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Design of a Zeroth Order Resonator UHF RFID Passive Tag Antenna with Capacitive Loaded Coplanar Waveguide Structures

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Additional information is available at the end of the chapter

## 1. Introduction

The use and development of Radio Frequency Identification (RFID) systems has undergone substantial growth in the past decade in many new areas. Some of these areas include wireless sensor systems, metamaterials and compact antennas [1-8]. However, much of this new growth has required more performance from traditional passive RFID systems. In particular, the need for more compact antennas with performances comparable to much larger resonant antennas is one such condition. To fulfill the requirements of compact antennas, researchers have developed various novel RFID antenna designs [2-4], including metamaterial-based RFID antenna designs [1,5-8] to improve the performance of RFID systems. Using composite right/left-handed (CRLH) transmission line (TL) based metamaterials to show the unique property of zeroth-order resonance (ZOR) [9,10] is one such method to reduce the overall size of an antenna. More specifically, a ZOR-TL can be used to make an electrically small antenna to appear electrically large; which leads to improved matching and radiation properties. This is done by producing a zero phase constant at a non-zero frequency (i.e. the wavelength of the travelling wave becomes infinite) on the TL. This is a unique property which makes the resonance condition independent from the physical dimensions of the antenna or TL [11-13] so it can be used to design miniature antennas for passive UHF RFID applications. The resonance of such antennas at any operating frequency only depend on its CRLH characteristics to acquire ZOR at that frequency and less to do with the physical dimensions of corresponding antenna.

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This chapter will focus on the design of ZOR antennas for passive UHF RFID tags. First, a brief introduction and working principles of RFID systems is presented using Friis's transmission equation. Then, the characteristics of CRLH transmission lines will be discussed and its Bloch impedance will be derived to introduce the ZOR concept. Then coplanar-waveguides (CPW) and its characteristics are presented. Then the design of a capacitive loaded CPW based ZOR antenna for passive UHF RFID tag is discussed. Finally, future work and conclusion about this chapter is presented.

2. Introduction to RFID systems

RFID technology has drawn great attention in the past decade. Recently it has been used in inventory control, managing large volumes of books in libraries and tracking of products in the retail supply chain [14,15]. Its usage is growing and replacing the bar code technology used for the purpose of object identification and recognition. A bar code requires a clear line of sight and a small distance between the object and the laser bar code scanner (which is a limitation) whereas RFID works at microwave frequencies so it can identify the object from a distance, it does not require line of sight for its operation and unlike bar codes it can also store some additional information which makes it very attractive as compared to bar codes [1].
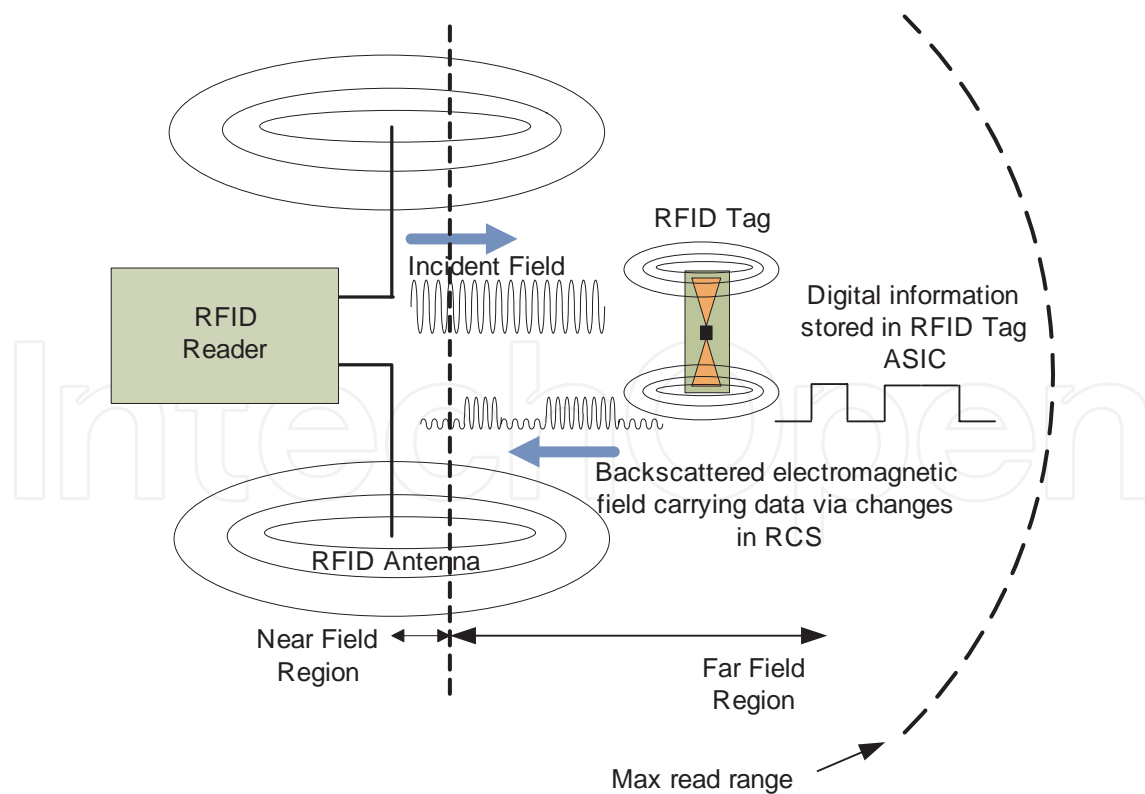
Figure 1. Overview of RFID System

