An Inverted-L Antenna Based on Finite Ground Plane with Zigzag Structure

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***Abstract* — A key focus of this paper is to investigate the influences of finite ground plane on the monopole inverted-L antenna in mobile phone. Based on this, a ground plane with a zigzag parasitic structure is originally proposed, combined with a typical inverted-L antenna, the overall novel structure overcomes the issues of low radiation efficiency and impedance mismatching caused by the finite ground plane in compact status. At GSM 900 band, the minimum value of S_{11} decreases to -27.5dB from -5dB, and the relative bandwidth of such new antenna reaches to 24% (VSWR<2), which is about three times as wide as that of the conventional monopole inverted-L antenna, effectively expanding the monopole antenna's bandwidth, and making it a great potential in practical application.**

***Index Terms* — Inverted-L antenna, finite ground plane, zigzag.**

I. INTRODUCTION

Due to the ongoing system miniaturization and market requirements, a small-size and light-weight mobile phone is being of the latest trends. However, with the miniaturization of the mobile phone, the distance between the phone's antenna and the ground plane is inevitably getting closer and closer, and the size of ground plane is, equally, becoming smaller and smaller, which significantly reduces the radiation efficiency of the antenna and undermines the impedance matching characteristic greatly at low frequency, such as at GSM900 band. Based on such fact, there have been several investigations with optimal strategies [1-8] for solving this issue. For example, in the work of [2], it employed a zigzag monopole antenna instead of a linear monopole on a hand-held device, which reduced the length of the antenna and the current flowing along the body of the handset, and improved the impedance matching to the feed line of the small antenna too. In literature [4], it studied the design considerations of plane inverted-F antenna (PIFA) on a finite ground plane for achieving desired input and radiation characteristics, etc. Many efforts, indeed, have been made to analyze and study the influences of finite ground plane (FGP) on the antenna's performance. However, such researches are mainly based on PIFA and complete FGP, while the effect of incomplete FGP on inverted-L antenna in mobile has hardly been touched on up to now.

Taking into consideration of such problems and the inverted-L antenna that commonly used in mobile phones, an inverted-L antenna with a zigzag parasitic structure is presented, which not only efficiently deals with the low radiation efficiency problem in the compact structure of mobile, but also remarkably improves the impedance matching characteristic and broadens the bandwidth at low frequency. Through numerical simulations and measurements on prototype hardware, the minimum value of S_{11} decreases to -27.5dB from -5dB, and its relative bandwidth improves to 24% (VSWR<2), which is about three times that of the conventional monopole antenna at GSM900 band. That is, the operating bandwidth of the monopole gets widened enormously.

II. INFLUENCE OF THE FINITE GROUND TO THE ANTENNA'S PERFORMANCE

As can be indicated in Fig.1.(a), Inverted-L antenna is a widely-used monopole antenna which enables to realize the gain and impedance characteristic of dipole through the mirror effect of the infinite ground plane. However, owing to the inherent drawback that inverted-L antenna has only one resonant frequency, it cannot satisfy the requirements of dual GSM frequency bands. Therefore, it is transformed as depicted in Fig.1.(b) which possesses two resonant frequencies.

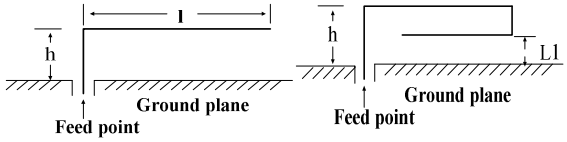
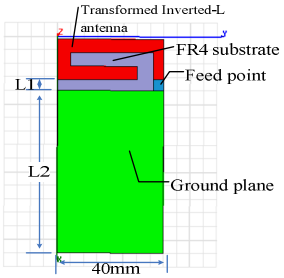


Fig.1. Structure of the Inverted-L antenna.
(a) normal inverted-L antenna
(b) transformed inverted-L antenna

