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HIGH FREQUENCY MOBILE LOOP ANTENNAS

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INTRODUCTION

In a country such as New Zealand there are many places where VHF or UHF mobile radio is unsatisfactory or prohibitively expensive. In these circumstances many mobile radios use the HF (2-6 MHz) band, and commonly employ a 2 metre high helical whip antenna (an electric field antenna) on the vehicle.

This paper discusses high frequency loop antennas (magnetic field antennas) which have been developed at the Physics and Engineering Laboratory to replace the whip antennas. The loops are suitable for mounting on the roof of a vehicle or the deck of a small ship. They may also be used for fixed stations.

Prototypes undergoing field trials by the major users of mobile radios in New Zealand at present have a power rating in excess of 100 watts. The tuning may be fixed, or continuously variable over a 3:1 frequency range in the 2-10 MHz band. The loops are matched to 50 ohms and have a 3 dB bandwidth of the order of 12 kHz. Rectangular loops about 1.5m x 0.4 m, made from 2.5 cm diameter copper tubing, have a maximum groundwave efficiency which is comparable with that of 2m helical whips, but the skywave performance of the loops is superior.

During the development of the loop antennas, several were constructed in such a way as to introduce a controlled amount of "antenna effect", thereby largely filling in the nulls in groundwave response. However the nulls are of little consequence, because the most effective HF propagation mode over distances of the order of 10 - 200 Km is the high angle skywave.

The hypothesis advocated here is that if skywaves are to be used then the mobile antennas should be magnetic antennas (loops). Such antennas should give uniform performance at all ranges from zero to the order of 200 Km.

COMPARISON OF MAGNETIC AND ELECTRIC ANTENNAS

The HF antenna mounted on a vehicle is generally of the order of a fiftieth of a wavelength above the ground, and is of similar size. Being so small and so close to the ground the antenna is to all intents and purposes on the surface, where vertical magnetic fields and horizontal electric fields tend to zero. In this situation a whip (an electric field antenna) will respond to the vertical electric field, and a loop (a magnetic field antenna) will respond to the horizontal magnetic field. A groundwave is received well on either a whip or a loop, because its electric field is vertical, and its magnetic field is horizontal.

The fields of a steeply downcoming HF skywave are complicated by the ground-reflected fields and a standing wave pattern is observed close to the ground. A further complication is that the skywave has two circularly polarized components, one of which is usually stronger than the other. The resultant standing wave in the vicinity of the mobile receiving antenna will appear to have a vertical electric field and an elliptically-polarized horizontal magnetic field, but the electric field will be weak and the magnetic field will be strong. In this situation the nulls in the loop response become insignificant, and the loop is superior to the whip. Figure 1 shows the expected maximum field strength versus distance for groundwaves and skywaves at 5 MHz.

COMBINED MAGNETIC AND ELECTRIC ANTENNAS

There may be occasions when an antenna with the skywave response of a loop and the groundwave response of a whip is useful. Such a device may be made from a loop antenna by adding components which allow it to act also as a whip. The centre point of the base of the loop is connected to a ground plane with a tunable loading coil. The loop is resonated, and the loading coil is also resonated; when both circuits are correctly tuned the nulls in groundwave response of the loop are found to be significantly "filled in". If it is desired to use this technique without a ground plane the lower portion of the loop is screened and the loading coil is connected between loop and screen. A slight loss in maximum efficiency occurs with this construction. The prototypes being tested at present have screened bases, but production loops will probably dispense with this refinement.

ANTENNA MATCHING

The small HF mobile antenna is highly reactive, and if it is to be useful, the reactance must be "tuned out" so that the antenna may be matched to the tranceiver by a transformer or pi-coupler. A series "loading coil" is used to tune a whip (in the helical whip the loading coil is spread out along the whip). A loop antenna is resonated by a series capacitor.

A resonated whip has an input resistance of the order of 50 ohms, so it is a reasonable match to a 50 ohm transmission line. A resonated loop has a series input resistance of the order of 0.1 ohm, and is most conveniently matched to 50 ohms by a transformer with a toroidal ferrite core and a turns ratio, m, of the order of 20:1.

COMPARISON OF EFFICIENCY AND BANDWIDTH OF LOOPS AND WHIPS

A convenient, although not rigorous, definition of the groundwave efficiency, η, of a small mobile antenna, is the ratio of radiation resistance, R_r, to series input resistance, R_s.

$$\eta = \frac{R_r}{R_s}$$

when the loop is matched to the same series input resistance as the whip (by using a 1:m coupling transformer) the relative groundwave efficiency becomes

$$\frac{\eta \text{ loop}}{\eta \text{ whip}} = \left(\frac{4\pi m A m}{\lambda h}\right)^2$$

where n = number of turns in loop
A = area of loop
h = height of whip
λ = wavelength

The relative skywave efficiency is a function of angle of elevation of the desired ray as well as the polarization; it is always higher than the relative groundwave efficiency for ranges from 0 - 200 kilometres.

A two metre high mobile whip has a groundwave efficiency of the order of 1% (-20dB) at 5 MHz. The 1.5 x 0.4 metre prototype loops we have made have groundwave efficiencies of the same order as a 2 metre whip.

The bandwidth of the antennas may be derived from the formula for the bandwidth of a single tuned circuit. When a loop antenna is transformer coupled to a transmission line which is terminated in its characteristic impedance the bandwidth between -3dB points is given by

$$2\Delta f = {}^{R}s/\pi\, L_1\, m^2$$

where L_1 = loop inductance.

Similarly, a matched whip antenna has a bandwidth given by

$$2\Delta f = {}^{R}s/\pi\, L_2$$

where L_2 = loading coil inductance.

