An Analysis of the Effective Radiation Efficiency of the Normal Mode Helical Antenna Close to the Human Abdomen at 150 MHz

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1. INTRODUCTION

In VHF-band mobile portable radios for business purposes, the normal mode helical antenna (NHA) [1],[2] in monopole structure is commonly used with the radio attached to operator's trouser belt so as not to interfere with the operator's duty as in Fig. 1. Thus, the antenna operates in the close vicinity of the human abdomen, and the antenna performance is strongly influenced by the effect of antenna-human body electromagnetic couplings.

The NHA-human body coupling problem has been studied experimentally, and clarified that significant gain reduction takes place [3]. However, little has been investigated on the mechanism of that gain reduction analytically. In particular, consideration on dissipated power losses caused by impedance mismatch and ohmic resistance on the helix should be involved in the analysis since the axial length of the NHA is typically less than 0.1-wavelength at a frequency of 150 MHz, which causes a narrow bandwidth and a low radiation resistance.

In this paper, the NHA close to the human abdomen at 150 MHz has been analyzed in relation to antenna axial length and antenna-to-human body spacing as parameters. The analysis has been made based on radiation efficiency in terms of the available power which permits the effect of impedance mismatch loss and ohmic loss of the helix wire to include in the calculation, and thus represents the effective radiation efficiency under practical use condition. Furthermore mechanism of reducing the radiation efficiency has been clarified by investigating contributions of the dissipated powers to the total power loss.

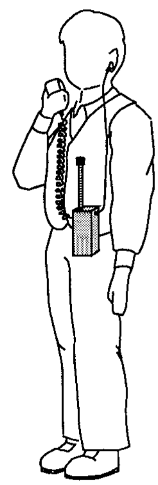

Fig. 1 Business Portable Radio

2. ANTENNA STRUCTURE AND HUMAN BODY MODELING

Figure 2 shows the NHA close to the human abdomen. The NHA has a dipole structure fed by a coaxial cable through a U-balun and a matching capacitor C. Table I exhibits three kinds of helix dimension investigated in this paper (pitch P, number of windings N and axial length L). The human body is modeled in cylindrical shape with a diameter of 22 cm and a height of 170 cm, and is approximated to a wire-grid model with 11 circles and 16 straight lines. The NHA is located at a distance D from the human body and at a middle height of 85 cm.

The human body can be treated as a lossy dielectric material and the surface impedance is calculated from the biological parameters of the human tissue as

$$Z_S = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\varepsilon}} \qquad (1)$$

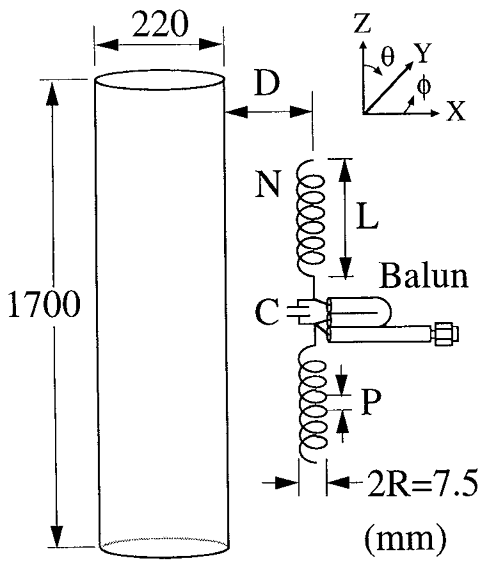

Fig. 2 Analytical Model

Table I Helical Structure

	Antenna Type		
	ANT1	ANT2	ANT3
P	1.3	1.9	3.4
N	45	48	48
L	59	92	163

(mm)

where ε and μ are electric and magnetic permittivity, σ is conductivity, ω = 2π*f* and *f* is the frequency. In this paper, ε and σ are set to be 57.7 and 1.5 S/m, and μ in free space is used. In order to simulate the human body by the wire-grid method, the diagonal elements in the impedance matrix are changed to include the lumped load impedances calculated from the surface impedance [4].

3. RADIATION EFFICIENCY IN TERMS OF AVAILABLE POWER

Figure 3 shows the equivalent circuit of the NHA close to the human body and the relationship between the dissipated powers. The equivalent circuit includes the balun and the matching circuit of a parallel capacitor C, and excited by a generator V_g with an internal impedance Z_g. The balun is approximated to the ideal transformer with the ratio of 1:4. With a radio placed in free space, the input impedance seen from the terminal a-a' is obtained from the following equation:

$$Z_{in} = \frac{1}{4}\frac{Z_a Z_c}{Z_a + Z_c} \qquad (2)$$

where Z_a is the helix impedance and Z_c is the capacitor's impedance. If the input impedance Z_{in} and the generator impedance Z_g are in the conjugate-matched condition, we obtain the following:

