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DUAL-BAND YAGI-UDA ANTENNA FOR WIRELESS COMMUNICATIONS

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Abstract—A novel Yagi-Uda antenna with dual-band (915–935 MHz and 1760–1805 MHz) is presented. Branch structures are used to realize dual-band performance. The geometrical parameters for the branch structures are optimized to explore the antenna to operate satisfactorily in the two bands. Prototype is manufactured and measured, and the results are in good agreement with the simulated ones. In the two operating bands, the proposed antenna achieves directional radiation and the performances that VSWR < 2, gain 5–6.6 dBi and front-to-back ratio 6–9.1 dB, making it suitable for the non-fixed base station backhaul in wireless communications.

1. INTRODUCTION

GSM communication is used more and more widely. In GSM communication system, which is a cellular communication system, the base station is fixed, and the users are mobile. In some special cases, when there are many more people gathered than usual (such as World Expo and Olympics) the channel capacity may be inadequate that leads to the problem of communication congestion and influences the normal communication. Under such circumstances, the non-fixed base station will be a useful means that play an important role to solve the above problem. The backhaul from the non-fixed base station to the fixed one is a point-to-point communication, so a directional antenna is needed to keep correspondence between them. In this paper, we utilize the guard bands of GSM communication, by which the channel capacity is improved, to design a dual-band antenna on the guard

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bands for the backhaul communication from the non-fixed base station to the fixed one. The guard bands of GSM are 915–935 MHz for GSM900 and 1760–1805 MHz for GSM1800.

As a classic antenna, due to its high directivity, simple structure, easy to feed and low cost, Yagi-Uda antenna is widely used in wireless communications, but the bandwidth of the antenna is narrow. Throughout the last several years, there have been many contributions in the design and optimization of Yagi-Uda antenna for specific applications [1–17]. For example, a small and slim printed Yagi-Uda antenna was designed for vehicle GPRS system application [15]. Also, a successful attempt to improve the gain of a single Yagi-Uda array using a periodic band gap (PBG) structure was proposed in [16], which is used for wireless computer networking. Additionally, a broad-band quasi-Yagi antenna achieving a measured 48% bandwidth is presented for radar systems and millimeter-wave imaging arrays in [17].

In this paper, for the backhaul from the non-fixed base station to the fixed one in the wireless communication, a novel dual-band Yagi-Uda antenna is proposed. Simple branch structures are used to achieve the dual-band performance. The proposed antenna is characterized by its simple structure, easy to fulfil and thus low cost. It can realize directional radiation in bands 915–935 MHz and 1760–1805 MHz with VSWR < 2, gain 5–6.6 dBi and front-to-back ratio 6–9.1 dB, which can satisfy the application requirements excellently.

The organization of this paper is as follows. In Section 2, we present the geometry and design concept of the proposed antenna. In Section 3, design and optimization of important parameters are presented. The simulated and measured results are given in Section 4. Finally, we draw the conclusions in Section 5.

2. ANTENNA CONFIGURATION AND DESIGN THEORY

Figure 1 shows the configuration of the proposed antenna. The dual-band Yagi-Uda antenna is composed of the director, driver and reflector. In order to operate in the two application bands, the antenna is designed with simple and easy fulfilled branch structures that are made up of some short and long elements.

The driver and reflector have a similar branch structure. To alleviate the interaction between short and long elements, we place the short element of the driver and reflector next to each other, as shown in Figure 2(a). For the director, if the same structure as the driver and reflector was selected, the long element would be equivalent to a reflector in the high-frequency band, and then it would cause the

