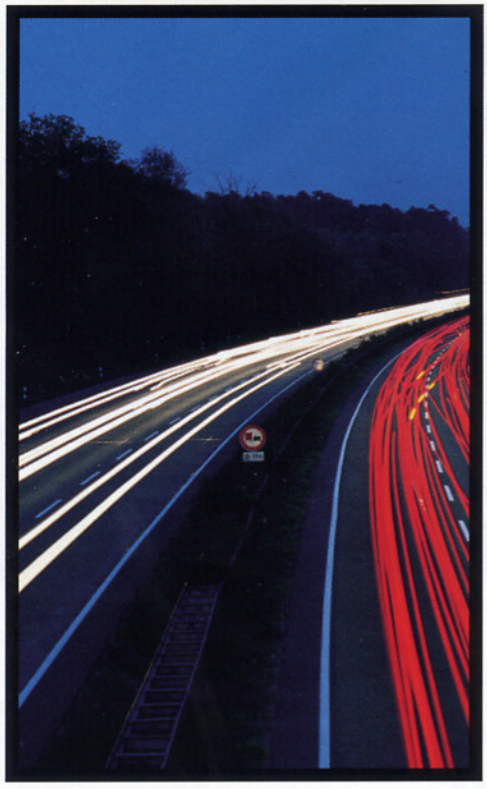
Meanwhile, a new crop of risktakers – highway officials in Massachusetts – recently placed their bets on the backscatter technique and the solution that Texas Instruments TIRIS and MFS Network Technologies has to offer. The success that California has had in implementing Title 21 influenced Massachusetts Turnpike officials in deciding they could not afford not to install AVI systems.

With one of the nation's highest concentrations of vehicles on the eastern seaboard, Massachusetts has long recognized its highway problems. In addition to the congestion problems experienced in California's moderate climate, the Commonwealth's highways are also battered by far more severe weather.

By the end of 1995, TIRIS AVI systems were installed on all four lanes of the Third Harbor Tunnel that links Logan International Airport to Boston and the mainland. AVI systems are planned for other bridges, tunnels and turnpike entrances throughout the Commonwealth system. Thanks to Title 21 and state-of-the-art AVI systems, such as TIRIS, Massachusetts – one of the original 13 Colonies – once again joins the ranks of frontrunners.

EXPERIENCE, ADAPTABILITY COUNT

As installed AVI systems become more commonplace, the number of suppliers will first balloon and then contract as those with staying power emerge. Standardization from governmental efforts can only assist in the stabilization of the market. But by far the most important ingredients in the mix are experience and ability to adapt. They count in this market.



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TIRIS technology by Texas Instruments