Research Article

Microstrip Folded Dipole Antenna for 35 GHz MMW Communication

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A microstrip asymmetric folded dipole antenna on chip is proposed in this paper. The construction of balun feed line is adopted to provide wideband. A new design procedure based on the odd-even mode method to calculate the input impedance of an asymmetric strip folded dipole antenna is presented. The folded dipole antenna has the advantage of small size, low profile, low cost, and so forth. The measured results show that a miniaturized antenna has the bandwidth of more than 14.2% ($VSWR \leq 2$); gain of the antenna is 5.7 dB at 35 GHz.

1. Introduction

Recently, substantial knowledge about the 35 GHz millimeter-wave (MMW) channel has been accumulated and different architectures have been analyzed to develop new MMW communication systems for commercial applications. MMW technique has been used as a favorite data transmission means for wireless or mobile communications. MMW integrated antenna, as the most effective reconnaissance tool, is popularly applied in many fields and becomes more and more indispensable. As is used in various fields for a highly attractive solution, several rigorous requirements for antennas such as small size, wide bandwidth, and stable radiation pattern are under consideration when the antenna is applied [1–3].

In this paper, a strip asymmetric folded dipole antenna and a new design procedure based on the odd-even mode method to calculate the input impedance of the antenna have been proposed to realize wide bandwidth and high gain. The method is explicit and simple. The construction of balun fed by microstrip is used to provide 180 phase difference and wideband. In order to integrate the antenna on chip, the structure traditional analysis method, and high frequency characteristic of antenna have to be taken into account.

2. Antenna Design

The configuration of the proposed antenna is shown in Figure 1. The antenna is constructed by using microstrip folded dipoles connected with a balun feed line on a bottom substrate having a thickness of 0.635 mm and a relative permittivity of 2.2. The asymmetric strip folded dipole is designed on the top of the substrate, which has a thickness of 0.1 mm and a relative dielectric constant of 2.2. The values of design parameters are listed in Table 1.

The strip asymmetric folded dipole is shown in Figure 2. The geometries such as L , b , d , s , W_1 , and W_2 are adjusted to tune the input impedance and to widen the bandwidth. The antenna is accompanied without ground plane, so its radiation pattern is similar to the dipole of the same length l , but it provides about four times larger input impedance than that of the conventional dipole when $l \leq \lambda/2$. The length of a single-wire dipole is usually $\lambda/4 \leq l \leq \lambda/2$ for best directivity with no side lobes. Usually, l is about half wavelength and $s < 0.002\lambda$. The separation distance b between the two strip transmission lines of the folded dipole should not exceed 0.05λ .

According to the traditional analysis method [4], the excitation of a folded dipole is decomposed into two fundamental

TABLE 1: Values of design parameters (all in millimetres).

L	d	s	b	$W0$	$W1$	$W2$	$W3$	$W4$	$l1$	$l2$	$l3$	$h1$	$h2$	ϵ_1	ϵ_2
3.44	0.12	0.1	0.11	0.6	0.318	0.462	0.13	0.1	0.237	0.13	0.87	0.1	0.635	2.2	10.2

FIGURE 1: The construction of the antenna: (a) side view; (b) top view.

FIGURE 2: The schematic diagram of strip asymmetric folded dipole.

modes: the transmission line mode and unbalanced antenna radiation mode, as described in Figure 3, where I_a is the antenna current of the dipole and I_T is the transmission line current. The feed port input impedance of folded dipole is given by [5]:

$$Z_{in} = \frac{2(1 + \gamma)^2 Z_D Z_T}{(1 + \gamma)^2 Z_D + 2Z_T}, \quad (1)$$

FIGURE 3: Current distribution on a folded dipole.

FIGURE 4: A strip asymmetric folded dipole in antenna mode.

where Z_D is the input impedance of strip dipole antenna with length of L and width of $W1$. Z_T is the input impedance of the asymmetric strip. Consider

$$Z_T = jZ_c \tan\left(\frac{\beta L}{2}\right), \quad (2)$$

where Z_c is characteristic impedance of transmission line and $K(k)$ is the elliptic function; $K'(k) = K(k')$, $k'^2 = 1 - k^2$,

$$Z_c = \frac{120\pi}{\sqrt{\epsilon_r}} \frac{K(k)}{K'(k)},$$

$$\gamma = \frac{\ln \left[4C + 2\sqrt{(2C)^2 - (W_1/2)^2} \right] - \ln W_1}{\ln \left[4C + 2\sqrt{(2C)^2 - (W_2/2)^2} \right] - \ln W_2}, \quad (3)$$

$$C = \frac{b}{2} + \frac{W_1}{4} + \frac{W_2}{4},$$

where $2C$ is the distance between middles of two strip dipole line and $(1 + \gamma)^2$ is the impedance ratio. Since Z_D and Z_T are

FIGURE 5: Equivalent two-port network for strip asymmetric folded dipole.

FIGURE 6: Equivalent network with electric and magnet wall.

too complicated to be calculated, so an explicit and simple method is presented.

The design procedure involves two steps. The first is to calculate the input impedance of asymmetric strip line in transmission mode. The second step is to calculate the input impedance of asymmetric folded dipole in antenna mode. Then according to the traditional method equivalent input impedance is obtained [4].