A RFID system consists of a RFID reader and a RFID tag. An overview of a typical RFID system is shown in Fig. 1. RFID systems comprise of RFID tags or transponders which are fairly simple, small and inexpensive devices at one end and a reader which is relatively complex and a bigger device on the other end. Application Specific Integrated Circuits (ASICs) are attached to the tag antenna and are used for sensor applications, to harvest energy, communicate and store information for later recovery. The reader emits an electromagnetic field which contains power and timing information for use by the passive RFID. If a RFID tag comes within the range (also known as the interrogation zone [1]) it receives the information which is fed to the ASIC and in response the ASIC switches its impedance states between a lower and higher value in a predetermined fashion as shown in Fig. 2. By changing the impedance states the ASIC changes the radar cross-section (RCS) of the tag antenna thus changing the backscattered power. This backscattered power is collected at the reader and is used for tag identification and information. The maximum distance for which a reader can successfully identify a tag is known as max read range.

RFID tags are usually classified into three categories: active tags, semi-passive tags and passive tags [1]. An active tag has a dedicated power supply for operation on the tag. A semi-passive tag has an integrated power supply attached to it and it only starts working when electromagnetic power transmitted by the reader is incident on the tag. This feature enhances the maximum read range of the tag [1] because less power is required from the incoming incident field from the reader. A passive tag has no power source attached to it and it harvests power for its operation from the incident electromagnetic field transmitted by the reader.
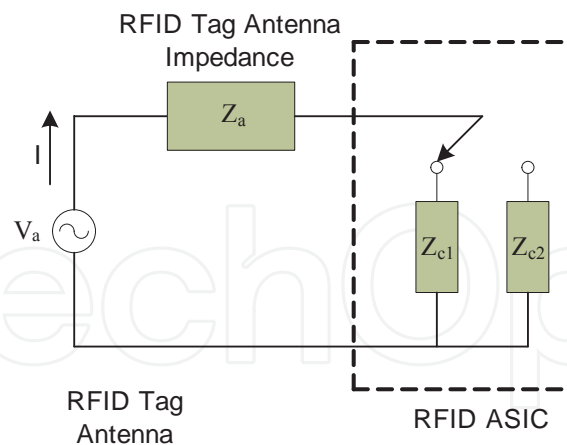
Figure 2. Thevenin equivalent circuit of RFID tag

