A Compact Single/Dual-Band Printed Inverted-F Type Antenna Structure

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Abstract: In the first part of the paper a compact version of a printed inverted-F type antenna is presented. The compactness is achieved by placing the necessary matching line at the side of the feeding line with the main radiator - not at the other side of the feeding line, as for the ordinary IFA. Another advantage is the possibility of an additional λ/2-resonance along the matching line, which is connected to the ground-plane over a via. By using the two first resonances a dual-band antenna can be designed - that has been done in the second part of this paper. Our novel antenna structure is well suited for small mobile communication devices or PC-cards operating within the ISM 2.4 and 5 GHz bands. Bluetooth and the WLAN standards IEEE 802.11 a, b, g are the most important applications within the above mentioned frequency bands. The antenna structures have been optimized using a commercial FDTD tool. These designs have been validated with measurements on fabricated prototypes - together with additional FEM-simulations.

Keywords: printed dual-band antenna, inverted-F antenna, WLAN

1. Introduction

A lot of integrated antennas for mobile communication devices are based on the planar inverted-F antenna (PIFA) or the integrated inverted-F antenna (I-IFA) - sometimes called printed inverted-F antenna [1], since these antenna types are compact and have a sufficient bandwidth for most applications. So far in mobile phones PIFA-based concepts are mostly deployed for GSM standards, because there is not enough space available on the printed circuit board (PCB) for a printed multi-band antenna. On the other hand, in cell phones with the Bluetooth feature a printed IFA at the side or bottom edge of the multi-layer substrate is used as BT antenna, operating in the 2.4 GHz ISM band. Here it is important to use as less area on the PCB as possible for this antenna, since manufacturers need the limited space on the PCB for the other electronics.

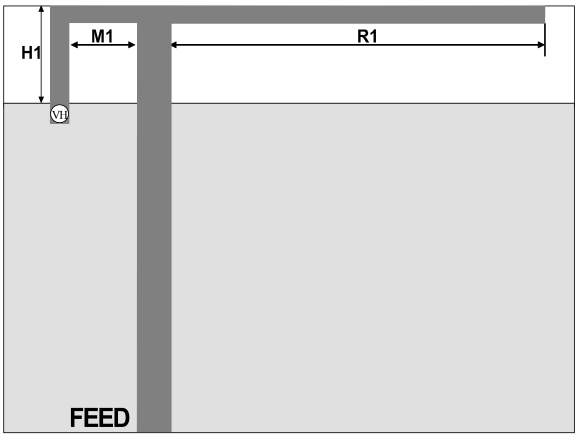


Fig. 1: Ordinary integrated inverted-F antenna (IIFA)

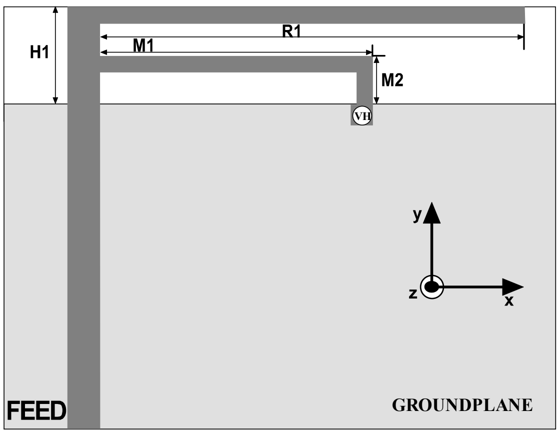


Fig. 2: Compact Bended-h antenna (BhA)

Another field of application for the presented antenna structures are wireless local area networks (WLANs). WLANs are becoming increasingly popular, since they provide high speed connectivity and easy access to networks without requiring wiring. Most of the current WLAN products being deployed are based on the IEEE 802.11b standard operating at 2.4 GHz with data delivery rates of up to 11 Mbps. WLAN devices with IEEE 802.11a operate within the 5 GHz ISM band. This standard provides more bandwidth and channels than the first one, resulting in data rates up to 54 Mbps. There are single and dual-band WLAN PCMCIA-cards available for laptop computers. Alternatively, for PCs in general a external WLAN card, that is connected to the computer via the USB port, can be used (USB stick WLAN card). Other upcoming applications are PDAs or Pocket PCs with the WLAN feature - either with an additional tiny card (wireless compact-flash card) or with a directly integrated WLAN module including the antenna. So far only single-band devices for IEEE 802.11b are on the market, except the PCMCIA card type. For all the above mentioned WLAN applications it is important to have a very compact antenna that needs minimal space on the board. Additionally, for dual-band operation it is necessary to have a multi-resonant antenna.

