

Reduced Amount of Conductive Ink with Gridded Printed Antennas

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Abstract

It becomes more and more common to print tag antennas using electrically conductive ink for mass-produced Radio Frequency IDentification (RFID) tags. Electrical properties of the ink are mostly determined by conductive (e.g. silver) particles mixed into the ink solution. Since silver is relatively expensive it is desirable to minimize the amount of ink used per antenna. This paper illustrates how the printed conductor area of the antenna can be reduced by applying a grid pattern to an existing antenna geometry and to what extent the gridding can be performed without significantly degrading of the antenna electrical properties. Two common antenna structures are used as an example. It is also shown that by slightly modifying the original antenna geometry it is possible to even further reduce the amount of used ink.

Keywords

RFID, Silver Ink, Printed Antennas

I. Introduction

To reduce the total amount of expensive ink used to manufacture an RFID antenna the structure should have as small paint area and thickness as possible. It was previously shown how conductive ink thickness impacts the radiation efficiency of printed antennas [1], why a study into the possibility of antenna area reduction was performed.

The simplest way of antenna area reduction is to choose a geometrically small antenna structure. An ordinary thin half-wave dipole could present a good choice except there are some limitations with its application for RFID. The thin half-wave dipole has a bandwidth of just few percent [2], making it very exposed for change in resonant frequency when put close to dielectric or conductive materials. In a harsh environment, even a small scratch on the paint could break a conductor and cause antenna malfunctioning, as shown in [3] for various types of random physical damage. Antenna structure for RFID applications should therefore be wideband and have reasonable size and conductor width.

A wide dipole antenna with nearly quadratic patches that is known to be relatively wideband [4] was chosen for primary investigation. In order to decrease the total amount of applied ink, solid surface areas are reduced through applying a grid pattern. Next, the same procedure is applied to a bowtie antenna.

Gridded antennas have been investigated before. They were used for example to achieve transparency when used as GPS antennas with glass substrates in car windshields [5]. It is also common to wire-approximate different

antenna surfaces in computational electromagnetics [6]

This paper describes how the application of different grid density to the patches of two common antenna geometries changes total print area and antenna properties. It is shown that when the printed area becomes too small, as compared to the original one, the antenna properties might become unsatisfactory. It however also appeared possible to retain good antenna properties through small modifications of the antenna length to width ratio.

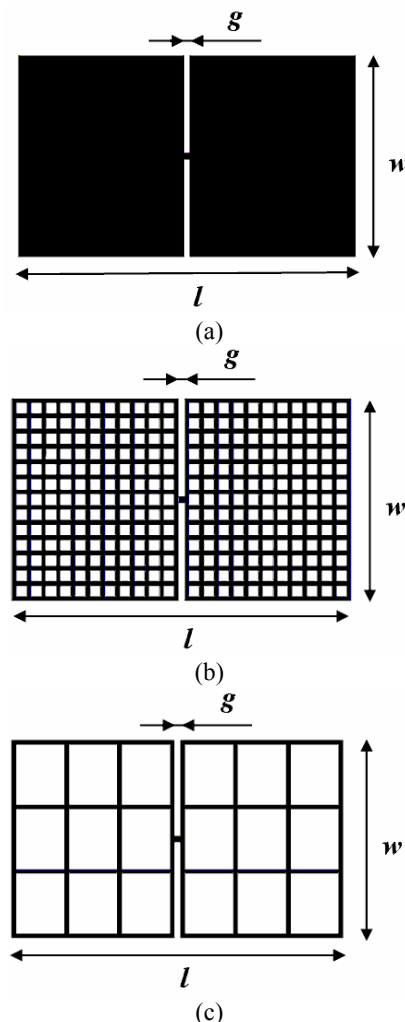


Figure 1. Wide dipoles of same characteristic dimensions l , w , and g , printed with solid conductors (a), gridded with 14 horizontal and 12 vertical 2mm lines per patch in (b) and with 4 horizontal and 4 vertical 2mm lines per patch in (c).