A common method to describe the RFID wireless communication system is the following Friis transmission equation [16]:

$$P_r = P_t \frac{G_r G_t \lambda^2}{(4\pi R)^2} q \tag{1}$$

where P_r is the power received by RFID tag, P_t is power transmitted by RFID reader, G_r is the gain of tag antenna, G_t is the gain of reader, λ is free space wavelength of the operating frequency of reader, R is distance between reader and tag and q is impedance mismatch factor ($0 \leq q \leq 1$) between impedance of the antenna on the tag and the input impedance of the ASIC on the tag. Equation (1) assumes a perfect polarization match between the antenna on the reader and the antenna on the RFID tag. Reorganizing (1) and solving for R, the following equation for determining the read rang of a tag can be derived [17,18] as:

$$R = \frac{\lambda}{4\pi} \sqrt{\frac{q G_t G_r P_t}{P_r}} \tag{2}$$

If the minimum power required for tag operation is P_{th} then Equation (2) can be written as

$$R_{max} = \frac{\lambda}{4\pi} \sqrt{\frac{q G_t G_r P_t}{P_{th}}} \tag{3}$$

Equation (3) is useful for designers to determine the maximum operating range of the tag. Typically the approach by a designer is to maximize the R_{max}. One way of achieving this is to minimize the mismatch between tag antenna and ASIC impedances or design a receive antenna on the RFID tag with a maximized gain G_r.
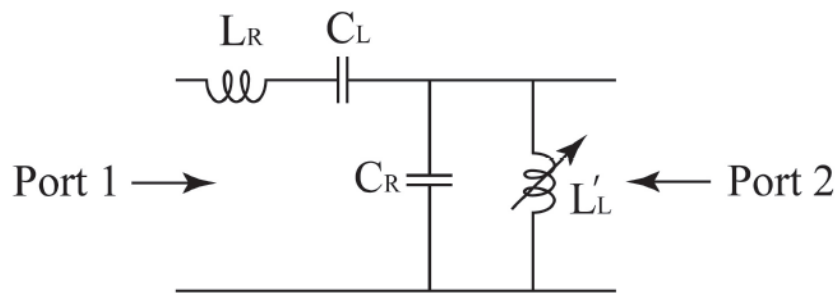

Figure 3. Reconfigurable CRLH-TL

3. Introduction to left-handed propagation

To help illustrate the use of ZOR properties to improve the gain and matching of a compact antenna on a passive UHF RFID tag, several properties of left-handed (LH) propagation will be introduced and summarized here. It is well known that the equivalent circuit of a traditional printed microstrip TL consists of a series inductance and a shunt capacitance. The series inductance is caused by the current travelling down the printed TL and the shunt

capacitance represents the capacitance between the printed signal conductors on one side of the board and the reference or ground plane. In fact, this inductance and capacitance exists on every printed TL (traditional or CRLH) because in the propagating band current is travelling down the TL and there is always capacitance between the conductors supporting this current and a reference conductor. When introducing the CRLH-TL, this series inductance and shunt capacitance is referred to as the parasitic values and are denoted in Fig. 3 as L_R and C_R. The subscript R stands for right-handed (RH) propagation.

Next, to support LH-propagation, a series capacitance and a shunt inductance is introduced. These values are shown in Fig. 3 and are denoted C_L and L_L, respectively. The subscript L stands for left-handed propagation. More particularly, the series capacitance is in series with the inductance and the shunt inductance is in parallel with the shunt capacitance. Therefore, to achieve LH-propagation, C_L and L_L should dominate over the values of L_R and C_R. Closer observation of the equivalent circuit in Fig. 3 shows that the LH-values will only dominate over a certain band which is called the LH-propagating band. When the RH-values of L_R and C_R are dominant, this is called the RH-propagating band. When both the RH- and LH-values are equal; this is called the transition frequency between the RH- and LH-propagating bands or simply the transition frequency. In practice, the series capacitance is usually introduced by defining interdigital capacitors down the length of the TL [10]. The shunt inductance has been introduced in many different ways such as split ring resonators and shunt stubs [10].

