

Development of Smart Card Key System for Motorcycles

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ABSTRACT

A motorcycles' smart card key system (duplex electric wave communication key system) with both, user-friendliness and antitheft certainty has been developed for the first time in the world. The system can unlock a main-switch, seat and console-box by one-push operation. The main-switch is changed to a knob type from the conventional key type. To protect the key cylinder from excess input torque, a torque-limiter was installed in the mechanism. An on/off switch that can stop the communication function at anytime was added on the smart card key because a motorcycle can be parked just outside a shop or other location when the main switch is still on and vehicle can be started. The lock and unlock available area was determined from the viewpoint of user's convenience. The function and layout of the communication system was determined by the performance of using one low frequency transmitting antenna. A factor and an analysis technique for influences of radio noises from other electrical components on the vehicles and surrounding environments was clarified.

1. Introduction

Keyhole shutters and immobilizers have been used in motorcycle steering lock systems with the aim of enhancing antitheft toughness. Also, steps for increased ease of operation have included modifying the keyhole shutter and making it possible to unlock the seat with the main key, but further modifications are needed for the sake of convenience and antitheft toughness. These backgrounds led the authors to focus on the smart card key systems (duplex electric wave communication key systems) that have been implemented into automobiles for both convenience and antitheft toughness. After determining the issues involved in putting such a system on a motorcycle and listing ways of dealing with them, the industry's first smart card key system on a motorcycle was developed and applied to the large-size scooter FORZA (Fig. 1).



Fig. 1 Photo of new FORZA

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2. Development Goals

The following were selected as their development goals for the smart card key system.

- (1) Enhancing convenience
 - To reduce the total number of operations involved in all unlocking and locking by at least half as compared to conventional large-size scooters
- (2) Assuring theft tightness
 - To design a measure to hinder the breaking and the tampering on the main switch knob (because main switches are exposed, as a peculiar issue to motorcycles)
 - To protect from theft when motorcycles are parked in front of the home or a shop and the smart card key is within communication range, a peculiar issue to motorcycles
 - To design it for preventing theft by direct wire connection to the ignition circuit
- (3) Securing communication
 - Two types of communication are used with smart key systems: low frequency (LF) communication and ultra high frequency (UHF) communication. Whereas UHF communication has plenty of capacity, establishing communication is an issue with LF communication, so this was also set as a development goal.

3. System Construction

Figure 2 shows the layout of the developed smart card key system in an actual motorcycle, and Fig. 3 illustrates the system overview. To put a smart card key system on a motorcycle, the authors succeeded in creating a simple system configuration by providing satisfactory communication performance with a single LF antenna and integrating the smart ECU with the mechanical portion to make the steering lock module. The core components of this smart card key system are the steering lock module, LF antenna, UHF receiver and the smart card key, which the user carries. The functions of the core components are explained below.

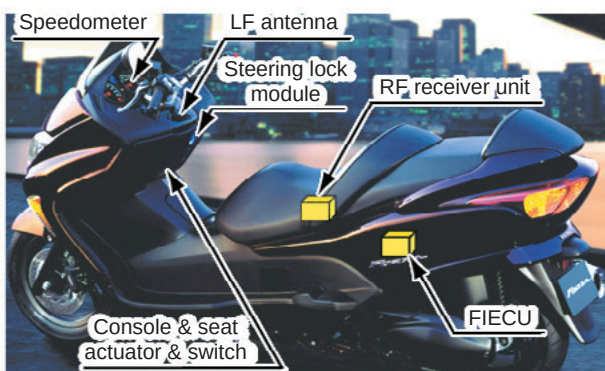


Fig. 2 Layout of smart card key system

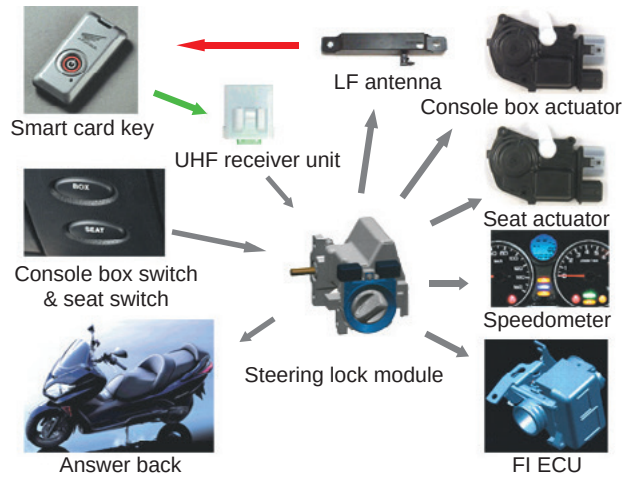


Fig. 3 Overview of smart card key system

3.1. Steering Lock Module

The steering lock module contains the main switch knob, knob torque limiter mechanism, cylinder, knob block solenoid, knob push switch, steering lock mechanism, main switch (contact point), the body (the case) and smart ECU. Figure 4 shows the structure. Figure 5 shows the diagram of the electrical system, of which the smart ECU is the central component.

