Electromagnetic Simulations of a W-loop Antenna Attached on a Rear Window of a Car

Taichiro Sato[1], Yoshihide Yamada[1], Kazushige Ogino[2]

[1] *Electrical and Electronic Engineering Department, National Defense Academy*

1-10-20 Hashirimizu, Yokosuka, Kanagawa, 239-8686 Japan, yyamada@cc.nda.ac.jp

[2] *FUJITSU TEN LIMITED*

1-2-28 Gosyodori, Hyougo-ku, Kobe, Hyougo, 652-8510 Japan, ogino@ftms.ten.fujitsu.com

Abstract

In order to apply the digital terrestrial TV service, a W-loop antenna had been developed. This antenna has very broad band characteristics of frequency range 470～716MHz. This antenna has the feature of placing an antenna between heater lines at a rear window of a car. Electrical performances are studies through experiment. However, design methods are not sufficiently clarified.

In this paper, antenna design methods of a developed W-loop antenna are studied through electromagnetic simulations. First, a broad banding process of a W-loop configuration is clarified. It is shown that almost the needed frequency band width can be achieved by a W-loop configuration. In order to fulfil the entire band width, a parasitic wire is adapted. Next, antenna input impedance change when an antenna is attached on a glass is studied. Reduction of antenna input resistance is shown. Finally, calculated and measured results of VSWR characteristics are compared. Rather good agreements are obtained. Moreover, frequency characteristics of radiation patterns are studied. Radiation loss factors are clarified. Antenna impedance matching is shown to become the main factor.

1. INTRODUCTION

In Japan, a digital terrestrial TV service has been started. This system uses the frequency range of 470MHz～716MHz. In order to receive this service in a car, a very wide band antenna is requested. A patch type antenna that had excellent VSWR characteristics was proposed[1]. Received level changes in accordance with antenna positions were also reported[2]. And the W-loop antenna was developed by Fujitsu Ten Limited. The actual situation of an antenna is shown in Fig.1.The feature of this antenna is to place an antenna between heater lines at a rear window of a car. By the W-loop configuration and parasitic straight wires, sufficient electrical performances were achieved.

In this paper, performance principles are clarified through electromagnetic simulations. First of all, broad banding mechanisms of a W-loop antenna structure are studied. Next, antenna input resistance changes in a dielectric material loaded antenna is studied. Finally, simulated and measured results are compared.

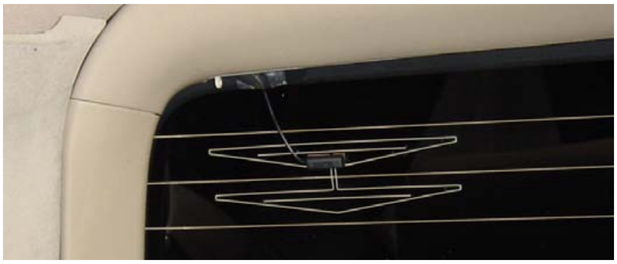


Fig.1 A W-loop antenna attached on a rear window of a car

2. FUNDAMENTAL STADY OF A W-LOOP ANTENNA

A. SIMULATION CONDITION

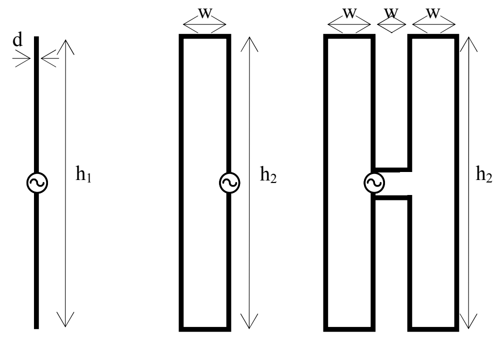
Simulation conditions are summarized in Table.1. A personal computer is used in calculations. As for electromagnetic simulator, a Method of Moment (MoM) based commercial simulator (FEKO) is used. An antenna is composed of small segments whose sizes are λ/100 of a calculation frequency. Here, λ is wavelength. A window is modelled by a dielectric plate of infinite width. In calculation, memory size is 753KB and calculation time is 36 second.

