SMALL INDUCTOR LOADED MOBILE PHONE ANTENNA

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Abstract: *In this paper a size reduction technique of the Planar Inverted-F Antenna (PIFA) is presented. Using an 18 nH lumped inductor in addition to a small 0.3 cm^3 PIFA located on a 5 mm thick dielectric foam above a 40 × 100 mm^2 ground plane it is possible to reduce the resonant frequency by 33 % for a fixed physical size. The measured –6 dB bandwidth is 6.7% with a peak radiation efficiency of 88 %.*

1. INTRODUCTION

The Planar Inverted-F Antenna (PIFA) is widely used in cellular phones primarily due to the compactness and size [1]. The demand for smaller communication devices for personal communication systems has led to a constant search for methods to reduce the cellular phone dimensions. However, the wavelength does not decrease, due to the higher frequency bands used, with the same speed as the size of the mobile phones. Even the widely used PIFA tent to become too large, and thus a demand exist in order to decrease the volume of the antenna.

Several ways to reduce the antenna size exists. However, all are at the expense of lower antenna gain and bandwidth [2]. This follows from the fact that an antenna is used to transform a bounded wave into a radiated wave [3]. An antenna performs this transformation, however, only with a poor efficiency when it is much smaller than the wavelength [4]. The loss in antenna gain can to some extent be compensated for by amplification. This is obviously not the case for the bandwidth. If the impedance match is much better than required within a smaller bandwidth than required, broad banding techniques could be used to increase the bandwidth [5]. For a given cellular configuration, the design of the antenna should be done in order to use the total volume available [6-7]. There exist an upper theoretically limit that are never reached, and the design of small antennas is thus a trade off between bandwidth and gain for the antenna chosen to the given application [2, 8].

Size reduction can be accomplished, simply by shortening the antenna, however, having a consequence of reducing the radiation resistance considerably and making the input impedance more capacitive. The latter can be compensated for by the use of one or more inductors connected in series with the antenna for cancellation of the capacitance, and thus improve the impedance match [9], and hence the efficiency [10]. The idea of using a lumped inductor in conjunction with an antenna has often been used in conjunction to low frequency antennas where the physical size might be several hundred meters, but up to date it has found little use in mobile telephony [11].

In [11] it is demonstrated that the highest advantage is gained by placing the inductor at the center of each antenna arm, instead of at the input. For many practical applications it is more suitable to place the inductor almost at the input. In this way no inductors is located on the antenna element itself, but rather on the supporting structure or on the ground plane. But this is a trade-off between the actually requirement to the antenna performance and the cost of the antenna including the lumped components. Collin [11] discusses the idea in connection to monopoles and dipoles, but here the use of a lumped inductor is adapted to the PIFA.

In fact, the main objective of this paper is to present the results of numerical and experimental investigations of the size reduction of a PIFA by the use of a lumped inductor. To analyse the antenna, the method of moment computer program, IE3D, was used to predict the performance of the antennas in terms of the radiation efficiency and reflection coefficients [12].

2. MATERIALS AND METHODS

The presented antenna configuration consists of a 40 mm long, 1.5 mm wide and 5 mm high PIFA located on a 40 × 100 mm^2 ground plane. The antenna is located at the edge and parallel to the 100 mm edge, as illustrated on

Figure 1. The feed point is located 5 mm from the edge where a 90-degree bend forms the short to the ground plane. In the cases where the inductor is incorporated on the antenna element, a 0.5 mm wide gap is cut in the antenna arm. The cut is moved from almost at the feed point, the 0.5 mm case towards the open end, the 33 mm case. A lumped 18 nH (standard value) inductor is used in the measurements [13]. The inductor has an effective inductance of nearly 20 nH in the frequency range of interest, thus a 20 nH lumped inductor is used in the simulations.

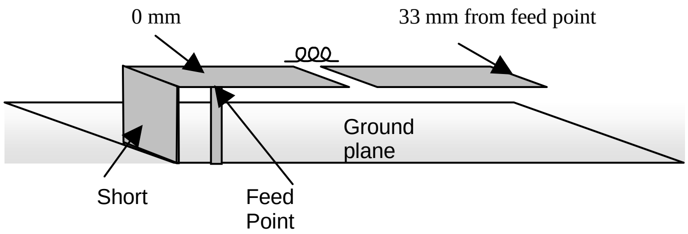

Figure 1. Illustration of the PIFA located above a ground plane. The gap illustrates the location of the lumped inductor; the dielectric foam is not shown.

The simulated resonant frequency of the PIFA without any inductor is 1.80 GHz, but it decreases to 1.2 GHz when a 20 nH inductor is mounted in the gap located 0.5 mm from the feed point.