When the user pushes the main switch knob (knob push switch), seat switch or box switch, the smart ECU starts up and performs two-way authentication with the smart card key. When the main switch knob is pushed and verification is performed, the knob can then be turned and at the same time the steering lock is released. When the motorcycle is in this state and the switch is turned to the ON position, the main power is turned on and an operating permission ID is sent to the FI-ECU. When the seat switch is pushed and verification is performed, the seat actuator is operated, and when the box switch is pushed and verification is performed, the console box actuator is operated.

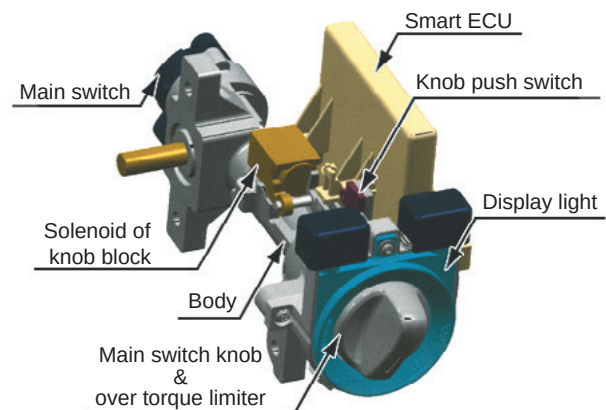


Fig. 4 Structure of steering lock module

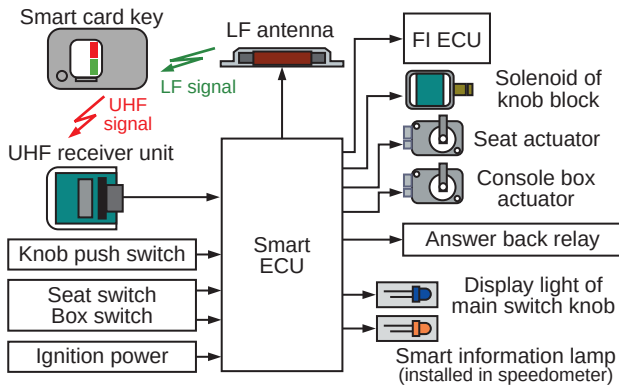


Fig. 5 Electric system diagram

3.2. LF Antenna

An LF signal (133 kHz) is sent from the LF antenna to the smart card key.

3.3. UHF Receiver

A UHF signal (320.65 MHz) from the smart card key is received by the UHF receiver and data is sent to the smart ECU inside the steering lock module.

3.4. Smart Card Key

If the LF signal transmitted from the vehicle is received and verified, a UHF signal is returned to the motorcycle. To protect motorcycles from theft when they are parked in front of a house or a shop (see Section 5.2 for details), the smart card key has a switch to turn communication on and off and an LED indicator showing whether communication is on or off.

Figure 6 shows a circuit block diagram, and Fig. 7 shows the operation timing chart. The three-axis antenna converts the LF signal sent as electric waves to an electric signal. The IC receiving LF receives this electrical signal, starts up, amplifies the signal and converts it to digital data. After the IC receiving LF starts up, the CPU starts up, uses the digital data to check the ID, and only if the ID is verified, sends an ID signal to the UHF transmission circuit. The UHF transmission circuit returns a UHF signal based on the ID signal.

