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MODIFIED TRANSMISSION LINE ANTENNA ON A CONDUCTING BOX

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1 Introduction

To date, the antenna most widely used for portable communication transceivers is the monopole. This antenna has good efficiency and bandwidth, but is obtrusive and susceptible to damage. More recently, there have been investigations of inverted F antennas for such applications [1,2]. Compared with the monopole, these antennas show improved cross polarization response, which has found to be desirable for urban radio environments [3]. In this paper, the properties of a number of modified transmission line antennas (MTLAs) are presented. Emphasis has been given to maximizing the bandwidth and cross polarization properties of these antennas, with a given maximum antenna dimension.

2 Analysis of the designs

An example of an MTLA is shown in fig 1. The dimensions of the antennas presented in this paper are limited to (60 x 25 x 20) mm, with the exceptions of antennas 5 and 7. These antennas are constructed from copper wire of radius 0.5 mm and are resonant at approximately 1000 MHz. They have been mounted on a conducting box of dimensions (105 x 60 x 18) mm.

A simple model for an MTLA is shown in figure 2. Note that the two vertical radiators are separated by a horizontal conductor and mounted on a perfect ground plane. In this case, simple theory dictates that when the distance from the horizontal wire to the ground plane is small, the structure behaves as a short circuited transmission line of length ℓ, resonant at the wavelength $\lambda = 2\ell$. Although this model explains the basic properties of the MTLA, it ignores the following :-

(i) In an MTLA, the distance from the horizontal conductor to the ground plane is not negligible, so energy can be radiated out from this part;
(ii) In an MTLA, the distance from the horizontal conductor to the ground plane is not always constant, so the characteristic impedance of the transmission line is not constant with position along the line;
(iii) The ideal model assumes a straight transmission line. In an MTLA, the transmission line is bent so that mutual coupling exists between adjacent elements on the structure;
(iv) The ground plane of and MTLA mounted on a conducting box is finite, so there is incomplete cancellation of the horizontal currents in the ground plane.

Because of the deficiencies in this simple model, computer modelling has been chosen for this study. The input impedance and radiation pattern of each of the antennas mounted on the box has been calculated using the Numerical Electromagnetic Code (NEC-2) [4]. A wire grid model has been employed with 198 segments for the box and 16-20 segments for the antenna itself. Measurements of a number of these MTLAs show that, in all cases, the resonant frequency as predicted by NEC falls within 4% of the measured value.

3 Current distribution and bandwidth

Table 1 shows the various parameters of a number of MTLAs. As predicted by the simple transmission line model, each model exhibits a current node approximately half way along its length. Unlike the simple model, which indicates a resonance for $\lambda = 2\ell$, the MTLAs are resonant for $1.33\ell < \lambda < 1.69\ell$. These discrepancies can be attributed to the following reasons. Firstly, the perfectly sinusoidal current distribution of the simple model is perturbed when a current node falls on a sharp bend in the structure [5]. Also, bending the horizontal conductor of the antenna creates mutual coupling between certain elements of the structure. The degree of coupling is dependent on the interelement spacing, introducing loadings which are largely asymmetrical. It has been noted that length, l, required for resonance at 1000 MHz is minimized when the coupling between adjacent conductors is low, i.e. when the conductors are far apart (refer to antenna 5), or when the mutual inductance between adjacent conductors is positive (for antennas 4 and 6). Conversely, l is maximized when the mutual inductance between adjacent elements is negative (for antennas 1 and 3). This observation confirms the results of Fenwick [6] .

For all the MTLAs tested, the radiation resistance (Rrad) was determined primarily by the height of the vertical conductors. Antenna 6 is typical, with Rrad increasing from 67 Ω to 150 Ω as the height increases from 10 to 20 mm. Nevertheless, some variation in Rrad has been noted for antennas of the same height (see antennas 2,3,4,6 in table 1). This can be attributed to changes in the transformation ratio, due to the horizontal conductors of each antenna, as noted by Fenwick [6].

The radiation resistance of each antenna is also dependent on the dimensions of the conducting box. Table 2 shows the change in bandwidth with the length of the box, L, for antenna 6. The bandwidth steadily increases with increasing L, but decreases when mounted on an infinite ground plane, suggesting that there may be an optimum box length. Similar results have been observed by T. Taga *et. al.* [1].

4 Radiation pattern

The radiation pattern of antenna 4 as predicted by NEC is shown in fig 4. This result is typical of antennas 1-4 and 6. For these antennas, the vertical response predominates and the xy plane response is almost omnidirectional. Variations in the vertical response for the xy plane are due to phase shifts between the vertical conductors and non-central mounting of these elements on the box. Such effects could be used to advantage i.e. by orienting the antenna in such a way as to reduce radiation in the direction of the user.