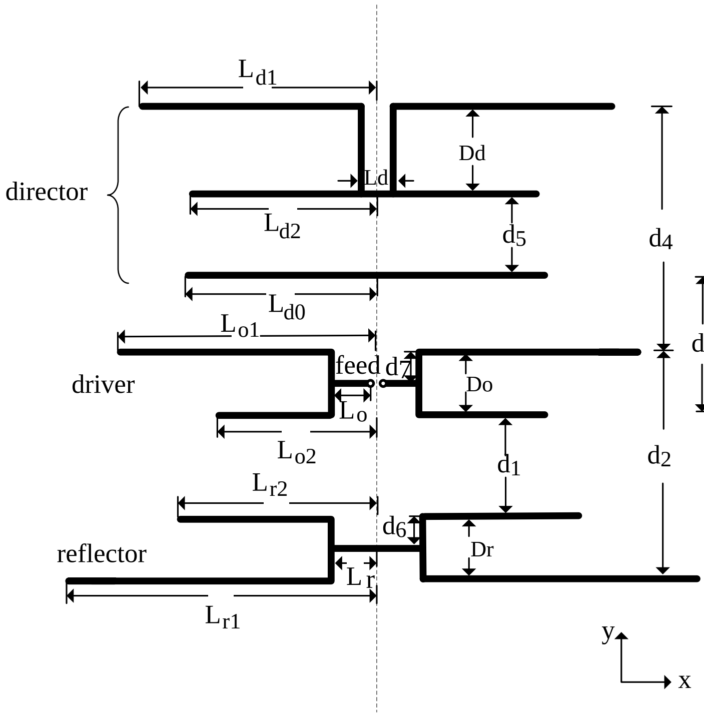


Figure 1. Configuration of the proposed antenna.

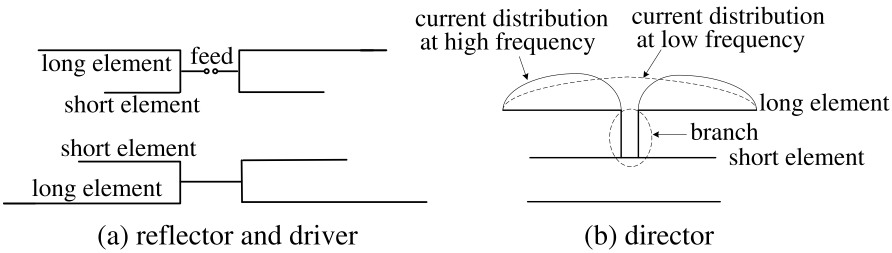


Figure 2. Explanation for each part of the proposed antenna, (a) for the reflector and driver, and (b) for the director.

radiation direction reversed. Therefore, we adopt the structure that the long and short elements are connected by a branch as shown in Figure 2(b), in which the branch length should be around one fourth of the wavelength of the center frequency for the high-frequency band. When the antenna operates in the low-frequency band, the branch is in the short-circuit state, so the long element works as a reflector at this time. On the other hand, when the antenna operates in the high-frequency band, the branch is in the open-circuit state, that is to say, the long element equals to two short elements that can be regarded as two directors [18, 19]. Because the two equivalent directors deviate from the antenna center, their director effect may be weak, and the radiation direction may be influenced, and thus another director element is placed in front of the branch structure to enhance the director effect in the high-frequency band. The current distributions at high and low frequencies are shown in Figure 2(b). The proposed structure with a proper parameter design and optimization may meet the requirement of the dual-band performance.

3. DESIGN AND OPTIMIZATION OF STRUCTURE PARAMETERS

It is not difficult to discern that the short elements of the branches are mainly used for the high-frequency band, while the long elements are mainly for the low-frequency band. But in fact, because of the influences between the structure parameters, it is difficult for the short and long elements to operate in their own individual band as we expect. The performances vary greatly with structure parameters. If improper structure parameters are designed, the radiation directions at some frequencies may reverse to the reflector, or the antenna cannot achieve good performances in the two bands simultaneously. In short, it is difficult and crucial to determine the structure parameters in the design process. The design of the antenna includes the determination of initial structure parameters and optimization of the initial structure according to the dual-band performance requirement.