2. FDTD/FEM-Simulations and Measurements on Prototypes of Single-Band Antennas

Our first objective is the design of a compact printed antenna for the ISM 2.4 GHz band intended for Bluetooth or WLAN (802.11b) applications. In Fig. 2 our compact antenna structure is depicted. Because of its shape, the structure is called bended-h antenna (BhA). During the optimization it turned out that the structure in Fig. 3 has the best bandwidth for single-band operation within the mentioned ISM band. Here the matching line is located above the ground plane - this special antenna is called single-band BhA.

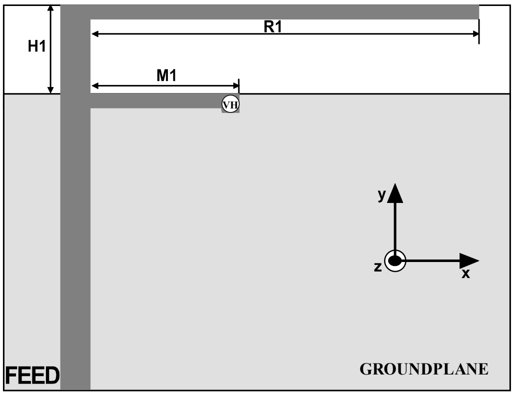


Fig. 3. Single-band BhA

Antenna	IIFA	BhA
R1	24	22.5
M1	7	22.5
H1	5	5
W (Ant.)	1	1
W (Feed)	1.55	1.55

Tab. 1: Dimensions in mm of IIFA and BhA

The 3D FDTD field simulator EMPIRE™ [3] was used to optimize the structure in terms of bandwidth and resonance frequency. Prototypes of an ordinary integrated IFA (Fig. 4) and our bended-h antenna (Fig. 5) have been built to verify the FDTD simulations. The dimensions for these antennas are given in Tab. 1. A board size of 50 mm x 50 mm was used. The substrate parameters were RT/duroid 5870 with an ε_r of 2.33 and a thickness of 508 μm (20 mil). As mentioned above, the BhA structure needs less area on the board than the ordinary IIFA, but reaches nearly the same bandwidth and matching values as the FDTD/FEM simulations and measurements in Fig. 8 up to Fig. 10 indicate. The FEM simulations have been carried out with the software HFSS™ [4]. The HP NWA 8722C has been used for the measurements on various prototypes.

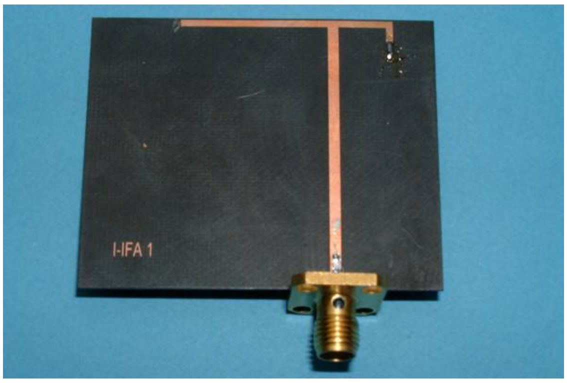


Fig. 4: Ordinary integrated inverted-F antenna (IIFA)

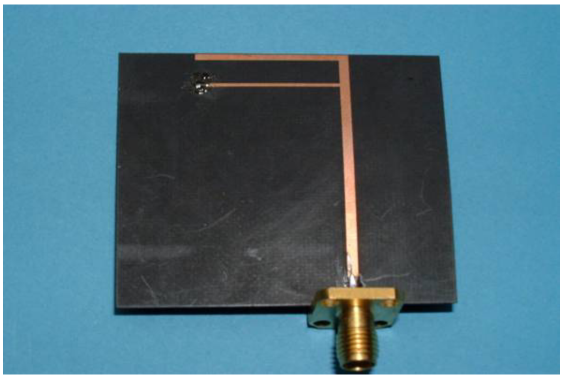


Fig. 5: BhA prototype w/ SMA connector

Fig. 6: Single-band BhA (thin version)

