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Triband Automobile Antenna for AM-FM Receiver and Mobile Telephone

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In recent years, mobile telephones have become popular in many countries. At present, many users have one antenna for communication by mobile telephone and another for AM-FM reception. These antennas spoil the appearance of the automobile, and a fixed type mobile telephone antenna may be damaged while the automobile is being machine-washed. It is said that an automobile with a mobile telephone antenna is more likely to be stolen because it draws attention.

To solve these problems, Fujitsu TEN has developed an automobile antenna that can be used in three bands, for AM, FM, and mobile telephone. This new antenna is driven by a motor to store its element inside the automobile. The new antenna is a three-segment rod antenna that has the same form as ordinary AM-FM receiving antennas. When the antenna is fully extended, it can be used as both an AM-FM receiving antenna and a mobile telephone antenna. The antenna has almost the same electrical performance as those dedicated to the individual bands.

1. Introduction

The mobile telephone enables us to exchange information easily between the inside and outside of the vehicle. Mobile telephones have become popular not only in the U.S.A. (Figure 1) but also in many other countries, including Japan.

In both the U.S.A. and Japan, most users have one antenna for the mobile telephone and another for an AM-FM broadcast receiver.

The element of a conventional AM-FM receiving antenna sold by Fujitsu TEN for use in Japan is 1 meter long, and the element of one for use in the U.S.A. is 90 centimeters long. These antennas are driven by motors and can be drawn into the automobile. Ordinary mobile telephone antennas have a maximum length of about 70 centimeters. Many of them are a fixed type and cannot be stored inside the automobile.

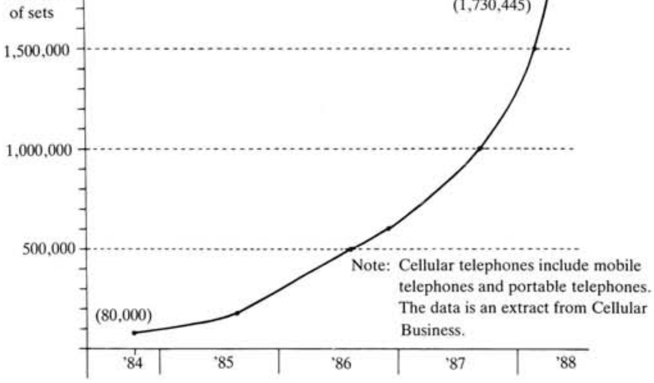


Figure 1. Number of cellular telephones registered in the U.S.A.

For the above reasons, it is thought that there is a strong need for commercial-scale production of an antenna that can be used in three frequency bands (AM, FM, and mobile telephone bands) and does not spoil the design of the automobile.

The three frequency bands in Japan are from 500 to 1700 kilohertz for AM broadcasting, from 76 to 90 megahertz for FM broadcasting, and from 860 to 940 megahertz for mobile telephone communication. The three frequency bands in the U.S.A. are 500 to 1700 kilohertz for AM, 88 to 108 megahertz for FM, and 824 to 896 megahertz for mobile telephone. These frequency bands are quite different from one another, and the mobile telephone band requires a bandwidth from 70 to 80 megahertz. Thus it is hard for one antenna to deliver optimum results for all three frequency bands, regardless of whether the antenna has specifications for use in the U.S.A. or Japan. Based on these facts, we started developing a triband automobile antenna for AM-FM receivers and mobile telephones (herein called the triband automobile antenna).

Before starting the development of the triband automobile antenna, we established the following targets:

① The triband automobile antenna must have the same gain and impedance characteristics as AM-FM receiving antennas and mobile telephone antennas.
② The triband automobile antenna must have the same appearance as AM-FM receiving antennas.
③ The triband automobile antenna must enable a mobile telephone to be used while an AM or FM broadcast is being received.
④ The triband automobile antenna must extend and contract, and must be stored inside the body of the automobile when it is not in use.
⑤ The triband automobile antenna must be for general purposes and usable on as many types of automobiles as possible.