Unlike the simple model, which predicts zero radiation from the horizontal conductors, these antennas exhibit some horizontal radiation, although significantly lower than the vertical radiation. This is due to the incomplete cancellation of current in the horizontal conductors by their images in the top of the conducting box. Attempts have been made to improve the horizontal response by altering the geometry of the antenna. Antenna 4 has been designed such that all currents in the horizontal conductors in both the x and y coordinate directions are in phase, thus preventing current cancellation by adjacent conductors. However, there is negligible improvement in the horizontal response, although the Rrad and bandwidth increase markedly (as discussed in Section 3). Also, the horizontal response is affected only slightly by increasing the height of the horizontal conductors. This suggests that the cancellation of currents in the horizontal conductors by their images in the box is the primary cause for the limited horizontal response of the MTLAs tested.

Following this observation, antennas 5 and 7 have been designed to improve the horizontal response in the yz and xz planes respectively. The radiation pattern of antenna 7 is shown in figure 5. Although these designs violate the maximum antenna dimensions, useful comparisons with the other antennas have been made. In each case the grounding point of the antenna was moved to the side of the box to create a "horizontal radiator", as shown in figure 3. The average improvement in the xz plane horizontal response for antenna 7 is 6 dB over all other designs, and for antenna 5 the improvement is 1.5 dB. The improvement in horizontal response for antenna 7 is greater than that for antenna 5, despite the former's shorter horizontal radiator (20 mm) compared with antenna 5 (26 mm).

This result suggests that it is the dimension of the box parallel to the direction of the horizontal radiator that determines the radiator's effectiveness, in the same way that the radiation resistance of the vertical conductor of an MTLA is increased, up to a certain point, by increasing the length of the box.

5 Conclusions

The characteristics of a number of MTLAs mounted on a conducting box have been presented. In each case the bandwidth is largely determined by the antenna height, but is also dependent on the horizontal winding and the dimensions of the conducting box. Antennas 1-4 and 6 have limited cross polarized response, which limits their usefulness for urban radio environments. On the other hand, antenna 7 shows improved cross polarized response. Further investigation is required to determine the performance of these antennas with different mounting arrangements, and the effect of the shape and dimension of the conducting box.

6 Acknowledgement

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7 References

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Table 1 - Antenna characteristics

MTLA #	Resonant freq. MHz	Antenna length at resonance, wavelengths	Z at resonance (Ω)	Bandwidth (%)	Gain over reference, dB
Ref. (λ/4 monopole)	1035	-	81	>20	0
1	1015	0.69	80	14	-0.9
2	985	0.64	107	18	-1.0
3	1000	0.74	123	23	-0.5
4	950	0.59	149	24	-1.3
5	970	0.61	126	25	-1.2
6	995	0.60	151	18	-1.6
7	1020	0.63	102	17	-1.3

