Development of integrated TV/GPS film antenna

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Abstract

With the spread of car navigation systems over recent years, antennas, such as for TV and GPS, are now more widely used in cars. For TVs and GPS installed at car dealers or car shops in particular, such antennas are often placed in the car interior to prevent accidental / malicious damage or theft, and for considerations of convenience.

Since the GPS antennas have to receive circularly polarized waves however, they take the form of patch antennas, which pose problems such as impaired aesthetic appearance when installed on the dashboard.

To resolve such issues we developed an integrated TV/GPS film antenna by creating a film antenna for GPS and combining it with a TV antenna. The resulting product is simple to install and gives good aesthetic appearance when installed.

This paper discusses the methods that were used to realize a GPS antenna on a film, and presents the features of the newly developed product.

1 Introduction

We have recently developed an integrated TV/GPS film antenna composed of a TV broadcast reception antenna ("TV antenna" below) and a GPS reception antenna ("GPS antenna" below) integrated on the same piece of film. This new antenna was employed in FUJITSU TEN's car navigation system marketed in July 2004. (Fig. 1.)

This paper describes, from the viewpoint of the principles of circularly polarized waves, the technology for realizing a GPS antenna on a film which was the key to the development. It also discusses the features of the newly developed product and its prospects for the future.

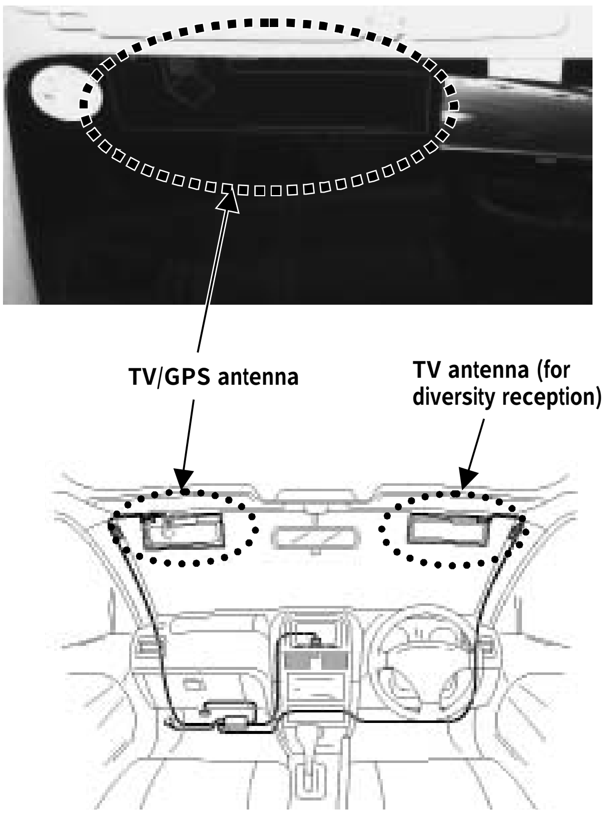

Fig.1 Integrated TV/GPS film antenna installed in car

2 Background to the development

Increasingly it is being required of in-vehicle TV, GPS and other antennas that they be "unobtrusive" so as to prevent damage and enhance aesthetic appearance, etc. This is being achieved by eliminating protrusions and integrating different antennas together.

The development of film-type TV antennas is already advanced; as long ago as 1999 FUJITSU TEN commercialized a TV film antenna that is stuck on the inside of a windshield. However, the GPS antennas that are widely employed in car navigation are of a 3-dimensional structure - patch antennas - because they have to receive circularly polarized waves, and such antennas encounter problems such as impaired aesthetic appearance when installed on a dashboard. (Fig. 2.)

Accordingly, FUJITSU TEN set out to realize an "unobtrusive" antenna of an innovative kind, by developing the first GPS film antenna able to receive circularly polarized waves and integrating it with a TV film antenna.

Fig.2 GPS patch antenna for car navigation

3 Motion principle of a circularly polarized wave antenna

3.1 About circularly polarized waves

Generally speaking, there are two types of radio wave: linearly polarized and circularly polarized. The field of the former does not change its does not change the direction of its electric field over time, while the field of the latter rotates the direction of its electric field over time. Depending on the direction of such rotation, circularly polarized waves are divided into right- and left-polarized waves.

Table 1 gives examples of the use of polarized waves for various telecommunications and broadcasting applications.