To meet the above conditions, we developed the following components by making good use of the technology accumulated by Fujitsu TEN:

① An antenna element that uses coils having a band separation function and can be used in the three frequency bands
② A power feeding section with a feed point inside the body of the automobile to enable the antenna to be driven by a motor
③ A branching filter that enables simultaneous use of an AM-FM radio receiver and a mobile telephone and minimizes the loss of high-frequency signals

Figure 2 shows the antenna that we developed by uniting the above new components with the technology used in existing motor-driven antennas. The antenna fully meets the conditions described above.

Table 1 lists the specifications of the antenna.

This report introduces the structure of the components of the triband automobile antenna, its characteristics, and an example of its mounting on an automobile, chiefly with discussion of electrical characteristics.

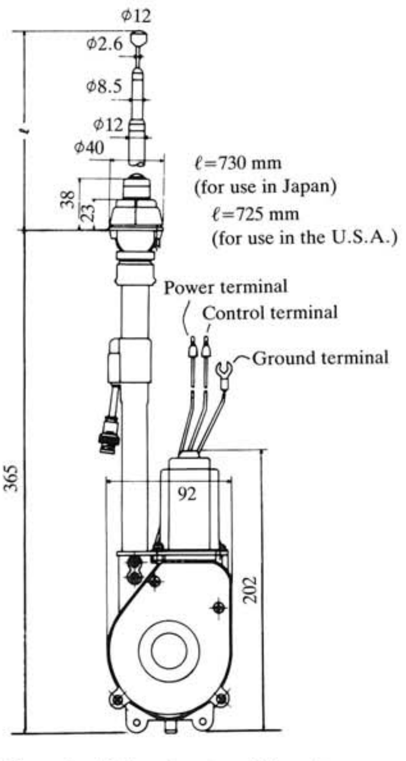


Figure 2. Triband automobile antenna

Table 1. Specifications of the triband automobile antenna (when the element is fully extended)

	For use in Japan	For use in the U.S.A.
Type	3-segment motor-driven rod antenna	3-segment motor-driven rod antenna
Transmission frequency band	915 – 940 MHz (for mobile telephone)	824 – 849 MHz (for mobile telephone)
Reception frequency band	500 – 1700 kHz (for AM broadcasting) 76 – 90 MHz (for FM broadcasting) 860 – 885 MHz (for mobile telephone)	500 – 1700 kHz (for AM broadcasting) 88 – 108 MHz (for FM broadcasting) 869 – 896 MHz (for mobile telephone)
VSWR	1.9 or less (in mobile telephone band) 10 or less (in FM broadcast band)	1.9 or less (in mobile telephone band) 10 or less (in FM broadcast band)
Gain	2 dBi or more (in mobile telephone band)	2 dBi or more (in mobile telephone band)
Received voltage	Same as for 1 m whip antenna (in AM broadcast band)	Same as for 0.9 m whip antenna (in AM broadcast band)

2. Structure

2.1 Antenna element

Figure 3 shows the principle of operation of the antenna.

The mobile telephone antenna consists of the first section, the second section, and phasing coil 1. The AM-FM receiving antenna consists of the mobile telephone antenna, phasing coil 2 above the mobile telephone antenna, and the third section above phasing coil 2. If the wavelength at the center frequency of the mobile telephone band (900 megahertz in Japan and 860 megahertz in the U.S.A.) is λ_0, the first section is $3\lambda_0/8$ long, the second section $5\lambda_0/8$ long, the third section about 350 millimeters long, phasing coil 1 about $\lambda_0/4$ long, and phasing coil 2 about $\lambda_0/2$ long.

In the mobile telephone band, phasing coil 1 of the triband automobile antenna increases the gain by making the currents in the first and second sections the same in phase and reducing the opposite phase current components between the first and second sections. The antenna works as a colinear array antenna and has higher horizontal gain than an ordinary quarter-wavelength whip antenna.

Phasing coil 2 increases the reactive component in the mobile telephone band. Consequently, in the mobile telephone band, current distribution in the third section above the coil is about 10 decibels lower than in the first and second sections under the coil. Thus the portion below phasing coil 2 works as a mobile telephone antenna.

The reactance of phasing coil 2 is low in the AM and FM broadcast bands because their frequencies are much lower than in the mobile telephone band. Consequently, the entire element works as an AM-FM broadcast receiving antenna.

