Advanced Infrared Beacon with Increased Communication Capacity

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Infrared beacons have been installed on roads since the beginning of the 1990s, many of which are now reaching the point when they need to be replaced. For the replacement, we have developed an advanced infrared beacon that has increased communication capacity. It enables upgraded traffic signal control and provides detailed traffic information by collecting tracking data of vehicles. The beacon can be also used for the Signal Information Drive System (SIDS), which promotes eco driving by providing drivers with the signal information on the route. This paper outlines the advanced infrared beacon, the development challenges and our manufacturing efforts.

Keywords: infrared beacons, communication capacity, communication speed, communication range

1. Introduction

An infrared beacon (IR beacon) is a roadside device that provides bidirectional communications with an in-vehicle device. Since the beginning of the 1990s, such beacons have been developed as the key infrastructure of the Universal Traffic Management Systems (UTMS), which aims at safe and smooth traffic operations as well as environmental protection. The IR beacon is widely used in a range of UTMS subsystems, including the Advanced Mobile Information Systems (AMIS), Public Transportation Priority Systems (PTPS), Mobile Operation Control Systems (MOCS), and FAST emergency vehicle preemption systems (FAST). Approximately 54,000 beacons (figure for the number of infrared transmitter/receivers (beacon heads)) across Japan, as of March 2011. However, these IR beacons get older and are due to be replaced because of having been 20 years since they were installed.

The National Police Agency (NPA), the managing agency, has studied possible functional and performance improvements in order to update these IR beacons. Based on these studies, NPA published the Specification for Advanced Infrared Beacons[(1)] in March 2013. The specification defines that the advanced IR beacons will be used for the Signal Information Drive System (SIDS), which collects the probe data (tracking data of a vehicle's driving route) to refine the signal control and provide the signal information on the route to help more eco driving.

Based on this specification, we developed an advanced IR beacon, aiming to release it to the market in the latter half of FY2013. This paper describes the development requirements and details of our work to overcome the challenges that we faced during the process.

2. Advanced Infrared Beacon

2-1 Infrared beacon

An IR beacon is a roadside device that provides bidirectional communications through infrared signals between beacon heads installed above roads and in-vehicle devices. The communication link that transmits information from the IR beacon to the in-vehicle device is called the Downlink (DL) and the reverse is called the Uplink (UL).

The basic function of the IR beacon (the AMIS functions) is infrastructure-to-vehicle communication. The IR beacon collects the traveling time of a vehicle from one beacon to another as a UL data and provides traffic information like traffic conditions and estimated traveling time between the IR beacons to the in-vehicle device as a DL data.

Additional functions of the IR beacon include the PTPS[*1], MOCS[*2], and FAST[*3] functions, which are activated only when the IR beacon communicates with a dedicated in-vehicle device for special vehicles, such as public buses, commercial trucks, and emergency vehicles. The IR beacon that receives UL data from such a special vehicle's in-vehicle device changes the types of DL data from a general one to a specific one, or controls traffic signals so that special vehicles can traverse intersections safely. The beacon is also equipped with a vehicle detector that can count the number of vehicles passing under its head.

2-2 Signal information drive system (SIDS)

The SIDS function was added as a new capability of the advanced IR beacon. This section provides a summary of SIDS.

The advanced IR beacon collects the probe data (tracking data of a vehicle's driving route) as the UL data in addition to the conventional vehicle traveling time data between IR beacons. The probe data is then processed by a central unit and other processors in the Traffic Control Center to contribute to advancing traffic signal control and traffic information accuracy.

The advanced IR beacon provides the signal information on the route (based on the traffic signal operating schedule) as DL data for the new in-vehicle devices that support the IR beacon. After receiving the signal information on the route, the new in-vehicle device displays driving suggestions on the navigation system screen for fuel-efficient driving and safety. Such driving suggestions include: recommended speed to cross the next traffic intersection with the green signal (non-stop driving support); advice to slow down because the next traffic signal will change to red soon (speed reduction support for red signal); and advice to get ready to start the car because the waiting traffic signal will change to green soon (prompt start support) (**Fig. 1**).