Satellite broadcasts for moving objects usually use circularly polarized waves so that reception will be possible whatever the direction of the moving object.

Table 1 Polarized waves and their applications

Polarized wave (field component orientation)		Applications
Linearly polarized waves	Horizontally polarized	FM and TV broadcasts
	Vertically polarized	Cell phones
Circularly polarized waves	Right polarized	GPS and BS broadcasts
	Left polarized	Mobile satellite broadcasting

3.2 Requirements for reception of circularly polarized waves

Fig. 3 shows a model of the propagation of circularly polarized radio waves. It can be seen that the direction of the electric field rotates with time relative to the axis of wave progression.

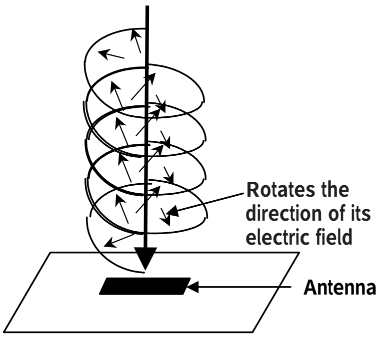

Fig.3 Example of circularly polarized wave

For an antenna to receive these radio waves, the current which flows at an antenna must be the same as the direction of the electric field of radio waves. That is, in order for the antenna to receive circularly polarized waves, the current that flows in the antenna must rotate over time. To obtain such a rotating current, it suffices to employ orthogonal currents that have a 90° phase difference. (Fig. 4.)

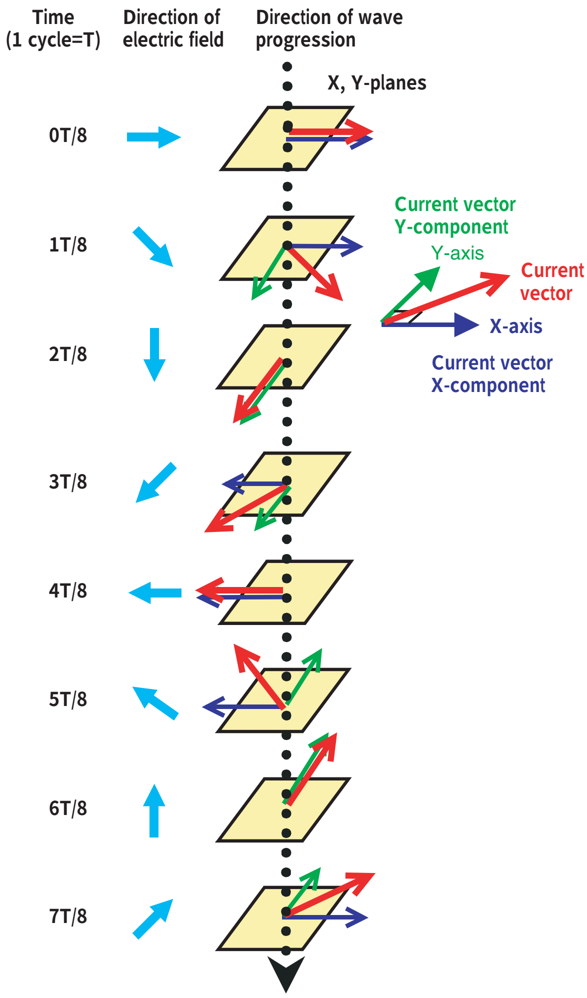

Fig.4 Motion principles of circularly polarized waves

Thus, provided that currents with a 90° phase difference flow orthogonally in an antenna, it can receive circularly polarized waves.

4 Measures to realize the new product

4.1 Problems with the conventional technology

Fig. 5 shows the crossed dipole type of film antenna for circularly polarized waves, according to the conventional technology. It deploys in cross formation 2 dipole antennas for receiving linearly polarized waves, and uses a phase shifter to shift by 90° the linearly polarized wave component signal received by one of those antennas. But with this type of antenna, the film has to be patterned on both sides in order to form the crossed antennas, and furthermore balanced-to-unbalanced conversion circuits and shifted-phase synthesis circuits are needed in order to feed power to the dipole antennas. Hence this type of antenna has problems such as a large-size power feed and high costs.