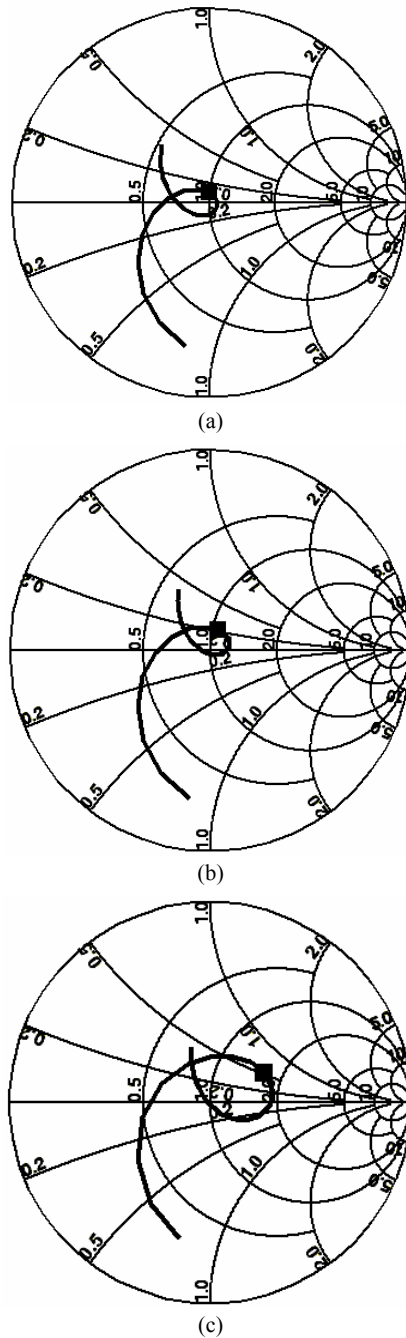


Figure 2. (a)-(c) Simulated Smith charts for printed dipoles shown in Fig.1 (a), (b) and (c) respectively. Frequency sweep range is 500-1500 MHz with the marker at the European RFID frequency of 868 MHz.

II. Gridded Antennas

A grid pattern was applied to the wide dipole antenna shown in Fig. 1 (a), where the characteristic dimensions are $l=161\text{ mm}$, $w=96.5\text{ mm}$ and $g=3\text{ mm}$. A different number of vertical and horizontal grid lines of varying width have been applied and all structures were simulated with the 3D electromagnetic modeling software *Ansoft HFSS v9.0*. Examples with 4 and 14 horizontal, and 4 and

12 vertical 2mm lines per patch are shown in Fig. 1 (b) and (c) respectively.

Fig. 2 show corresponding simulated Smith charts for antennas in Fig. 1. The frequency is swept from 500 to 1500 MHz with the marker at 868 MHz for reference (European RFID band). The impedances for the antennas in Fig. 1(a) and Fig. 1 (b) appear to be almost equal, while the impedance for the antenna in Fig. 1 (c) slightly differs.

Change in impedance leads to mismatch between tag and antenna, resulting in decreasing RFID read range. Fig. 3(a) shows a comparison between impedance mismatch and relative printed area for a different number of equally spaced 2 mm lines per patch. Number of vertical lines in a grid varies from 2 to 26 and the number of horizontal lines is adjusted to give non-printed areas close to a square. Mismatch is represented by input return loss plotted as a function of number of lines (which is directly proportional to printed area). Comparison is made at operating frequency of 868 MHz and for average input return loss values within the frequency band 780 to 1180 MHz. The solid antenna in Fig. 1 (a) is taken as a reference having 100% of printed area. It is clear that gridding with 6 lines (38% printed area) already brings input return loss below -15dB, which corresponds to a Voltage Standing Wave Ratio (VSWR) of 1.5, a custom estimate for antenna functionality.