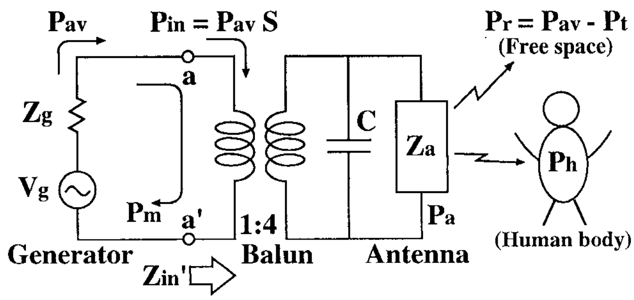

Fig. 3 Equivalent Circuit and the Dissipated Power Relations

$$Z_{in} = Z_g^* \qquad (3)$$

where the asterisk (*) denotes the complex conjugate. When the radio approaches a human body, the helix impedance is changed to be Z_a', and the input impedance becomes Z_{in}' according to eq. (2). The input power P_{in} applied to the antenna is expressed by the following equation:

$$P_{in} = \frac{1}{2}\frac{|V_g|^2 \operatorname{Re}(Z_{in}')}{|Z_g + Z_{in}'|^2} = P_{av} \cdot S \qquad (4)$$

where $P_{av} = \dfrac{|V_g|^2}{8\operatorname{Re}(Z_g)}$,

and $S = \dfrac{4\operatorname{Re}(Z_g)\operatorname{Re}(Z_{in}')}{|Z_g + Z_{in}'|^2} \leq 1$

Re[X] represents the real part of X and P_{av} denotes the available power from the generator. *S* expresses the ratio of power delivered to the antenna to power available from the generator, which is unity under the conjugate-matched condition. Let us define radiation efficiency η with respect to the available power using the following relationship:

$$\eta = \frac{P_r}{P_{av}} = \frac{P_{av} - P_t}{P_{av}} \qquad (5)$$

$$P_t = P_h + P_a + P_m$$

where P_r is the power radiated into the air, P_t is the total power loss, and P_h and P_a are the powers absorbed in the human body and dissipated in the helix wire due to its ohmic resistance, respectively. P_m is the power loss due to the impedance mismatch. The relationship of these powers is illustrated schematically in Fig. 3. Usually, radiation efficiency is defined as the ratio of total radiated power to the net power accepted by the antenna P_r/P_{in} [5]. Our definition in (5) is a measure of how effectively the antenna converts

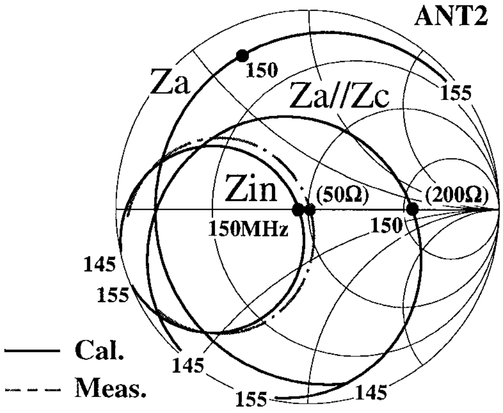

Fig. 4 Impedance Characteristics in Free Space

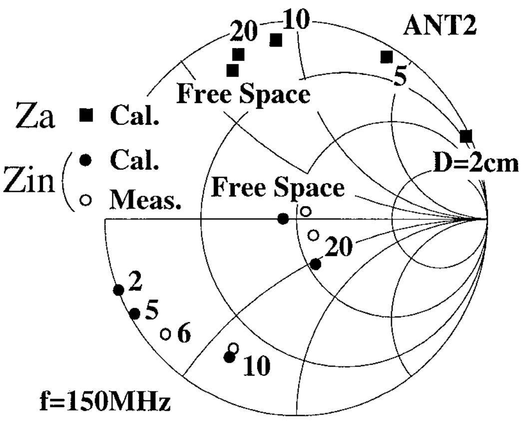

Fig. 5 Impedance Characteristics Close to the Human Body

available power P_{av} into transmitted power P_r. This radiation efficiency is analogous to transducer power gain in the design of two-port networks (e.g. amplifiers) in circuit theory [6], and represents the effective radiation efficiency which includes the effect of impedance mismatch P_m, and thus is useful in considering the performance under practical use condition.

4. ANALYTICAL RESULTS

A. IMPEDANCE CHARACTERISTICS

Figure 4 shows the impedance characteristics of the ANT2 in Table I in free space. The figure illustrates the helix impedance Z_a and the input impedance Z_{in}, along with the Z_a, Z_c parallel impedance $Z_a//Z_c$ for understanding impedance matching behavior. It is shown from Z_a that the NHA has a self-resonance frequency of about 150 MHz. Z_a is located on a equi-conductance circle of 5 mS at 150 MHz, and $Z_a//Z_c$ is modified to a pure resistance of 200 Ω by a capacitor C of 32 pF, and then $Z_a//Z_c$ is divided by 4 by a balun to become Z_{in} of 50 Ω. From Fig. 4, the measured Z_{in} are in very good agreement with the calculated ones.

Figure 5 exhibits the Z_{in} vs. human body-antenna distance D relation at 150 MHz. As can be seen from Z_a (black squares), the inductive reactance increases as the antenna approaches the human body. This phenomenon is different from its dipole antenna counterpart, in which the reactance becomes capacitive in the vicinity of the human body [4]. Z_a is converted to Z_{in} by a capacitor C and a balun according to eq. (2), and has the capacitive reactance as indicated by the black circles in Fig. 5. The white circles show the data measured by a 30-year-old man, which agree very well with the calculated data.

