A Small Planar Inverted F Antenna with Capacitive and Inductive Loading

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Abstract

The development of very small antennas significantly influences the miniaturization of handheld devices. In this paper a planar and symmetric antenna is build up. A capacitive loading for this planar inverted F antenna (IFA) is presented. For a further size reduction an inductive loading is investigated. The method of moments (MOM) is used to model the antenna and measurements are carried out for verification.

I. INTRODUCTION

In nearly all technical categories miniaturization is one of the major goals. Electronic devices are reduced in size and at the same time their function range increases. In addition the demand for multiple input multiple output (MIMO) systems requires more than one single antenna in a device. Sometimes the devices have to operate within different networks so they have to come up to different required standards. Thus an increasing demand on flexible thus wireless devices requires a sophisticated antenna design, which should focus not only on bandwidth and operating frequency but also on antenna size and the connection to the front end. It is commonly known, that size reduction decreases the antenna bandwidth whereas the impedance is also diminished [1], [2] and [3]. The challenge is to find the trade off between size, impedance and bandwidth for a specific service and antenna.

Starting with a short summary about classical parameters of an IFA, section II a transmission line model for this antenna is presented in section III. Capacitive loading of a planar and symmetric IFA with no use of a ground plane is presented in section IV. For another kind of reactive loading size reduction due to inductive loading is chosen (section V). Simulations and measurements are carried out for demonstration.

II. PARAMETERS OF A PLANAR IFA

The planar design of an IFA and the relevant parameters are shown in figure 1.

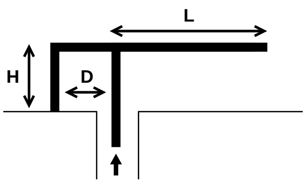

Fig. 1. Classical parameters of an IFA.

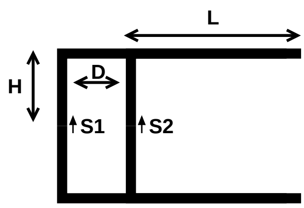

Fig. 2. Symmetrical build up of an IFA for higher input impedance and symmetrical feeding to adapt to state of the art front end amplifiers.

The sum of the length L and the height H effects the resonant frequency of the antenna by

$$T = H + L \approx \lambda/4 \quad . \tag{1}$$

If the height is low, a capacitive coupling between the ground plane and the upper part of the antenna occurs, hence the sum T can be reduced. In the following all parameters are normalized to the resonant frequency so that results are very general. The distance D between the vertical

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parts of the antenna has no effect onto the resonant frequency but to the input impedance. Thus the distance is predestinated for impedance matching. For further information refer to [4]. It is well known that a small ground plane has a great effect to properties like input impedance, resonant frequency and so on. Simulations predict that a quadratic ground plane for the used antenna has to have an edge length of more than two wavelengths. For integration into a hand held device and a resonant frequency of 2.44 GHz or 5.2 GHz this size is not acceptable. By using the image method it is possible to produce an antenna which is independent of ground plane effects, easier to build up, and cheap. In addition it is shown in [2], [5] and [6] that a symmetrical fed antenna is more insensitive to its surroundings and the input impedance is twice that of the normal IFA. Modern front end amplifiers use a symmetrical structure hence by the use of a symmetrical feed the matching network can be eliminated. It is necessary to discuss the feeding point of the antenna. The antenna can be fed either in the middle of the left, signed in figure 2 by $S1$, or in the middle of the right vertical arm, indicated by $S2$. The current flow is mainly on the inner vertical arm of the IFA. If the source is placed in the left arm like $S1$ in figure 2 the input impedance is up to three times that placed on $S2$ in figure 2. Simulation results are shown in figure 3.

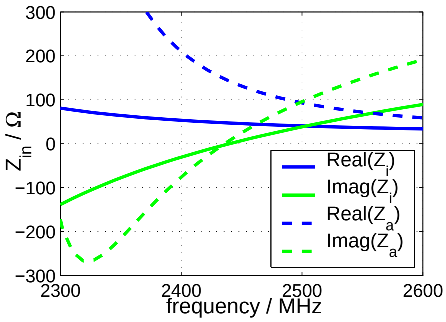

Fig. 3. By placing the source on $S1$ instead of on $S2$, see figure 2, the input impedance is increased by three times.

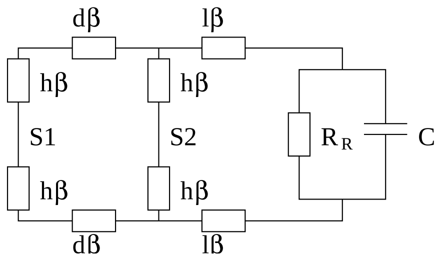

Fig. 4. Transmission line model of an inverted F antenna with capacitive loading.