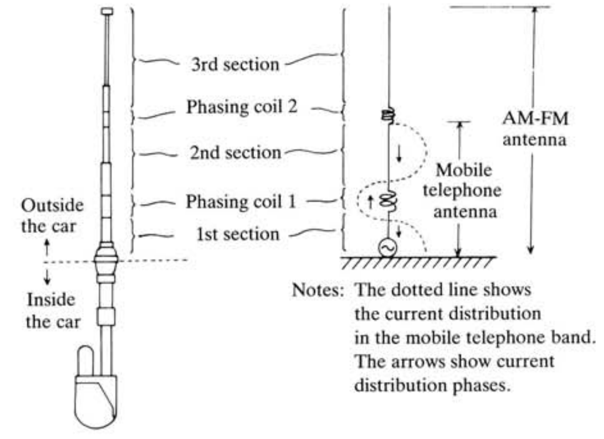


Figure 3. Principle of operation of the antenna element

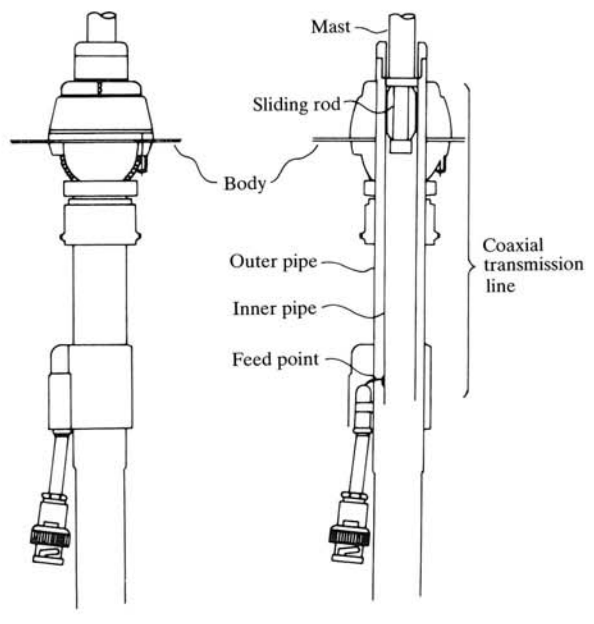


Figure 4. Structure of the power feeding section

2.2 Power feeding section

The element described above can be used independently. For the triband automobile antenna to be used for general purposes, we have designed it so that the antenna element can be stored inside the automobile and the feed point is inside the automobile instead of outside. For impedance matching, we have determined the distance between the body surface and the feed point to be $\lambda_0/2$, where λ_0 is the wavelength at the center frequency of the mobile telephone band. With this design, we have achieved a voltage standing-wave ratio (VSWR) of 1.9 or less in the mobile telephone band and 10 or less in the FM broadcast band. The design also reduces loss and enables the antenna to be used for general purposes.

Figure 4 shows the structure of the power feeding section.

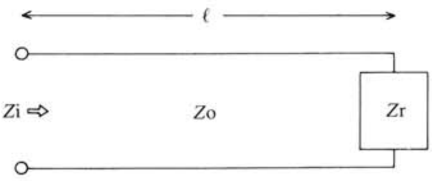


Figure 5. Equivalent circuit viewed from the feed point

As shown in Figure 4, the triband automobile antenna is coaxial between the element base and the feed point. The antenna is designed so that the element can have the same impedance as mobile telephone transceivers, i.e., 50 ohms. Thus the equivalent circuit of the antenna, viewed from the feed point, is as shown in Figure 5.

If Z_i is the input impedance viewed from the feed point, Z_r the element impedance, Z_0 the characteristic impedance of the transmission line, and l the line length, the following can be derived:

$$Z_i = Z_0 \frac{Z_r + Z_0 \tan\beta\ell}{Z_0 + jZ_r \tan\beta\ell} \tag{1}$$

where $\beta = 2\pi/\lambda_0$ (propagation constant).

When $Z_0 = Z_r$ (= 50 ohms), the input impedance Z_i viewed from the feed point is equal to Z_r (50 ohms) and has no relationship with the line length l.

However, as described below, it is difficult in practice to set the characteristic impedance of the transmission line Z_0 of the triband automobile antenna to 50 ohms.