For the prototype, the measured resonant frequency for the PIFA without any inductor is 1.60 GHz, and 1.06 GHz when an 18 nH inductor is mounted. The relative decrease in resonant frequency is approximately 33 % in both cases. The deviation is mainly due to the cable used in the measurements, the simulated ideal assumptions, i.e., loss less and free space, as compared to the Rohacell material used for the prototype, and the deviation between the actual prototype and the model used in the simulation.

3. RESULTS

In total three different prototypes have been measured with respect to radiation efficiency and reflection coefficient. The results are shown in Figure 2.

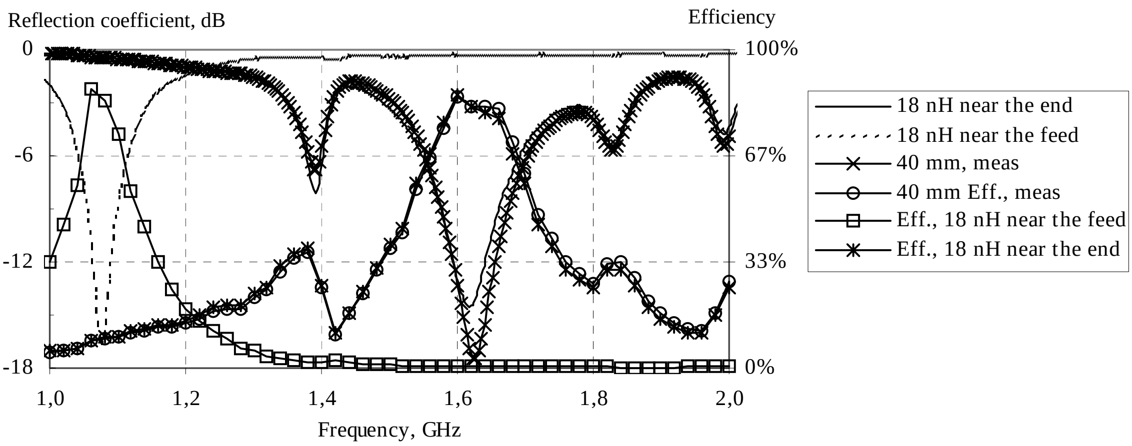

Figure 2. Measured reflection coefficient and radiation efficiency versus frequency for three scenarios, i.e., without any inductor and with and 18 nH inductor located close to the feed point and thirdly closely to the open end of the antenna arm.

For the PIFA without any inductor the resonant frequency is 1.60 GHz having a peak return loss of 16.5 dB. The bandwidth within which the reflection coefficient is better than –6 dB, hereafter just bandwidth is 9.1%. The measured efficiency is above 63 % within this frequency range, having a peak of 85 %.

By loading this antenna with an inductor soldered at the gab, just 0.5 mm from the feed point, the resonant frequency is 1.06 GHz, having a bandwidth of 6.7%. The peak efficiency is 88%. Locating the inductor at the very end of the antenna arm, i.e., 1 mm from the open end the resonant frequency is 1.60 GHz and follows the same curve as the no-inductor-case. Also the peak efficiency is unchanged 85 %. This is not surprisingly since the current is zero at the end of the antenna arm, hence this validates the model.

Various locations of the inductor have been simulated, spanning from almost at the feed point (0.5 mm) toward the open end (33 mm). The simulated resonant frequency and relative bandwidth as a function of the location of the inductor, i.e., the distance from the feed point to the inductor, is shown in Figure 3. The reflection coefficient at the resonant frequency and the peak efficiency as a function of the inductor location is shown in Figure 4.

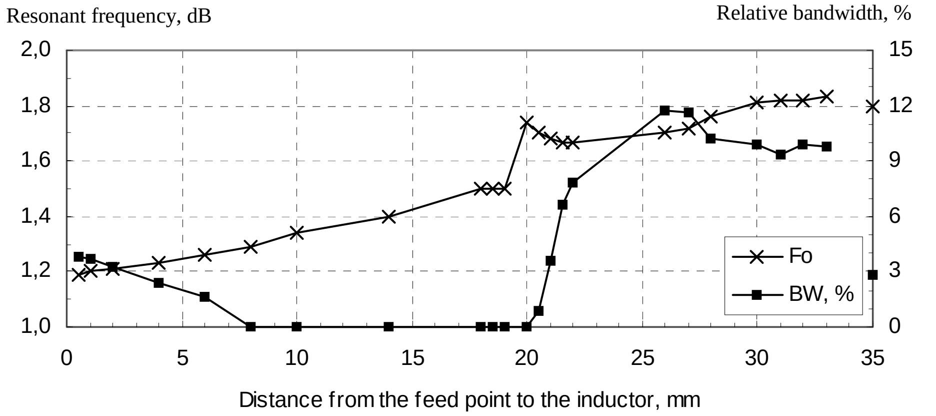

Figure 3. Simulated resonant frequency and relative bandwidth versus the inductor location.