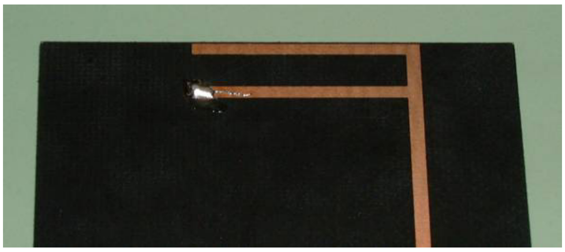


Fig. 7: Single-band BhA (thick version)

We have built a few prototypes of the single-band BhA. The results of two of them – the thin version of Fig. 6 and the thick version of Fig. 7 – are displayed in the diagramms Fig. 9/10.

Fig. 8: best result for the ordinary IIFA

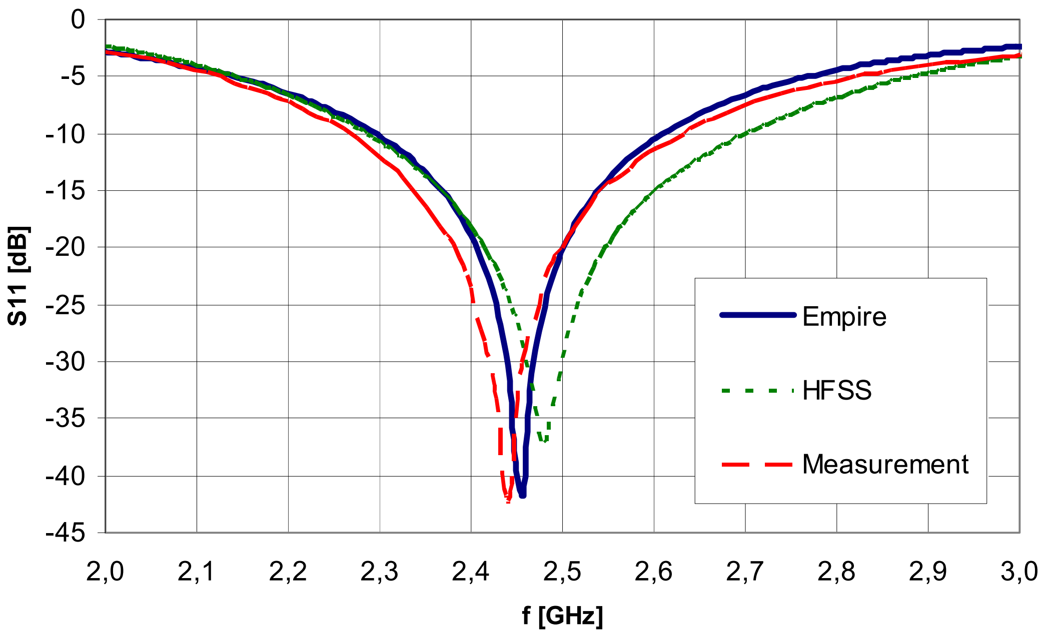


Fig. 9: Return Loss of Single-band Antenna (thin version)

