

PRINTED RFID TAG ANTENNAS WITH MINIMAL PERFORMANCE DEGRADATION WHEN BENT

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In some wireless applications, such as Radio Frequency IDentification (RFID), printed antennas are attached to non-flat surfaces or flexible substrates such as paper or soft plastics. This might cause distortion to the communication system because of unwanted bending of the antenna structure. Previous work has shown that bending of traditional half wavelength dipole antennas with thin conductors can significantly reduce the operating range of a passive RFID system. In this paper we investigate if printed dipoles with wide conductor strips is less sensitive to this kind of distortion. Computer simulations and verifying measurements are used to study the effects of dipole bending. Results show that a carefully designed printed dipole can be a good choice for applications where distortion due to bending of antenna structures might occur.

1. Introduction

One of the ways to achieve low cost mass production of microwave antennas is to print them with conductive ink onto paper or other suitable substrate. With the RFID applications this paper substrate may have glue on its backside and together with an Application Specific Integrated Circuit (ASIC) form an RFID tag that could easily be attached to the objects to be identified [1]. If the antenna attached to a flexible substrate however is attached to objects with soft or non-plane surface, it can be affected by various distortions such as bending. In some cases it might also be necessary to stick the tag over a corner of an object. The distortion in the structure due to bending will generally affect the performance of the tag antenna and cause performance degradation to the RFID system, especially when operating at microwave frequency. Previous work has shown how bending traditional thin half wavelength dipole and folded dipole antennas can severely degrade the performance of a passive RFID system [2]. In this paper we consider if printed dipoles with low length- to width ratio (i.e. made of wide conductor strips), referred to as *fat dipoles*, could be a convenient choice for antennas in RF applications where distortion due to bending of the antenna structure might occur. Fat dipoles

are known to be relatively wideband [3-4] and our initial studies have shown them to also be relatively tolerant to bending. For in-depth studies initial antenna dimensions are taken from a non-distorted fat dipole case. Extensive modelling is then carried out by varying the antenna geometry parameters and monitoring the change in input impedance caused by bending of the antenna structure. Finally key results are verified by measurements.

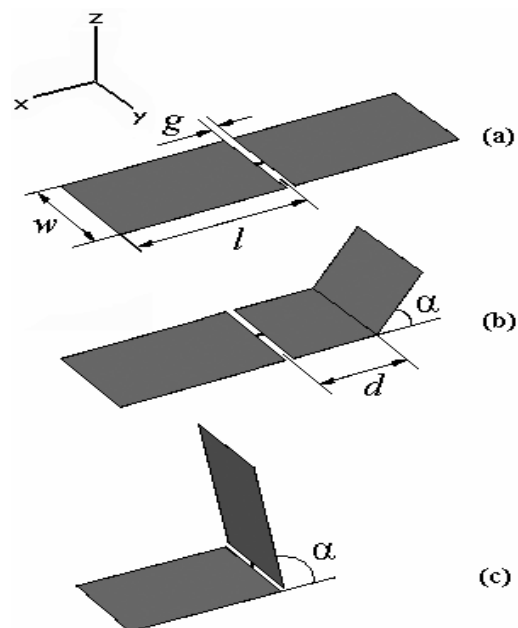


Figure 1: (a) Undistorted fat dipole, (b) fat dipole with one arm bent 45° towards the z-axis at $d=l/2$ and (c) fat dipole bent 90° at feed point .