Figure 6 shows a typical coaxial transmission line of the coaxial line shown in Figure 4. The characteristic impedance Z_0 of this transmission line can be calculated from the following:

$$Z_0 = \frac{138}{\sqrt{\varepsilon_s}} \log \frac{D}{d} \ [\Omega] \tag{2}$$

where ε_s is the dielectric constant.

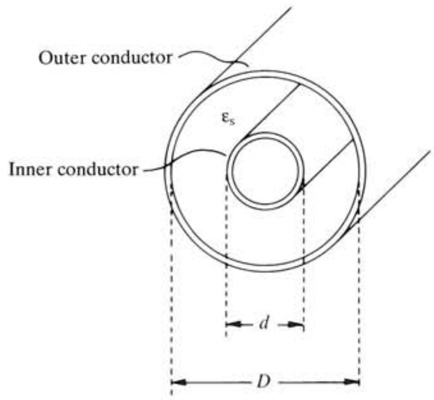


Figure 6. Coaxial transmission line

The diameter of the inner pipe (d) of the triband automobile antenna is determined to be 14 millimeters by the diameter of the lowermost antenna mast. The inside diameter of the outer pipe (D) cannot be made larger, considering the mounting of the antenna on an automobile.

For Z_0 in equation (2) to be 50 ohms, D must be 32 millimeters or more (because $\varepsilon_s \geqslant 1$). If a resin insulator is inserted between the outer and inner pipes to provide sufficient mechanical strength, D becomes larger because εs becomes greater than 1. The triband automobile antenna is hard to mount on a vehicle under this condition.

Instead of setting Z_0 to 50 ohms, we made the line length l of the power feeding section half the wavelength λ_0 at the center frequency of the mobile telephone band. If l in formula (1) is $\lambda_0/2$, Z_i is equal to Z_r (50 ohms); that is, the input impedance viewed from the feed point is equal to the impedance of the antenna element.

In frequency bands other than the mobile telephone band, the capacitance of the power feeding section increases in the AM broadcast band and the VSWR in the FM broadcast band becomes worse, because the impedance of the coaxial-structure section still remains low. The loss of high-frequency AM or FM signals increases accordingly. Thus the impedance of the coaxial-structure section should be as near 50 ohms as possible.

We carefully selected the resin insulator between the outer and inner pipes. We made the outer pipe 22 millimeters in outside diameter, slightly larger than the diameter of existing antennas.

The above outside dimension of the outer pipe is the minimum size required to provide the triband automobile antenna with the necessary electrical and mechanical characteristics.

2.3 Branching filter

The triband automobile antenna connects to an AM-FM broadcast receiver and a mobile telephone transceiver through a branching filter.

Figure 7 shows the circuit components of the branching filter.

The branching filter has three terminals. One is the antenna terminal, which connects to the feed point of the triband automobile antenna. Another is the TEL terminal, which connects to the mobile telephone transceiver through a 50-ohm cable. The other is the AM-FM terminal, which connects to the AM-FM broadcast receiver through a low-capacitance cable.

A high-pass filter is formed between the antenna and TEL terminals. Thus signals in the mobile telephone band are transmitted with an insertion loss of 0.1 decibel or less and a VSWR of 1.1 or less, and unwanted signals beyond the mobile telephone band are eliminated.

A notch filter is formed between the antenna and AM-FM terminals. This notch filter eliminates only signals in the mobile telephone band and suppresses them by 35 decibels or more.

2.4 AM broadcast reception performance improvement circuit

As described in Section 2.2, the triband automobile antenna limits the diameter and length of the pipes in the power feeding section. Although the antenna showed satisfactory electrical performance in the mobile telephone and FM broadcast bands, the limited diameter and length caused the problems described below.