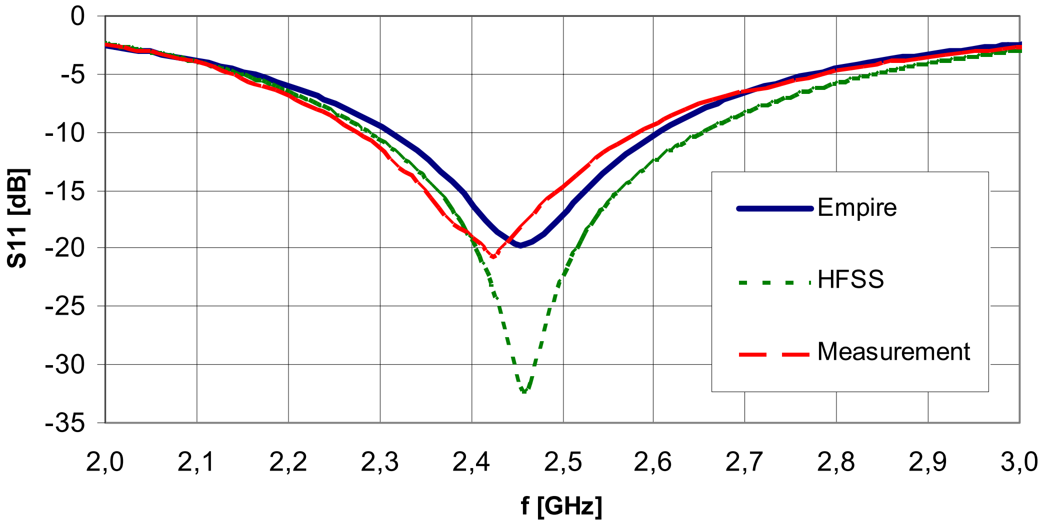
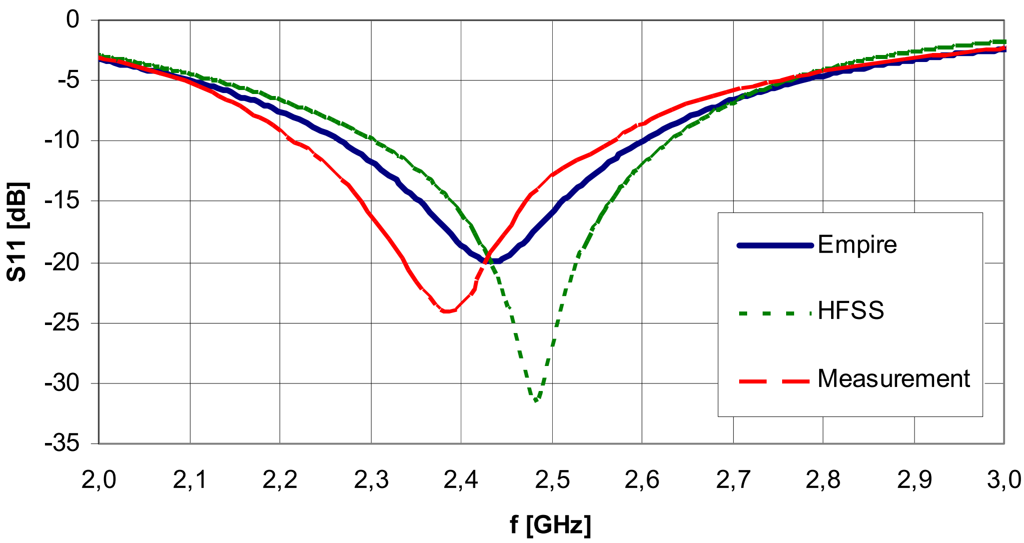


Fig. 10: Return Loss of Single-band Antenna (thick version)



3. FDTD/FEM-Simulations and Measurements on Prototypes of Dual-Band Antennas

In the open literature there are less papers on printed multi-band antennas, compared to the many publications on multi-band PIFAs. In [2] a so-called stacked IFA for dual-band operation is presented. The PCB-area needed for this antenna structure is quite large, due to its stacked assembly. Our dual-band antenna presented in the following has a more compact design. The qualitative outline of the structure is shown in Fig. 2 and is called dual-band bended-h antenna (dual BhA). Our objective in this section is to design a compact dual-band antenna for WLAN operation within the ISM 2.4 and 5 GHz bands. The matching line (secondary radiator) with its dimensions M1 and M2 (see Fig. 2) is located in the reactive near-field of the main radiator, yielding a coupling between main and secondary radiator. The bandwidth for the 2.4 GHz resonance of the main radiator is reduced compared to the single-band BhA of section 2 – in this case there is just a little coupling between main radiator and the matching line above the ground-plane. But a bandwidth of around 100 MHz is sufficient for the lower ISM band from 2.40 to 2.4835 GHz. For the IEEE 802.11a standard altogether three subbands exists. The first subband is from 5.15 to 5.25 GHz and it allows up to 16 dBm transmitting RF power. The second one is from 5.25 to 5.35 GHz with 23 dBm maximum power, and the third one, mainly intended for outdoor applications, is from 5.725 to 5.825 GHz with 29 dBm max. power. The overall BW is therefore 675 MHz. The length and position of the secondary radiator has been optimized with EMPIRE™ to have approx. 100 MHz of bandwidth in the lower ISM band and close to 675 MHz for the three subbands within the 5 GHz ISM band. In Fig. 11 one prototype of the dual-band BhA on duroid substrate is depicted. In the next figure the measurement setup with an non-soldered SMA connector is displayed. The return loss results are shown in Fig. 13. The agreement between the two simulations methods FDTD and FEM and also with the measurement results is very good – especially for the lower ISM band. The S_{11}-parameter displayed in the Smith Chart gives even more insight to the electrical behavior of the antenna. In Fig. 14/15 the results of Empire and HFSS within the Smith Chart are presented.