2. Bending fat dipoles

While in [4] guidelines are presented for designing a wideband fat dipole we here introduce bending to this kind of structures by bending one antenna arm with angles α up to 90° applied at different positions d , as illustrated in Fig. 1. Investigations show that worst case scenario when bending the fat dipoles at one point is when bending 90° at feed point, as in Fig. 1(c). Thus it is interesting to find out if some antennas can withstand such bending and still maintain a VSWR beneath 1.5 which corresponds to an input return loss of about -14dB. While in [4] fat dipoles' length- to width ratio and feed gap are varied for achieving wideband properties we here vary these parameters with the desire to achieve antennas with input impedance 50Ω at the frequency 2.45 GHz and that can withstand substantial bending. While antenna arm length is kept with constant length l , the antenna length- to width ratio is swept from $l/w = 0.90$ to $l/w = 20$ with feed gap- to length ratio ranging from $g/l = 0.025$ to $g/l = 0.10$. Wider antennas are not considered since we are only looking at bending by rotating one antenna arm around a vector with only a y-component towards the antenna normal (the z-axis). Designs with wider antenna arms could be more likely to be distorted by bending in the way of rotating around a vector with an x-component. Wider antennas also tend to have input impedance with real part less than 50Ω . Antenna structures are simulated in free space and all calculations are carried out by Finite Integration Techniques (FIT) [5]. Looking into frequency sweeps of each antenna structure is a way of investigating different scaling of the antenna. By assuming perfect impedance matching at each frequency for the undistorted antenna, the performance degradation caused due to bending can be further illustrated by calculating the relative input return loss at each frequency.

3. Antennas with minimal performance degradation when bent

The input impedance response to changes in width and feed gap for a fat dipole with $l = 44.2$ mm bent 90° at feed point is illustrated Fig. 2(a). The overall picture closely resembles the one described in [4] for undistorted fat dipoles. Fig. 2(b) presents the comparison of the Smith

Charts for an antenna with $l = w = 44.2$ mm and $g = 2.3$ mm being flat and being bent 90° at feed point. Deflection in input impedance when bending antennas with other dimensions tend to behave in the same manner. We have restricted our search to antennas with input impedance close to 50Ω , maintaining a VSWR beneath 1.5 when bent 90° at feed point. Some of the antennas investigated are designed for the frequency 2.45 GHz and their dimensions and relative input return loss when bent 90° at feed point are shown in Table 1.

Antenna	1	2	3
Feed gap, d (mm)	0.8	2.3	5.5
Width, w (mm)	27.0	44.2	21.0
Arm length, l (mm)	27.0	44.2	76.3
Calculated relative S11 when bent 90° at feed (dB)	-9.6	-18.8	-15.4
Measured relative S11 when bent 90° at feed (dB)	-10.0	-16.1	-17.4

Table 1: Dimensions and robustness against bending for some fat dipoles.

If a perfect impedance matching is assumed at each frequency of an antenna, the relative input return loss at each frequency when bending the antenna is directly proportional to the distance between each frequency in the Smith Charts for the non-distorted and the bent antenna. For antenna number 2 in Table 1 this relative input return loss is illustrated in Fig. 2(c). One can see that electrically relatively larger fat dipoles tend to be more robust to bending. Elongated antennas might however be more likely to suffer from bending simply because of their length. All studied electrically large fat dipoles have the same tendency to tolerate more significant bending. Also their input impedance in this case is deflecting from purely real and incurs some imaginary part. For such antennas to be useful one must be able to implement impedance matching of the imaginary component of the input impedance [6].

