Realization of a Wide-Band Wire Inverted-F Antenna Utilizing Wire-Grid Modeling

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Abstract

In this paper, a new wire inverted-F antenna (WIFA) is proposed, which is structured by wire-grid modeling of a thick WIFA. This novel WIFA, which is hereafter referred to as Wire-Grid Inverted-F Antenna (WG-IFA), shows 39.2% bandwidth on VSWR. Also it shows VSWR<1.2:1 all over the GSM frequency band, 890-960 MHz. The constituent wires in the wire-grid model are very thin and indirectly form thick arms for the antenna. As a result, modeling and design procedure can be done easily and fast by NEC, which is a one-dimensional Method of Moment (1-D MoM) based software.

1. Introduction

For mobile communication systems, it is very important to develop small and low-profile antennas for the miniaturization of communication equipment. The inverted-F antenna (IFA) is particularly known for its abilities to allow a simple impedance matching in a low-profile design and to produce both vertically and horizontally polarized electric fields [1]. Therefore, the IFA has already been widely applied to mobile communication systems [2]. It is known that when the IFA height from a conducting ground plane is approximately one-tenth of the wavelength, the frequency bandwidth on VSWR is approximately 8% considering VSWR<2:1 [3,7]. To broaden the IFA bandwidth, some techniques have previously been proposed including decreasing the size of the ground plate [6], adding a parasitic element [7], and introducing dual resonance concept [8]. However, the most successful method in bandwidth enhancement has been replacement of the IFA horizontal element by a planar conducting patch, forming a planar IFA (PIFA) [4]. The maximum bandwidth which is 25%, is achievable only when the PIFA is located on a large conducting plate [4].

In the present work, by utilizing a tactic called wire-grid modeling [10], in a procedure similar to that used in [9] for designing a very wideband sleeve dipole antenna, a WG-IFA is introduced with 39.2% bandwidth. This bandwidth is about 5 (1.5) times more than that of an ordinary WIFA, 8% (PIFA, 25%). To analyze the antenna, NEC software (NEC Win Pro. V1.1a) is used, which is a 1-D MoM based software very efficient for analyzing wire antennas.

2. Modelling, Design and Optimization

We start with a WIFA with the typical dimensions as described in [3]. To improve bandwidth, the thickness of the antenna wires must be increased because it is well known from antenna theory that the thicker the antenna constituent wires are, the more bandwidth is. But there is a problem restricting the wire thickness of WIFA. In fact, NEC result is fundamentally designed to model only very thin wires. A thin wire is a segment that its length over its radius is greater than 8 (L/R>8). Because WIFA segments are very small relative to bandwidth, increasing wire thickness decrease the analysis accuracy. Fortunately, an Extended Kernel is incorporated into NEC Win Pro V1.1a software which lets the designer accurately model thicker wires (L/R>2). Because in this work we are going to achieve very large bandwidth, even this kernel is not accurate enough but it can help us to considerably approach the optimum result in an initial attempt. Therefore, utilizing this kernel the thick WIFA is modelled and optimized for maximum bandwidth all over the GSM frequency band (890-960 MHz). During the optimization, the wire radii are set fixed at $0.018\lambda_0$, and S (known as matching pin distance), L and h are considered as variable. Because NEC Win Pro. V1.1a is not equipped with optimization ability, the same two-way software interface between NEC and MATLAB, used in [12], is utilized to manage the optimization procedure and perform the analysis and the relevant calculations automatically. The optimization algorithm is a globally optimal one introduced in template matching in image processing [11], as used in [12]. Template matching can find a template by a complete search in the sub images, a matter that needs lots of time [11]. The distinguishing feature of this method is the capability of existence recognition of proper results in the defined region by means of low-resolution search in the first step, in order to stop the processing on undesired region and wasting time. The optimized antenna, having the dimensions reflected in Fig. 1, renders 23% bandwidth. The related VSWR is shown in Fig. 4.

