

SMALL INDUCTOR LOADED MOBILE PHONE ANTENNA

J. Thaysen^{1,2} and K. B. Jakobsen¹

¹Technical University of Denmark, www.dtu.dk

²Nokia Denmark, www.nokia.com

jth@oersted.dtu.dk

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 cm³ PIFA located on a 5 mm thick dielectric foam above a 40 × 100 mm² 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 tend 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 mm² 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.

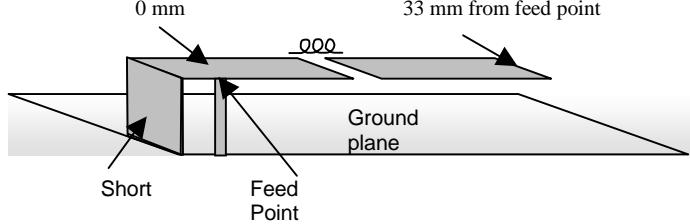


Figure 1. Illustration of the PIFA located above a ground plane. The gap illustrates the location of the lumped inductor; the dielectric foam is not shown.

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.

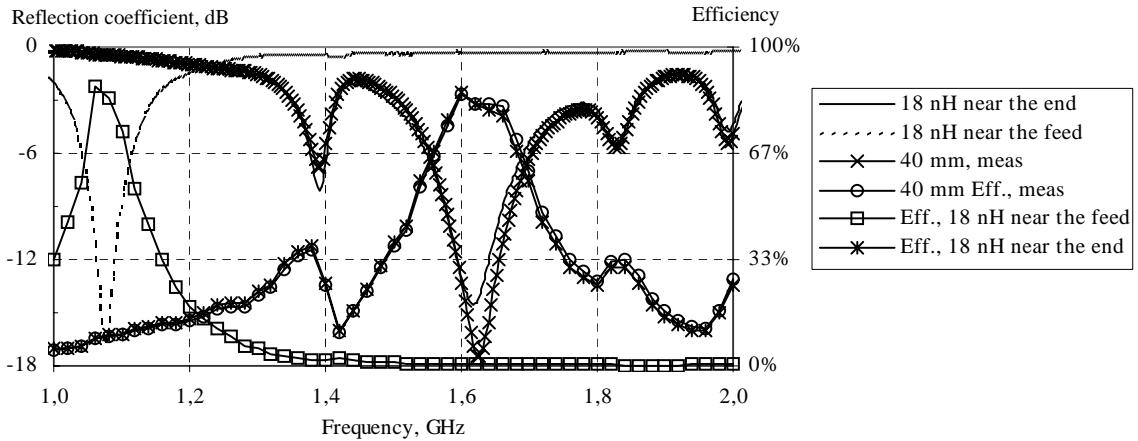


Figure 2. Measured reflection coefficient and radiation efficiency versus frequency for three scenarios, i.e., without any inductor and with and 18 nH inductor located close to the feed point and thirdly closely to the open end of the antenna arm.

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.

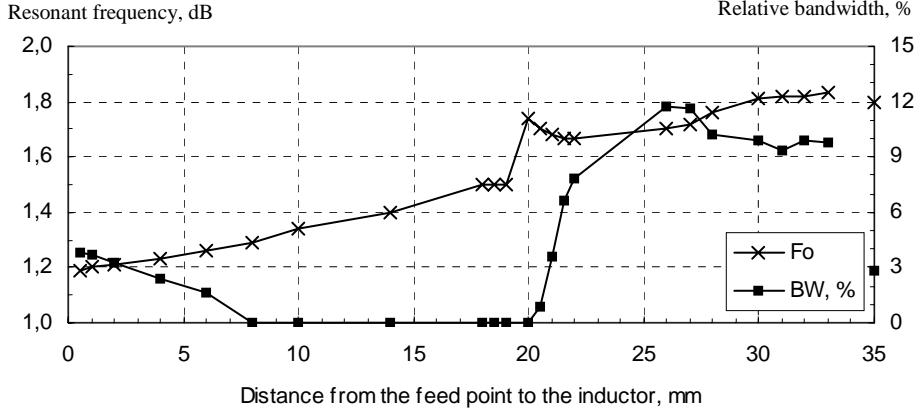


Figure 3. Simulated resonant frequency and relative bandwidth versus the inductor location.

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).