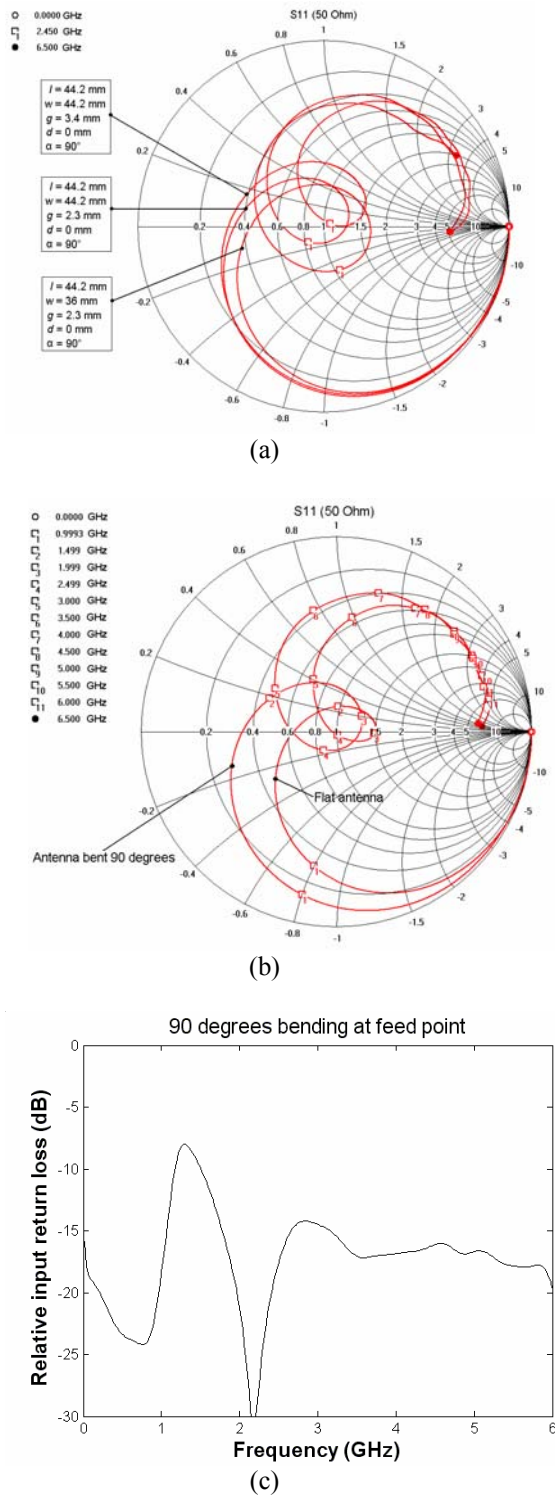


Figure 2: (a) Smith Chart for antennas bent 90° at feed point with different width w and feed gap g . (b) Smith Chart for antenna number 2 when non-distorted and when bent 90° at feed point. (c) Relative input return loss for antenna number 2 assuming perfect impedance match at each frequency.

Analysis shows that the larger input impedance mismatch the system can tolerate, the more

robust the antenna will be to distortion due to bending, and the longer it will be. For antennas with 50 Ω real input impedance, antenna number 2 with its total electrical length and width of $l=w=0.72 \lambda$, for free space wavelength $\lambda=122$ mm, is here the smallest antenna found to withstand such bending without serious performance degradation. For the verification of results, the antennas described in Table 1 were manufactured from thin metal sheets and relative measurements were carried out using an *Agilent E8364 PNA Series Network Analyzer*.

In present research no special attention is paid to the antenna radiation patterns. In RFID applications tag antennas are usually randomly oriented and antenna radiation pattern is a very specific issue as the structures with narrow-angle radiation patterns could be disadvantageous due to significant performance loss when misaligned. All studied antenna structures however demonstrate similar tendencies in the change of radiation patterns. When one antenna arm is bent the radiation pattern is tilted away from the z-axis an angle proportional to the bending angle and the wider the dipole strip is, the more isotropic the radiation pattern becomes. Antenna number two for example changes its maximum directivity from 3.8 dBi in the yz-plane in the undistorted case to 3.4 dBi in direction 45° from the z-axis towards the positive x-axis when bent 90° at feed point.

4. Conclusion

With the aid of computer simulations, parameter sweeps have been done for a printed fat dipole in order to find an antenna structure that could withstand significant physical distortion caused by bending one arm of the antenna structure. Results show that there are 50 Ω fat dipoles that could withstand the introduced bending while maintaining a VSWR beneath 1.5. The trade off for achieving these dipoles is in increased electrical size of the antenna structure than what is necessary for the same type of structures designed for flat non-flexible substrates. This in turn could though make flexible-substrate structures even more susceptible to bending. The most promising fat dipoles have been manufactured and the effect of bending has been measured. Results are encouraging and such structures could be used for applications where substantial bending might occur.

References

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