Z_a indicates input impedance if the source is placed on the left side, Z_i if the source is placed on the right. The resonant frequency is identical for both feeding points.

III. Transmission Line Model of an IFA Antenna

The transmission line model of a capacitively loaded IFA is shown in [7]. For the symmetrical antenna with loading on $S1$ the transmission line model is shown in figure 4.

β indicates the wave number in free space and l, d, and h are the length, the distance, and the height of the antenna related to the relative sizes by

$$l = L \cdot \frac{\lambda}{100}, \quad d = D \cdot \frac{\lambda}{100}, \quad h = H \cdot \frac{\lambda}{100} \quad . \tag{2}$$

The length of the open circuit line T consisting of two times $h\beta$ and two times $l\beta$ can be reduced, if a capacity is used on the open end of the transmission line. The same effect occurs, if there is an inductive loading in the middle of the right vertical part. In this case the feeding of the antenna is in the middle of the left side at $S1$. In the following this feeding point is used.

IV. Size Reduction by Capacitive Loading

A capacitive loading of the IFA can be done by connecting a capacity between the ends of the two horizontal arms. Simulations, carried out with FEKO [8], using a variable capacity placed as mentioned before and fixed geometrical dimensions show that the antenna resonant frequency is reduced as the capacity is increased. But at the same time the bandwidth and input impedance are reduced, too. In [4] the volume of the sphere is used to build up the capacity. A planar design is shown in figure 5.

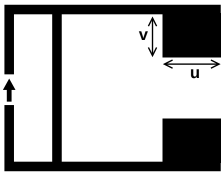

Fig. 5. Capacitive loaded planar IFA with the parameters v and u.

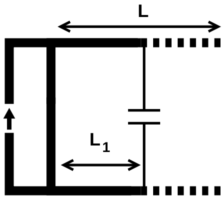

Fig. 6. Length T can be reduced by capacitive loading.

By varying the length u of the capacity and the height v of the capacity the resonant frequency and the input impedance Z_{in} can be influenced as shown on figure 7 and 8.

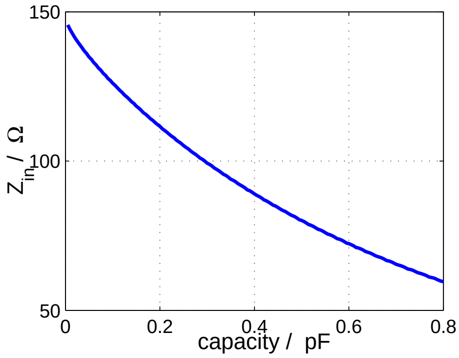

Fig. 7. Input impedance dependent on the capacitive loading.

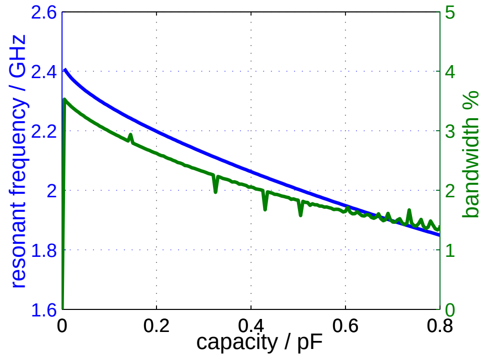

Fig. 8. Simulation result for a capacitive loaded IFA by varying the parameters u and v.

V. Size Reduction by Inductive Loading

By inserting an inductance in the frequency determining line T, equation 1, at the place of $S2$, figure 2, the relative length can be reduced. For investigation by simulations the basic model is an unloaded IFA with a resonant frequency of 2.44 GHz. The L, D and H are fixed for all simulations relative to 2.44 GHz. The source is placed on $S1$ in figure 2. Now a concentrated variable inductance is placed on $S2$. As the inductance increases, the resonant frequency decreases. The input impedance gets smaller and the bandwidth of the antenna is reduced. For different inductances the bandwidth, the resonant frequency, and the input impedance are shown in figure 9 and 10. Decreasing the resonant frequency means the relative

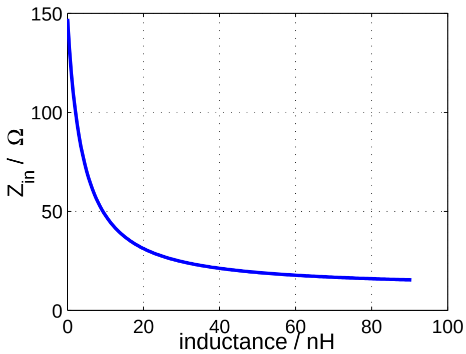

Fig. 9. Input impedance at resonant frequency for different inductive loading.