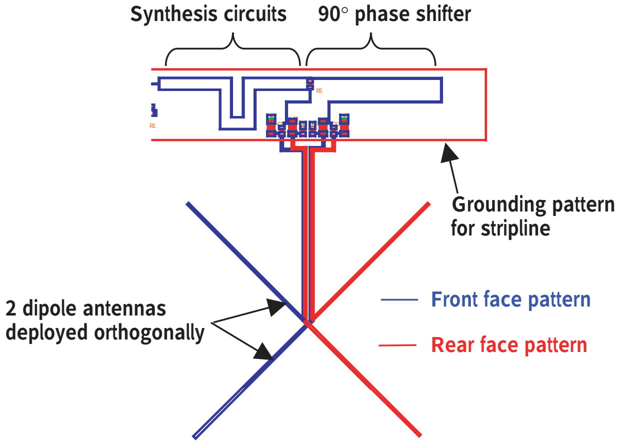

Fig.5 Crossed dipole antenna

4.2 Concepts for resolving the problems

The policy adopted to resolve the above problems was to configure a circularly polarized wave antenna comprising a film patterned on one side only and employing simple power feed circuits. To realize such policy, we aimed to use an existing linearly polarized wave antenna as basis and adapt it for circularly polarized waves. The monopole type of linearly polarized wave antenna shown in Fig. 6 requires grounded power feed on one side of its element, which means it would have poor installability if rendered into a film antenna. Therefore, we opted for the loop type of linearly polarized wave antenna as the basis for the present development.

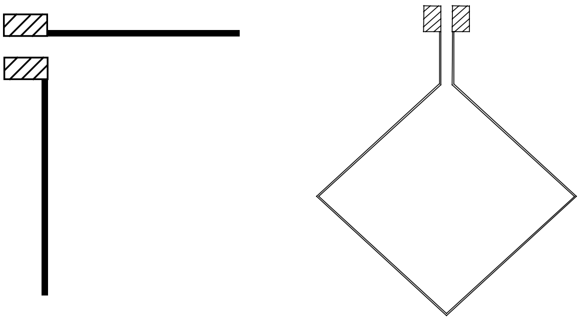

Fig.6 Linear polarized antenna

4.3 Policy for realizing the development

A 1-wavelength loop antenna, which makes 1 cycle equal to 1 wavelength of the reception frequency, is an antenna that has polarized waves in the horizontal direction and therefore has no current flowing through it in the vertical direction. As mentioned in 3.2 above, to have an antenna receive circularly polarized waves, it is necessary to generate current in the vertical direction with phase shifted by 90°, in addition to current in the horizontal direction. It is not possible to obtain these 2 currents with a loop antenna alone.

Accordingly in the present project, we devised the measure of employing, in addition to the loop antenna, an element that would generate current in the vertical direction. Adding such element to the loop antenna made it possible to synthesize horizontal and vertical reception signals and generate current in 2 directions.

Fig. 7 shows the newly developed GPS film antenna. Since positioning the element directly over the loop antenna in a vertical orientation would have caused turbulence in the current flowing through the loop, we instead adopted a method of using a parasitic element that is positioned such that its end portion lies adjacent to the loop. The length of such portion was made equal to one half of a wavelength, so that the element resonates effectively with the vertically oriented component of the polarized waves. Furthermore, the intersecting wave discrimination (described later) permits optimal adjustment of the junction length and junction gap between the loop antenna and the parasitic element, thus making possible a 90° phase shift. (Patent pending.)

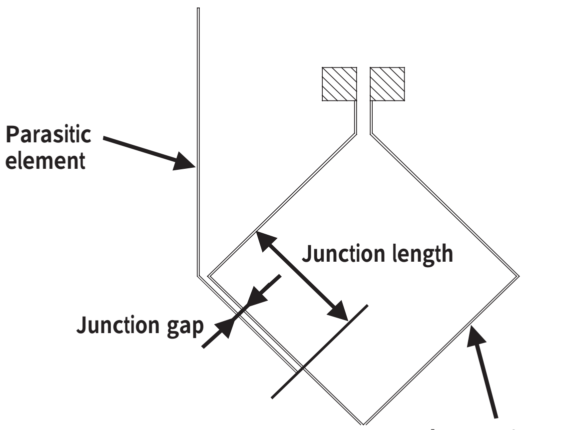

Fig.7 Developed GPS film antenna

4.4 Validation via simulation

Simulation tools were used to verify that this method generates a current distribution that satisfies the requirements for circularly polarized reception in an antenna. (Fig. 8.)