The center frequencies of the two designed bands are $f_{0L} = 925\,\text{MHz}$ and $f_{0H} = 1782\,\text{MHz}$, and the relevant wave lengths are represented by λ_L and λ_H. Assuming $\lambda_0 = (\lambda_L + \lambda_H)/2$, L_{o1}, L_{r1}, L_{d1}, d_2 and d_4, as shown in Figure 1, are designed initially on the basis of the three-element Yagi-Uda antenna with $2L_{o1} = 0.453\lambda_L$, $2L_{d1} = 0.451\lambda_L$, $2L_{r1} = 0.479\lambda_L$, and $d_2 = d_4 = 0.25\lambda_0$, while L_{r2}, L_{o2}, L_{do}, L_{d2}, d_1, d_3 and d_5 are designed initially on the basis of the four-element Yagi-Uda antenna with $2L_{o2} = 0.463\lambda_H$, $2L_{r2} = 0.486\lambda_H$, $2L_{do} = 2L_{d2} = 0.461\lambda_H$ and $d_1 = d_3 = d_5 = 0.25\lambda_H$. The parameters D_d, D_o and D_r are critical factors that determine the dual-band radiation directions. If the values of them are too large, the radiation may be bidirectional, while if too small, the radiation direction in the high-frequency band may be reversed to the reflector. In addition, the inadequate L_d value will also lead to the radiation direction reverse.

Therefore, proper initial values should be designed to guarantee the dual-band directivity basically. The initial values of D_d, D_o, D_r and L_d are designed individually as 3.5 cm, 2 cm, 2 cm and 1 cm. Then set $L_r = L_{r2}/2$, $L_o = L_{o2}/2$, $d_6 = D_r/2$, and $d_7 = D_o/2$. With the above initial parameters determined, the initial structure is obtained.

Generally speaking, the reflector affects the input impedance and front-to-back ratio greatly, but the gain not obviously, and the driver is the key factor that influences the input impedance, while the director produces obvious effect on the front-to-back ratio, gain and input impedance all together [19]. The interlaced effect of the performance parameters makes the design very complicated, for which the differential evolution (DE) algorithm [20–23] is used to optimize the structure parameters of the proposed antenna and make a tradeoff between the concerned performances.

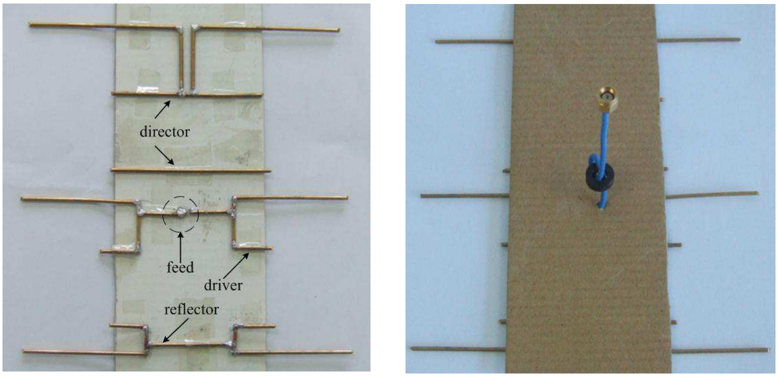
It is a multi-objective optimization problem. The design objectives of the proposed antenna are to maximize the front-to-back ratio $FBR(x, f)$ and gain $G(x, f)$, and achieve an input impedance $Z(x, f)$ of approximately 50 ohm in the two bands. We take the method that weighs multi-frequency and multi-objective functions and combines them linearly to form a single objective function to be solved. The objective function is expressed as follows,

$$F(x,f)=\sum_{i=1}^{M}\left[a\times G(x,f_i)+b\times FBR(x,f_i)-c\times\left|50-\mathrm{Re}(Z(x,f_i))\right|\right.$$
$$\left.-d\times\left|\mathrm{Im}(Z(x,f_i))\right|\right] \tag{1}$$