Table.1 Simulation conditions

Computer	Xeon3.6GHz, Memory4GHz
Electromagnetic simulator	Method of Moment（FEKO）
Frequency	400MHz～800MHz
Antenna segment	λ／100
Window	dielectric plate (thickness：5mm) ε_r=6.5, tanδ=0.024
Used memory	753KB
Calculated time	36sec

B. WIDE BANDING METHOD

Here, antenna broad banding mechanism is studied. In Fig.2, antenna structures are shown. As a fundamental structure, a half wavelength dipole antenna is considered. As broad banding structures a folded dipole antenna and a W-folded antenna are studied. In this case, the central frequency is 450MHz. Calculated VSWR characteristics are shown in Fig.3. In the case of a dipole antenna, feeder line impedance of 75Ω is used. In the cases of a folded and a W-folded antenna, feeder line impedance of 300Ω is used. By employing folded structures, antenna input resistances are increased up to about 4 times of a dipole antenna resistance. This value agrees well with the theoretical value of a folded structure. In comparing band widths of a dipole and folded structures, band width is expanded about 2 times by a folded structure. In the case of a W-folded structure, band width is expanded to 3 times of a dipole antenna. As a result, about 200MHz band width is achieved in VSWR<3. In order to satisfy the complete band width of 470MHz to 716MHz, one more resonant part is requested in the higher frequency region. For this purpose, a parasitic wire is expecting.



(a)dipole (b)folded (c)W-folded

d=0.5mm, h_1=324.8mm=0.54, h_2=304mm=0.51 λ , w=24mm=0.04 λ

Fig.2 Antenna structures used for broad banding study

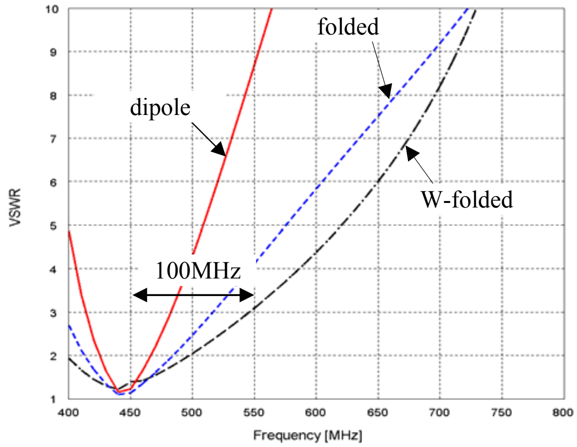


Fig.3 VSWR characteristics

C. INFLENCES OF DIELECTRIC LOADING

Fig.4 shows a half wavelength dipole antenna embedded in a dielectric material. Dielectric materials have infinite width and thickness. Study frequency is selected 500MHz. In accordance with ε_r change, antenna length (h) is changed so as to achieve resonance. Antenna diameter (d) is set 2mm. Calculated results are shown in Fig.5. Antenna resonant lengths are shown by a broken line. Antenna input resistances are shown by a solid line. It is recognized that antenna input resistances decrease in accordance with the inverse ratio of $\sqrt{\varepsilon_r}$. In the case of ε_r=4, antenna input resistance becomes the half of ε_r=1 case.

Physical explanation of these phenomena is considered as follows. First of all, charges induced on a dipole become proportional to ε_r in consideration of the electrostatic capacitance between two metallic rods. On the other hand, antenna (rod) length becomes inverse proportional to $\sqrt{\varepsilon_r}$. So, amount of current which correspond to the amount of charge become proportional to $\sqrt{\varepsilon_r}$. Consequently, input resistance become inverse proportional to $\sqrt{\varepsilon_r}$.

In the case of an antenna is attached on a glass, even though dielectric area is not sufficient, input resistance decrease is expected. So, when a W-folded antenna is attached on a glass, input resistance reduction is expected.

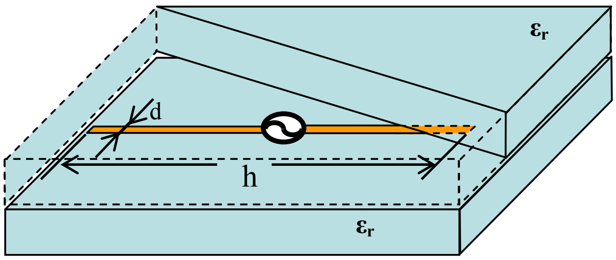


Fig.4 A dipole antenna embedded in a dielectric material

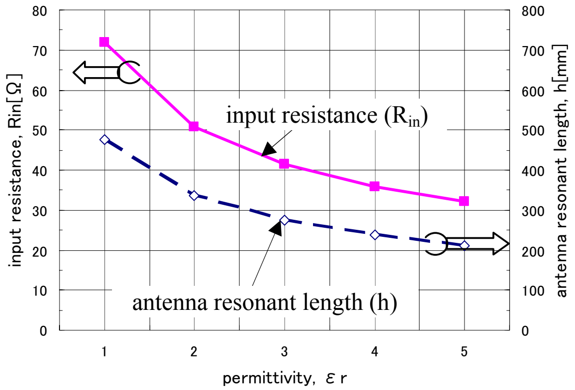


Fig.5 Antenna input resistance changes depending on dielectric constant changes

3. DEVELOPED W-LOOP ANTENNA

In Fig.6, the developed W-loop antenna configuration is shown. In the case of actual use, this antenna is attached on a rear window of a car. And this antenna is surrounded by heater lines as shown in Fig.1. So, the W-folded antenna shape is modified. Calculated antenna currents are shown in Fig.6. All current directions of a W-loop portion become the same. So, it is ensured that the folded antenna concept is satisfied also in the w-loop configuration.

