AN ACCURATE AND SIMPLE DETERMINATION OF SMALL LOOP ANTENNA CHARACTERISTICS AT VHF BAND

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1. Introduction

Small loop antennas for pager are often used at VHF band. As well, antennas for portable FM radio receiver and portable TV set are operated at VHF band. The antennas are required to be as small, light and inexpensive as possible. For such terminals, a small loop antenna is best because of the low loss of the matching circuits, the smaller size, and the favorite effect of human body.

For small antennas, it is important to measure and calculate the antenna characteristics accurately because the matching circuits are very sensitive to the input resistance (below 1 ohm) and the antenna efficiency (below 10 %) is the critical design factor.

Many authors used network analyzer to measure the antenna characteristics [1,2,3]. Due to the principal limitation of network analyzer, the measured results had some errors and did not have the accuracy to measure the antenna characteristics of a small loop antenna. Instead of network analyzer, we use a impedance analyzer (HP4291A) and a simple test fixture(modified HP16093A). Using HP4291A and the simple test fixture, we show that it is possible to measured the resistance of the small loop antenna in accuracy of a few mohm, and the efficiency in accuracy of a few percentage below 200 MHz.

For comparison with the measured results, we calculate the input impedance of the antennas by the method of moments (MoM) and a approximate theory (APT) which treats the antennas as lumped circuits. From the results, we show that the MoM predicts the measured results accurately whereas the APT cannot predicts the measured ones even at the frequency where the maximum dimension of the small loop antenna is about 0.05 wavelength.

In the following, Section 2 shows the accurate and simple measurement. In Section 3, we explain the MoM and the APT. The measured and calculated results of the input impedance and the efficiency are shown in Section 4. The frequency dependence of the conductivity of the antenna wire is also discussed in the section. Section 5 is the conclusion.

2. Accurate measurement by the simple method

Fig. 1 shows the loop antennas to be used as (a) a reference loop antenna (RLA) and (b) a small loop antenna (SLA) whose radii are 1 mm. All of the antennas were made of a single copper wire so as to have the same electrical properties. Measurement is performed by using a modified test fixture of HP16093A on the 2 m X 1.9m aluminum ground plane. Fig. 1.(c) shows the structure of the attachment part of the test

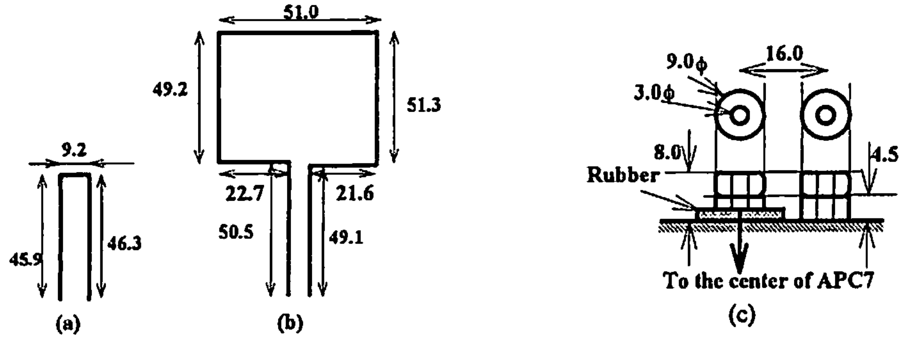

Fig. 1. The dimensions of (a) the reference loop antenna (RLA) and (b) the small loop antenna (SLA). (c) The detail of the test fixture to connect the antenna terminals. All dimensions are in mm.

fixture. Using the screws of the test fixture avoids tedious soldering works in measuring the antenna characteristics repeatedly and makes the measurement easy and reproducible.

First, HP4291A is calibrated by the open, short, and load standards with the additional one of the low loss air capacitor. Second, the errors caused by the test fixture are compensated by using a simple equivalent circuit model of the test fixture shown in Fig. 2.

Ztest is composed of series of the equivalent resistance and inductor of the test fixture to models the coaxial and parallel wire lines. Yopen is composed of the open capacitance and the radiation resistance. Ztest and Yopen is determined by assuming the impedance of two conditions to be known.

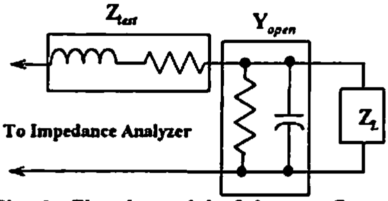

Fig. 2. Circuit model of the test fixture.