In the next step, we apply the wire grid modelling technique [10] by transforming the structure in Fig. 1 to an equivalent wire grid-modelled structure with equivalent radii and the same dimensions, as in Fig. 2 (a). Studies on wire grid modelling in [10] implies that a thin cylinder, i.e. a very thick wire ($2R=\lambda/10$), can be modelled by only 5 or 6 parallel thin wires, and increasing the number of parallel wires has no significant effect on the result. In the present work, however, for simplicity of the structure, each thick wire is realized by 4 parallel thin wires (see Fig. 2 (a)), with length the same as the thick wire and also with spacing the same as the diameter of thick wires in Fig. 1. The obtained WG-IFA has 34.8% bandwidth. After some tuning on the dimensions, the bandwidth improves to 39.2%, which is approximately five times greater than that of a typical thin WIFA [7]. The dimensions of the WG-IFA after tuning is shown in Fig. 2 (b) and Fig. 2 (c). Also, the related gain pattern all over GSM band is shown in Fig. 3.

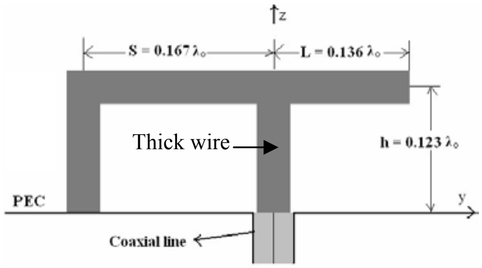
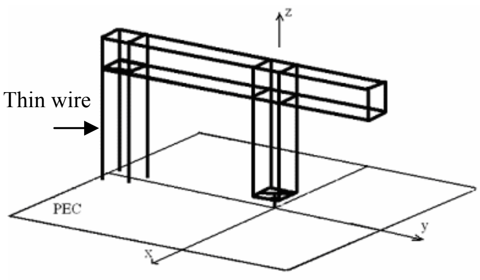
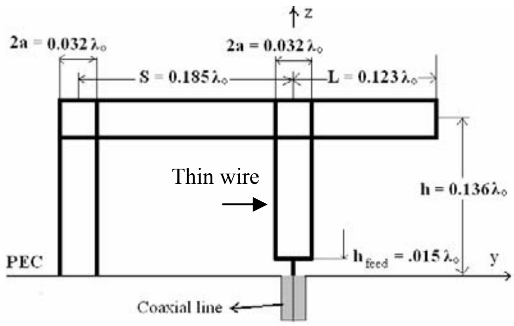


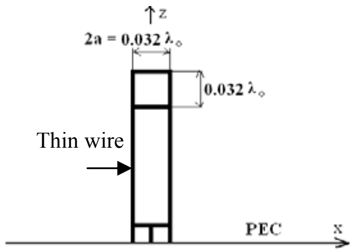
Fig. 1: Dimensions of the thick wire-modelled WIFA after optimization for maximum bandwidth, (all radii are $0.018\lambda_0$, f_o=0.925GHz)



a) 3-D view

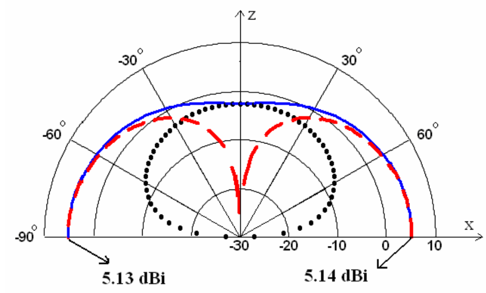


b) Side view

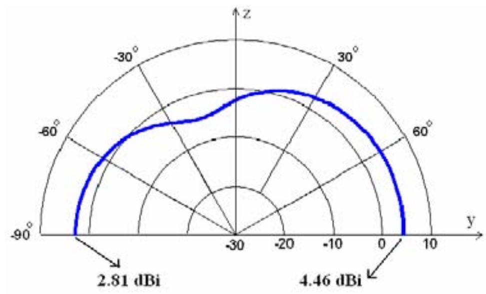


c) Cross view

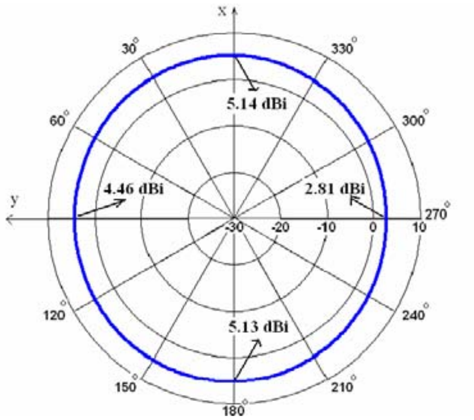
Fig. 2: General configuration and dimensions of the WG-IFA after tuning (for all thin wires, the radius is $0.009\lambda_0$)



φ=0 (deg)



φ=90 (deg)



θ=90 (deg)

Fig. 3: Gain Patterns of WG-IFA all over GSM frequency band (890-960MHz); ····· Horizontal (E_Φ), – – – Vertical (E_θ), —— Total.

