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Usefulness of Ferrite Antenna Applied to Mobile Communication Systems

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Use of ferrite antennas seems to have been mostly confined to radio receivers. This paper discusses usefulness of ferrite antenna applied to land mobile systems, where inductive communication system is utilized and transmitter as well as receiver employs ferrite antenna. Recent development of digital mobile communication systems has demonstrated its importance to various urban traffic systems such as traffic control, vehicle identification, and vehicle location. One of the typical communication systems appropriate for those systems is what is called "sign-post" system, in which mobiles communicate with sign-post stations scattered along the roadsides, with which the center equiped with a computer is linked by wire lines. Fig.1 shows a model of such a sign-post system arrangement, where locations of sign-post are shown by S_i (i=1,---n) and coverages in which mobiles communicate with sign-post stations are expressed by hatched areas. Since in the inductive communication system coverage is confined to relatively narrow areas by its nature of electromagnectic coupling, it would be quite suitable to realize the sign-post arrangement.

In addition to small size, ferrite antennas exhibit some remarkable features, when applied to systems discussed above; that is,

(1) high coupling efficiency, and
(2) flexible formation of communication coverage pattern.

Inductive communication link can be modeled by a circuit shown in Fig.2, where only a set of transmitter and receiver is shown as the typical one. One of the most important factors in the design is efficiency of power transfer between transmitter and receiver and hence the coupling efficiency η between transmitter and receiver antennas is defined as follows;

$$\eta = \frac{\text{Pr(power output of receiver antenna)}}{\text{Pt(power delivered to transmitter antenna)}} \quad . \qquad (1)$$

Since the communication link is essentially a magnetic coupling circuit, it is equivalently expressed by a network shown in Fig.3, in which notations for the network parameters are provided. The coupling efficiency η is expressed by using antenna parameters as follows;

$$\eta = \frac{(\omega M)^2}{4\, r_t\, r_r} \quad , \qquad (2)$$

where ω is angular frequency.

An example of the geometry for an antenna arrangement is shown in Fig.4, where two antennas are arranged in parallel. As the essential factor in Eq. (2), the mutual inductance M between two antennas can be obtained by

$$M = \frac{\mu_o}{4\pi} \mu_t N_t \mu_r N_r \oint_{c_t} \oint_{c_r} \frac{d\$_t \cdot d\$_r}{R} , \quad (3)$$

where d$ denotes line element (vector). As it can be seen from Fig's. (2) and (3), the mutual coupling M is desirable to be as large as possible. In the frequency range for inductive communications, typically below 250kHz, ferrite antennas show favorite characteristics with fairly high permeability (≥ 100) and low loss ($<10\Omega$). Thus, with ferrite antennas, high coupling efficiency can be realized rather easily. Communication coverage is found by calculating the output V_r of the antenna A_r, which is given by

$$V_r = \omega I_t M (\rho, \phi, z) . \quad (4)$$

Eq.(4) implies that the mutual inductance M determines patterns of communication coverage. The coverage pattern is different depending upon combination of antenna arrangement; that is, position and direction of axis of antennas. Several examples are shown in Fig.5. This is another significance of use of ferrite antenna; coverage pattern, thus antenna arrangement, may be selected to fulfil the system requirement. For instance, a circle pattern is selected when sign-post should be located on each lane, while a hyperbolic pattern is used when a narrow, long coverage is desired. This special feature distinguishes the system from conventional mobile system which utilizes electromagnetic wave propagation, that can not produce coverage pattern flexibly.

A practical example of the design parameter is given in Table 1, in which antennas are considered to possess the same dimensions($d_t=d_r=d$) and the same characteristics($N_t=N_r=N, \mu_t=\mu_r=\mu$). When antennas are placed on one line (e.g. on Z axis in Fig.4), the mutual inductance can be obtained by

$$M = \frac{\pi}{2} \mu_o \mu^2 N^2 (\frac{d}{2})^4 / R_z^3 , \quad (5)$$

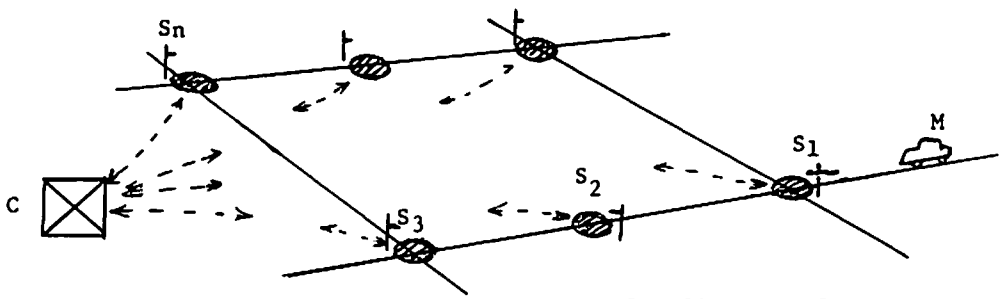
where R_z is the distance of two antennas on Z axis.

Dimensions of antenna used are 3 cm in diameter and 10cm in length. To make analysis simple, the length of ferrite is not taken into consideration. Here the coupling efficiency is found to be - 38.6dB (1=0dB). The usefulness of ferrite antennas has been evidenced by the practical operations such as bus priority and bus location systems. Effective utilization of its features would be quite instrumental in constituting digital mobile communication systems such as vehicle location systems.