Fig.7 shows a simulation model of a W-loop antenna on a glass. The glass is modelled by a dielectric plate of infinite expansion. By using this dielectric plate model, simulation loads are extremely reduced. Electrical field intensities in the vertical plain are shown in Fig.8. The high intensity area is concentrated within ±2cm in the Z axis. So, it is expected that the high ε_r region of 5mm thickness effectively influences antenna input resistance.

Calculated and measured VSWR characteristics are shown in Fig.9. In this case, a thin coaxial cable is used as a feed cable. The characteristic impedance of this cable is 75Ω. Measured result achieves VSWR of less than 4 in the objective frequency band. Although a dielectric plate of infinite width is used in calculations, calculated and measured results agree rather well.

The Smith chart expression of antenna input impedance is shown in Fig.10. Many kinks are observed. So, it is suspected that many complicated resonances are occurred on an antenna. Judging from the impedance locus in the low frequency, a larger loop size is considered preferable.

Radiation patterns of the E plain are shown in Fig.11. Radiation levels of 600MHz and 716MHz are similar. Peak levels become nearly 0dBi. The reason of peak level decrease from 2.15dBi is considered as follows. VSWR values of these frequencies are less than 2.5 in Fig.9. So, impedance miss match loss is about 0.5dB. Another loss factors are those depending on antenna conductor and dielectric material.

Antenna conductor loss is estimated about 0.05dB. Dielectric material related loss factors are loss of $\tan\delta$ and captured power in a dielectric plate. The $\tan\delta$ related loss is estimated to 0.5dB. So, other 1dB loss may be captured power. The peak level of 470MHz becomes –2.6dBi. The level reduction from the 600MHz level is produced by the impedance mismatch loss. As for summaries of radiation levels, $\tan\delta$ is one important factor of radiation losses. As the more important factor, antenna impedance matching should be considered.