where vector x represents the structure parameters of the antenna. Parameter f represents the frequency. M represents the number of the interested frequency points. The positive constants a, b, c and d are weights that control the contribution from each term to the overall objective function. The guiding principles for determining their values are to increase a when priority is given to the gain, increase b when priority is given to the front-to-back ratio and increase c and d when priority is given to the impedance matching. Thus, by adjusting a, b, c and d, we make a tradeoff between the performance parameters. The proposed antenna is optimized to determine x that maximizes the objective function. Variable ranges are as follows: the range of $2L_{r1}$ is $0.45\lambda_L \sim 0.5\lambda_L$, and $2L_{r2}$ is $0.45\lambda_H \sim 0.5\lambda_H$. $2L_{o1}$ is $0.43\lambda_L \sim 0.5\lambda_L$, and $2L_{o2}$ is $0.43\lambda_H \sim 0.5\lambda_H$. $2L_{d1}$ is $0.42\lambda_L \sim 0.5\lambda_L$, and $2L_{d2}$ is $0.42\lambda_H \sim 0.5\lambda_H$. d_1, d_3 and d_5 are all $0.15\lambda_H \sim 0.4\lambda_H$, and d_2 and d_4 are both $0.15\lambda_0 \sim 0.4\lambda_0$. During the optimization process, a method of moments code (NEC2) [24] performs the task of analyzing the antenna. The optimized structure parameters of the proposed antenna are given in Table 1.

Table 1. Structure parameters of the proposed antenna (unit: cm).

Parameter	Dimension	Parameter	Dimension
L_{r1}	8.15	D_r	1
L_{r2}	4.05	D_o	2.19
L_r	2.03	D_d	3.2
L_{o1}	8.12	d_1	4.17
L_{o2}	3.86	d_2	7.35
L_o	2.32	d_3	3.67
L_{d1}	7.69	d_4	8.52
L_{d2}	3.76	d_5	3.83
L_d	0.5	d_6	0.8
L_{do}	4	d_7	0.51



(a) front view of the antenna (b) rear view of the antenna

Figure 3. Fabricated dual-band Yagi antenna, (a) is the front of the antenna and (b) is the back of the antenna.

4. SIMULATED AND MEASURED RESULTS

A prototype of the dual-band Yagi-Uda antenna with the dimensions optimized above is manufactured. The photograph of the fabricated antenna is shown in Figure 3. The elements are constructed of brass wires with radius of 1.1 mm, and an epoxy resin plate is attached to the antenna to provide mechanical supporting and fixing. There are many types of balun as described in [25], and a method of choke magnetic ring is taken here, as shown in Figure 3(b). For the balun design is not the emphasis in this paper, we do not make a further study on it here. The measurement of the prototype is carried out by a HP8753D network analyzer in a microwave anechoic chamber, and the measured results are shown in Figures 4 and 5.

In Figure 4, the antenna VSWR with respect to a 50 Ohm impedance transmission line is illustrated. As seen, there are two operating bandwidths with VSWR < 2 which cover the bands 915–935 MHz and 1760–1805 MHz, and the simulated and measured results are in agreement on the whole. The measured bandwidth is a little wider than the simulated one, which is mainly caused by the choke magnetic ring on the feed line that is used for decreasing the current on the cable sheath.

Radiation patterns of the fabricated prototype are measured at 920 MHz and 1780 MHz in the H-plane (yz-plane) and E-plane (xy-plane). The measured results, along with the simulated ones, are shown in Figure 5. There is a good agreement between the measured results and simulated data. It is clearly observed that the prototype realizes the directional radiation at the two frequencies. The simulated patterns of other frequencies are not provided here, but they keep a high consistency in the bands 915–935 MHz and 1760–1805 MHz, respectively. The data of the gain and the front-to-back ratio of the prototype in the two bands are given in Table 2, from which we can see the front-to-back ratio values are 6–9.1 dB, and the gain values are 5–6.6 dBi. To achieve good performances of VSWR and front-to-back ratio, a reasonable tradeoff is made between the performance parameters during the design process, which makes the gain of the antenna is not very high, but still acceptable for the above-mentioned application.