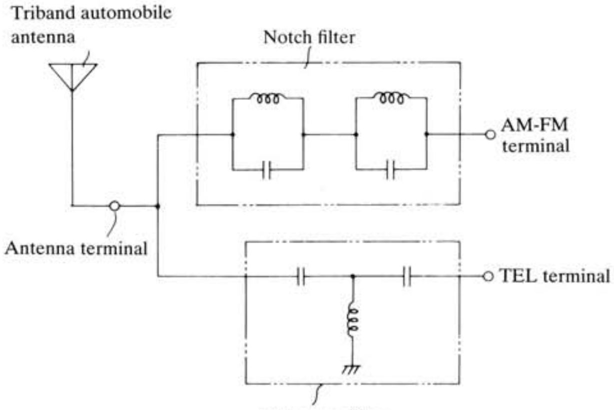


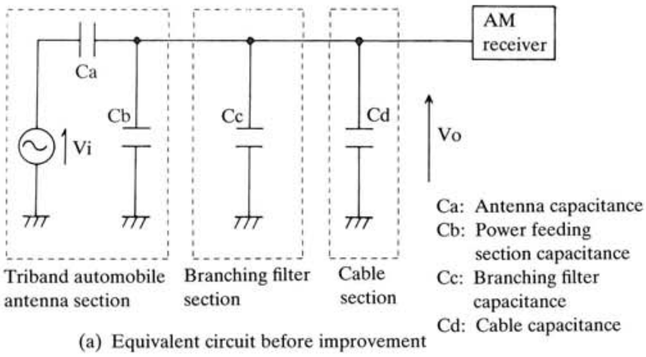
Figure 7. Branching filter circuit components

Figure 8a shows the equivalent circuit for the AM broadcast band formed when the triband automobile antenna is connected to an AM broadcast receiver through a 4-meter-long low-capacitance cable for automobile wiring.

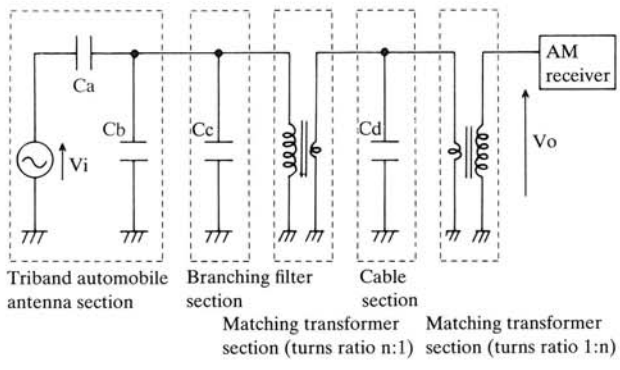
Unlike ordinary AM-FM receiving whip antennas, the coaxial structure of the power feeding section causes power feeding section capacitance (C_b) and the branching filter causes branching filter capacitance (C_c) in the triband automobile antenna. These two capacitances cause the voltage loss calculated from the following:

$$\triangle V = 20 \log \left(\frac{C_a}{C_a + C_d} \right) Vi - 20 \log \left(\frac{C_a}{C_a + C_b + C_c + C_d} \right) Vi \text{ [dB]}$$

where C_a is antenna capacitance and C_d is cable capacitance.



(a) Equivalent circuit before improvement



(b) Equivalent circuit after improvement

Figure 8. Principle of improving AM broadcast received voltage characteristics

$\triangle V$ is 3 decibels for the triband automobile antennas for use in both Japan and the U.S.A. (when C_a = 15 pF, C_b = 45 pF, C_c = 10 pF, and C_d = 120 pF).

An ordinary AM-FM receiving whip antenna (reference antenna) for use in Japan has an element length of 1 meter, and the one for use in the U.S.A. has an element length of 90 centimeters. The triband automobile antenna has an element length of 70 centimeters. The difference in element length between these antennas causes the difference in induced voltage calculated from the following:

$$\triangle V = 20 \log \left(\frac{1}{0.7}\right) \text{ [dB]}$$

or

$$\triangle V = 20 \log \left(\frac{0.9}{0.7}\right) \text{ [dB]}$$

$\triangle V$ between the triband automobile antenna for use in Japan and the reference antenna for use in Japan is 3 decibels, and $\triangle V$ between the triband automobile antenna for use in the U.S.A. and the reference antenna for use in the U.S.A. is 2 decibels.

As seen from the above, the output voltage of the triband automobile antenna that we developed for use in Japan is 6 decibels lower than the reference antenna for use in Japan. The output voltage of the triband automobile antenna for use in the U.S.A. is 5 decibels lower than the reference antenna for use in the U.S.A.

Figure 8b shows the circuit developed to remove the output voltage difference.

