Open-Ended Two-Strip Meander-Line Antenna for RFID Tags

Hae Won Son, Gil Young Choi, and Cheol Sig Pyo

ABSTRACT—A new meander-line antenna consisting of two open-ended strips is proposed for a compact and broadband UHF radio frequency identification tag. An equivalent circuit model for the proposed antenna is derived and used to perform a simple and wideband impedance match to an arbitrary complex impedance of a tag chip without any additional matching network. The performance of the proposed antenna is validated by comparing calculated and measured results, which show good agreement.

Keywords—RFID tag antenna, meander antenna, wideband antenna.

I. Introduction

In this letter, a novel compact antenna suitable for a passive RFID tag is proposed. The proposed antenna consists of two strips that are separated by a thin dielectric sheet and opened at their ends. The antenna has wideband characteristics, and its input impedance can be easily adjusted based on a simple equivalent circuit model. A similar antenna employing the two-strip configuration has been presented by Noguchi and others [1]. A folded dipole-like antenna using planar strips instead of wires was constructed, and its wideband characteristics were exploited. In [1], however, the two strips have equal length and width, and via holes are needed to short them at some points. The proposed antenna in this letter needs no via holes connecting the two strips, which reduces the fabrication complexity and cost. In addition, the length and width differences of the two strips are exploited to adjust the input impedance of the proposed antenna freely. The design methodology is validated through a comparison between the calculations and measurements.

II. Open-Ended Two-Strip Meander-Line Antenna

The proposed antenna structure is shown in Fig. 1 along with dimensional notations. The antenna is composed of two meander-shaped strips that are separated by a thin dielectric sheet. One is a radiating strip and the other is a feed strip. The radiating strip acts as a main radiator and is proximity coupled to the feed strip. The feed strip is parallel to the radiating strip and its two ends are opened. There is a tag chip feed at the center of the feed strip. For the proposed antenna, the unfolded length of the feed strip l_f should be usually shorter than that of the radiating strip l_r so that the resonant frequency of the antenna may not be affected by the feed strip.

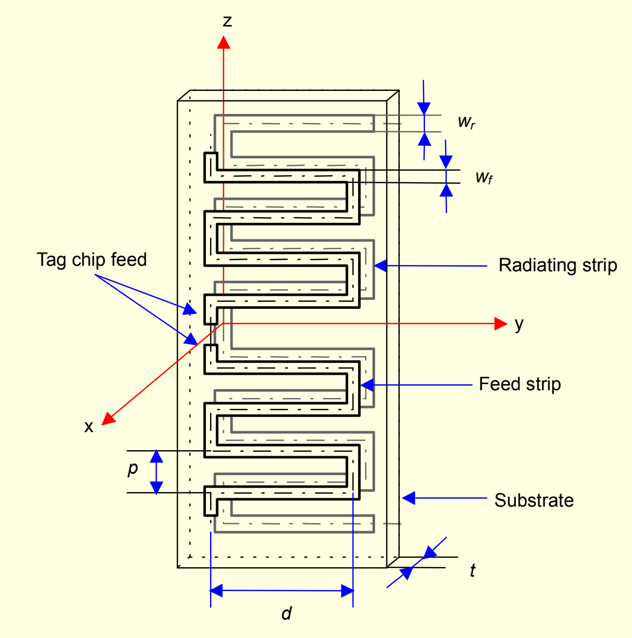

Fig. 1. Antenna structure.

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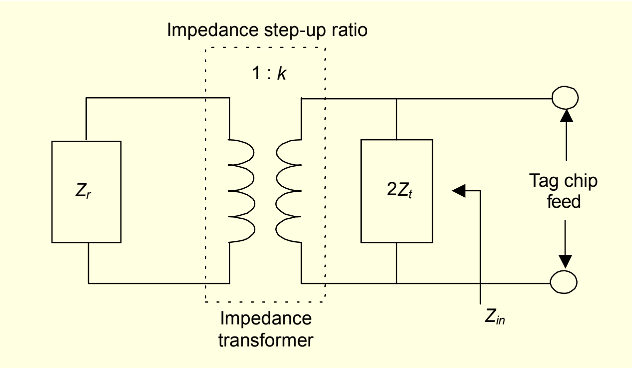

Fig. 2. Equivalent circuit.

The equivalent circuit of the proposed antenna is shown in Fig. 2, which is similar to that of a folded dipole antenna [2]. In the figure, Z_r is the equivalent impedance of the radiating strip, while Z_t represents the input impedance of the open-ended two-strip transmission line with the length of $0.5 \times l_f$.

Note that Z_r and Z_t are combined by a transformer with the impedance step-up ratio of k, which models the proximity coupling between the two strips. The value of k is a function of the width ratio w_f / w_r and the unfolded length ratio l_f / l_r of the two strips as well as the separation distance t, where w_r and w_f are the radiating and feed strip widths, respectively. In general, k increases as the width ratio w_f / w_r decreases and the length ratio l_f / l_r increases.