A CRLH-TL has several unique properties as a result of the introduction of C_L and L_L. The property used in this work is the sign change associated with the phase constant. The phase constant on a CRLH-TL is opposite to the phase constant on conventional RH-TL. This phase advance feature can be very useful for antenna designers and will be used in the next few sections to introduce the idea of ZOR antennas.

4. Coplanar-waveguide structures

The term "Coplanar" means sharing the same plane and this is the type of transmission line where the reference conductors are in the same plane as of signal carrying conductor. The signal carrying conductor is placed in the middle with a reference plane conductor on either side as shown in Fig. 4. The advantage of having both conductors in the same plane lies in the fact that it is easier to mount lumped components between the two planes and it is easier to realize shunt and series configurations. The CPW was first proposed by Wen [19] and since then have been used extensively in wireless communications [20,21].

The disadvantage of CPW is that it can be difficult to maintain the same potential between the reference and signal conductors throughout the signal trace. Nevertheless many advances have been made by using CPW such as novel filters [22] and right/left handed propagation on CPW lines [23].
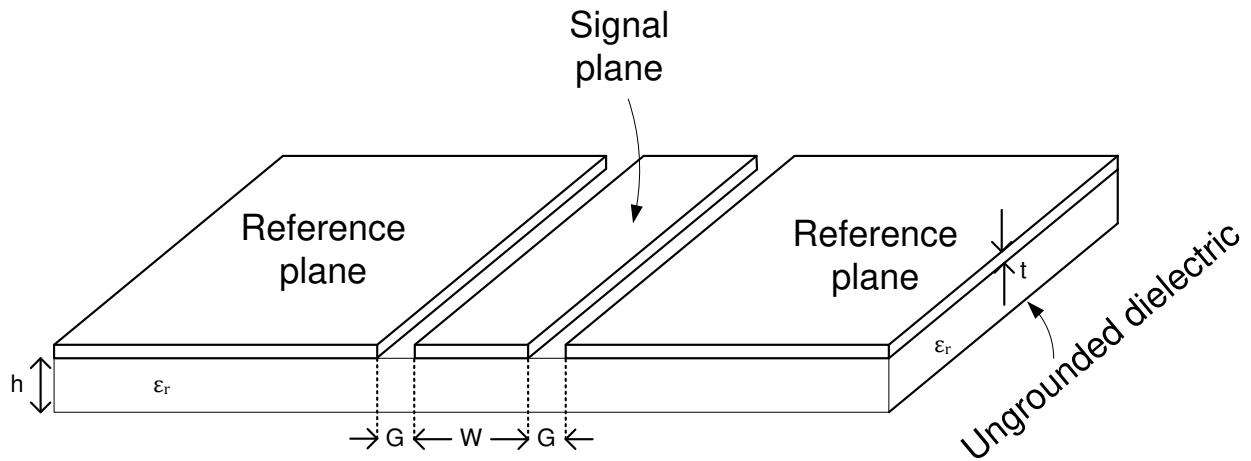
Figure 4. CPW transmission line on ungrounded dielectric