Note that all the antenna elements in WG-IFA are very thin wires, and hence, the modelling can be carried out by NEC-Win Pro V1.1 one-dimensionally, so very efficiently and fast. This way, the analysis time will be very less than that of other EM-softwares (e.g. HFSS) because they have to model thick wires with cylinders.

Also, it is noteworthy to make a comparison (as in Fig. 4) between the VSWR of the structure in Fig. 1 and the tuned and finalized WG-IFA in Fig. 2. As seen, the difference in central frequency is not very much. This confirms that the thick wire modelling in NEC (using thick wire extended kernel) helps us to approach the optimum result to some extent while requiring very little time.

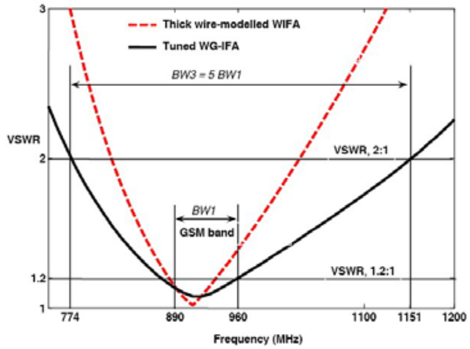


Fig. 4: Comparison between the VSWR of the thick wire-modelled WIFA and the tuned WG-IFA

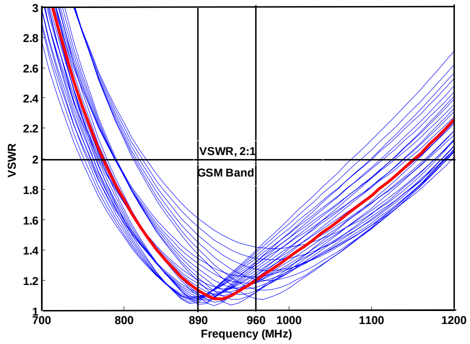


Fig. 5: The result obtained from yield analysis on the parameters, "h_{feed}" and "a" in Fig. 2. Variation ranges are: $0.01\lambda_0<h_{feed}<0.02\lambda_0$ & $0.012\lambda_0<a<0.02\lambda_0$

3. Yield Analysis

Before implementation of the antenna, it is essential to study the effect of inaccuracy in fabrication on the most crucial parameter, VSWR. By this study, the critical parts of the antenna, which need more precision in practice, are revealed. Beside, it is found that whether the required accuracies are achievable in practice or not. This study, which has been used in [9] for example, is called yield analysis. Two parameters in Fig. 2, "a" and "h_{feed}" that are the most critical (effective on VSWR) are included in this analysis. The VSWR of the optimized antenna along with the deviated ones in yield analysis are shown in Fig. 5. From this result, it can be expected that if the deviations in fabrication on "a" and "h_{feed}" do not exceed the range $0.01\lambda_0<h_{feed}<0.02\lambda_0$ and $0.012\lambda0<a<0.02\lambda_0$ (≈ 60% deviation), the measured VSWR will not exceed 1.6:1 all over GSM band.

4. Conclusion

In this work, a new wire inverted-F antenna (WIFA) was proposed, which was composed of thick wires, modelled by wire-grid modelling technique (WG-IFA). Taking this strategy, while the structure acted as a very thick and broadband wire antenna, the basic constituents were still very thin wires. As a result, the antenna could be analyzed and deigned by NEC (1D MoM-based software) with much more speed than other softwares such as IE3D or HFSS. The proposed WG-IFA not only had VSWR<1.2:1 all over the GSM frequency band (890-960 MHz), but also rendered VSWR<2:1 over the range 774-1151 MHz. This very wideband characteristic (BW=39.2%), which is approximately five times more than that of a typical WIFA, makes the WG-IFA a good candidate for many application other than GSM communications. The structure sensitivity to the fabrication error was also investigated by doing yield analyses on critical dimensions.

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