The circuit shown has matching transformers at both ends of the cable. This circuit reduces the apparent cable capacitance to the value obtained by dividing it by the square of the turns ratio of the transformers to reduce the voltage loss caused by cable capacitance, which is as much as 120 pF. With this circuit, the output voltage calculated from the following can be obtained:

$$V_0 = 201 \log \left(\frac{C_a}{C_a + C_b + C_c + C_d}\right) Vi \text{ [dB]}$$

$$\text{where } C_d' = \frac{C_d}{n^2}.$$

By this method, we reduced the output voltage loss in the AM broadcast band.

By setting the turns ratio n of the transformers to 6 and the capacitance over the AM broadcast band viewed from the receiver to 80 pF, we improved the AM broadcast reception characteristics of the triband automobile antenna for use in Japan to almost the same as those of the reference antenna for use in Japan. We made the same improvement in the triband automobile antenna for use in the U.S.A. as well.

One matching transformer is between the branching filter and the cable, and the other is between the cable and the AM-FM receiver. Band-pass filters for the FM band are connected in parallel with the transformers because the transformers cannot convey FM band signals.

Figure 9 shows the actual circuit.

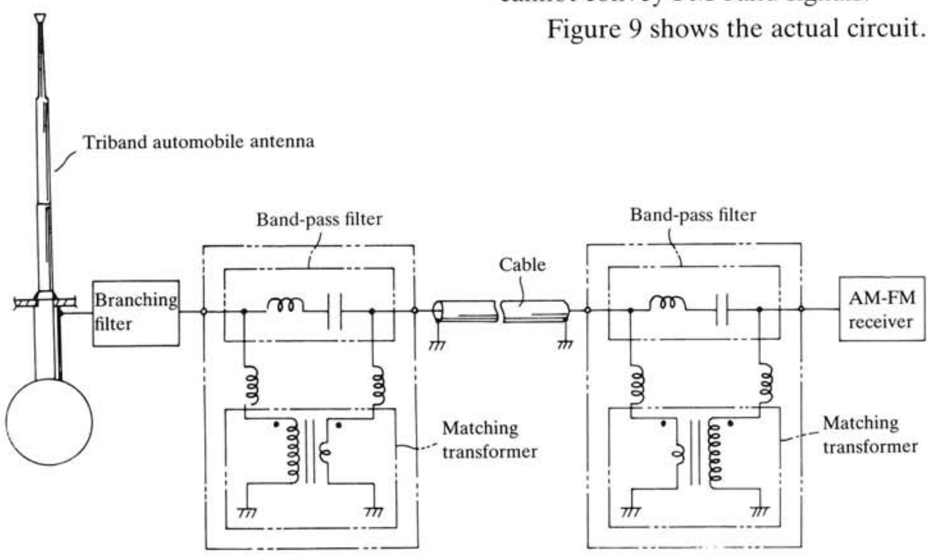


Figure 9. Circuit for improving AM broadcast reception voltage characteristics

3. Antenna performance

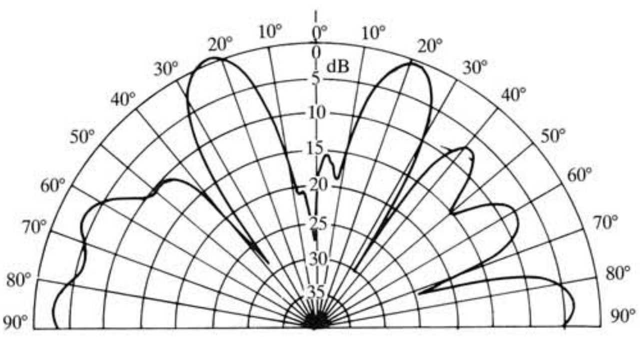
3.1 Characteristics in mobile telephone band

Figures 10a and 10b show vertical radiation patterns of vertically polarized waves in the mobile telephone band. The gain is about 3 decibels for the triband automobile antennas for use in Japan and in the U.S.A.