The simulations were able to verify that the method generates horizontal and vertical currents, that those currents excite with a 90° phase difference, and that the synthesized current resulting from those 2 currents rotates in the antenna. In other words, they verified that the antenna produced by the method constitutes a circular polarized antenna.

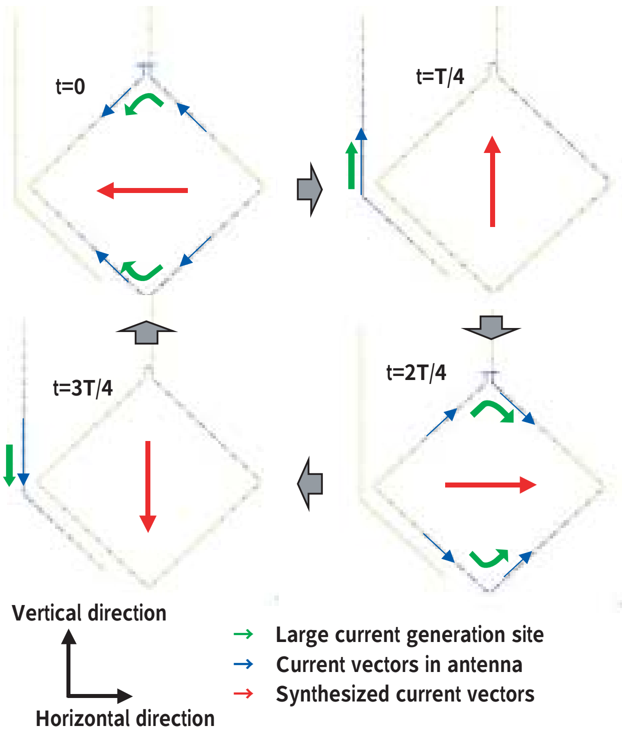

Fig.8 Simulations of current distribution

5 Configuration of newly developed product

The newly developed product is configured from antenna elements printed on a film, and pickup units that are connected to those elements. (Fig. 9.)

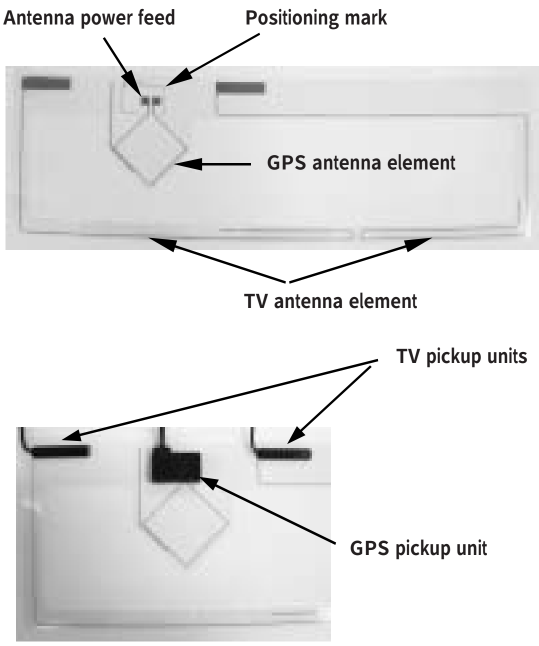

Fig.9 Product configuration (left side of windshield)

The size of the film antenna is 320×100mm, and the antenna elements are formed by printing silver paste onto colorless transparent PET (polyethylene terephthalate) film. The extreme weakness of the GPS reception signals means that the GPS antenna additionally requires an LNA (low noise amplifier) to be located directly under it; accordingly the GPS pickup unit incorporates an LNA. (Fig. 10.)

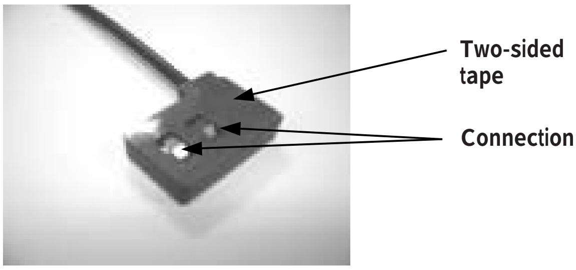

Fig.10 Pickup unit for GPS antenna

6 Features of the newly developed product

The construction is such that the antenna elements' power feed and the GSP pickup unit's connection terminals are stuck with two-sided tape. (Fig. 10.)