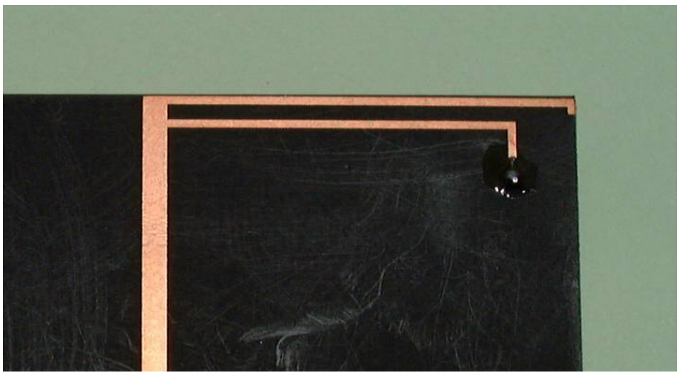


Fig. 11: Section with dual-band BhA

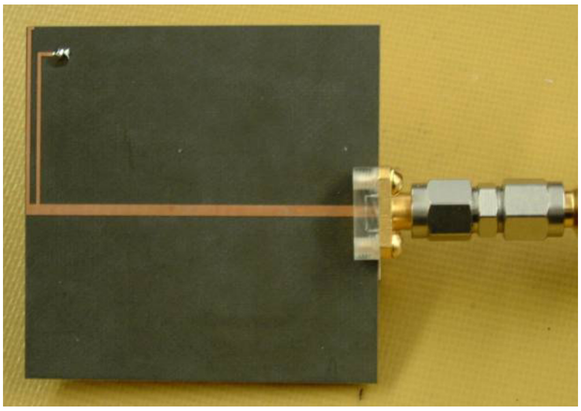
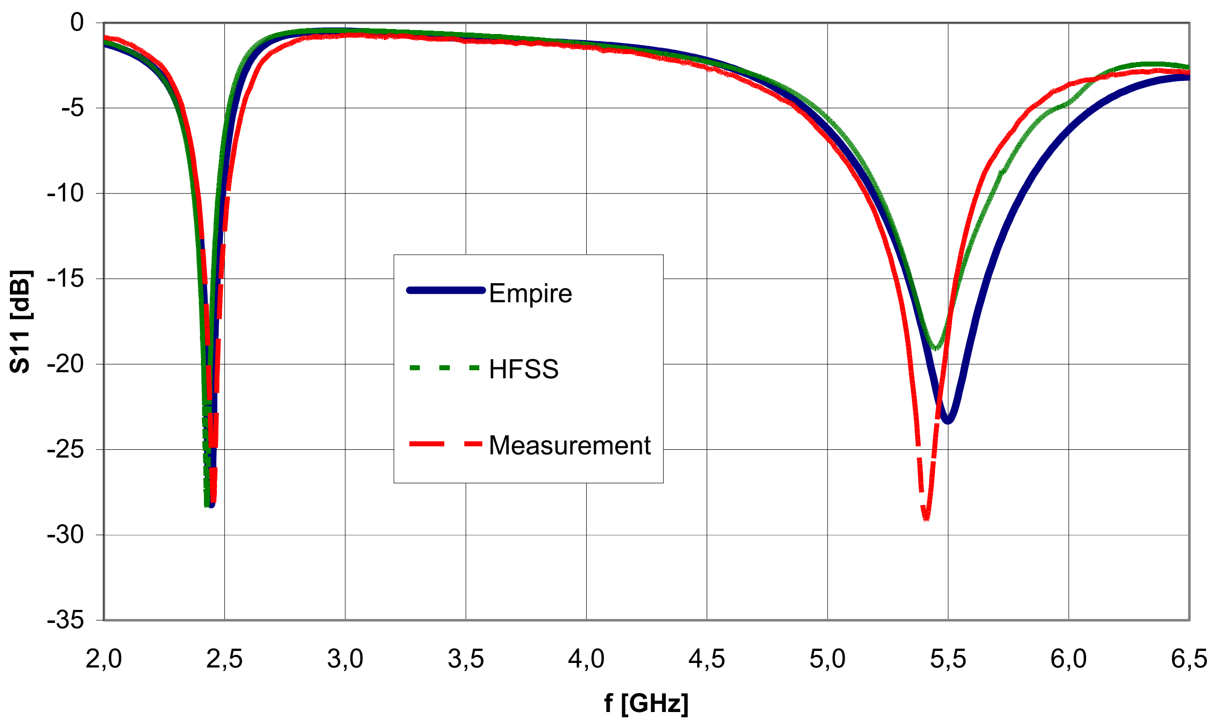