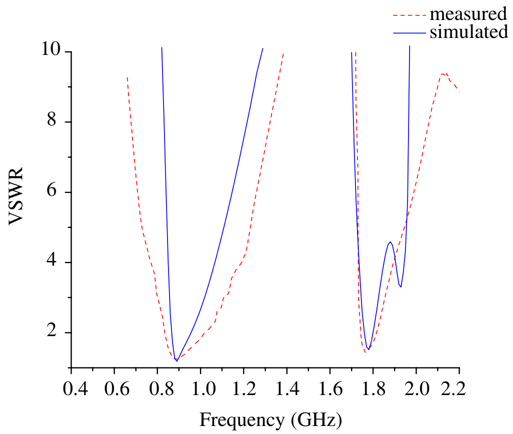
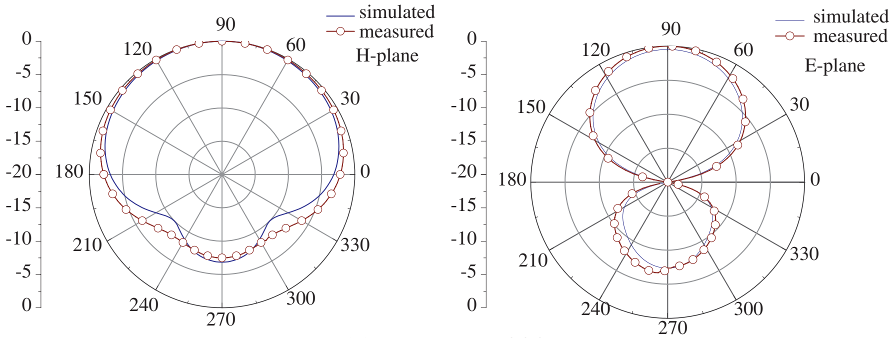
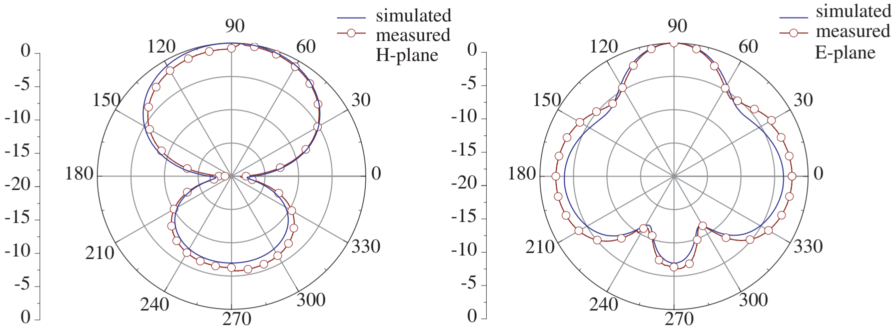


Figure 4. Simulated and measured VSWR of the proposed antenna.



(a) patterns at 920MHz



(b) patterns at 1780MHz

Figure 5. Simulated and measured radiation patterns in E-plane and H-plane at the frequencies 920 MHz and 1780 MHz, (a) for 920 MHz, and (b) for 1780 MHz.

Table 2. Values of gain and front-to-back ratio.

Band	Gain	Front-to-Back ratio
915–935 MHz	5–6 (dBi)	6.85–7.09 (dB)
1760–1805 MHz	5–6.6 (dBi)	6–9.1 (dB)

All the above results demonstrate that the proposed antenna performs excellently to meet the requirements of the application.

5. CONCLUSION

In this paper, a novel dual-band (915–935 MHz and 1760–1805 MHz) Yagi-Uda antenna has been proposed for the non-fixed base station backhaul in wireless communications. To achieve the dual-band performance, branch structures that are simple and easy to fulfil were used. The antenna configuration design and optimization methodology have been described. The qualitative discussions of the important parameters provide brief guidelines for the antenna designer. A prototype of the dual-band Yagi-Uda antenna was fabricated and measured with the results reaching the excepted values. In the two operating bands, the proposed antenna achieves directional radiation and performances that VSWR < 2, acceptable absolute gain 5–6.6 dBi and front-to-back ratio 6–9.1 dB.

The dual-band Yagi-Uda antenna features simple structure, easy to fulfil and thus low cost. We fabricated the prototype in the wire form. In actual engineering the antenna can also be realized in other forms. Based on the proposed design concept, it is expected to develop antennas for wider applications in modern wireless communications.

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