The resonant frequency increases from 1.2 to 1.8 GHz, when the inductor is moved towards the open end, from a position at 0.5 mm to 33 mm from the feed point.

Starting with a 45 MHz or 4 % bandwidth at 1.2 GHz (0.5 mm) the bandwidth drops due to mismatch, for locations in the range from 5-20 mm, hence no –6 dB bandwidth occurs. The maximum bandwidth of 14.5 % is obtained at 26 mm, and stabilises around 10 % when the inductor is located at positions near the open end of the antenna (30-33 mm).

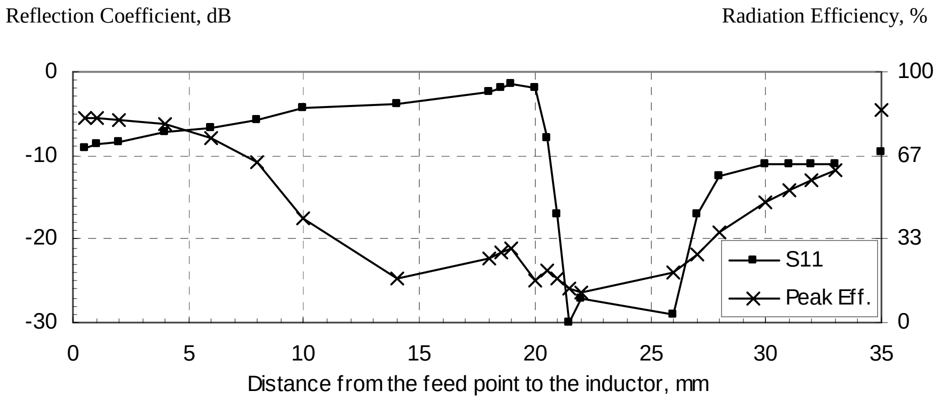

Figure 4. Simulated reflection coefficient and radiation efficiency versus the inductor location.

The peak efficiency starts at 75 % and ends at 60 % at the feed point (0.5mm) and the open end (33 mm), respectively. At locations below 5 mm the efficiency is higher than 75 %. A decrease is observed, and the efficiency is below 50 % from 10-30 mm. Above 31 mm the reflection coefficient is –11 dB and the efficiency exceeds 50 %, and peaks to 60 % at 33 mm. In between the efficiency has dropped to 17 % at the 21 mm location.

The reflection coefficient at the resonant frequency changes from –9 to –1.5 dB for the inductor location in the range from 0.5 and 20 mm. From 21 to 26 mm the reflection coefficient peaks at –30 dB, and setting at –11 dB for locations above 30 mm.

4. DISCUSSION

It seems likely that adding an inductor on the arm of the PIFA improves the performances. The best case with respect to resonant frequency reduction are obtained when the inductor is placed within the first few millimetres from the feed point, here the measured resonant frequency is decreased by 33 % from 1.6 to 1.06 GHz, the reflection coefficient is –16.5 dB, the bandwidth is 6.7 % and the radiation peak efficiency is 88%.

The PIFA is basically an inverted L antenna, that actually originates from a monopole with a bend such that most of the arm is parallel to the ground plane. This means that the feed point is moved by a certain distance from the ground, here 5 mm from the bend and 5 mm due to the antenna height. Meaning that the optimum location of the inductor is between 10.5 and 15 mm from the ground connection, i.e., almost one third the total length of 45 mm (length + height).

Collin [11] argues that the optimum location is at the centre of the arm of the monopole, of course we can't compare directly to the PIFA. Nevertheless, this actually holds for the impedance match. If the inductor is located between 21 and 26 mm a rather good simulated impedance match is observed, below –25 dB, in this case the decrease in the resonant frequency is not overwhelming, from 1.8 to 1.7 GHz, only. Moreover the radiation efficiency is below 25 %. This could indicate that the optimum location for an inductor on the PIFA is closer to the feed point.

Above 21 mm no significant resonant frequency reduction is obtained, however at 30 mm the bandwidth is 200 MHz (13 %), which is higher than the case of no inductor (50 MHz or 3 %). Thus, the higher bandwidth is at the expense of an inductor in terms of reduced efficiency and the cost of the inductor.

5. CONCLUSION

A 33 % reduction of the resonant frequency is accomplished by using an 18 nH lumped inductor in addition to a small 0.3 cm^3 PIFA located on a 5 mm thick dielectric foam above a 40×100 mm^2 ground plane. The measured –6 dB bandwidth is 6.7 % with a peak radiation efficiency of 88 %.

The shown PIFA is not fully optimised with respect to the occupied volume or resonant frequency. For practical use both the shape of the antenna and the location of the lumped inductor should be carefully chosen in order to get the best frequency bandwidth and efficiency performance for a given application.

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