Fig. 12: Measurement setup for dual-band BhA

Fig. 13: Dual-band Antenna on RT/duroid 5870



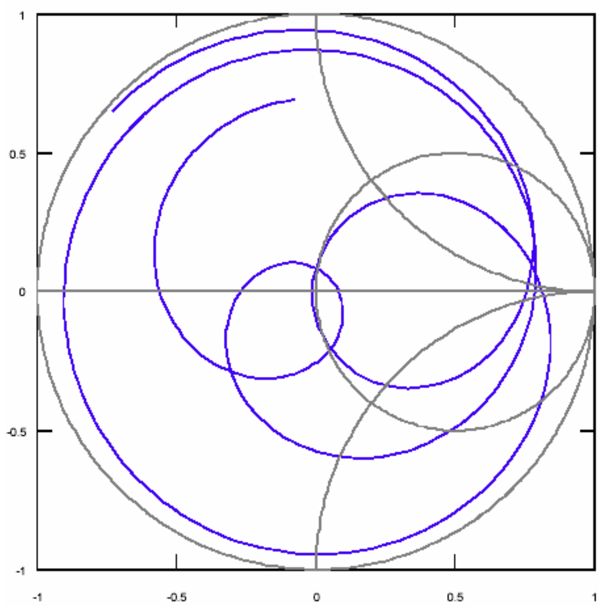


Fig. 14: S_{11} within Smith Chart simulated with FDTD

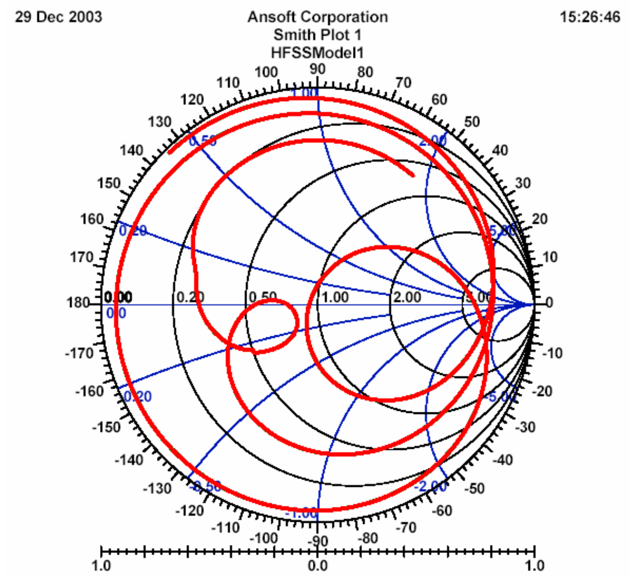


Fig. 15: S_{11} within Smith Chart simulated with FEM

After finsihing the design on RT/duroid we made a redesign on FR-4. An ε_r of 4.5 was assumed for the FDTD simulations. Fig. 16 is a photograph of one prototype. The agreement between FDTD-, FEM-simulation and measurement in Fig. 18 was surprisingly good, since the material parameters of FR-4 underlie high tolerances.