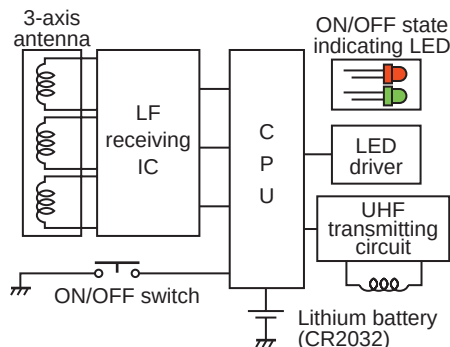


Fig. 6 Circuit diagram of smart card key

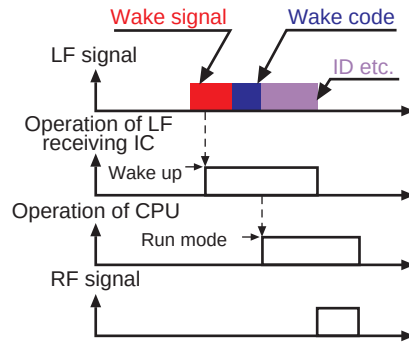


Fig. 7 Operation timing chart of smart card key system

4. Operability and User Usability

Specifications were chosen to enhance convenience. Table 1 compares the numbers of operations that need to be performed with motorcycles using the new system and with motorcycles using conventional key insertion systems. Additionally, in order to assure reliable operation, the system was designed so that the motorcycle will only operate when the user so intends and allows the user to check visually whether the system is locked or unlocked.

Table 1 Number of operations

System	Current system	Smart card key system
Operation modes		
Engine running to steering lock	6	3
Steering lock to engine start	7	3
Seat open	3	1
Console box open	5	1

4.1. Operation When Riding (Main Switch Knob Unlock)

When the user approaches the motorcycle and pushes the main switch knob, the smart ECU inside the steering lock module starts up and communicates with the smart card key. When two-way authentication is approved, the main switch knob unlocks (i.e., can be turned). When it is in the unlocked state, the SMART display light situated in the meter turns on, notifying the user that the main switch knob is unlocked. At the same time, blue lighting on the periphery of the knob turns on. Further, when the main switch knob is turned to ON, the main power comes on and an operating permission ID is sent to the FI-ECU. When the FI-ECU verifies the operating permission ID, the motorcycle is ready to run.

4.2. Operation When Dismounting (Main Switch Knob Lock)

When the main switch is turned to OFF, the smart ECU communicates with the smart card key in one-second intervals and the system keeps the main switch knob unlocked as long as there is two-way authentication. If the user moves more than 2.5 meters away from the motorcycle, a locking process takes place, wherein the main switch knob locks (i.e. cannot be turned) and the turn signal blinks to notify the user. Moreover, even if the user is close to the motorcycle, a locking process will take place if either of the following actions is performed.

- (1) The system is left alone for more than 20 seconds
- (2) The switch on the smart card key is turned to OFF

4.3. Operation of Seat and Console Box

When the rider approaches the motorcycle and pushes the seat switch, the smart ECU starts up and communicates with the smart card key. If two-way authentication is approved, the seat pops up. Also, when the rider approaches and pushes the box switch, the smart ECU starts up and communicates with the smart card key. If two-way authentication is approved, the console box opens. For locking the console box, the construction allows manually locking just as with conventional seats.

5. Assuring Antitheft Toughness

5.1. Protecting Main Switch Knob from Tampering

Because the motorcycle's main switch knob is exposed and accessible to anyone, a torque limiter mechanism was used that lets the knob rotate freely and protects the internal mechanics if excessive torque is applied to the knob. The structure is shown in Fig. 8. Usually the knob and inner joint are connected by a click ball, but this click ball releases when subjected to excessive torque so that the knob alone rotates freely. Figure 9 shows how this works. The operating torque of the torque limiter was set to be approximately three times that of normal operation so that it would not move during normal operation. Figure 10 shows the torque of different operations.

5.2. Antitheft Measures When Parked in front of House or Shop

One of the characteristics peculiar to a motorcycle that makes it so user-friendly is that it can be parked in front of a home or shop. When the smart card key to a motorcycle parked this way is within communication range, it is possible for the main switch knob to unlock and the engine to start. Therefore a communication ON/OFF switch was added to the smart card key so that the user can turn off the communication function freely.

A long press on the switch (at least for one second) causes the communication status of the smart card key to change from ON to OFF (or from OFF to ON). The user can also check the communication status with a short press of the switch and a look at the LED indicator.

5.3. Prevention of Theft by Direct Wire Connection to Ignition Circuit

After SMART verification, an ID signal is sent from the smart ECU to the FI-ECU. Only when the FI-ECU is approved by ID verification, the system allows operating of the ignition and the FI.