Since positioning accuracy is required for the sticking of the GPS pickup unit, positioning marks are provided as shown in Fig. 9 which enhance workability as well as sticking position accuracy. The positioning marks are formed from silver paste, like the antenna patterns, so as to keep their cost low. Furthermore, the marks are in the form of a broken line, so that although they are deployed in the GPS antenna's vicinity and their silver paste is conductive, excitation of unwanted current in the marks will be suppressed and they will exert no adverse effects on reception performance.

Use of 2-stage low-noise amplifying circuits for GPS in the GPS pickup unit's circuit configuration realizes low noise and high gain. And employment of a compact low-loss surface wave filter between the amplifier stages improves reception sensitivity and interference characteristics. The product also carries a surge absorbing element to prevent the interior circuits from breakage due to surges caused by static electricity on the connection terminals during installation or during other work on the product.

The newly developed product's GPS pickup unit (which is connected to the GPS antenna) has external dimensions 26mm×16mm×6mm (excluding protruding portions) and mass approx. 3g (excluding cable), making it compact and lightweight compared to traditional (FUJITSU TEN) patch antennas - it is roughly 1/4 of their volume and 1/10 of their mass.

7 Performance of newly developed product

7.1 Performance of GPS antenna

7.1.1 Performance of antenna element

The factors that are generally given weight in the performance of antenna elements are gain and directivity, etc. But with GPS antennas, there is an additional important performance factor: the degree of discrimination between intersecting polarized waves. This is because these are circular polarized antennas.

Table 2 provides a comparison of the performances of the antennas elements in conventional products and in the newly developed product, while Fig. 11 compares directivity between the two.

Table 2 Performance of antenna elements in new and current products

Feature evaluated	Target value	Measured value	
		New product (film type)	Conventional product (patch type)
Average gain (dBi)	0 or higher	0.0	2.0
Intersecting wave discrimination degree (dB, average)	13 or higher	16.1	16.9

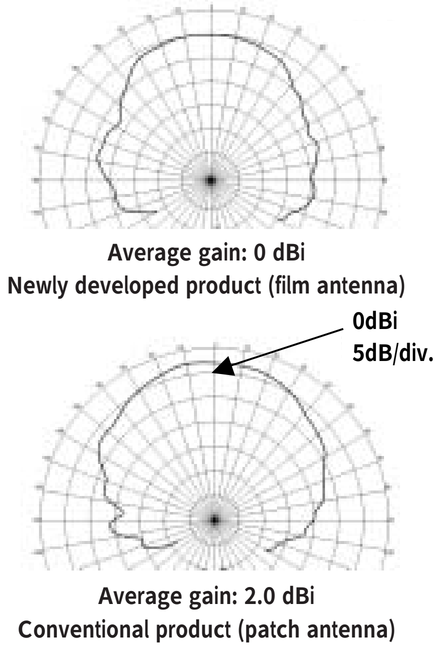

Fig.11 Directivity of new and current products

The intersecting wave discrimination degree of a GPS antenna is expressed by the right polarized wave gain minus the left polarized wave gain. The higher this value, the better is the antenna's performance in receiving right polarized waves (GPS signals). The relation between directivity (gain) and intersecting wave discrimination degree is shown in Fig. 12.

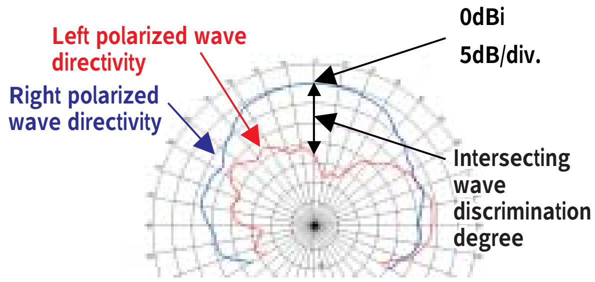

Fig.12 Right and left handed circularly polarized wave directivity and cross polarization discrimination

7.1.2 Performance with GPS

The positioning performance of the newly developed GPS antenna (film antenna + LNA) when combined with a GPS receiver and used in a stationary vehicle was compared with that of a conventional product (patch antenna + LNA) under the same conditions. The results are listed in Table 3.