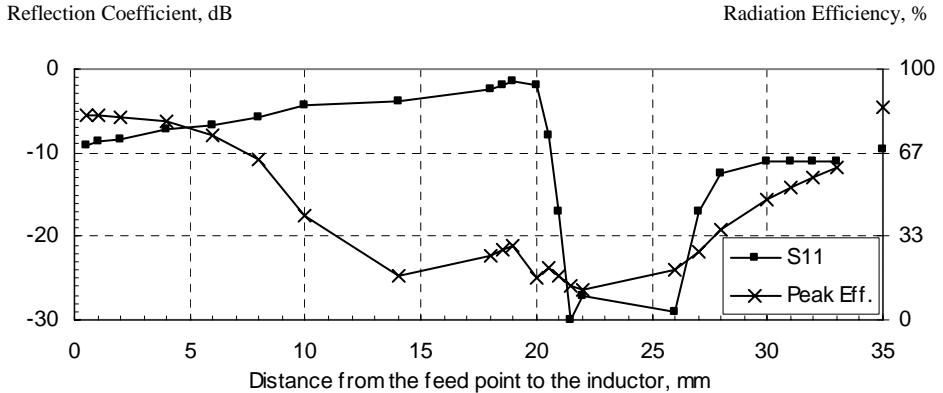


Figure 4. Simulated reflection coefficient and radiation efficiency versus the inductor location.

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 $40 \times 100 \text{ mm}^2$ 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.

REFERENCES

1. K. Hirasawa and M. Haneishi, "Analysis, design, and measurement of small and low profile antennas," Artech House, ISBN 0-89006-486-5, 1991.
2. R.F. Harrington, "Effect of antenna size on gain, bandwidth and efficiency," Journal of research of national bureau of standards, D-radio Propagation, vol. 64D, pp. 1-12, Jan 1960.
3. "The IEEE standard definitions of terms for antennas," IEEE Trans. AP, vol. 17, May 1969.
4. R.C. Hansen, "Fundamental limitations in antennas," Proc. IEEE, vol. 69, Feb. 1981.
5. H. A. Wheeler, "The wide-band matching area for a small antenna," IEEE Trans. AP, vol. 31, pp. 364-367, Mar. 1983.
6. L.J. Chu, "Physical limitations of omnidirectional antennas," J. App. Phys., vol. 19, pp. 1163-1175, Dec. 1948.
7. J.S. McLean, "A re-examination of the fundamental limits on radiation Q of electrically small antennas," IEEE Trans. AP, vol. 44, pp. 672-675, May 1996.
8. H.A. Wheeler, "Fundamental limitations of small antennas," Proc. IRE, vol. 35, pp. 1163-1175, Dec. 1947.
9. C. W. Harrington, "Monopole with Inductive Loading", *IEEE Trans. Antennas Propagat.*, pp.394-400, Jul 1963.
10. G. S. Smith, "Efficiency of electrically small antennas combined with matching networks," IEEE Trans. AP., vol. AP-25, pp. 369-373, May 1977.
11. R. E. Collin, "Antennas and radiowave propagation", McGraw-Hill, ISBN 0-07-011808-6, pp. 97-104, 1985.
12. "IE3D User's Manual, Release 8," Zeland Software, Inc., Fremont, CA, 2001.
13. Data sheet, www.coilcraft.com, Coilcraft inc., 2003.

射 频 和 天 线 设 计 培 训 课 程 推 荐

易迪拓培训(www.edatop.com)由数名来自于研发第一线的资深工程师发起成立，致力并专注于微波、射频、天线设计研发人才的培养；我们于 2006 年整合合并微波 EDA 网(www.mweda.com)，现已发展成为国内最大的微波射频和天线设计人才培养基地，成功推出多套微波射频以及天线设计经典培训课程和 ADS、HFSS 等专业软件使用培训课程，广受客户好评；并先后与人民邮电出版社、电子工业出版社合作出版了多本专业图书，帮助数万名工程师提升了专业技术能力。客户遍布中兴通讯、研通高频、埃威航电、国人通信等多家国内知名公司，以及台湾工业技术研究院、永业科技、全一电子等多家台湾地区企业。