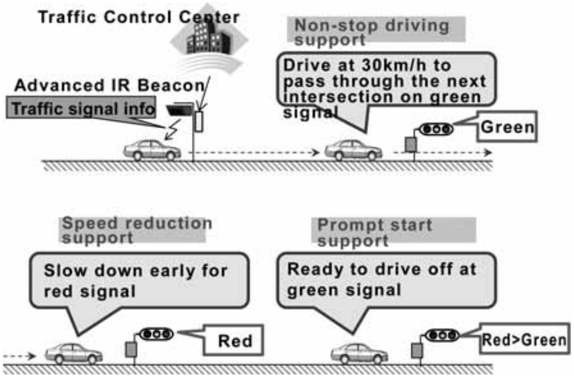

Fig. 1. Utilization of the Signal Information on the Route

2-3 Comparison between conventional and advanced infrared beacons

As mentioned earlier, the advanced IR beacon is now necessary to collect probe data as a part of the UL data in order to enable SIDS to provide the signal information on the route to a vehicle. The UL data size that the conventional IR beacon handled was 59 Bytes at maximum (actual data size excluding the header; the same applies to following data sizes), while the advanced IR beacon would need to handle a maximum of 955 Bytes, including the probe data. This is almost 16 times more data. The DL data size handled by the advanced IR beacon remains the same as before, which is 9,840 Bytes at maximum (**Table 1**)[(2)].

Table 1. Data Size Comparison

Items	Conventional IR beacon	Advanced IR beacon
UL data	Max. 59 Bytes	Max. 955 Bytes
DL data	Max. 9,840 Bytes	Max. 9,840 Bytes

An IR beacon and an in-vehicle device can communicate with each other only within the range that can be reached by the near infrared ray (communication area). Because the vehicle is moving, the time during which the vehicle remains in the communication area, that is, the communication time, is limited. To transmit the UL data with greater size within this limited time, the following enhancements were required: speedup of the UL transmission from 64 kbps to 256 kbps; UL receivable range expansion from the conventional range of between 3.4 and 5.0 meters (from the approaching direction to directly under the beacon head; the same applies to the following range descriptions) to a new range of between 3.4 to 6.0 meters; and DL transmission range expansion from the conventional range of between 1.3 to 5.0 meters to the new range of between 0.7 and 6.0 meters. To retain compatibility with conventional in-vehicle devices, the advanced IR beacon must continue to be able to receive conventional UL data transmitted at the rate of 64 kbps. Because of this, the advanced IR beacons must support two different UL communication speeds. Note that the DL communication speed remains 1,024 kbps, unchanged from the conventional model. Another issue was to improve the UL receiving sensitivity and the DL emission intensity, as infrared transmittance through the windshield has been decreased in recent years. The UL receiving sensitivity had to be increased from 0.5 μW/cm^2 to 0.3 μW/cm^2, and DL emission intensity had to be increased from 3.0 μW/cm^2 to 4.5 μW/cm^2 (**Table 2**)[(1), (2)].

Table 2. Comparison of Communication Speed and Area

Items	Conventional IR beacon	Advanced IR beacon
UL Communication Speed	64 kbps	64 kbps, 256 kbps
DL Communication Speed	1,024 kbps	1,024 kbps
UL Communication Area	3.4 m - 5.0 m	3.4 m - 6.0 m
DL Communication Area	1.3 m - 5.0 m	0.7 m - 6.0 m
UL Receiving Sensitivity	0.5 μW/cm^2	0.3 μW/cm^2
DL Emission Intensity	3.0 μW/cm^2	4.5 μW/cm^2

Further, the communication protocol between the IR beacon and the in-vehicle device was changed in order to make the best use of the new communication speed and range, as well as retaining compatibility with conventional in-vehicle devices[(1), (2)]. Details of the protocol change are not discussed in this paper. However, note that the UL communication area requirements must be fulfilled at both the far edges of the communication areas for the 64 kbps and for the 256 kbps. Further, the said edge of communication area for the 256 kbps must either be in the same position as that for the 64 kbps or farther position[(2)].

3. Development of Advanced Infrared Beacon

3-1 Challenges of development

As discussed in the previous section, the challenges to be made in the advanced IR beacon were: improvements to the UL communication speed; improvements to the UL receiving sensitivity; and increased DL emission intensity. The following sections describe details of each enhancement and the work undertaken to realize these improvements.