Table 3 Comparison of positioning performances using GPS receiver (when vehicle is stationary)

	New product (film antenna)	Conventional product (patch antenna)
Reception S/N (dB/Hz)	38.5	40.6
Number of acquisition satellites	4.8	5.3
Positioning rate (%)	81.4	88.2
Positioning accuracy (m)	25.1	24.0

Next, we compared the positioning performances (degrees of positioning track error) during travel along a test course, with the equipment being used as a locator. The results are shown in Fig. 13.

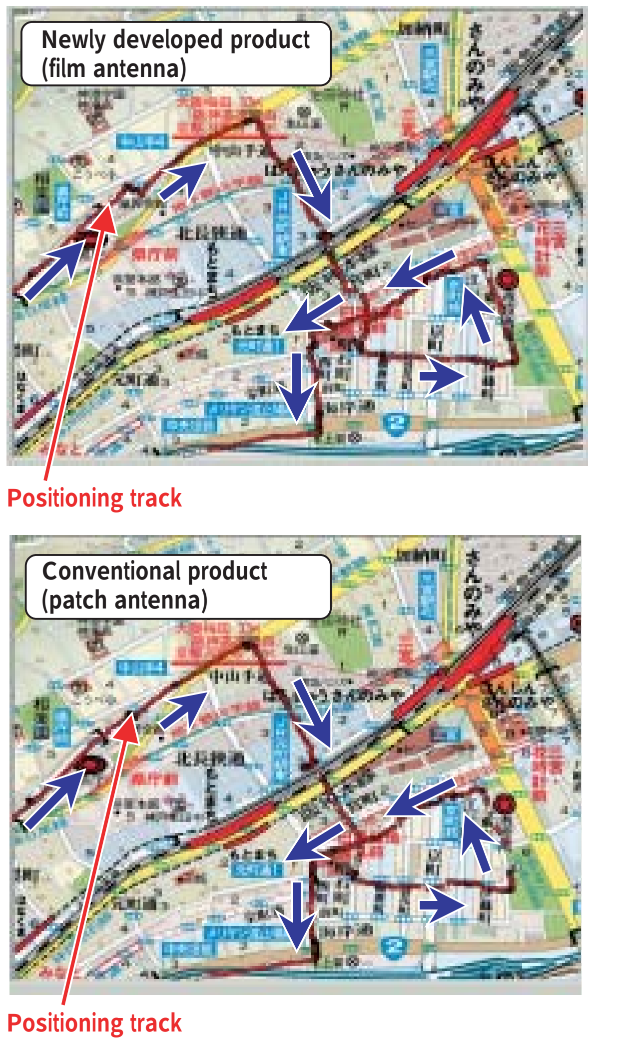

Fig.13 Comparison of positioning performances using GPS receiver(during travel)

The above results verified that, despite positioning error of around 1 meter when the vehicle is stationary and of several meters when it is traveling - such error being due to the difference in the antenna gains - the new product is capable of steady positioning performance under demanding conditions such as travel under elevated structures or along streets with high buildings, and thus is adequate to be employed for positioning in navigation systems.

7.1.3 Performance with navigation system

The new and conventional products were combined with real navigation units, and a comparison was made of their GPS positioning accuracies and performances under the following time-related conditions.

①Time up to first positioning after GPS reception is initiated

Focus of observation

Time taken to determine the car's position after GPS reception starts, when the car is driven with GPS reception initially turned off.

Method

Car was driven out of a built-up area parking lot into the streets, and the time required to determine the car's position was measured.

②Distance error rate

Focus of observation

Distance error when the car is driven using dead-reckoning navigation only.

Method

After learning the distance, the car was driven without the GPS antenna connected, and the distance error rate was calculated.

③Overall accuracy

Focus of observation

Overall positioning error performance during driving along real routes under a variety of conditions.

Method

The car was driven in long-distance travel and the rate of positional error occurring over a given distance was measured.

Table 4 lists the results of the comparisons of the newly developed product (film antenna) and the conventional product (patch antenna) under the above-described conditions.

Table 4 Comparison of positioning performance using navigation systems

Items evaluated	Test course	Result	
		New product (film antenna)	Conventional product (patch antenna)
①Time to first positioning	Built-up area	138 s	136 s
②Distance error rate	Suburbs	0.12%	0.12%
③Overall accuracy	Built-up area - mountains	0.025%	0.025%

These results demonstrate that when used with a navigation system, the newly developed integrated TV/GPS film antenna is able to provide performance comparable to that of a conventional patch antenna.