The one condition is to use the RLA whose input impedance is assumed to be exactly the calculated value (σ = 3.0e7[S/m] is adopted here) by the MoM. However the value of the conductivity has a small effect (below 10 mohm) on the input resistance of the SLA because the real and imaginary parts of Ztest are smaller than the ones of the input impedance. Another condition is to assume it to be perfectly open where nothing is connected to the test fixture.

From the measurement, it is found that the simple circuit model can be used below 200 MHz within 10 % accuracy. To measure more accurately or over 200 MHz would require to model the test fixture as F matrix (ABCD parameters) [4].

3. Calculation by the MoM and the APT

We calculated the loop antenna characteristics in two ways to compare the measurement.

One is based on the MoM. In the MoM, the current is expanded by a piecewise sinusoidal function. The MoM uses Galerkin's method and the thin wire approximation with the surface impedance of the wire [1]. Delta gap excitation is used and the convergence of the input impedance is attained by about 10 mm length of the subdivision.

Another is based on the APT which assumes that the antennas are small relative to the wavelength of operation, that is, the current on the wire is constant and the antennas are treated like as the circuit elements [5]. The lower the frequency would be, the more exact the approximation would be. However the following comparison between the MoM and the APT reveals that the statement is valid as for the input resistance whereas it is not true as for the input reactance. Therefor the APT can be used to check the validity of only the input resistance by the MoM at the very low frequency.

4. Results of the measurement, and the MoM and the APT

In the following, the measured results of the input resistance, the efficiency, and the input reactance of the SLA are shown and compared with the calculated results by the MoM and the APT.

4.1. Input resistance of the SLA

As doing by Wheeler cap method, we measured the input resistance with the copper box (20 cm W, 20 cm D, 20 cm H) and without the copper box . Then we calculated the measured radiation resistance by subtracting the resistance with the copper box from the one without the copper box.

Fig. 3 shows the measured resistance without the copper box and the measured radiation resistance. Fig. 3 also shows the input resistance of the APT with the conductivity being 3.0e7[S/m] and the one of the MoM whose conductivity is 2.0, 3.0, 4.0, 5.0e7[S/m]. In Fig. 3, the input resistance of the MoM without the conductor loss agrees well with the measured radiation resistance.

Comparing with the measured resistance without the copper box and the calculated one of the MoM of the various conductivity indicates that the conductivity changes from 5e7[S/m] at DC to 4e7[S/m] at 10 MHz, to 3e7[S/m] over 130 MHz. The radiation and input resistance of the APT become less than 90 % of the ones of the MoM over 50 MHz and 80 MHz respectively. Therefore the APT cannot be used even at 80 MHz where the maximum dimension (20 cm) of the antenna is about 0.05 wavelength.

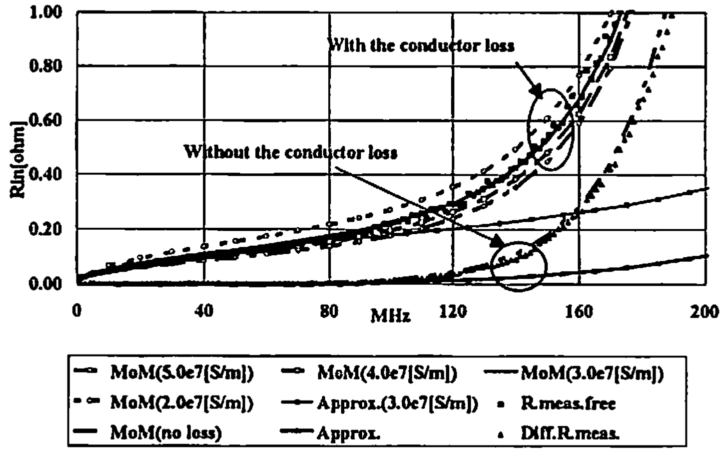

Fig. 3. The measured input resistance of the SLA without the copper box. The calculated input resistance is taken by the MoM and the APT with the various wire conductivity.

4.2. Efficiency of the SLA

The efficiency of the SLA was measured by Wheeler cap method [1,2,3]. Fig. 4 shows the measured results with the calculated efficiency of the MoM and the APT.

Over 110 MHz, the measured efficiency agrees well with the calculated one by the MoM whose conductivity is 2.0e7[S/m]. The result is inconsistent with the result from the input resistance mentioned above. As the efficiency is less dependent on the measured error than the resistance [2], the conductivity derived from the efficiency is considered to be more accurate.

