Analysis of Radiation Characteristics of Optically Transparent Antenna Using Transparent Conductive Thin Film

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ABSTRACT

In this study, the radiation efficiency of the antenna with respect to the thickness and conductivity of the transparent conductive film was investigated. As a result, it was found that the thickness of the transparent conductive film had a significant effect on the radiation efficiency of the antenna, and the radiation efficiency of more than 68 % was obtained for a monopole antenna using an ITO transparent conductive film with a thickness of 300 nm.

1. INTRODUCTION

In recent years, research and development on the Internet of Things (IoT) and the 5th generation (5G) mobile communication system have been attracting attention [1].

Antennas are indispensable and one of the most important components in these wireless systems. In particular, since array antennas are used in 5G systems to improve communication characteristics, it is a challenge to install a large number of antennas while maintaining aesthetics so as not to impair the design.

If the antennas could be made of optically transparent conductive materials, the placement and design of the antennas would be more flexible, and these antennas could be placed on the surface of optical displays, window panes, and even product covers and housings without compromising their appearance.

For antennas which use transparent conductive films, it is essential to have both good optical transparency and electrical characteristics, but there are not many studies on antenna performance such as radiation efficiency with respect to film thickness and conductivity [2].

By forming a very thin metal mesh layer on the transparent dielectric material, the radiation efficiency of the antenna can be ensured, but the optical transmittance is reduced.

In this study, the radiation efficiency of a monopole antenna using a transparent conductive film with respect to the film thickness and conductivity is investigated.

2. ANTENNA CONFIGURATION

Figure 1 shows the configuration of the monopole antenna investigated in this study, with the radiating element length ℓ = 20 mm, width w = 1 mm, ground plane width d = 80 mm, and feed point spacing g = 0.5 mm. The thickness t of the transparent conductive film is from 100 nm to 18 μm. The antenna shown in the Fig. 1 resonates at around 3.3 GHz (the element length is about a quarter wavelength).

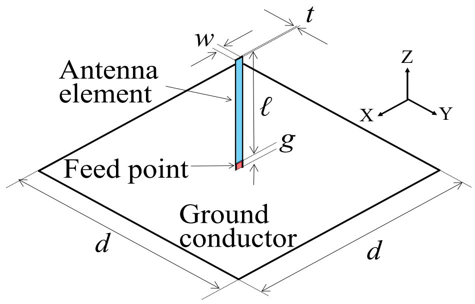

Fig. 1 Antenna configuration

3. RADIATION EFFICIENCY

Figure 2 shows the relationship between conductivity and radiation efficiency for transparent conductive films with thicknesses from t = 100 nm to 18 μm, obtained by electromagnetic field analyses.

Table 1 shows the skin depth and the radiation efficiency at film thicknesses of 100 nm, 1 μm, and 18 μm in Fig. 2.

As can be seen from the Fig. 2 and Table 1, the radiation efficiency of more than 90 % can be obtained when the film thickness is about the same as the skin depth.

It can be seen that as the conductivity of the transparent conductive film decreases, the skin depth also becomes deeper, and the radiation efficiency decreases significantly when the film thickness is thin.

4. CHARACTERISTICS OF ANTENNA MADE ON AN EXPERIMENTAL BASIS

Figure 3 shows a prototyped monopole antenna using a 300 nm-thick of Indium Tin Oxide (ITO) transparent conductive film (sheet resistance of 5 Ω, conductivity of 6.7 × 10^5 S/m, average transmittance of visible light 80 %) as the radiating element on a 0.7 mm glass plate.

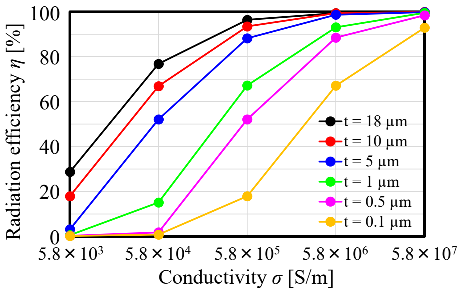

Fig.2 Relationship between conductivity and radiation efficiency for several film thickness

Table 1 Radiation efficiency for several film thickness

Conductivity σ [S/m]	Skin depth δ [μm]	Radiation efficiency η [%]		
		t = 18 μm	t = 1.0 μm	t = 0.1 μm
5.8×10^7	1.15	99.9	99.5	92.9
5.8×10^6	3.64	99.4	93.1	67.1
5.8×10^5	11.5	96.4	67.2	17.9
5.8×10^4	36.4	76.8	15.1	0.8
5.8×10^3	115	28.7	0.6	0.2

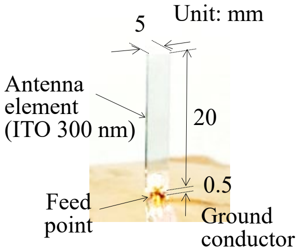

Fig.3 A prototyped antenna made on an experimental basis

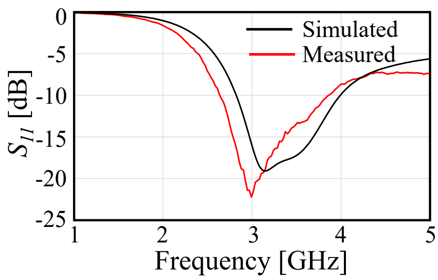

Fig.4 S_{11} characteristics obtained from measurement and simulation

Figure 4 shows the reflection characteristics S_{11} of the prototyped antenna shown in Fig. 3. As shown in the Fig. 4, it can be that the antenna resonates around 3 GHz and operates as an antenna.

Table 2 shows the results of the radiation efficiency of the prototype antenna measured by Wheeler method. As can be seen from the table, the radiation efficiencies of 68 % and 73 % obtained from measurement and electromagnetic field analysis, respectively.

The result show that it is possible to achieve both an optical transmittance of more than 80 % and a radiation efficiency of about 70 %, which can be used as an antenna.

Table 2 Radiation efficiency of the prototyped antenna made on an experimental basis

Radiation efficiency η	
Simulated [%]	Measured [%]
73.0	68.0

5. CONCLUSIONS

In this study, the radiation efficiency of the antenna with respect to the thickness and conductivity of the transparent conductive film was investigated. As a result, it was found that the thickness of the transparent conductive film had a significant effect on the radiation efficiency of the antenna, and the radiation efficiency of more than 68 % was obtained for a monopole antenna using an ITO transparent conductive film with a thickness of 300 nm. In addition, it was shown that the antenna can be flexibly implemented without compromising the design and aesthetics of the object on which it is mounted, as well as the design and arrangement of the antenna itself.

6. REFERENCES

[1] Jeffrey G. Andrews, et al., "What Will 5G Be?", IEEE Journal on Selected Areas in Communications, Vol. 32, No. 6, pp.1065-1082, June 2014.

[2] R. B. Green et al., "Optically transparent antennas and filters: A smart city concept to alleviate infrastructure and network capacity challenges," IEEE Antennas Propagation Magazine, vol. 61, no. 3, pp.37-47, June 2019.