7.2 Interference with TV antenna

Since a GPS antenna element and a TV antenna element are formed on the same film in the new product, the proximity of the two elements (patterns) is a cause for concern that they might interfere with each other. Fig. 14 shows the directivity (gain) characteristics of the GPS antenna element when the TV antenna element is present and when it is absent.

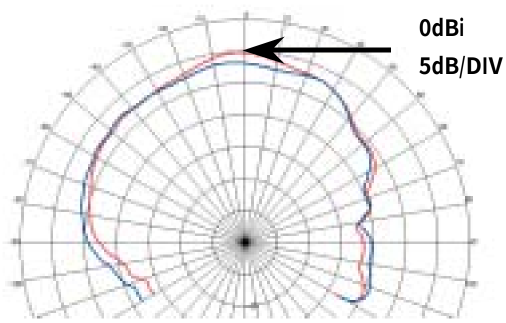

Fig.14 Directivity of GPS antenna element (with and without TV antenna element)

Conversely, Fig. 15 shows the directivity (gain) characteristics of the TV antenna element when the GPS antenna element is present and when it is absent.

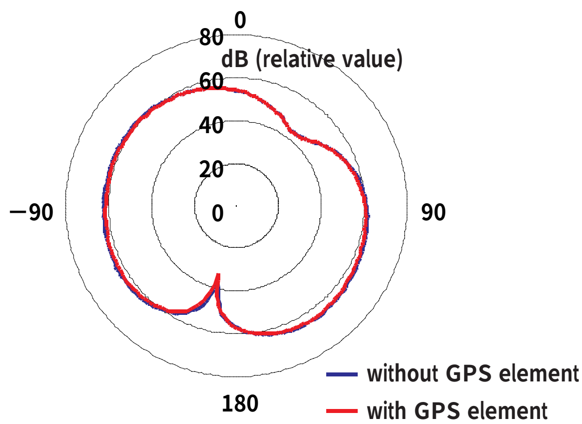

Fig.15 Directivity of TV antenna element (with and without GPS antenna element)

In both cases, the antenna's directivity is affected to a small extent (no more than ± 2 dB) by the presence of the other antenna, but it is evident that this produces almost no variation in the average gain.

With the super heterodyne receivers that are now widely used in TV tuners, the local signals used in the mixer circuits, or the higher harmonics of such signals, may leak through the antenna input terminals and exert adverse effects on the rest of the reception system. Such adverse effects are of particular concern in the newly developed product, where the TV and GPS elements are in proximity. Table 5 gives the results of a test in which the newly developed integrated TV/GPS film antenna was connected to a FUJITSU TEN navigation unit, the TV was tuned to a channel that could potentially interfere with GPS reception, and a comparison was made of the GPS reception condition when the TV was turned on and when it was turned off. These results confirmed that there is no adverse effect whatever.

Table 5 Effect of TV tuner local signal leakage on GPS reception (56-channel TV)

GPS reception signal S/N (dB/Hz)	With TV off	With TV on
	56	56

Further, in order to verify the service margin, a standard signal generator was connected to the system in place of the TV tuner, interfering waves were purposely generated using such generator, and the point at which GPS reception became affected was investigated. It was found that there was a margin of around 40 dB relative to the local leakage (including higher harmonics) control value for FUJITSU TEN products.

8 Conclusion and future prospects

In developing the integrated TV/GPS film antenna, we have realized a planar antenna for reception of circularly polarized waves - something considered problematic heretofore - and believe we have achieved major improvements in installability and in post-installing aesthetic appearance. What is more, the new product has been achieved using patterns printed on one side of the film only, making for extremely good cost competitiveness.

The antenna for receiving circularly polarized waves has potential to be developed for other applications such as ETC and satellite mobile broadcasting. We also hope to use this antenna in combination and integration with other items, thereby developing our antennas to be more compact and lower cost, as well as to require less time and work for installation, amid the swelling myriad of vehicle-installed antennas, which look set to proliferate further in the future.

Reference
"An answer to the constant proliferation of in-vehicle antenna types - Enabling reception of GPS and TV broadcasts with a single film antenna" FUJITSU TEN contribution to Nikkei Electronics October 25, 2004 issue

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