Log-periodic dipole array antenna as chipless RFID tag

S. Gupta, Gui Jun Li, R.C. Roberts and Li Jun Jiang

A passive chipless radio-frequency identification (RFID) tag based on a log-periodic (LP) dipole array is proposed, where the tailorable band-rejection property of the LP aperture is utilised to realise a large number of codes. The proposed tag principle is successfully validated by measurements, where the absence and presence of the band-rejection is shown to carry the bit information. Its fabrication simplicity is also demonstrated by its implementation on a flexible substrate. Finally, two different tag formation schemes, based on a specific set of resonance suppressions, are discussed in detail.

Introduction: Radio-frequency identification (RFID) systems have found diverse applications in the fields of communication, ticketing, transportation, logistics, tracking, inventory, human identification and security, to name a few [1]. A typical RFID system comprises an interrogator (also called a reader) and many tags (also called labels). Recently, there has been strong research interest in passive chipless RFID tags, where the absence of the power supply and the integrated circuits (ICs) has shown promise for low-cost RFID solutions [2]. Chipless tags, in particular, are useful in extreme environments such as extremely high or low temperatures that are not suitable for ICs. However, they are typically restricted to relatively small distances from the reader and suffer from a low number of bits that can be encoded [1–5].

Recently, we proposed a log-periodic (LP) dipole antenna aperture is proposed for use as an information coding element in a chipless tag [6] to realise a large number of bits. This Letter provides the experimental validation of the LP-based tag along with detailed discussion on its tag properties, with a focus on its design flexibility.

LP dipole array tag: A LP antenna has impedance and radiation characteristics that are repetitive as a logarithmic function of frequency, resulting in a multi-octave bandwidth property [7, 8]. It has widespread applications in communication systems, electronic warfare systems from ultra-high frequency to terahertz applications and ultra-wideband applications. A LP antenna consists of N number of resonant dipoles the dimensions of which are scaled by a constant parameter τ, as shown in Fig. 1*a*, along with the two angular parameters α and β chosen for a self-complementary design, i.e. $\alpha+\beta=\pi$ [9]. The antenna is fed with a differential feed at the centre of the aperture and its typical S-parameter response is shown in Fig. 1*b*, where a wideband matching response is seen, which is typical of LP antennas.

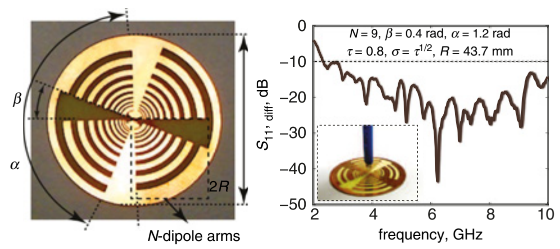

Fig. 1 *Planar LP antenna and its measured S-parameter response using 100 Ω differential probe (shown in inset)*

The physical parameters of LP antenna also shown in Figure

The discrete nature of resonant dipoles in a LP aperture can be used to encode information as was proposed in [6]. Each dipole pair in the LP aperture is responsible for far-field radiation within a specific frequency band. The relationship between two consecutive resonant frequencies of consecutive dipoles is $f_{n-1}/f_n=\tau$, for any n, which can be used to determine the desired rejection bands. The proposed tag thus consists of a LP antenna aperture from which a specific combination of resonant dipoles is removed to introduce a band-rejection in the gain response of the antenna, as first demonstrated in [10]. By choosing a specific *combination* of the resonant dipoles, the presence or absence of a null in the gain at a given frequency can be tailored, thereby realising a specific RFID code.

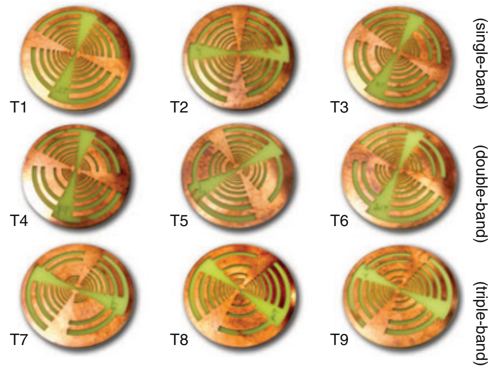

Fig. 2 *Various fabricated prototypes of printed LP antenna with single, double or triple band-rejection response*

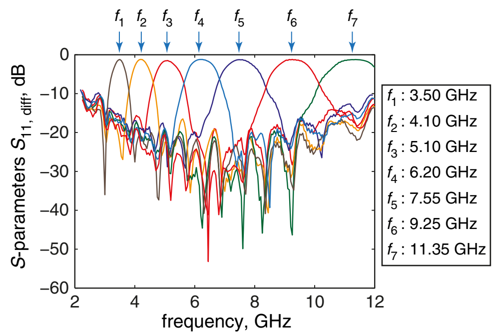

Fig. 3 *Identification of centre frequencies of rejection bands, corresponding to each dipole arm of LP aperture*

The consecutive resonant frequencies closely follow the relationship $f_n-1/f_n=\tau=0.8\forall n$

