On The Behaviour of Linear Dipole Antennas with Application to Passive Radio Frequency Identification Tags Operating at 869 MHz

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Abstract: Measurements are presented on the performance of passive RFID tags constructed from linear dipole antennas which operate at 869 MHz. Linear dipole antennas on FR4 substrate are considered. Maximum read range has been investigated by decreasing a full wavelength dipole antenna to an eight of a wavelength by multiples of two. Data are given for their resonant frequencies, return losses, surface current distributions and read ranges. Also presented are modified dipole structures for optimising the electromagnetic energy launched by the reader. Data for the study are calculated using CST microwave studio which applies finite integral technique on approximated perfect boundaries of the linear dipole antennas.

1. Introduction.

The current electronic product code (EPC) initiatives support a global deployment of RFID technology for efficient detection and location of inventory assets. The frequency and power requirements for the application are separately regulated by different countries thus making specification for RFID tag antennas to vary across the globe. However it is possible to use a dual band tag antenna to operate in different countries simply by it tuning to the desired frequency [1]. A folded dipole antenna [2] and, a planar wire type inverted-F tag antenna [3] have been reported for the application. In [4], the authors introduce a patch antenna with electromagnetic band gaps (EBG) ground plane and two-layer substrate for possible RFID tag application to metallic objects. Linear dipole antennas are particularly suitable for the purpose as they offer relative design freedom and also exhibit omni directional radiation characteristic. Equally desirable is their ability to conform to mounting surfaces of tagged objects.

The basic requirements for the RFID system are a hardware platform comprising the antennas, transponder chips, readers and controllers, and the software platform made up of the middleware and the enabled applications. The transponder chip matched to the antenna form a passive RFID tag which can be used to track assets such as large containers, pallets or individual items. The geometry and orientation of a tag antenna determine its ability to attract rectifiable electromagnetic energy from the interrogating field of the reader which is used to activate the transponder chip. By modulating the reflected wave through backscatter principle the transponder transmits back the 64 bits unique identification code contained in a factory pre-programmed chip. Real time application related information programme code can be incorporated into tags using electric erasable and programmable read-only-memory (EEPROM) through the controller.

Normally, for maximum power transfer at the operating frequency, the resonator impedance (which also represent the chip impedance) must be $Za^* = Ra - jX_a$ ohms or a complex conjugate of the dipole antenna's terminal impedance. Theoretically, the terminal impedance of a linear dipole is reputed to be $73 \pm j45$. In contrast, the input impedance of the load or transponder chip can be any complex number depending on manufacturer's specification. Often the load impedance is unknown thereby requiring the dipole antenna to be parameterised. Thus key design challenges have been to determine the optimal antenna configuration and also to matching the respective impedance values at the antenna-chip terminals. Furthermore, tags are required to be small in size and mechanically robust against vibrations. Linear dipole antennas which are low-cost, simple to manufacture and have low profile are suitable for the RFID antenna systems [5]. This work describes the behaviours of practical linear dipole antennas with application to passive RFID tags operating at 869 MHz. It also examines the variation of read ranges against the length of dipole antennas.

2. A Study of Linear Dipole Antenna for Passive RFID.

Fig. 1 shows the linear dipole antenna with each arm connected to the opposite terminals of the transponder chip. The transponder chip and part of the dipole structure are on FR4 substrate with dielectric constant, ε_r = 4.3 and height 0.7 mm. The dielectric layer has a rectangular shape with side length 13.7mm and width 6.3 mm. Each dipole arm is made up of cupper wire with length, $^{\ell}/_{2}$ and thickness 0.5 mm.

Initial investigation was carried out to understand the behaviour of the dipole structure when used on a passive RFID tag. For this, the dipole arms were decreased simultaneously from a full wavelength to an eight of a wavelength by multiples of 2. A set of range of values corresponding to different dipole structures (λ, $^{1}/_{2}\lambda$, $^{1}/_{4}\lambda$, $^{1}/_{8}\lambda$) was calculated and measured. Furthermore, each dipole structure was investigated for cases without and with a matching network across the antenna-chip terminals. Results are shown in Tables 1 and 2 respectively. In both cases, the highest read ranges correspond to $^{\ell}/_{2}$ = 76 mm while the lowest is when $^{\ell}/_{2}$ = 21.8 mm.