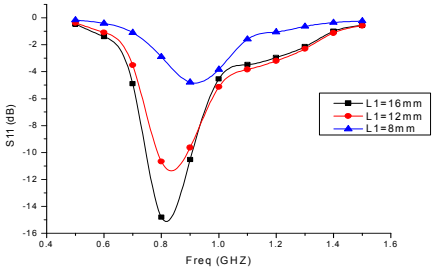
When the inverted-L antenna approaches the ground plane, the input impedance is highly capacitive. Furthermore, the capacitive reactance increases as the coupling distance decreases, which will seriously decrease the antenna's gain and radiation efficiency simultaneously. In the miniature of

mobile, the antenna's performance can be qualified equally well at GSM1800 band according to the fact that the size of ground plane is much larger than the wave length, so it can be considered as an infinite one, and consequently the image theory can be taken for analyzing. At GSM900 band, however, the mirror effect of the ground plane is not applicable anymore because the wave length, in this case, is comparable to the length of ground plane. Instead, it is usually deemed as an integral part of the antenna system. And in this circumstance, the finite ground will affect the antenna's gain and impedance matching characteristics. Based on these facts, in view of a typical mobile and the structure dimensions of the antenna (antenna patch width =5mm, slotting gap =4mm), as is shown in Fig.2 (a), numerical analysis has been done at GSM900 band. Through adjusting the distance between the antenna and the ground plane (L1) and the area of ground plane (40*L2), the influence of finite ground plane on the antenna's performance is quantitatively studied.

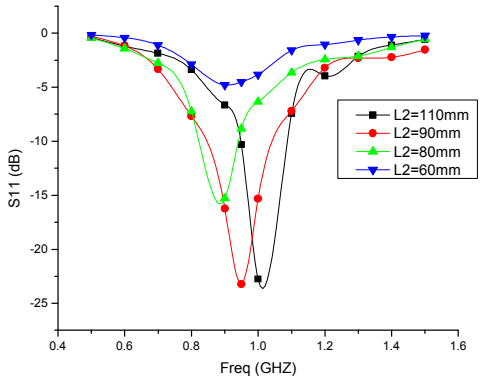
From Fig.2.(b), it can be observed that impedance matching of the antenna deteriorates with the decreasing of the height from the ground to the antenna. Moreover, the value of S_{11} is even worse at some values (L1=8mm，L2=60mm) that cannot meet CTLA standards if such case is much more serious, and this may result in failure application in phone antenna. As it can be seen from Fig.2.(c), the reflection coefficient of antenna is effectively reduced as the length of ground plane increases, and the matching bandwidth increases. When L2>80mm, the relative bandwidth of the whole antenna system including the inverted-L antenna and the finite ground plane reaches to 8% (VSWR<2), which, by and large, satisfies the demands of normally transmitting and receiving signals. However, such improvement of performance is at the expense of increasing the physical dimensions.



(a) Inverted-L antenna structure



(b) S_{11} graph (L1 changed, L2=60mm)



(c) S_{11} graph (L1=8mm.L2 changed)

Fig.2. Inverted-L antenna in phones and its simulation results.

III. A NOVEL FINITE GROUND PLANE WITH ZIGZAG STRUCTURE

The finite ground plane is a key factor that influences the performance of mobile antenna. The reason is that, in an antenna system with ideal infinite ground plane, the plane is mainly used as a mirror dipole in the monopole inverted-L antenna system as showed in Fig.3. (a). But for finite ground plane, it is not the case at all. It cannot be used as a mirror dipole any more, so the electrical performance of the antenna system is getting worse accordingly.

Therefore, in order to compensate for the finite ground's inadequateness, adding an open stub in the ground plane at the symmetric position of the monopole antenna to analog as a mirror dipole may be a possible and favorable approach. In consideration of the limitation of the phone's inside structure, and the fact that the newly added open stub primarily used to obtain impedance matching rather than increase the radiation resistance of the antenna, a zigzag structure can be employed to reduce its dimension size, specific structure as is shown in Fig.3 (b).