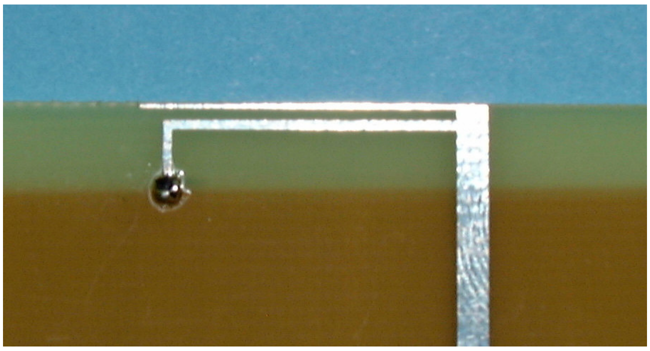
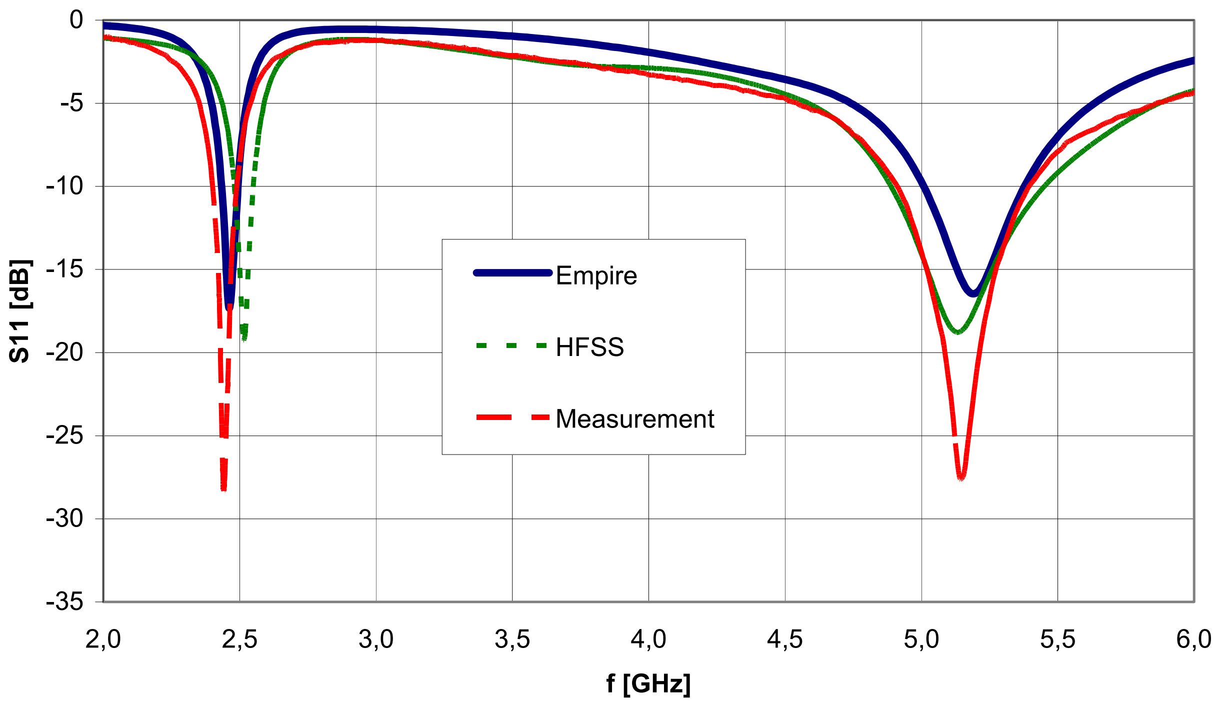


Fig. 16: Cut-out of dual-band antenna on FR-4

Fig. 17: Measurement setup with antenna on FR-4

An efficiency measurement has not been done by us, but we expect issues, especially for the 5 GHz ISM band. FR-4 might be used up to 2.5 GHz - but not for higher frequencies. For the future we will use a better material, like Rogers RO 4003.