Fig. 4 indicates that the efficiency can be measured over 3%. The efficiency of the APT differs from the one of the MoM by more than 3 dB over 110 MHz.

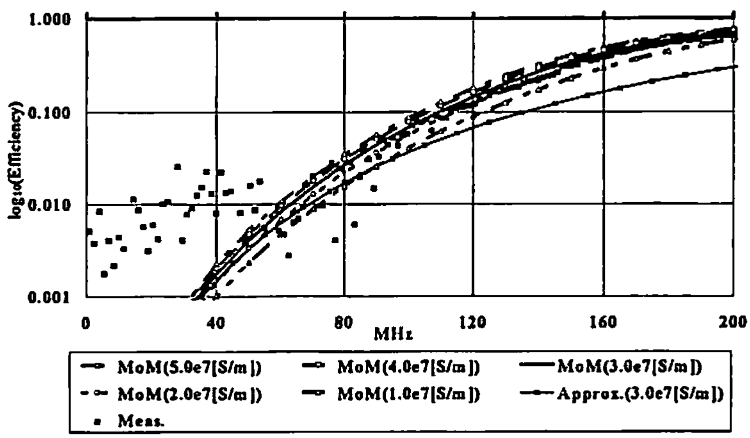

Fig. 4. The measured efficiency of the SLA and the calculated one by the MoM and the APT.

4.3. Input reactance of the SLA and the RLA

Because the input reactance of the SLA depends negligibly on the conductivity of the wire, Fig. 5 shows the measured result without the copper box with only the calculated results of the MoM and the APT without the conductor loss. The input reactance of the RLA is also included to show the discrepancy of the APT.

The measured input reactance agrees with the one of the MoM within 10 % error which reaches at 200 MHz. The input reactance of the APT is differ from the one of the MoM by over 20 % on the average. Even for the smaller antenna (RLA), the input reactance has error over 20 %.

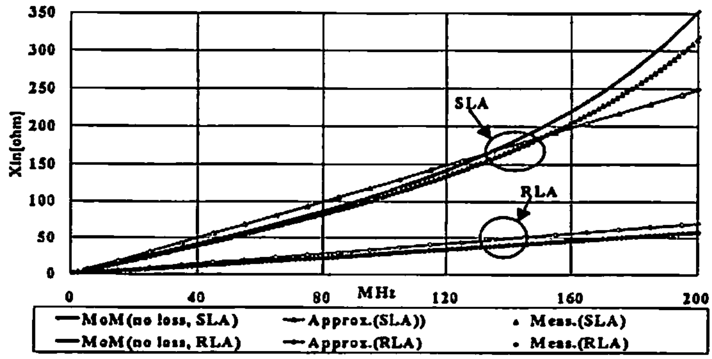

Fig. 5. The measured input reactance and the calculated one by the MoM and the APT.

5. Conclusion

We have shown the accurate and simple method to measure the low impedance of the small loop antenna below 200 MHz. By using the impedance analyzer HP4291A and the modified HP16093A test fixture, the resistance and the efficiency can be measured above 3 mohm and 3 % respectively in the easy way where there is no need to solder the wire to the ground.

We have found that the conventional approximate theory for the small loop antenna is not accurate even below the frequency where the antenna size is 0.05 wavelength. Therefore the MoM is required to obtain the accurate input impedance even at the very low frequency.

We have also found that the conductivity of the copper wire changes from 5e7[S/m] at DC to 2e7[S/m] at 200 MHz. The same results are obtained by the measurement of other pieces of copper wire.

We plan to reveal the frequency dependence of the conductivity in the near future because of the importance of the conductivity on the antenna efficiency and the resistance. We also plan to improve the accuracy and to extend the available frequency range by using the F matrix model.

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References

[1] N.Ishii and K.Ito : IEICE Trnas. Commun., Vol. E76-B, No.12, pp.1518-1525, Dec. 1993.
[2] I.Ida, T. Fujisawa, K. Ito and J. Takada : IEEE Int. Symp. APS, pp.1866-1869, 1993.
[3] I.Ida, J. Takada and K. Ito : Electronics Letters, Vol.30, No.4, pp.278-279, Feb. 1994.
[4] HP4291A operating manual, Hewlett Packard, 1995.
[5] W.L. Weeks : Antenna Engineering, Ch.2, McGraw-Hill, 1968.