2.1. Input Impedance of Transmission Line. The input impedance in asymmetric transmission can be viewed as two-series transmission line. An input impedance can be obtained by

$$Z_t = \left[Z_0 \left(\frac{Z_L + jZ_0 \tan(\beta l/2)}{Z_0 + jZ_L \tan(\beta l/2)} \right) \right], \quad (4)$$

where Z_0 is the characteristic impedance of a strip transmission line. The characteristic impedance of W_1 and W_2 strip is calculated by Agilent ADS or Ansoft Designer, respectively.

2.2. Input Impedance of Folded Dipole Antenna. In case of symmetrical geometry of microstrip antennas or arrays with any voltage excitation, generalize odd-even mode expansion method can be used. An asymmetric folded dipole in antenna mode can be viewed as symmetric two-port microwave network, as shown in Figures 4 and 5. The characteristic impedance can be determined by odd-even method. The symmetric plane F is magnet wall in even mode situation and electric wall in odd mode situation, respectively. The input impedance (resistance and reactance) of a very thin dipole of length l and diameter d ($l \gg d$) can be computed using either

FIGURE 7: Comparison with odd-even mode and literature [5] method.

FIGURE 8: The schematic diagram of balun.

FIGURE 9: The front of the proposed antenna.

FIGURE 10: The back of the proposed antenna.

FIGURE 11: The measured and simulated return loss of the proposed antenna.

FIGURE 12: The simulated return loss with different width of the ground.

FIGURE 13: E-plane radiation pattern at 35 GHz.

Pocklington's integral equation or Hallen's integral equation [4]. The equivalent radius of strip dipole can determine that Hallen's theory of cylindrical antennas could be extended to antennas having noncircular cross section [4].

To derive an equation for the input impedance, let us refer to the model of Figure 6. When the electric and magnet wall were taken at the F plane, odd admittance Y_o and even admittance Y_e at the terminals 1-1' are obtained, respectively. Consider

$$Y_i \left(\frac{L}{2} \right) = Y_{di} \frac{Y_L + jY_{di} \tan(\beta L/2)}{Y_{di} + jY_L \tan(\beta L/2)} \quad i = 1, 2, \quad (5)$$

where Y_{d1} , Y_{d2} is radiation admittance in correspondence of W_1 and W_2 strip dipole.

The odd mode excitation ($Y_L \rightarrow 0$) is as follows:

$$Y_{o1} \left(\frac{l}{2} \right) = jY_{d1} \tan \frac{\beta l}{2}, \quad Y_{o2} \left(\frac{l}{2} \right) = jY_{d2} \tan \frac{\beta l}{2}. \quad (6)$$

The even mode excitation ($Y_L \rightarrow \infty$) is as follows:

$$Y_{e1} \left(\frac{l}{2} \right) = -jY_{d1} \cot \frac{\beta l}{2},$$

$$Y_{e2} \left(\frac{l}{2} \right) = -jY_{d2} \cot \frac{\beta l}{2},$$

$$[Y] = \frac{1}{2} \begin{pmatrix} Y_e + Y_o & Y_e - Y_o \\ Y_e - Y_o & Y_e + Y_o \end{pmatrix},$$

$$Y_o = Y_{o1} + Y_{o2} \quad Y_e = Y_{e1} + Y_{e2}. \quad (7)$$

FIGURE 14: H-plane radiation pattern at 35 GHz.

The input admittance Y_d and input impedance Z_d are

$$Y_d = Y_o - Y_e, \quad Z_d = \frac{1}{Y_d}. \quad (8)$$

A solution of input impedance Z_{in} is similar to the traditional analysis method, when the input impedance Z_T in transmission line mode and the input impedance Z_d in antenna mode are obtained. The curves comparison with odd-even mode method and method of literature [5] is shown in Figure 7.

Balun is an electrical device that converts an unbalanced signal (two signals working against each other where ground is irrelevant) to a balanced signal (a single signal working against ground or pseudo-ground), and vice versa. It has many forms and may include devices that also transform impedance. Transformer baluns can also be used to match impedance of differing transmission lines.

A simple structure using the shown microstrip feeding in Figure 8 is designed for the proposed balun to extend the bandwidth. The length difference between two arms of transmission line is $\lambda/2$, where λ is the wavelength of microstrip [6–9].

3. Simulated and Experimental Results

The front and back view of the proposed antenna are shown in Figures 9 and 10, which has the similar size with the Chinese coin of one yuan.

The analysis of the proposed antenna is completed by using the Ansys HFSS. The simulated and measured S-parameter of the antenna from 30 GHz to 40 GHz are shown in Figure 11. It can be seen that the antenna has a simulation bandwidth of 5 GHz and a measured bandwidth of 3.5 GHz.

The central frequency has moved to 36.5 GHz. The simulated return loss with different width of the ground is shown in Figure 12. As width grew, the central frequency has moved to low frequency.

The measured E-plane and H-plane patterns at 35 GHz are shown in Figures 13 and 14, respectively. From the figures of radiation pattern, it is observed that gain of the antenna is 5.7 dB, lesser than the simulated result. It is considered that the measured results do not perfectly match the simulated results which are caused by the limits of manufacturing technology and the influence of measurement environment; all these deficiencies need to be considered seriously and improved in further research.

4. Conclusion

A microstrip folded dipole antenna on chip is proposed with 5 GHz bandwidth ($VSWR \leq 2$) and central frequency of 35 GHz. It has been demonstrated that the design takes the advantages of small size, wide impedance bandwidth, and stable radiation pattern. A new odd-even mode design procedure to calculate input impedance for asymmetric strip folded dipole is presented. It was verified that it is explicit and simple by another method [5] and another experiment.

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