3-2 Improvements to the uplink communication speed

The previous section described that the advanced IR beacon must support two UL communication speeds, 64 kbps for conventional UL data and 256 kbps for the new UL data. The simplest circuit configuration for this is receive the UL signal via a Photo Diode (PD), digitalize the signal through amplifier and filter circuits, and identify the speed using the communication IC (Pattern 1 shown as **Fig. 2**). It was very difficult to adjust the signal levels for the two different speeds using a single amplifier and filter set.

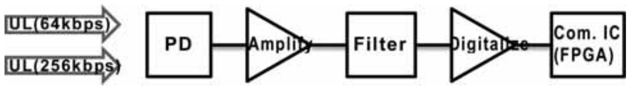

Fig. 2. Circuit Configuration in the UL Signal Receiver (Pattern 1)

To work around this problem, the circuits after the PD were duplicated. By having a dedicated amplifier and filter for each of 64 kbps and 256 kbps speeds made analog adjustment of signal levels relatively simple (Pattern 2 shown in **Fig. 3**). This mechanism enabled reception of the UL signals at two different transmission speeds.

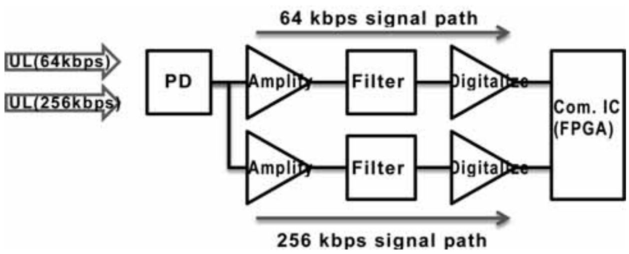

Fig. 3. Circuit Configuration in the UL Signal Receiver (Pattern 2)

3-3 Improvements to UL receiving sensitivity

The UL communication area and receiving sensitivity were enhanced by optimizing the amplifier and filter circuits.

However, there is a problem that the IR beacon receives reflections of own DL emission from the road surface as noise. This required us to design a filter circuit that could efficiently attenuate the 1,024 kHz and 512 kHz elements, which are the major frequency elements of the DL signals, because their encoding type is the Manchester encoding. In addition to a low-pass filter that cuts off high frequency elements (**Fig. 4, right**), a trap circuit that intensively attenuates frequencies at about 1,024 kHz and 512 kHz (**Fig. 4, left**) was installed. Further, the low-pass filter and the trap circuit were designed to use the same coil (**Fig. 4, bottom**) to maximize usage of the limited space and reduce parts costs. The each parts were also adjusted so that the far edge of the communication area for the 256 kbps extends to the same position as that for the 64 kbps, or farther position.

3-4 Increasing the DL emission intensity

In order to enhance the DL communication area and emission intensity, a near-infrared LED with a high-output

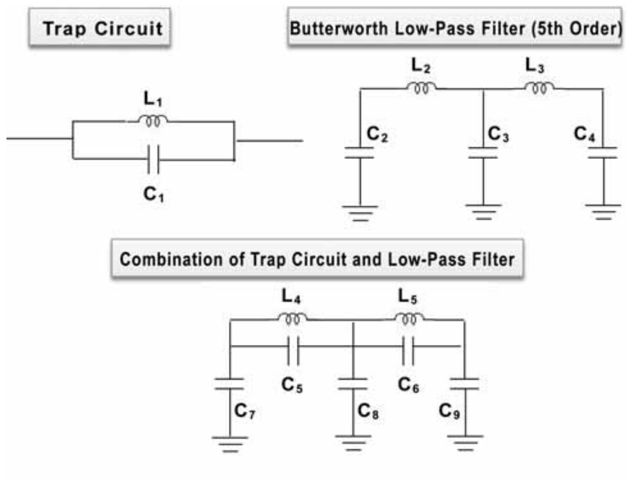

Fig. 4. Filter Circuit

and wide radiation angle was adopted. The model selected was a surface-mounted LED package that can be installed on the circuit board using an automatic mounting machine to ensure higher manufacturing quality and better cost performance.

Utilization of this LED secured a DL emission intensity greater than that of the specified standard across the expanded DL communication area. However, it was found that the in-vehicle device could not receive the DL data at around the close side of DL communication area. The cause of this signal reception issue was interference between the light for vehicle detection and the light for DL communication. Details of this problem and countermeasures taken are described below.