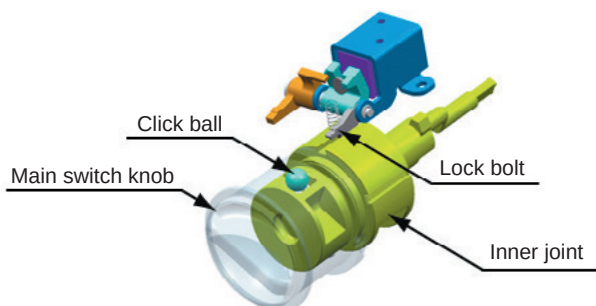


Fig. 8 Structure of over torque limiter

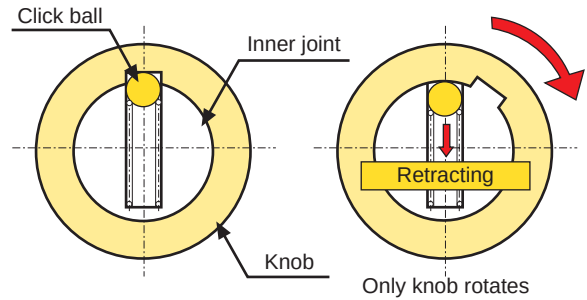


Fig. 9 Operation of over torque limiter

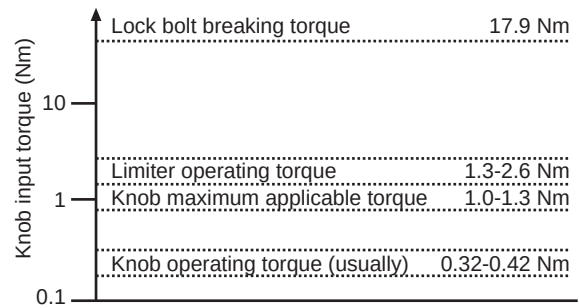


Fig. 10 Knob input torques of each operating

6. LF Communication Specifications

6.1. Unlocking Range and Locking Range

User-friendliness for the following two scenarios was considered, and the unlocking range was set at a radius of 0.8 m (with the main switch knob at the center) in the 180 degrees at the back (height 0.7 - 1.3 m). The unlocking range is shown in Fig. 11.

- (1) The rider may push the main switch knob (i.e. knob unlock) before sitting or during sitting on the rider's seat
- (2) The user may carry on the smart card key in the pocket of his trousers or jacket

The locking range was set at a radius greater than 2.5 m from the vehicle center (middle of the wheel base), a distance at which it could be sure that the user had definitely left the vehicle. Figure 12 shows the locking range.