B. RADIATION CHARACTERISTICS

Figure 6 shows the calculated and measured radiation patterns in the horizontal plane close to the human body together with in free space. The radiation pattern is omnidirectional in free space. In the presence of the human body, a gain more than 0 dBd is obtained in the opposite to the human body (x-direction) for D=20cm, however, the whole radiation pattern shrinks less than 0 dBd for D=10cm, indicating a low radiation efficiency.

Figure 7 illustrates the radiation efficiency vs. distance D relation calculated by eq. (5). Significant efficiency reduction can be observed with decreasing D. When D=2cm, the radiation efficiency is 20 dB less than that of a whip antenna for portable telephones at 800 MHz (η = -3dB) [7]. However, the radiation efficiency of ANT3 is 10 dB greater than that of ANT1. In order to investigate the mechanism for this phenomena, the dissipated powers appeared in eq. (5) are

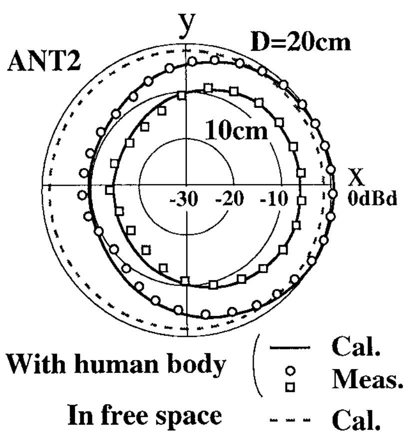

Fig. 6 Radiation Patterns

calculated.

Figure 8 shows the powers P_h, P_a, P_m and P_t of ANT1 to ANT3. The powers are normalized to the available power P_{av}. It can be seen from Fig. 8 that when D<10cm the ratio of P_m to P_t is considerably higher than that of P_h to P_t, indicating that the mismatch loss P_m is the major factor in the total power loss P_t. In addition, the NHA with a shorter axial length, ANT1, promotes that tendency. However, when D>10cm the ratio of P_a to P_t increases and the ohmic loss is the major factor in P_t, particularly in ANT1. As explained in this manner, there is a different mechanism in determining the dissipated powers as the distance D varies, which results in the maximum value of P_h at D from 10 to 20 cm.

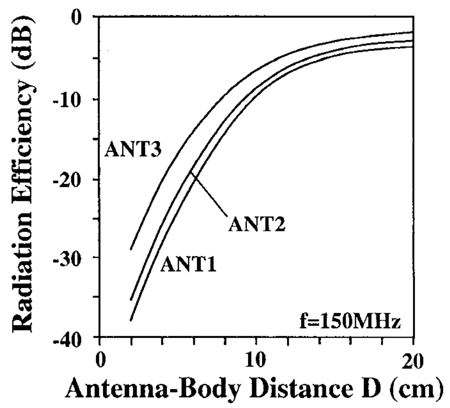

Fig. 7 Radiation Efficiency vs. Distance D

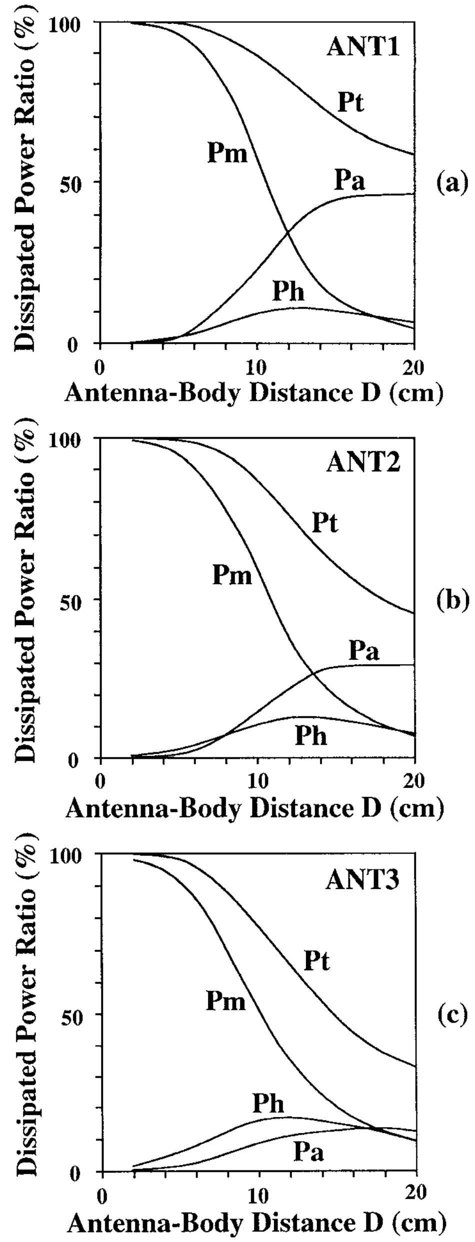

Fig. 8 Dissipated Powers vs. Distance D

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