A novel antenna system, thus, composed of inverted-L antenna and the novel ground plane, is constructed. In practical application, the zigzag structure can be attached to the phone's gap so that it will not enlarge the phone size but can effectively solve the phone antenna' miniaturization problem.

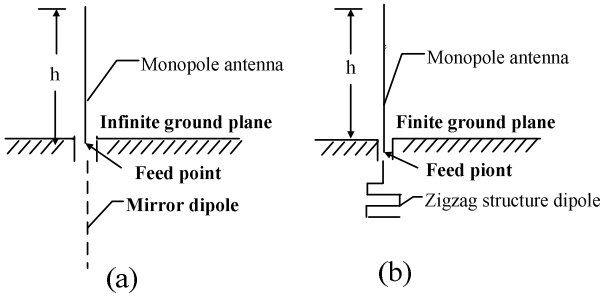
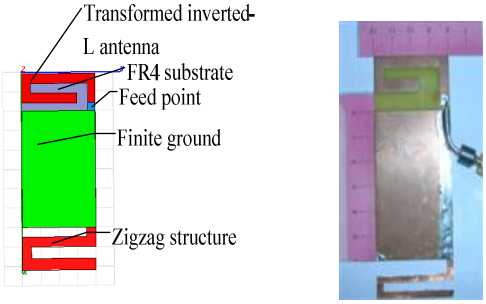


Fig.3. Schematic diagram of the finite ground with zigzag structure

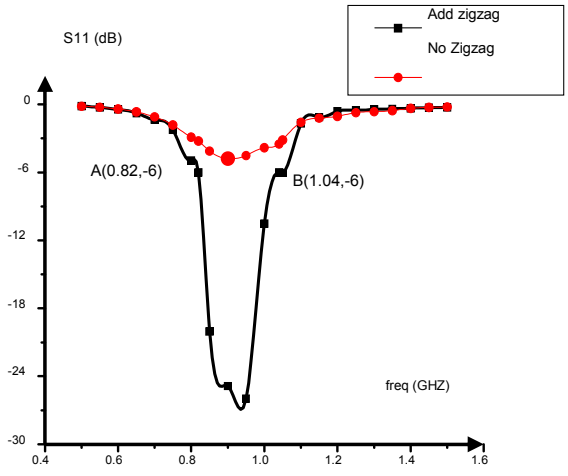
IV. NEW INVERTED-L ANTENNA SYSTEM SIMULATION AND MEASUREMENT VALIDATION

A. Simulation validation

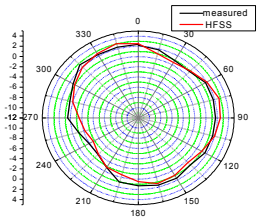
To validate the efficiency of the new added zigzag structure of the finite ground plane on the performance of compact inverted-L antenna, and allowing for the previous failure cases, that is, as showed in Fig.4. (a), ground plane' length is 60mm, width is 40mm,respectively. Inverted-L antenna's patch is 5mm, width is 4mm, and height is 8mm respectively. Zigzag structure height is 6mm and width is 6mm, Fig.4. (b) is the prototype of the analog board, in which the feed line of the antenna through a 50-ohm Cable to feed, here the size of the model in strict accordance with the design requirements .From Fig.4. (c), it can be clearly seen that the impedance matching characteristic of this new antenna system is greatly improved. At GSM 900 operating band, the minimum value of S11 decreases to -27.5dB from -5dB, and the -6dB bandwidth increases to 24% from zero, which is about 3 times as wide as that of the normal operation bandwidth (8%). From Fig.4. (d) and (e), it is obvious that the directional patterns (E-plane and H-plane) have no significant sag but have a better Omni-directivity. These results powerfully demonstrate that the new ground plane with zigzag parasitic structure has excellent performance.