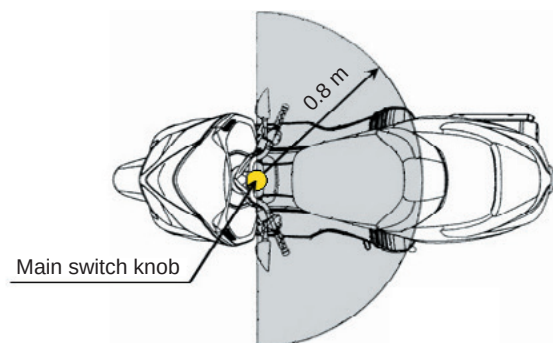


Fig. 11 Unlocking available range

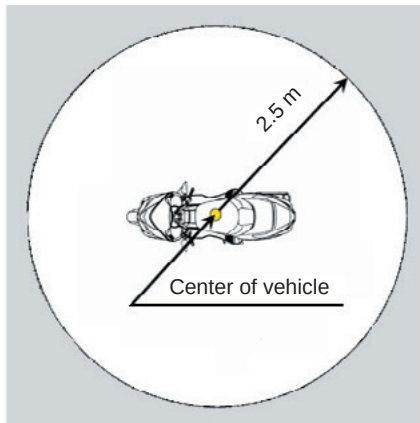


Fig. 12 Locking available range

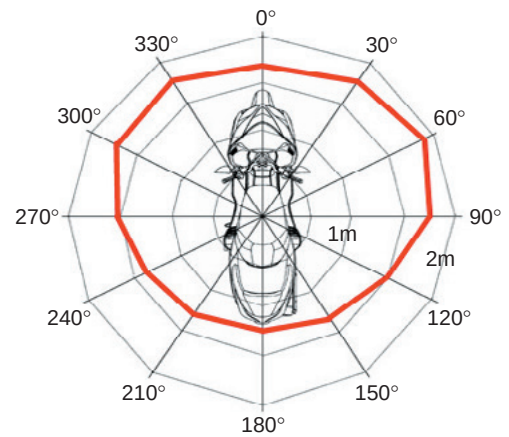


Fig. 14 Communication range

6.2. LF Receiving Sensitivity Margin and Communication Performance in Actual Motorcycle

This smart card key system's communication performance is affected by LF communications. To allow a single LF antenna to perform both locking and unlocking functions, the LF antenna was installed just above the main switch knob. Covering the entire unlocking range requires to enable communication within 1.0 m from the LF antenna installation point, while locking the knob at more than 2.5 m from the motorcycle center requires assuring that communication is not approved at more than 2.14 m from the LF antenna installation point. Figure 13 shows the voltage induced in the smart card key receiving antenna during communication⁽¹⁾. With a 12 dB margin for the unlocking side, a 3 dB margin for the locking side and by using a layout that optimizes the placement of the LF antenna, it was possible to build a system with just one LF antenna.

Figure 14 shows the test results of the communication range with an actual motorcycle. The results indicated that the unlocking range shown in Fig. 11 was covered, and was smaller than the locking range shown in Fig. 12.

6.3. Impact of Motorcycle Own Noise on LF Communications

A radiation electromagnetic noise from the motorcycle's electric components and harness was detected, therefore the impact of this noise on LF communication was examined⁽²⁾. The greater the fluctuation in electric current per unit of time, and the closer the distance from the part emitting the noise, the greater the impact on LF communication tended to be.

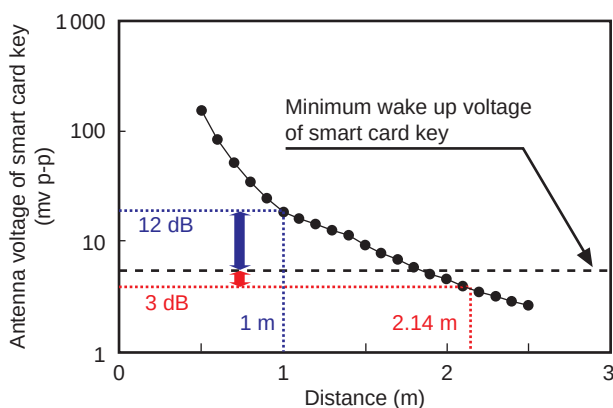


Fig. 13 Relation between distance and voltage of antenna

As an example, Fig. 15 shows a noise waveform occurring between both antenna terminals when the smart card key was close to the main harness and the electric current was varied. In response to a one-time change in electric current, a resonance begins in the antenna's tuning frequency and afterwards is attenuated. This is the result of LCR parallel resonance formed by the antenna circuit and it is commonly known that the attenuation quickens when the value of Q (resonance sharpness) is smaller.

The following types of electromagnetic noise caused by current change from proximity of the noise source are radiated at intervals shorter than the LF communication time (48-63 msec). Therefore it is impossible to avoid these even if communication is retried at the time of LF communication.

- (1) Radiation from motor harness of electronically controlled transmission
- (2) Radiation from ignition coil
- (3) Radiation from charge regulator harness
- (4) Radiation from LF antenna harness
- (5) Radiation from main harness ground and +12 V line

In the development process, by conducting a wire layout change in the harness and measures to prevent leakage of radiation electromagnetic noise, it was enabled to obtain LF communication performance necessary for unlocking. Induced voltage in the LF receiving antenna was measured, and the value of the noise to signals (LO determination threshold of the regular signal) was designated as the S/N ratio. The results are shown in Fig. 16.