Table 1 A Practical Example of Design Parameters

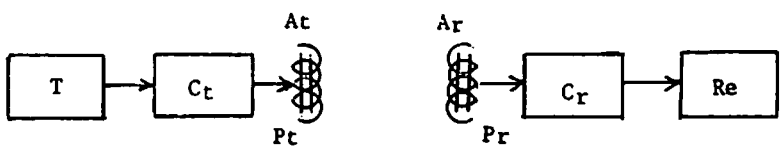
f	I_t	N	μ	r	d	R_z	M	η	V_r
100	100	100	100	10	0.03	3	3.7×10^{-7}	1.37×10^{-4}	12
KHZ	mA	turns		Ω	m	m	H		mV

Fig. 1 Sign-post Communication System



S: Sign-post Stations
M: Mobile Station
C: Center

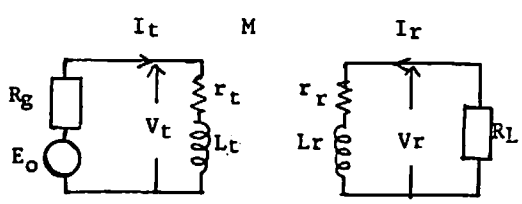
Fig. 2 A Set of T-R Link



T: Transmitter Circuit
Re: Receiver Circuit
C: Coupling Circuit
A: Antenna
P: Power

Subscripts t and r denote for transmitter and receiver, respectively.

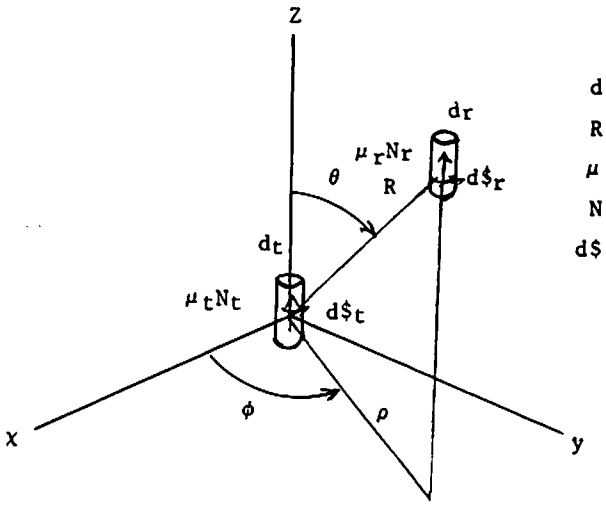
Fig. 3 Equivalent Circuit of Antenna System



M: Mutual Inductance
L: Self Inductance
r: Loss Resistance
ω: $2\pi f$ f: frequency

R_g: Source Resistance
R_L: Load Resistance
E_o: Source

Fig. 4 Coordinate System



d: Diameter of Antenna
R: Distance of Two Antennas
μ: Permeability
N: Number of Turns
d$: Line Element

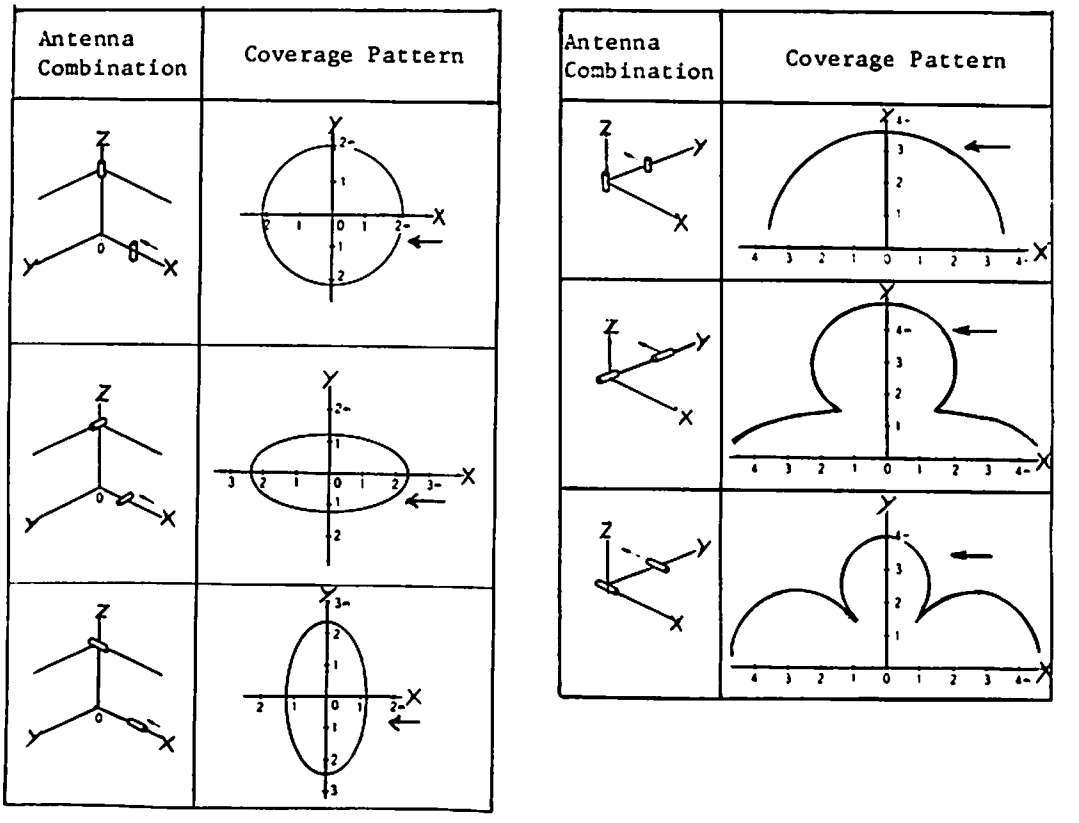



Fig. 5 Coverage Patterns