Table 2 - Effect of conducting box length, antenna 6

L, mm	Bandwidth, %
23	3
46	5
69	9
92	20.5
105	18
infinite ground plane	3.5

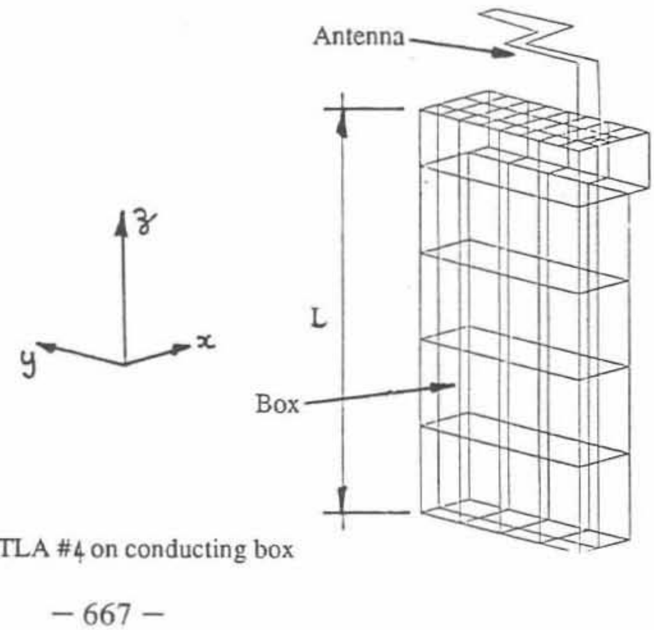

Fig 1 - MTLA #4 on conducting box

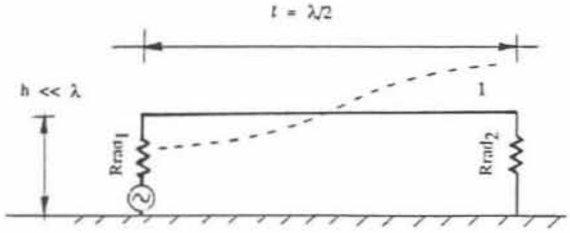

Fig 2 - Transmission line model of MTLA

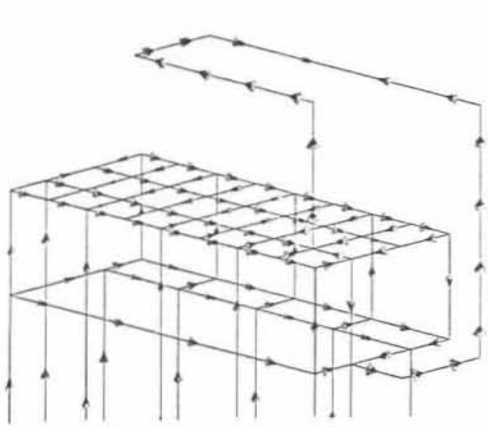

Fig 3 - MTLA # 7 on conducting box

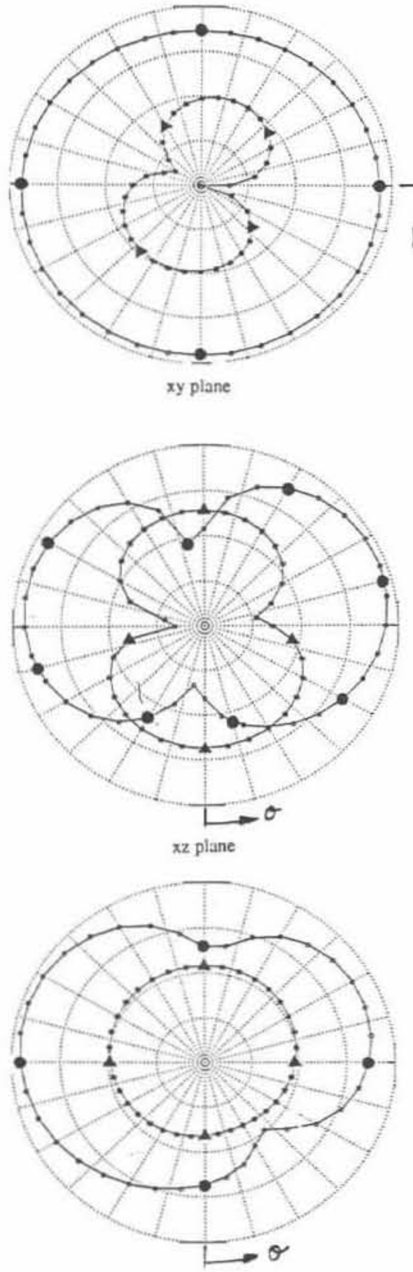

Fig 4 · Radiation pattern of MTLA # 4
(Scale for Figs 4 and 5 - outside ring = 0 dB_{ref},
scale = 10 dB/div ● = vertical, ▲ =horizontal)

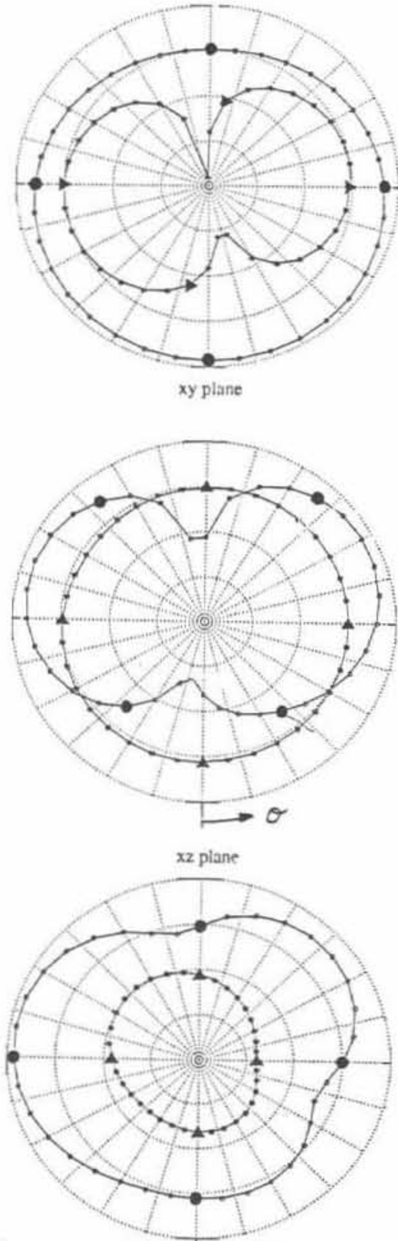

Fig 5 - Radiation pattern of MTLA # 7