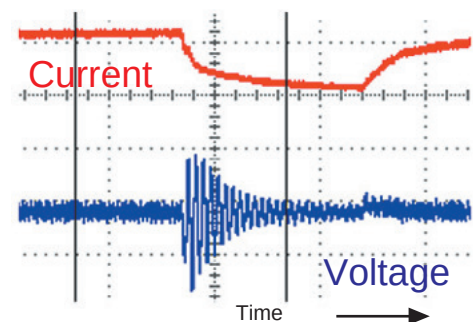


Fig. 15 Voltage waveform at spike noise reception

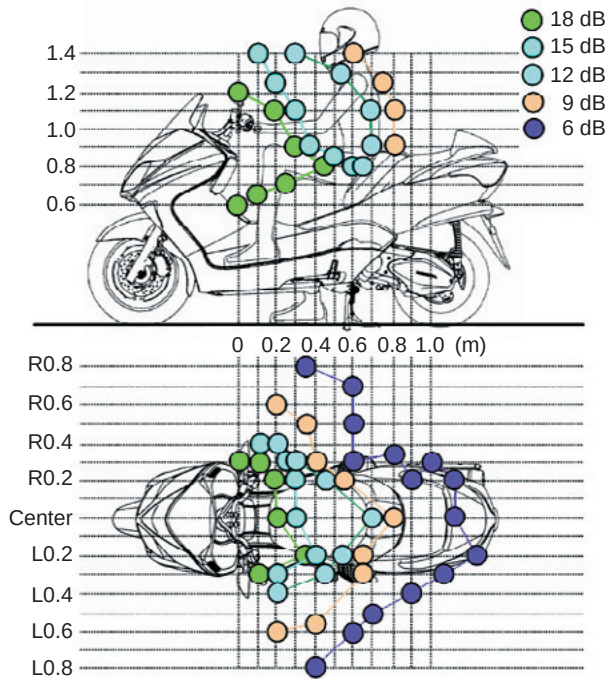


Fig. 16 S/N ratio under engine running

6.4. Impact of Environmental Noise on LF Communication

Continuous electromagnetic noise that exists in the environment to use motorcycles is thought to have an impact on LF communication, so this was checked as well. To prevent a draining of battery when the smart card key is started up continuously by picking up continuous noises, the smart card key performs noise judging after starting up. If it determines that the input is noise, it stops operations and prohibits restarting until the noise is cut off.

In this case LF communication becomes impossible, and to prevent this situation, the electric field intensity at which the smart card key starts up was set to be greater than the results of measurements taken in the field. Figure 17 shows the characteristic electric field intensity at which smart card keys start up.

The electric field characteristics were measured in various environments, including the area around broadcast equipment. As an example, a measurement result around a train guidance radio is presented here. Figure 18 shows the measurement result (measurements by a spectrum analyzer).

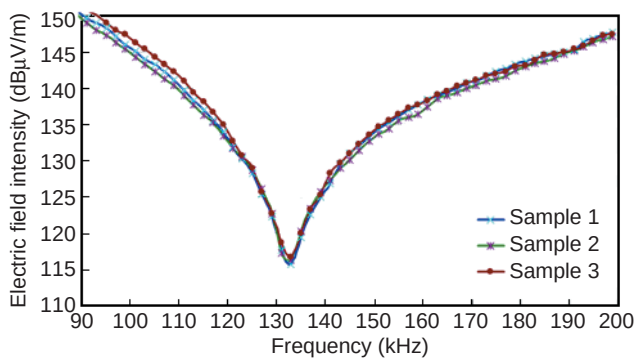


Fig. 17 Electric field intensity characteristics of smart card key starting

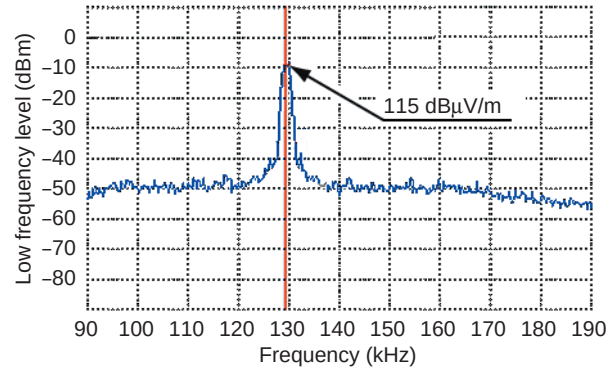


Fig. 18 Electric field intensity by train guidance radio system

7. Conclusion

The industry's first smart card key system for motorcycles was built.

- (1) This system established a unique operation pattern for motorcycles and reduced the number of operations compared to the conventional key insertion systems.
 - Number of operations to start engine: 1/2 (reduction of 50%)
 - Number of operations to unlock seat: 1/3 (reduction of 67%)
 - Number of operations to unlock console box: 1/5 (reduction of 80%)
- (2) The system provided antitheft measures for cases where the vehicle is parked in front of a house or a shop, which is an issue with motorcycles.
- (3) The system provided protection against tampering of the main switch knob, as another motorcycle issue.
- (4) The communication range as a motorcycle smart card key system was defined, and a system that enabled communications with a single LF antenna was built.

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