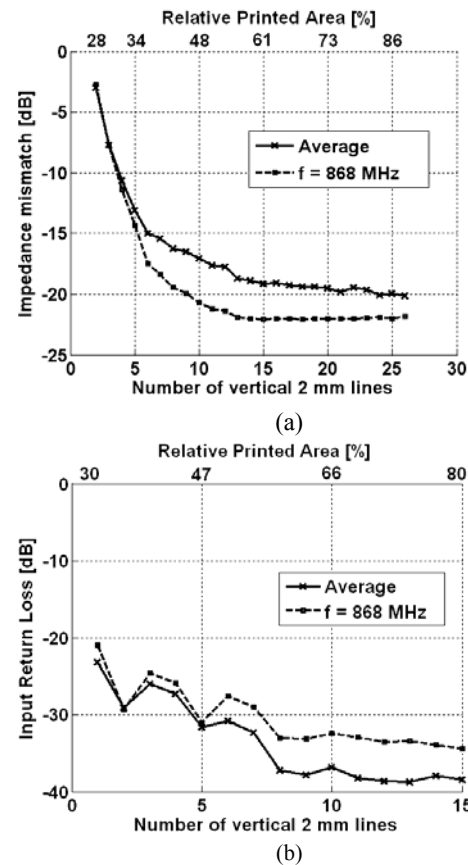


Figure 3. Input return loss of: (a) antenna shown in Fig. 1 (a) gridded with varying number of 2 mm lines per patch and (b) for the bowtie antenna, Fig. 4 (a).

The same grid procedure as described for the wide dipole has also been applied to the bowtie antenna shown in Fig. 4 (a). The bowtie antennas in Fig. 4 (a)-(c) all have the characteristic dimensions $l=124\text{mm}$, $\alpha=30^\circ$ and $g=1\text{mm}$. Results from gridding the bowtie structure are presented in Fig. 3 (b). It is clear that this structure is actually suitable for a very low density grid.

The antennas in Fig. 4 were printed on paper substrate and their transmission towards a reference antenna at 1m distance was measured with aid of an *Agilent E8364 PNA Series Network Analyzer*. Transmission parameters are presented in Table I. Difference in received power between the solid antenna in Fig. 4(a) and the ones in Fig. 4(b) and (c) is about 2 dB.

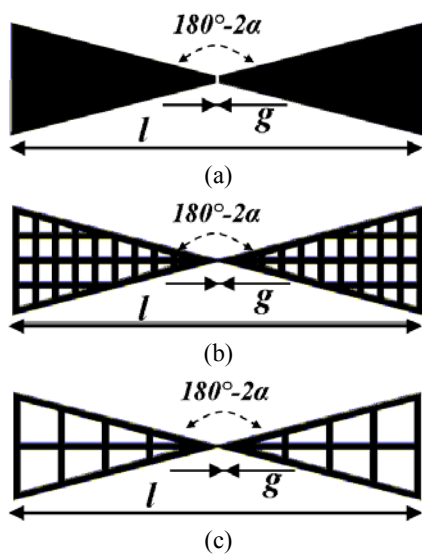


Figure 4. Bowtie antennas of same characteristic dimensions l , α , and g . Printed with solid conductors (a), gridded with: 3 horizontal and 9 vertical 2mm lines per patch (b), and with 1 horizontal and 4 vertical 2mm lines per patch (c).

While above procedure may be conducted by any person skilled in graphics or printing techniques, even better wire approximations can be made by also applying antenna engineering skills. For example, the wide dipole with only 3 vertical and 3 horizontal 2mm lines per patch shows input return loss of -8dB according to Fig. 3(a). By sweeping the length to width ratio for the wide dipole it was found that the characteristic dimensions, $l=140\text{mm}$, $w=75\text{mm}$ and $g=3\text{mm}$ provide input return loss of almost -20dB. The bowtie structures with low density grids are actually relatively good as they are. From Fig. 3(b) it is clear that the bowtie structure with no internal wires at all (only a conductor along the periphery) already has an input return loss below -20 dB. It should however be mentioned again that a bowtie structure with only thin framing wires is very susceptible for damage if used in a harsh environment.