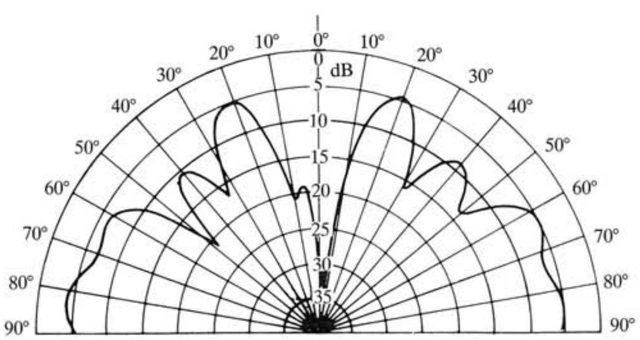
Figures 11a and 11c show the VSWR characteristics in the mobile telephone band. The VSWR is 1.9 or less for the triband automobile antennas for use in Japan (in the band from 860 to 940 megahertz) and in the U.S.A. (in the band from 824 to 896 megahertz).

3.2 Characteristics in FM broadcast band

Figures 11b and 11d show the VSWR characteristics in the FM broadcast band. The VSWR is 10 or less for the triband automobile antennas for use in Japan (in the band from 76 to 90 megahertz) and in the U.S.A. (in the band from 88 to 108 megahertz).

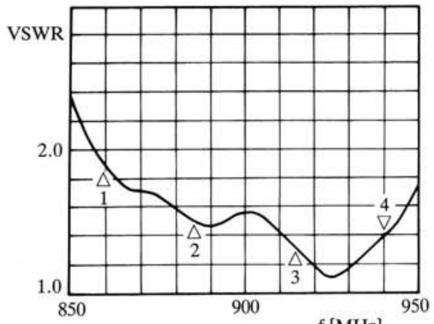


(a) Triband automobile antenna for use in Japan



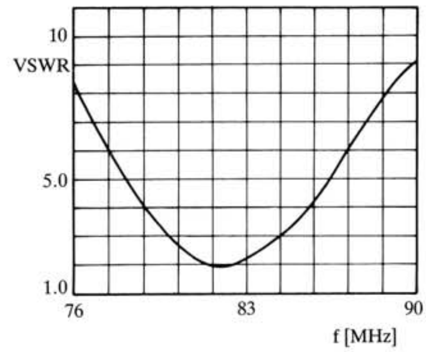
(b) Triband automobile antenna for use in the U.S.A.

Figure 10. Vertical radiation patterns of vertically polarized waves in the mobile telephone band

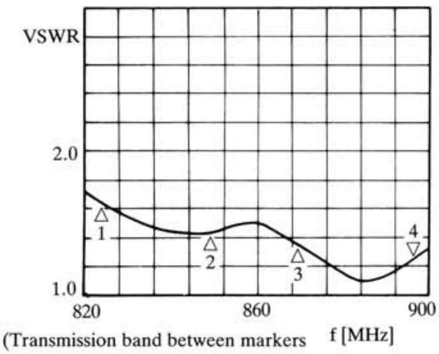


(Reception band between markers 1 and 2, transmission band between markers 3 and 4)

(a) Mobile telephone band (in Japan)

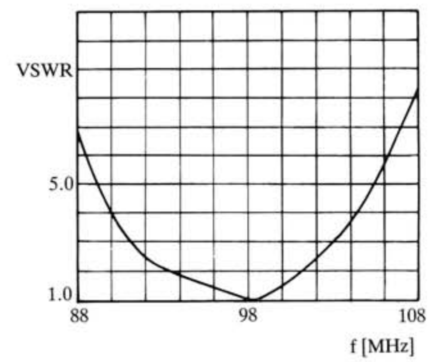


(b) FM broadcast band (in Japan)



(Transmission band between markers 1 and 2, reception band between markers 3 and 4)

(c) Mobile telephone band (in the U.S.A.)



(d) FM broadcast band (in the U.S.A.)

Figure 11. VSWR characteristics

Tables 2a and 2b list the measured FM broadcast band signal reception voltages. The values were measured with an antenna mounted on a 1 meter diameter metal disc. The tables also list the voltages measured with the reference antennas for comparison. During measurement, broadcast signals were received.

3.3 Characteristics in AM broadcast band

Tables 3a and 3b list the measured AM broadcast band signal reception voltages. The values were measured with an antenna mounted on a 1 meter diameter metal disc.

4. Example of mounting on automobile

Figure 12 shows an example of an automobile with the triband automobile antenna mounted, and wiring.