Near the resonant frequency f_0 of the radiating strip, its impedance can be approximated as a function of frequency f, which follows in a similar manner as [1]:

$$Z_r \approx R_{r,0} + jR_{r,0}Q_r\left(\frac{f}{f_0} - \frac{f_0}{f}\right), \tag{1}$$

where $R_{r,0}$ and Q_r are the radiation resistance and quality factor of the radiating strip, respectively. Equation (1) can be expressed in terms of admittance $Y_r(=1/Z_r)$ as follows:

$$Y_r = G_r + jB_r \approx \frac{1}{R_{r,0}}\frac{1}{1+u^2} + j\left(-\frac{1}{R_{r,0}}\frac{u}{1+u^2}\right), \tag{2}$$

where $u = Q_r\left(f/f_0 - f_0/f\right)$.

The admittance $Y_t(=1/Z_t)$ is given by

$$Y_t = jB_t = j\frac{1}{Z_0}\tan\left(\frac{\pi l_f}{v_p}f\right) \quad \text{if } l_f < l_r, \tag{3}$$

where Z_0 and v_p are the characteristic impedance and phase velocity of the two-strip transmission line, respectively.

From (2) and (3), the input admittance of the antenna $Y_{in}(=1/Z_{in})$ is given by

$$Y_{in} = G_{in} + jB_{in} = \frac{1}{k}G_r + j\left(\frac{1}{k}B_r + \frac{1}{2}B_t\right). \tag{4}$$

At $f = f_0$, the components of the antenna admittance become

$$G_{in,0} = G_{in}(f = f_0) = \frac{1}{kR_{r,0}} \tag{5}$$

$$B_{in,0} = B_{in}(f = f_0) = \frac{1}{2Z_0}\tan\left(\frac{\pi l_f}{v_p}f_0\right). \tag{6}$$

It is noted from (5) and (6) that the proposed antenna can be matched to arbitrary tag chip admittance $Y_{chip}\,(=G_{chip}+jB_{chip})$ by proper adjustments of k, Z_0, and l_f.

In (4), the two terms from B_r and B_t of the input susceptance B_{in} have opposite slope and cancel each other in the range of $f \approx f_0 \pm f_0/(2Q_r)$. This makes the proposed antenna have wideband characteristics. To maximize the impedance bandwidth for the required voltage standing wave ratio (VSWR), the canceling rate should be adjusted properly by changing the value of Z_0, which determines the slope of B_t near the resonant frequency. As the quality factor of the resonant strip moves higher, the slope of B_r becomes steeper. And therefore, to cancel the value of B_r, the slope of B_t should be increased by lowering the value of Z_0. When $w_f/w_r<1$, Z_0 mainly depends on the feed strip width-to-separation ratio w_f/t, and w_r has only a minor effect on it.

III. Antenna Design and Results

An open-ended two-strip meander-line antenna with wideband characteristics was designed and prototyped for an RFID tag chip with an input impedance of (35-j82) Ω. The design parameters of the prototype antenna are $w_r = 2.5$ mm, $w_f/w_r = 0.6$, $l_r = 260$ mm, $l_f/l_r = 0.8$, $p = 7$ mm, $d = 19$ mm, and $t = 0.127$mm. The antenna was printed on a thin substrate of polytetrafluoroethylene (PTFE) ($\varepsilon_r = 2.2$, $\tan\delta = 0.001$) using copper traces ($\sigma = 5.8 \times 10^7$ S/m) with a thickness of 18 μm.

Figure 3 shows the calculated and measured input impedance of the antenna. The numerical calculations were carried out using CST MW Studio. The proposed antenna is a kind of center-fed dipole antenna symmetric to the xy-plane. Thus, the antenna impedance was measured by measuring 1/2 of the dipole over an 80×80 cm^2 ground plane and multiplying the measured impedance by 2.

The calculated input impedance of the radiating strip is also plotted in the figure for reference. The resonant frequency f_0 of the radiating strip is 912 MHz, at which the radiation resistance $R_{r,0}$ is 18 Ω and the quality factor Q_r is 18. The width ratio w_f/w_r and feed strip length l_f were tuned for $G_{in,0} \approx 2G_{chip}$