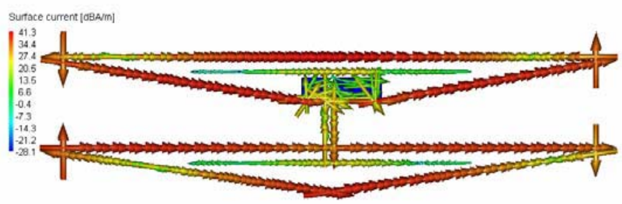


Fig.6 Structure of a W-loop antenna

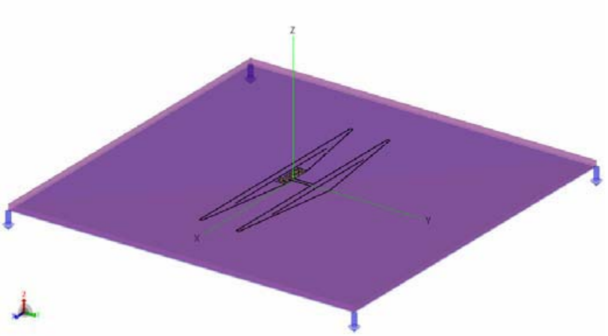


Fig.7 A W-loop antenna on a dielectric plate

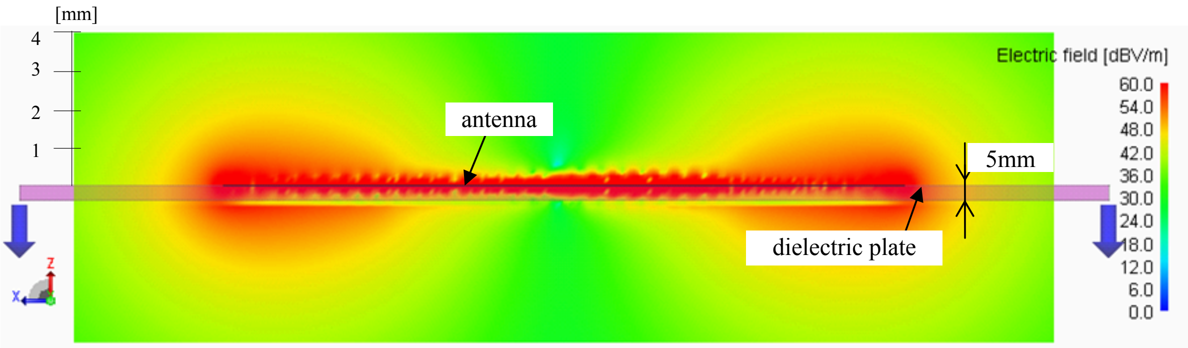


Fig.8 Electrical field intensities in the vertical plane

4. CONCLUSIONS

Antenna design methods of a developed W-loop antenna are studied through electromagnetic simulations. First, a broad banding process of a W-loop configuration is clarified. It is shown that almost the needed frequency band width can be achieved by a W-loop configuration. In order to fulfil the entire band width, a parasitic wire is adapted. Next, antenna input impedance change when an antenna is attached on a glass is studied. Reduction of antenna input resistance is shown. Finally, calculated and measured results of VSWR characteristics are compared. Rather good agreements are obtained. Moreover, frequency characteristics of radiation patterns are studied. Radiation loss factors are clarified. Antenna impedance matching is shown to become the main factor.

REFERECES

[1] R.Shimizu et. al.,"A development of window-attachable mesh antenna for TV-VHF", 2005 National Convention of IEICE, B-1-136, P.136, September 2005

[2] S.Fukushima et. al.,"A study on Vehicular Antenna Cnsidered Degital Terrestrial TV Wave Scattered on the Interior Surface of Vehicle", 2006 National Convention of IEICE, B-1-177, P.177, March 2006

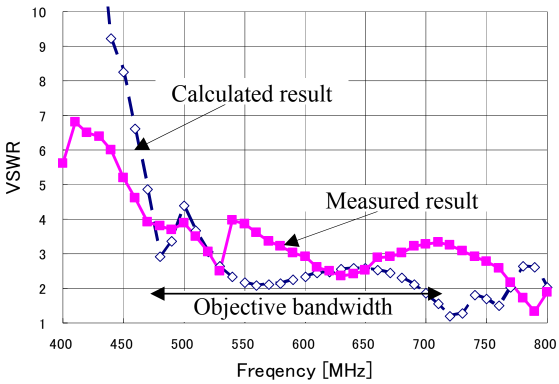


Fig.9 VSWR characteristics (feeder impedance is 75Ω)

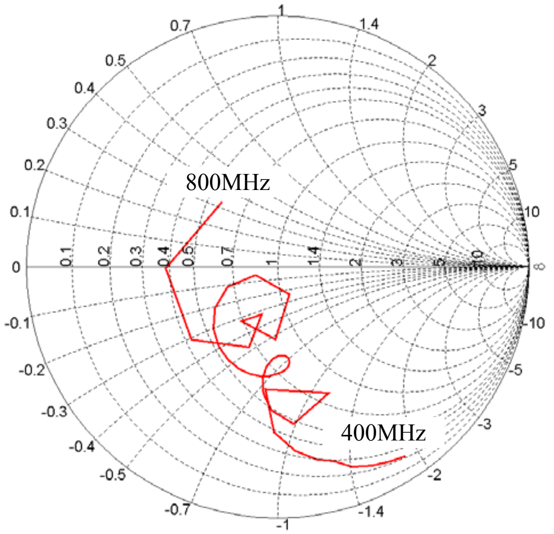


Fig.10 Smith chart of antenna input impedance

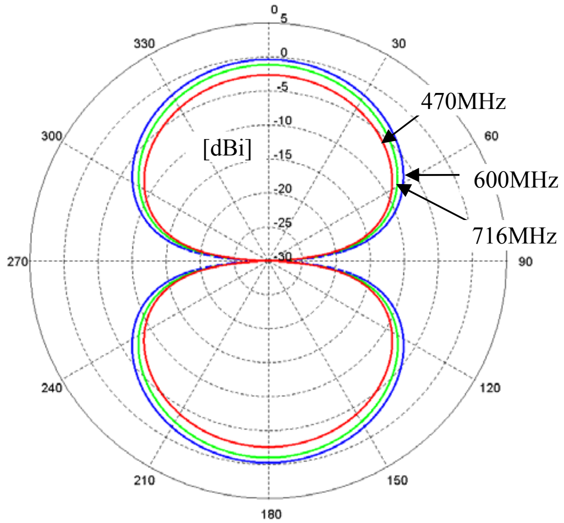


Fig.11 E-plain radiation patterns