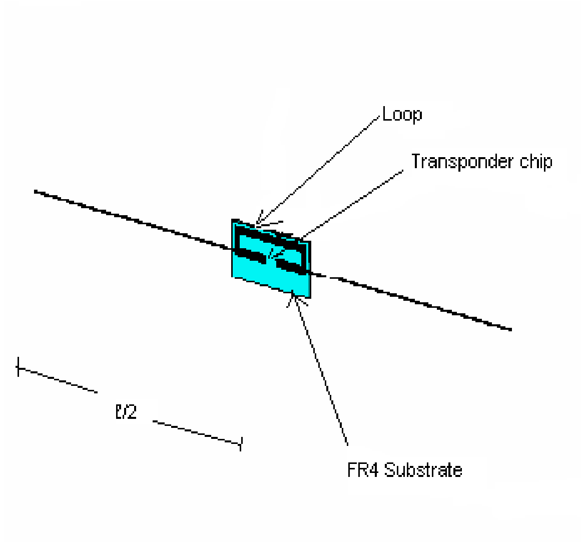

Fig. 1. A linear dipole antenna with application to passive RFID tags operating at 869 MHz.

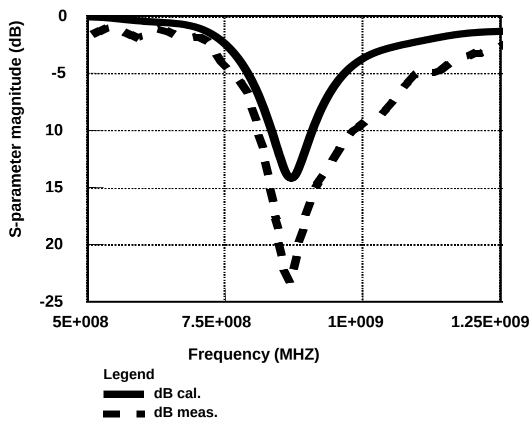

Fig. 2. Calculated and measured return losses for the passive RFID dipole antenna shown in Fig. 1 with operating frequency at 869 MHz. MHz = megahertz; dB = decibel; dB cal. represents the calculated return loss; dB meas. represent measured return loss.

Dipole structure	**$^{\ell}/_{2}$(mm)**	**d(mm)**
Full wavelength, λ	173	18
Half wavelength, λ/2	86.2	50
Quarter wavelength, λ/4	43	0
One eight of a wavelength, λ/8	21.8	0

Table 2: The variation of the read range against the length of the dipole antenna shown in Fig. 1 without a loop connected across the antenna-chip terminals. $^{\ell}/_{2}$ is the length of one arm of the dipole antenna and is measured in mm, d is the read range measured in mm.

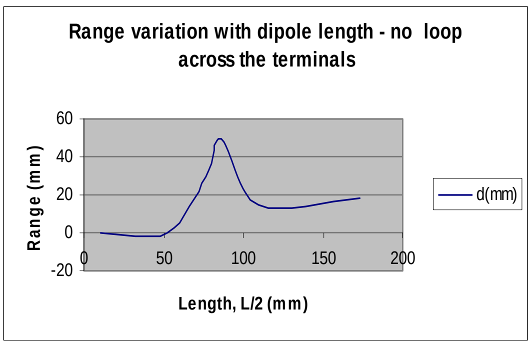

Fig. 4. The variation of the read range against the length of the dipole antenna shown in fig. 1 without a loop connected across the antenna-chip terminals.