The relative bandwidth is then given by $L_2/m^2\, L_1$

A typical mobile loop antenna has a bandwidth of 12 kHz whereas a 5 MHz, 2 metre high whip has a bandwidth of about 125 kHz.

At first sight the narrow bandwidth of the loop antennas may give tuning problems, but this is not borne out in practice. The tuning is found to be more stable than that of the whips. A more significant feature is the startling improvement in signal to noise ratio when a loop is used for reception. The explanation for this is thought to be that the loop antenna filters out strong interfering signals which would otherwise overload the receiver.

CONCLUSION

Practical HF loop antennas have been constructed for use in the mobile service. The prototypes were generally of the form shown in Figure 2g, but experience suggests that the simpler form of Figure 2e will be adequate for most applications. Some of the loops had two turns, which could be connected either in series or in parallel, but they gave no significant improvement in performance over a single turn loop. Nulls in groundwave response can be reduced if required, skywave response is much better than that of a whip, and the narrow bandwidth of the loops makes them ideal for reception, giving an improved signal to noise ratio. They have a power rating in excess of 100 watts, and give a better overall performance than a 2 metre high helical whip antenna at 5 MHz.

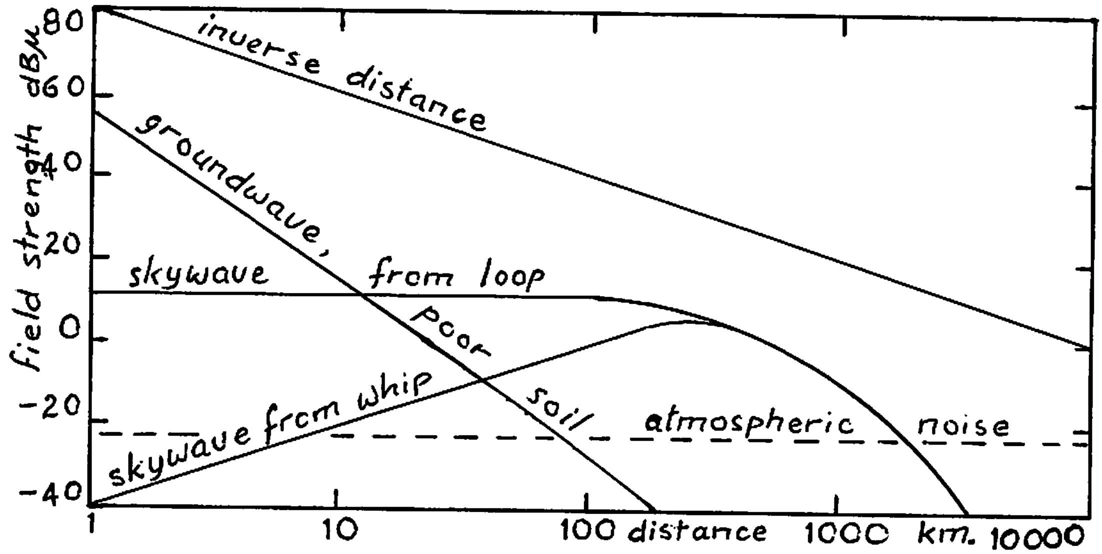

FIGURE 1 INCIDENT ELECTRIC FIELD STRENGTH for 1 watt radiated at 5 MHz at noon in winter, mid-latitude, $f_oF_2 > 5$ MHz at 400 km.

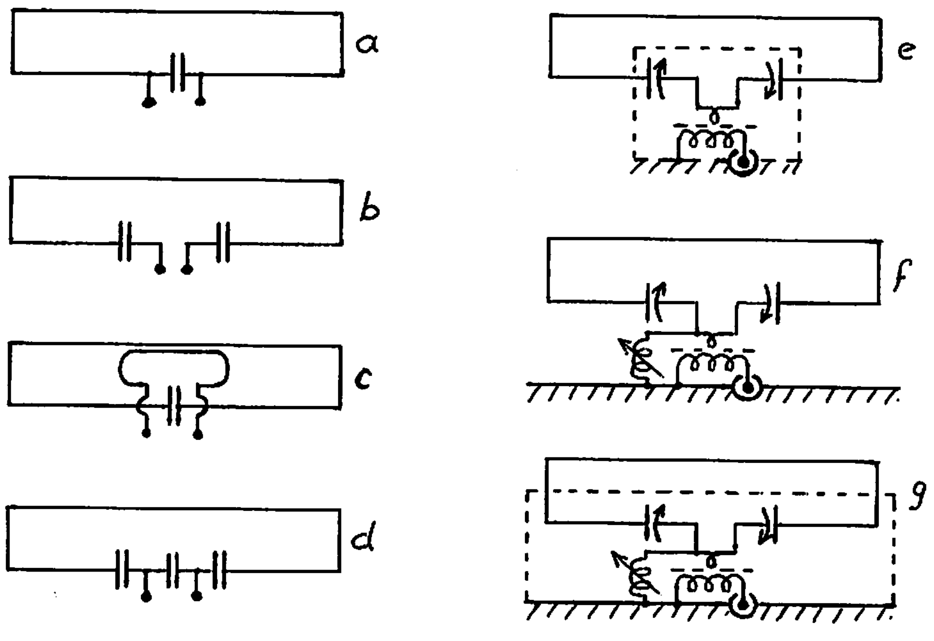

FIGURE 2 DEVELOPMENT OF LOOP ANTENNAS

a. Parallel tuning
b. Series tuning
c. Link matching
d. Capacitance matching
e. Transformer matching
f. Reduced nulls - ground plane
g. Reduced nulls - screened loop