Fig. 18: Return Loss of Dual-band Antenna on FR4



Finally, we present our simulation results in terms of current distributions at the two first resonance frequencies. In Fig. 19/20 the current density |**J**(x,y)| at the front side of the substrate with the antenna structure (top) and at the back side with the ground plane (bottom) are depicted. At a frequency of 2.5 GHz there is a matched λ/4-resonance along the main radiator. For a frequency of 5.5 GHz there is a λ/2-current distribution along the matching line (secondary radiator). In between of the two surface plots the FDTD model can be seen in the two figures.

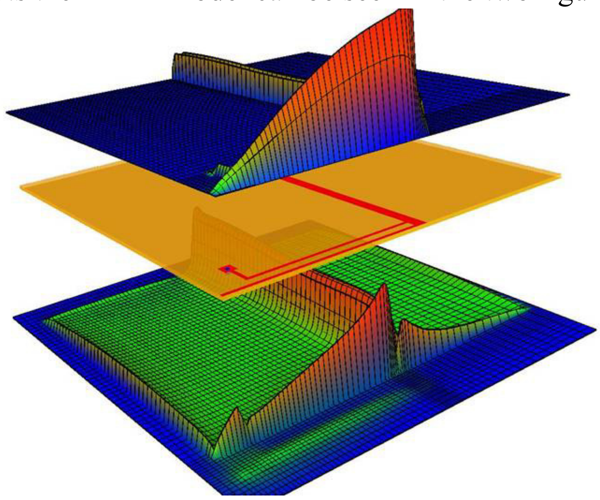


Fig. 19: Simulated current density |**J**(x,y)| @ 2.5 GHz in top and bottom layer (ground plane)

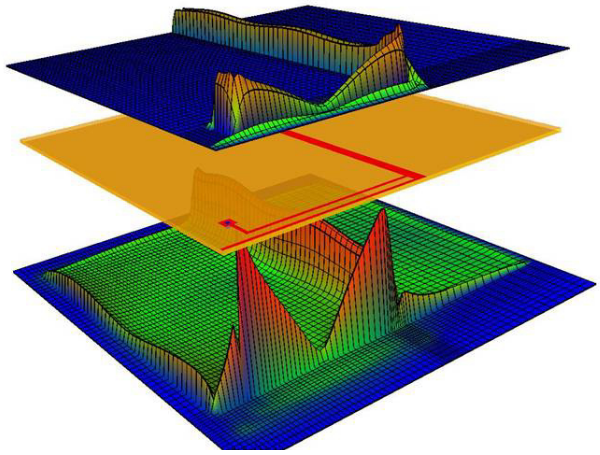


Fig. 20: Simulated current density |**J**(x,y)| @ 5.5 GHz in top and bottom layer (ground plane)

4. Conclusions

In this paper a compact single/dual-band antenna structure, printed on a substrate, was presented. The design is compact, cost-effectively and precisely to manufacture. The single-band antenna structure presented in the second section has a compact design compared to the ordinary printed IFA and has a similar performance in terms of bandwidth and matching. It might be a candidate for mobile communication devices with Bluetooth or IEEE 802.11 b/g WLAN operation. The second antenna presented is a very compact dual-band antenna for the 2.4 and 5 GHz ISM bands and might be used for dual-band WLAN operation for the standards IEEE 802.11 a, b/g.

References

[1] M. Ali and G. Hayes, "Analysis of integrated inverted-F antennas for Bluetooth applications", *2000 IEEE AP-S Conference on Antennas and Propagation for Wireless Communication*, Massachusetts, pp. 21-24, Nov. 2000.

[2] K.-L. Wong, "Planar Antennas for Wireless Communications", pp. 226 – 228, John Wiley & Sons, Inc., Hoboken, New Jersey, 2003.

[3] IMST GmbH, “User manual for the 3D EM time-domain simulator Empire”, www.empire.de/empire.pdf, June 2002.

[4] Agilent, *HFSS - User and reference manual*

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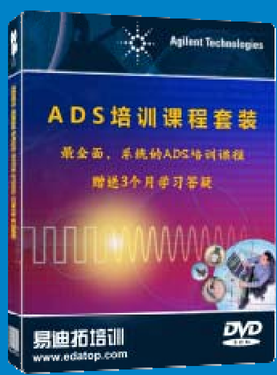

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