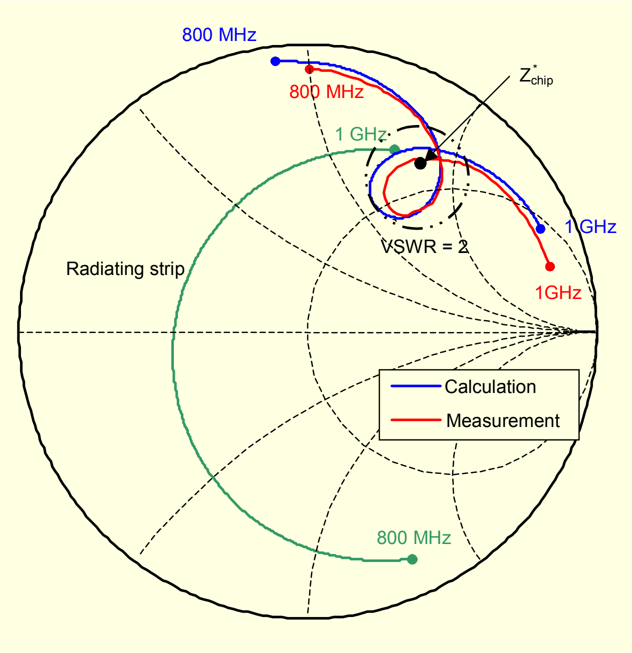

Fig. 3. Antenna input impedance.

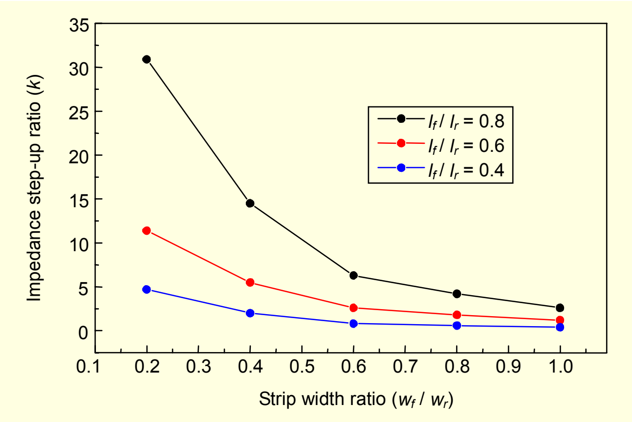

Fig. 4. Impedance step-up ratio vs. strip width and length ratios.

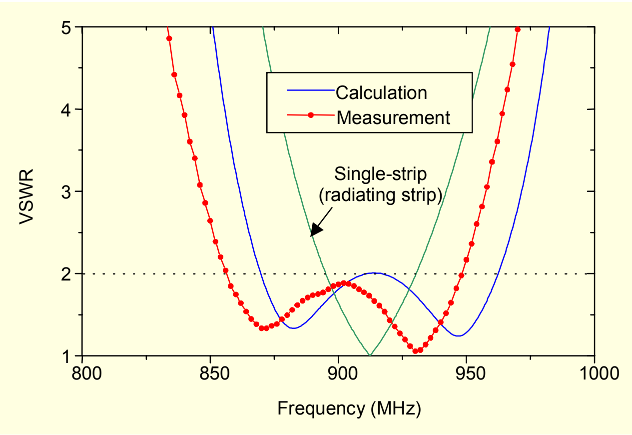

Fig. 5. VSWR vs. frequency.

(that is, $k \approx 6.3$) while satisfying $B_{in,0} \approx -B_{chip}$, which gives the maximum bandwidth for a VSWR less than 2. Figure 4 presents the calculated values of k versus the width and length ratios. It is observed that k increases as the width ratio w_f/w_r decreases and the length ratio l_f/l_r increases. The canceling rate of input susceptance was adjusted properly by tuning the feed strip width-to-separation ratio w_f/t, which results in the change of the value of Z_0. As shown in Fig. 3, the calculated and measured impedance exhibit wideband characteristics with α shapes around the complex conjugate value of the tag chip impedance.

The calculated and measured VSWRs of the prototype antenna are shown in Fig. 5. The calculated bandwidth ratio of the antenna is about 10%, and the measured VSWR of the antenna closely agrees with the calculated one. The VSWR of a matched single-strip antenna with the same dimensions as those of the radiating strip is also shown in Fig. 5, and its bandwidth ratio is 3.8%. The bandwidth of the proposed antenna is 2.6 times wider than that of the single-strip antenna. The antenna produces an omni-directional radiation pattern with linear polarization like a typical dipole antenna. The calculated directivity of the antenna is about 2.0 dBi. The radiation efficiency of the antenna by calculation considering ohmic and dielectric loss is 77 to 93% over the entire impedance bandwidth.

IV. Conclusions

An open-ended two-strip meander-line antenna has been proposed for a passive UHF RFID tag. The antenna can be directly matched to the arbitrary complex impedance of a tag chip, and wideband characteristics can be obtained by properly adjusting the impedance step-up ratio and the characteristic impedance of the two-strip transmission line. The prototype of the antenna was fabricated and measured, and the results agreed well with the calculations. In the proposed structure, there is no via hole between the two strips, and the fabrication complexity and cost can be reduced as compared with the shorted two-strip antenna [1]. According to the simulated results of the radiation efficiency, the dielectric loss from a more lossy substrate ($\varepsilon_r = 2.2$, $\tan\delta = 0.02$) is less than 1.3 dB over the entire impedance bandwidth, and a cheaper substrate may also be used for fabrication to reduce cost further.

References

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