Dipole Structure	**$^{\ell}/_2$(mm)**	**d(mm)**
Full wavelength, λ	173	180
Half wavelength, λ/2	86.25	310
Quarter wavelength, λ/4	43	110
One-eight of a wavelength, λ/8	21.8	3

Table 2: The variation of the read range against the length of the dipole antenna shown in Fig. 1 with a loop is connected across the antenna-chip terminals. $^{\ell}/_2$ is the length of one arm of the dipole antenna and is measured in mm, d is the read range measured in mm.

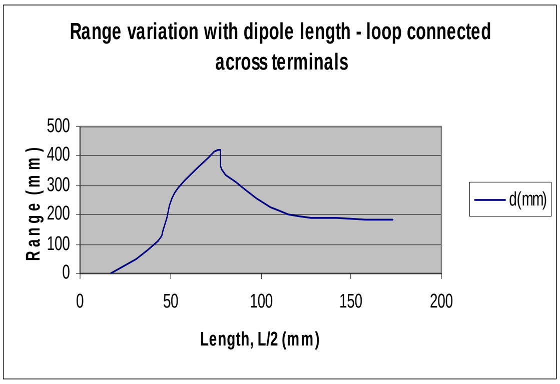

Fig. 4. The variation of the read range against the length of the dipole antenna shown in Fig.1 with a loop is connected across the antenna-chip terminals.

3. Surface Current Distribution and Radiation Pattern.

Dipole Structure	Without matching loop		With matching loop	
	Φ = 0°	Φ = 90°	Φ = 0°	Φ = 90°
Main lobe magnitude	2.1 dBi	2.2 dBi	2.2 dBi	2.3 dBi
Main lobe direction	180°	90°	180°	90°
Angular width (3dB)	77.9°		77.7°	

Table 3. Computed farfield directivity (Theta) with Phi varying between 0° and 90°

Although the dipole antenna is symmetrically connected to the transponder chip, current distribution is not uniform over the entire length. It is observed that at the operating frequency, there is approximately zero current at the extremes and at the middle. It is further observed that the phase of maximum current is 0^0 and then repeats half cycles later at 180^0. The current pits at 90^0, and then, one half cycle later at 270^0.

Simulated farfield result shows that the main lobe magnitude increases slightly by 4.7% when Φ varies between 0^0 and 90^0 and without a matching loop connected across the antenna-chip terminals. Similarly, the same parameter increases in magnitude by 4.5% when a matching loop is connected. On the other hand, the angular width decreases by a negligible 0.26 % when a matching loop is connected. The main loop direction remains unaffected in both cases as Φ varies between 0^0 and 90^0. For the cases without and with the matching loop, the cross-polarisation figure is better than 2 dBi. The loop lowered the antenna's impedance and as a result, high concentration of electromagnetic energy is observed around the loop. The read range is proportional to the electromagnetic field intensity. Of course, the loop lowered the reflection coefficient but improved read range.

4. Conclusion.

The behaviour of linear dipole antenna with application to RFID systems operating at the UHF band has been investigated. A half wavelength dipole gives a greater range when compared to a full wavelength, quarter wavelength or an eighth of a wavelength. According to simple theory, the maximum read range for a half wavelength dipole antenna operating at 869 MHz is when the length of each arm of the dipole ($^{\ell}/_{2}$) is 86mm. However measured results show maximum read range was recorded when $^{\ell}/_{2}$ is 76mm. This adjustment is necessary as part of the antenna was printed on a circuit board, and the dielectric will have loaded the antenna causing it to be slightly shorter than the free space half-wavelength. Also dipoles routinely require trimming to compensate a capacitive end effect. There is relatively good correlation between the impedance value and what you would practically expect as the impedance of a linear dipole antenna. Again, the correlation can not be perfect due to the fact that the dipole structures are on boards containing chips, thus the substrates will alter the impedance values by virtue of their dielectric constants. It was observed that improved read range can be achieved for the cases of when the length of the dipole's arm is between 76mm and 86mm depending on the tag orientation and height with reference to floor. This study can be applied to cases where the dipole antenna is connected to unknown impedance of a passive RFID chip.

Acknowledgments.

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