易迪拓培训课程列表：<http://www.edatop.com/peixun/rfe/129.html>



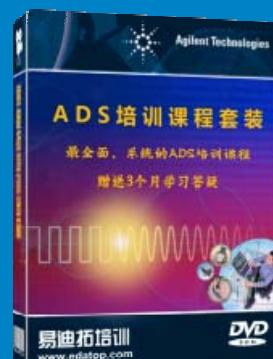
射频工程师养成培训课程套装

该套装精选了射频专业基础培训课程、射频仿真设计培训课程和射频电路测量培训课程三个类别共 30 门视频培训课程和 3 本图书教材；旨在引领学员全面学习一个射频工程师需要熟悉、理解和掌握的专业知识和研发设计能力。通过套装的学习，能够让学员完全达到和胜任一个合格的射频工程师的要求…

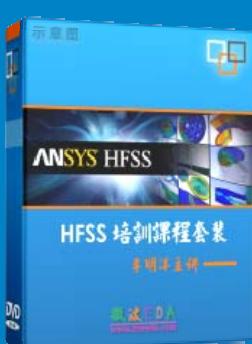
课程网址：<http://www.edatop.com/peixun/rfe/110.html>

ADS 学习培训课程套装

该套装是迄今国内最全面、最权威的 ADS 培训教程，共包含 10 门 ADS 学习培训课程。课程是由具有多年 ADS 使用经验的微波射频与通信系统设计领域资深专家讲解，并多结合设计实例，由浅入深、详细而又全面地讲解了 ADS 在微波射频电路设计、通信系统设计和电磁仿真设计方面的内容。能让您在最短的时间内学会使用 ADS，迅速提升个人技术能力，把 ADS 真正应用到实际研发工作中去，成为 ADS 设计专家…



课程网址：<http://www.edatop.com/peixun/ads/13.html>



HFSS 学习培训课程套装

该套课程套装包含了本站全部 HFSS 培训课程，是迄今国内最全面、最专业的 HFSS 培训教程套装，可以帮助您从零开始，全面深入学习 HFSS 的各项功能和在多个方面的工程应用。购买套装，更可超值赠送 3 个月免费学习答疑，随时解答您学习过程中遇到的棘手问题，让您的 HFSS 学习更加轻松顺畅…

课程网址：<http://www.edatop.com/peixun/hfss/11.html>

CST 学习培训课程套装

该培训套装由易迪拓培训联合微波 EDA 网共同推出, 是最全面、系统、专业的 CST 微波工作室培训课程套装, 所有课程都由经验丰富的专家授课, 视频教学, 可以帮助您从零开始, 全面系统地学习 CST 微波工作的各项功能及其在微波射频、天线设计等领域的设计应用。且购买该套装, 还可超值赠送 3 个月免费学习答疑…



课程网址: <http://www.edatop.com/peixun/cst/24.html>



HFSS 天线设计培训课程套装

套装包含 6 门视频课程和 1 本图书, 课程从基础讲起, 内容由浅入深, 理论介绍和实际操作讲解相结合, 全面系统的讲解了 HFSS 天线设计的全过程。是国内最全面、最专业的 HFSS 天线设计课程, 可以帮助您快速学习掌握如何使用 HFSS 设计天线, 让天线设计不再难…

课程网址: <http://www.edatop.com/peixun/hfss/122.html>

13.56MHz NFC/RFID 线圈天线设计培训课程套装

套装包含 4 门视频培训课程, 培训将 13.56MHz 线圈天线设计原理和仿真设计实践相结合, 全面系统地讲解了 13.56MHz 线圈天线的工作原理、设计方法、设计考量以及使用 HFSS 和 CST 仿真分析线圈天线的具体操作, 同时还介绍了 13.56MHz 线圈天线匹配电路的设计和调试。通过该套课程的学习, 可以帮助您快速学习掌握 13.56MHz 线圈天线及其匹配电路的原理、设计和调试…



详情浏览: <http://www.edatop.com/peixun/antenna/116.html>

我们的课程优势:

- ※ 成立于 2004 年, 10 多年丰富的行业经验,
- ※ 一直致力并专注于微波射频和天线设计工程师的培养, 更了解该行业对人才的要求
- ※ 经验丰富的一线资深工程师讲授, 结合实际工程案例, 直观、实用、易学

联系我们:

- ※ 易迪拓培训官网: <http://www.edatop.com>
- ※ 微波 EDA 网: <http://www.mweda.com>
- ※ 官方淘宝店: <http://shop36920890.taobao.com>