The motor section of the triband automobile antenna has a power terminal, control terminal, and ground terminal. The power terminal connects to the positive terminal of the automobile battery, which supplies 12 volts. The ground terminal connects to the negative (0-volt) terminal of the battery. The control terminal connects to the power supply linked with the ignition key (ACC) and is supplied with 12 volts when the key is on. In other words, when the driver turns on the ignition (ACC ON), 12 volts is supplied to the control terminal and the antenna extends. When the ignition is off (ACC OFF), the voltage at the control terminal becomes 0 and the antenna retracts into the automobile.

To store the triband automobile antenna while the automobile engine is running, the user operates the local antenna control switch. This operation is needed when the user stores the automobile in a garage or washes the automobile.

Table 2. FM broadcast reception voltage

(a) For use in Japan

Antenna \ Frequency (MHz)	85.1	86.5	88.1
AM-FM receiving whip antenna with 1 m long mast	44	58	44
Triband automobile antenna	44	56	44

[dBμV]

(b) For use in the U.S.A

Antenna \ Frequency (MHz)	88.1	97.25	101.75
AM-FM receiving whip antenna with 0.9 m long mast	44	42	28
Triband automobile antenna	43	42	44

[dBμV]

Table 3. AM broadcast reception voltage

(a) For use in Japan

Antenna \ Frequency (kHz)	558	1008	1431
AM-FM receiving whip antenna with 1 m long mast	72	70	46
Triband automobile antenna	72	68	48

[dBμV]

(b) For use in the U.S.A

Antenna \ Frequency (kHz)	558	1008	1431
AM-FM receiving whip antenna with 0.9 m long mast	70	70	44
Triband automobile antenna	72	68	47

[dBμV]

The above function and operation protect the triband automobile antenna from damage. The antenna is also protected from theft and mischief because it is stored while the automobile is parked.

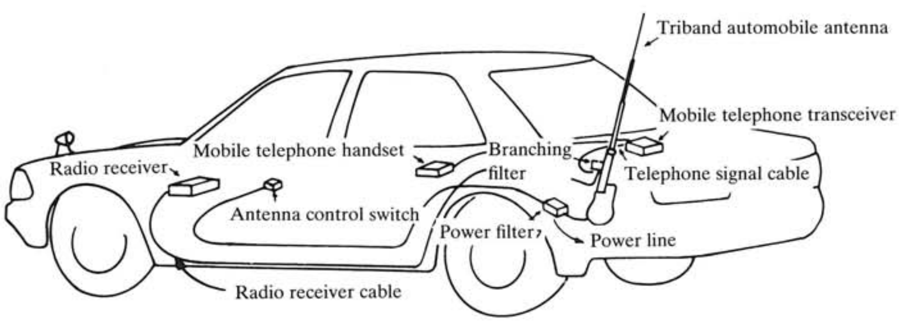


Figure 12. Example of mounted triband automobile antenna

5. Conclusion

The triband automobile antenna is a rod antenna that has the same appearance as ordinary motor-driven antennas. The triband automobile antenna is a result of combining a conventional AM-FM broadcast receiving antenna and a conventional mobile telephone antenna into one unit. This new antenna enables stable reception and transmission without detracting from the appearance of the automobile.

The triband automobile antenna is raised and lowered by a motor. It is automatically drawn into the automobile when the user turns off the ignition. This new antenna is convenient to users who are worried about theft or mischief.

If a forced-storage switch is added, it is convenient to the user because the triband automobile antenna is protected from damage when the user places the automobile in a garage or washes the automobile.

The triband automobile antenna has three stages of rod elements and requires a 23 mm diameter hole for mounting. With these features, the antenna can probably be mounted on an automobile if there is a space 370 millimeters long, 100 millimeters wide, and 60 millimeters deep in the trunk. The triband automobile antenna for use in Japan and the one for use in the U.S.A. have slightly different dimensions and circuit constants, but they are the same in appearance. A version for use in Europe can also be produced.

It is likely that various types of communication equipment will be mounted in automobiles in the future. We think that various types of automobile antennas must be combined at higher levels. The triband automobile antenna is the first try at combined antennas; we will propose products that really meet users needs from now on.

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