Several properties of the CPW-TL in Fig. 4 are derived next. These expression will be used later to describe the ZOR-RFID antenna. The attenuation and phase constants can be derived by performing a quasi-static analysis of a CPW [24]. The phase velocity and characteristic impedance equations can be written as [24]:

$$v_{cp} = \left(\frac{2}{\varepsilon_r + 1} \right)^{1/2} c \tag{4}$$

and

$$Z_{0cp} = \frac{30\pi}{\sqrt{\varepsilon_{re}^t}} \frac{K(k_e')}{K(k_e)} \tag{5}$$

where

$$k_e = \frac{W_e}{(W_e + 2G_e)} \cong k + \frac{(1 - k^2)\Delta}{2G} \tag{6}$$

$$k = \frac{W}{W + 2G} \tag{7}$$

$$\Delta = (1.25 t / \pi)[1 + \ln(4\pi W / t)] \tag{8}$$

$$k' = \left(1 - k^2\right)^{1/2} \tag{9}$$

$$\varepsilon_{re}^{t} = \varepsilon_{re} - \frac{0.7(\varepsilon_{re} - 1)t / G}{\left[\frac{K(k)}{K(k')}\right] + \frac{0.7t}{G}} \tag{10}$$

and

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2}\left[tanh\{1.785\log(h / G) + 1.75\} + \frac{kG}{h}\{0.04 - 0.7k + 0.01(1 - 0.1\varepsilon_r)(0.25 + k)\}\right] \tag{11}$$

Here W is the width of the center conductor, G is the spacing between the center conductor and the reference conductor, ε_r is the relative permittivity of the dielectric, c is the speed of light and t is the thickness of the conductor. K(k) is the complete elliptic integral of the first kind and the ratio K(k)/K(k′) has been reported in [24,25] as:

$$\frac{K(k')}{K(k)} = \frac{1}{\pi}ln\left[2\frac{1+\sqrt{k}}{1-\sqrt{k}}\right] for\ 0.707 \leq k \leq 1 \tag{12}$$

and

$$\frac{K(k')}{K(k)} = \frac{\pi}{ln\left[2\frac{1+\sqrt{k'}}{1-\sqrt{k'}}\right]} for\ 0 \leq k \leq 0.707 \tag{13}$$

Using equations (4)-(13) the attenuation constant due to ohmic losses can be calculated as [24]:

$$\alpha_c^{cw} = 4.88*10^{-4}R_s\varepsilon_{re}Z_{0cp}\frac{P'}{\pi G}\left(1 + \frac{W}{G}\right)\left\{\frac{\frac{1.25}{\pi}ln\frac{4\pi W}{t} + 1 + \frac{1.25t}{\pi W}}{\left[2 + \frac{W}{G} - \frac{1.25t}{\pi G}\left(1 + ln\frac{4\pi W}{t}\right)\right]^2}\right\}dB\ \bigg|\ unit\ length \tag{14}$$

where

$$P' = \left(\frac{K}{K'}\right)^2 P \tag{15}$$

$$P = \begin{cases} \frac{k}{(1-\sqrt{1-k^2})(1-k^2)^{3/4}} & for\ 0.0 \leq k \leq 0.707 \\ \frac{1}{(1-k)\sqrt{k}}\left(\frac{K}{K'}\right)^2 & for\ 0.707 \leq k \leq 1.0 \end{cases} \tag{16}$$

and

$$R_s = \sqrt{\rho\pi f\mu} \tag{17}$$

The attenuation constant due to dielectric losses is [24]:

$$\alpha_d = 27.3 \frac{\varepsilon_r}{\sqrt{\varepsilon_{re}}} \frac{\varepsilon_{re} - 1}{\varepsilon_r + 1} \frac{\tan \delta}{\lambda_0} \; dB \bigg| \; unit \; length \tag{18}$$