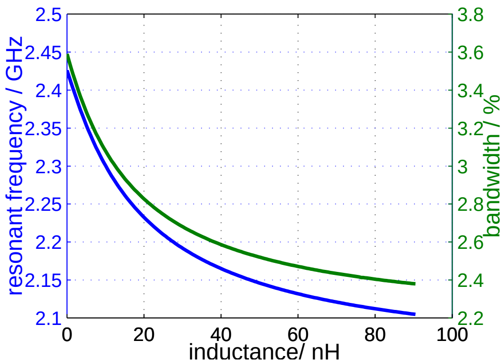

Fig. 10. Resonant frequency and -6 dB bandwidth dependent on inductive loading of an IFA.

size of the antenna is reduced. By the use of the inductive loading the size can be reduced between 20% and 30% compared to an ordinary IFA.

VI. Measurements

The inductively loaded IFA is built as shown in figure 11. The resonant frequency without inductive loading is 5.2 GHz ($\lambda = 5.77cm$). The design parameters are $D = 3.47\lambda/100$, $H = 7.8\lambda/100$ and $L = 15,6\lambda/100$. The bandwidth and resonant frequency of the unloaded antenna are suitable for WLAN. By inductive loading according to section V with 5 nH, 10 nH and 22 nH the resonant frequency can be reduced up to 650 MHz. The variation in matching, see figure 12, is according to the matching network for all measurements. The matching can be improved by a specific matching network for every antenna.

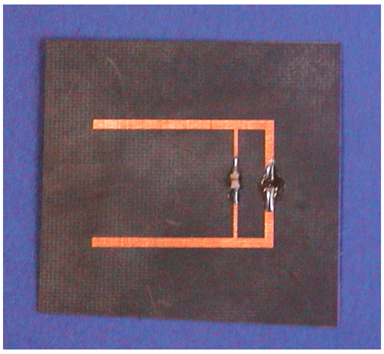

Fig. 11. Photo of the used IFA loaded with an inductance.

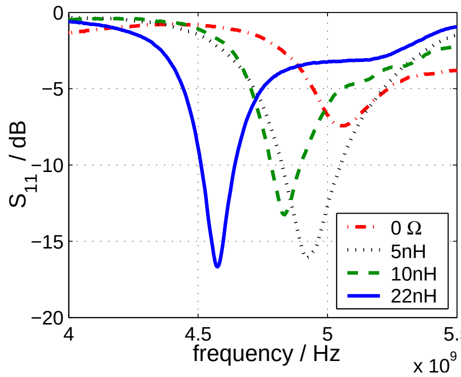

Fig. 12. Measurement results of the reflection coefficient for different inductive loadings. The unloaded IFA has a resonant frequency of 5.2 GHz. The geometrical parameters are fixed and different inductances are placed on the IFA.

To build an antenna which work at 5.2 GHz the antenna size has to be made smaller. The measured gain in the main beam direction is still nearly the same with and without an inductive loading of 22 nH, approximately 2 dBi.

VII. Conclusion

In this paper it is shown that the size of a planar IFA for integration in mobile devices can be reduced by inductive or capacitive loading. In addition, by using a symmetrical feed, it is possible to enlarge the input impedance and to connect the antenna easily to a state of the art front end.

References

[1] R. C. Hansen. Fundamental Limitations in Antennas. *Proceedings of the IEEE*, 69(2):170–182, February 1981.

[2] H. A. Wheeler. Small Antennas. *IEEE Transactions on Antennas and Propagation*, AP-23:462–469, July 1975.

[3] James S. McLean. The Radiative Properties of Electrically-Small Antennas. *IEEE International Symposium on Electromagnetic Compatibility*, pages 320–324, August 1994.

[4] Stephan Schulteis, Christian Waldschmidt, Christiane Kuhnert, and Werner Wiesbeck. Design of a Capacitively Loaded Inverted F Antenna for Wireless-LAN Applications. *Proc. International ITG-Conference on Antennas, Berlin*, 178:187–190, September 2003.

[5] A.T. Arkko. Effect of Ground Plane Size on the Free-Space Performance of a Mobile Handset PIFA Antenna. *Proceedings International IEE Conference on Antennas and Propagation*, pages 316–319, April 2003. Conf. Publ. No. 491.

[6] H. Morishita, H. Furuuchi, and K. Fujimoto. Performance of balance-fed antenna system for handsets in the vivincy of human head or hand. *IEE Proceedings Microwave Antennas Propagation*, 149(2):85–91, April 2002.

[7] C. R.Rowell and R.D. Murch. A Capacitively Loaded PIFA for Compact Mobile Telephone Handsets. *IEEE Transactions on antennas and Propagation*, 45(5):837–842, May 2002.

[8] http://www.feko.info.