The IR beacon emissions the near-infrared ray in an almost vertical direction from its head towards the oncoming vehicle to detect a vehicle passing, and this light for vehicle detection uses the same wavelength (850 nm) as the light for DL communication. The near edge of the DL communication area used to be 1.3 meters from the beacon head towards the vehicle's approaching direction, but this became 0.7 meters in the advanced IR beacon. This resulted in the emission area of the DL light overlapping with the vehicle detection light emission area, causing interference between the two lights at the near side of the DL communication area (**Fig. 5, left**). Although details are not discussed

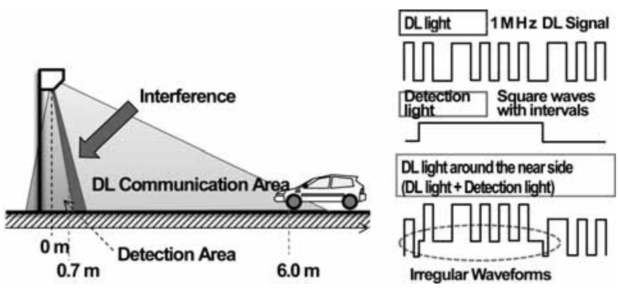

Fig. 5. Interference between DL light and Vehicle Detection light (Conceptual Representation)

here, the interference of the vehicle detection light with the DL light does not influence vehicle detection performance in principle. On the other hand, the interference reduces the DL communication quality because the DL signal is a pulse (**Fig. 5, right**).

To resolve this problem, we first attempted to optically eliminate the interference between the DL light and the vehicle detection light. As the DL communication area could not be changed because its specifications are fixed, we therefore attempted to shift the emission center axis of the vehicle detection light from the vertical direction of the beacon head towards the vehicle's direction of movement. However, this method requires an extra component to optically separate the emission ranges, which would add extra costs, as well as a risk of having to commit a large amount of time on design and quality evaluation at the commercial level.

We then considered a method to eliminate the influence from the interference to the DL communication. Concretely, we synchronized the emission timings of the vehicle detection light and the DL light. In this way, the vehicle detection light does not affect the DL communication even though the vehicle detection light and the DL light are interference (**Fig. 6**). This idea provided a low-cost and low-risk solution to the interference problem.

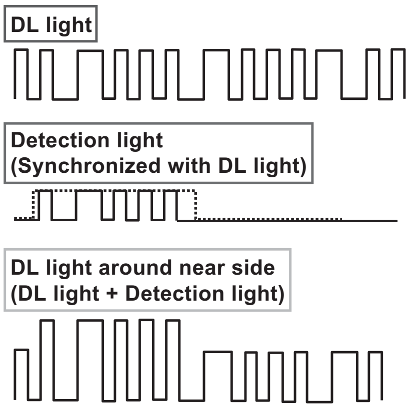

Fig. 6. Synchronization of DL light and Vehicle Detection light (Conceptual Representation)

4. Conclusion

We successfully developed an advanced IR beacon that supports SIDS through the following functional enhancements: improvement of communication speed; improvement of UL receiving sensitivity; and increased DL emission intensity. The next step is installation of the SIDS infrastructure, in addition to actual replacement of the existing IR beacons with the advanced IR beacons. Development of in-vehicle devices that support the advanced IR beacon is also underway. We expect that the increasing number of vehicles that mount the new in-vehicle device for the advanced IR beacon and SIDS will contribute to global environmental protection through more eco driving, along with safer driving leading to a reduction in road accidents.

Technical Terms

*1 PTPS: System to provide smooth public transport by shortening the time for a bus to pass through intersections by controlling traffic signals and securing a priority lane according to the time of day.

*2 MOCS: System to support efficient distribution and business transportation by taxis and trucks by utilizing time and position data collected from such vehicles.

*3 FAST: System to support the movement of emergency vehicles to ensure prompt arrival at an accident site and reduce the risk of further accidents caused by such emergency vehicles.

References

(1) National Police Agency, Spec. No. 1019: Specification for Advanced Infrared Beacons Ver. 2 (Mar. 15, 2013)

(2) UTMS Society of Japan, Infrastructure-to-Vehicle Interface Standard for Advanced Infrared Beacon (May 7, 2013)

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