TABLE I

TRANSMISSION PARAMETERS FOR SAMPLE ANTENNAS

Antenna (in Figure number)	Fig. 4(a)	Fig. 4(b)	Fig. 4(c)	Fig. 5(a)	Fig. 5(b)	Fig. 5(c)
Transmission Parameters S12 (dB)	-24.7	-26.5	-26.4	-26.3	-25.7	-29.5

III. Finite Conductivity and Thin Conductor Lines

An obvious way to further decrease total amount of printed area would be to apply a grid pattern with lines less than the 2mm wide. Some problems might however occur with lines being too thin if the printed antennas are to be fabricated using flexographic printing technology. Printed silver based ink has higher sheet resistances than for example copper foil. While a $35\mu\text{m}$ thick copper foil has sheet resistance of about $0.5\text{m}\Omega/\text{sq}$, an ink-printed conductor has sheet resistance in the order of $50\text{m}\Omega/\text{sq}$. Since total conductor resistance is proportional to cross-section area of the conductors, gridding printed antennas with thinner lines will lead to higher ohmic losses with following lower radiation efficiency. Even if the printed traces have high enough conductivity, general limitations in the Flexographic printing technique lead to difficulties with positive lines less than 0.1-0.2mm and negative lines less than 0.3-0.4 mm wide. Fig. 5 (a)-(c) show bowtie antennas having 3 horizontal and 9 vertical lines printed with line widths 1, 0.6 and 0.3 mm respectively. These antennas were printed on paper substrate and capability of transmission to a reference antenna at 1m distance was measured. From the transmission parameters presented in Table I it is clear that as the 2, 1 and 0.6 mm line width antennas produce almost the same power, there is an additional 3dB decrease with the 0.3 mm antenna.

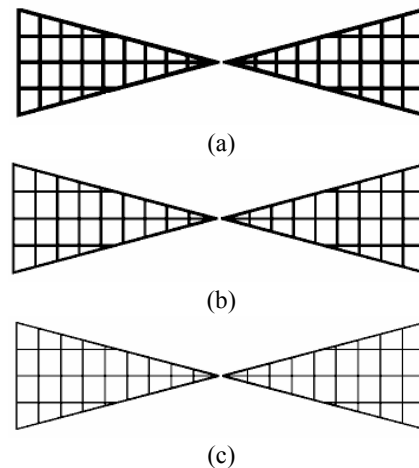


Figure 5. Bowtie antenna having 3 horizontal and 9 vertical lines per patch printed with line width: (a) 1, (b) 0.6 and (c) 0.3 mm.

IV. Conclusions

Ink savings of more than 50% can easily be achieved by substituting solid antenna areas with grid patterns. In a multimillion unit production line this saves a significant amount of expensive silver ink. Since the characteristic antenna geometry is not changed, this procedure does not require deep knowledge in antenna theory but can be performed for example by specialists from printing industry. Further savings can be achieved by an even less dense grid, but requires antenna modeling to maintain critical antenna parameters. Too small number of narrow grid lines however makes the antenna more susceptible for physical damage. Measurements also show that with the printing technique used, the line width should not be less than 0.6mm as this severely decreases the antenna radiation efficiency.

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References

1. A. Koptioug, P. Jonsson, T. Olsson, J. Sidén and M. Gulliksson, "On the behavior of printed RFID tag antennas, using conductive paint", in the Proceedings of Antenn-03, Kalmar, Sweden, 2003.
2. W.L. Stutzman, G.A. Thiele, "Antenna Theory and Design, 2nd ed.", p. 168 ISBN 0-471-02590-9, John Wiley & Sons 1998.
3. T. Olsson, A. Koptioug, "Statistical analysis of antenna robustness", Antennas and Propagation, IEEE Transactions on, Vol. 53, Issue 1, pp.566 – 570, Jan. 2005.
4. J. I. Kim, B.M. Lee and Y. J. Yoon, "Wideband Printed Dipole Antenna for Multiple Wireless Services", Applied Microwave & Wireless Magazine, pp. 70-77, September 2002.
5. G. Clasen, R. J. Langley, "Patch antennas constructed from meshes", Antennas and Propagation Society International Symposium, 1999. IEEE, Volume 4, pp. 2638 – 2641, 11-16 July 1999.
6. G. J. Burke, A. J. Poggio, "Numerical Electromagnetics Code (NEC) – Method of Moments", Technical Document 116, AFWL-TR-76-320, Naval Ocean Systems Center, San Diego, CA, July 1977.