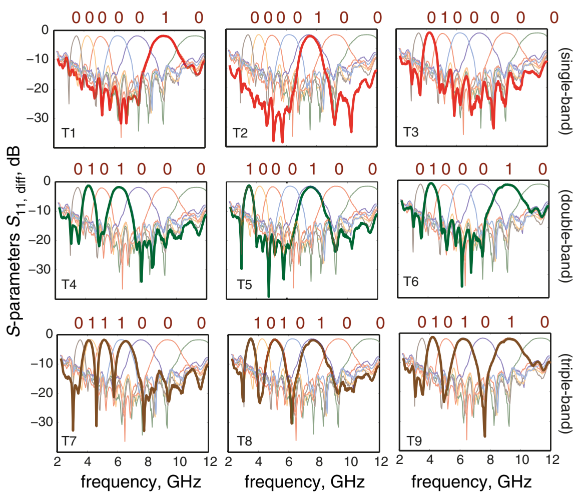

Fig. 4 *Measured S-parameters of various LP tags of Fig. 2*

To validate this concept, various LP tags were fabricated, with some of the prototypes shown in Fig. 2. The substrate used is FR4 with $\varepsilon_r=4.4$ and a thickness of 0.8 mm. The various tags differ from each other in the combination of band rejections. To characterise the specific frequency band associated with each resonant dipole, one set of tags was measured where only one resonance is suppressed at a time (similar to the first row of Fig. 2), ranging from the centre to the edge of the LP aperture. Fig. 3 shows the corresponding S-parameters, where the key frequencies can be easily identified and associated with the corresponding dipole arm on the LP aperture. Now, once those frequencies are known, their various combinations can be formed to realise specific RFID codes. Fig. 4 shows the measured S-parameters of the various tags shown in Fig. 2 where the presence and absence of a resonance is indicated as a binary bit. In each case, a distinct frequency response is clearly seen which successfully validates the proposed tag principle.

Benefits and features: The proposed tag is a completely passive and chipless tag, thereby being suitable under extreme environmental conditions, and compatible with planar printed circuit board fabrication. In addition, it offers design simplicity where the aperture plays the dual role of an efficient radiator and a coding element. To illustrate the fabrication flexibility of the proposed tag, an example tag was printed on a flexible substrate (DuPont Kapton HN) with $\varepsilon_r = 3.4$ and 25 µm thickness, as shown in Fig. 5. The corresponding *S*-parameters successfully demonstrate the code information.

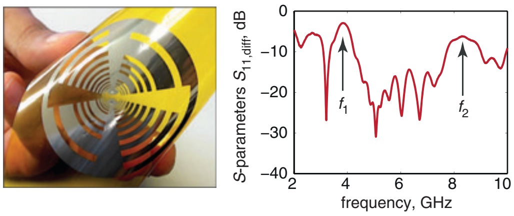

Fig. 5 *Photograph of LP tag antenna printed on flexible substrate and its corresponding S-parameter response to illustrate RFID code*

The number of possible codes, for a given aperture size, depends on the number of radiating dipoles *N*, which can be controlled by choosing the growth parameter τ. The tag formation can take two possible approaches, as shown in Fig. 6: (a) suppressing the resonance located along the diagonals (two opposite quadrants) as is used in this Letter and (b) suppressing the resonances located in all four quadrants resulting in larger code combinations. In the first case, the total number of codes that can be encoded is 2^N. In the second case, it is found using full-wave simulations that when two *consecutive* resonances are suppressed, the two neighbouring resonances combine, leading to a poor VSWR as illustrated in Fig. 6. Consequently, not all combinations can be used and suppressing two consecutive resonances is thus not allowed. In this case, the total number of tag combinations forms a Fibonacci number, i.e. $F_m = F_{m-1} + F_{m-2}$, with $F_0 = 0$ and $F_1 = 1$. For example, the total combinations possible in a LP aperture with say $N = 7$ dipoles are $F_{14} = 377$.

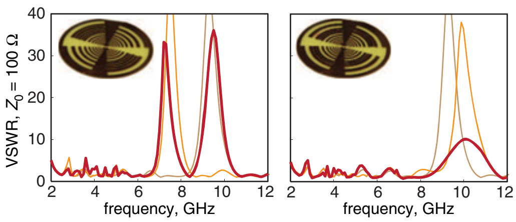

Fig. 6 *Example of tag formation schemes and their typical VSWR responses obtained using FEM-HFSS*

Finally, the proposed tag is frequency scalable and intrinsically broadband, and is thereby capable of a fast interrogation response. Moreover, the field-of-view of the LP antenna is large (typically larger than 120°) due to its dipole-like bidirectional radiation pattern, thereby making the tag suitable for interrogating from a bigger radiation space.

Conclusion: An experimental validation of a passive chipless RFID tag has been successfully shown using *S*-parameter characterisation, both on a rigid and a flexible substrate to illustrate its design flexibility. The number of possible codes on a given LP aperture has been shown to depend on the choice of the resonance suppression scheme, whereby in each case a large number of code combinations can be achieved. The proposed solution is thus expected to provide a chipless tag solution for large bandwidth RFID systems, by offering tag simplicity and a large code combination.

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One or more of the Figures in this Letter are available in colour online.

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