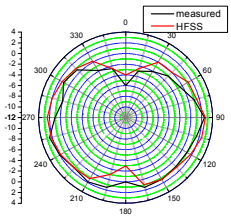


(a) Schematic diagram of antenna (b) Antenna physical picture



(c) S_{11} paragraph





(d) E-plane pattern (e) H-plane pattern

Fig.4. The novel antenna system with zigzag structure

B. Measurement validation

For further verifying the validity of proposed structure, it is applied to a genuine flip mobile phone. The zigzag structure of finite ground plane uses a copper foil with a sticky and adhesive bending at the gap of the phone ,as showed in Fig. 5.

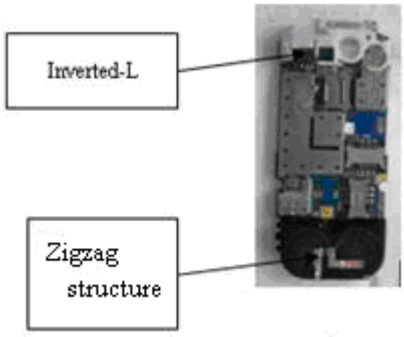
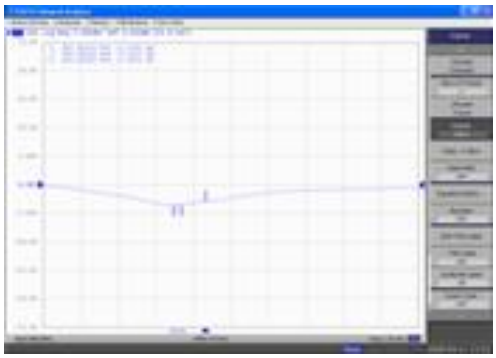
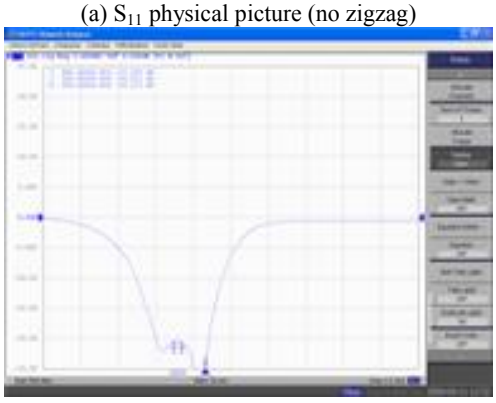


Fig.5. Novel inverted-L antenna system physical picture



(a) S_{11} physical picture (no zigzag)



(b) S_{11} physical picture (add zigzag)

Fig.6. S_{11}measurement physical picture

Measurements of S_{11} physical picture are shown in Fig.6 (a) and (b). Apparently, the results are in good agreement with the simulated ones, which further validates the reliability of the results. So it can be concluded that finite ground plane with zigzag structure improves the whole system's performance a lot as characterized in table I. In the table, at GSM900 band, Total Isotropic Sensitivity (TIS) increases from -100 dBm (no zigzag) to -103 dBm with a 3dBm's enhancement, and Total Radiated Power(TPR) , at the same time, changes from 22.4~23.5dBm to 29.9~30.9 dBm, which improves about 7dB.

TABLE I

MEASUREMENT RESULTS COMPARISON WITH OR NOT ZIGZAG STRUCTURE

Measurement band	Test channel	TRP(dBm)(Max) with zigzag structure	TIS(dBm) with zigzag structure	TRP(dBm)(Max) no zigzag structure	TIS(dBm) no zigzag structure
GSM 900	975	29.9	-103.5	22.4	-99.5
	37	30.9	-103.0	23.5	-100.0
	124	30.9	-103.0	23.2	-99.5

VI. CONCLUSION

This paper proposes a novel finite ground with zigzag structure which efficiently improves the performance of inverted-L antenna system in phones' compact structure. Through simulation and experimental verification, it proves that the new antenna has a good matching performance and bandwidth. At present, this technology has been applied to actual production in mobile.

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