Here $\tan(\delta)$ is the loss tangent of the dielectric and the total attenuation can be written as:

$$\alpha_{cwp} = \alpha_c + \alpha_d \tag{19}$$

Thus, the phase constant can be calculated as [20]:

$$\beta_{cpw} = \frac{2\pi f}{v_{cp}} \tag{20}$$

Next, these expressions will be used to introduce the interdigital capacitor loaded CPW which will then be used to design a ZOR-RFID antenna.
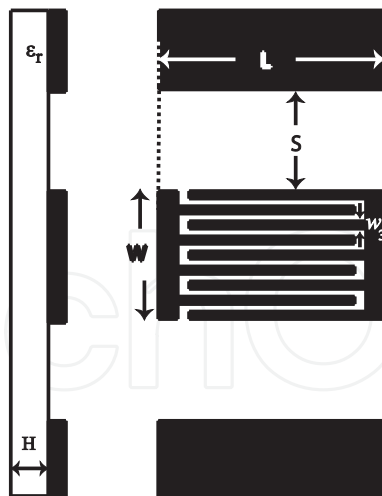
5. Interdigital capacitor loaded CPW

An Interdigital capacitor loaded transmission line provides a series resonance. The Zeroth Order Resonance (ZOR) of an interdigital capacitor loaded CPW has been investigated and reported in [26]. The equivalent transmission line model of an interdigital capacitor loaded transmission line is shown in Fig. 5 and consists of two symmetric transmission lines interconnected with a series capacitance. The host transmission line has been shown equally divided into two parts. Since the size of the unit cell is much smaller than the guided wavelength, the transmission line can be modeled with an equivalent circuit with a series inductance and shunt capacitance (as discussed in Section 3).
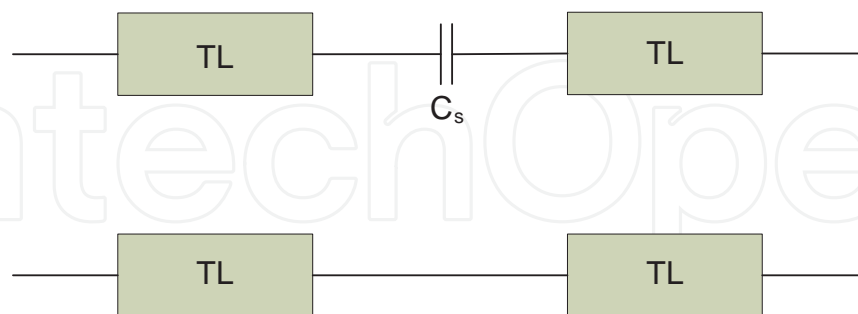
Figure 5. Equivalent circuit model of interdigital capacitor loaded

The geometry (layout) of the interdigital capacitor based unit cell is shown in Fig. 6. The capacitance between the interdigital capacitor and bilateral ground plane is fairly small as compared to the series capacitance of the interdigital capacitor so it can be neglected. This unit cell can be repeated periodically to design the ZOR antenna.

Figure 6. Interdigital capacitor loaded CPW unit cell

Since the unit cell will be repeated periodically and will be symmetric about the port of the antenna, it will resemble the TL in Fig. 5. Therefore, the propagation constant γ (where $\gamma = \alpha + j\beta$) and characteristic impedance (also known as block impedance) Z_B can be expressed in terms of an ABCD matrix as [20]:

$$\cosh \gamma L = A \tag{21}$$

and

$$Z_B = \frac{B Z_0}{\sqrt{A^2 - 1}} \tag{22}$$

Here L is the length of the unit cell and Z_0 is the characteristic impedance of the CPW. The propagation constant of the TL is $\gamma_{CPW} = \alpha_{CPW} + \beta_{CPW}$ where α_{CPW} and β_{CPW} can be calculated from (19) and (20), respectively.

Next, the ABCD matrix of the circuit shown in Fig. 5 can be determined as [20]:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{CPW} = \begin{bmatrix} \cosh \frac{\gamma_{CPW} L}{2} & Z_0 \sinh \frac{\gamma_{CPW} L}{2} \\ Y_0 \sinh \frac{\gamma_{CPW} L}{2} & \cosh \frac{\gamma_{CPW} L}{2} \end{bmatrix} \tag{23}$$

and

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{inter\text{-}digital\ capacitor} = \begin{bmatrix} 1 & \frac{1}{j\omega C} \\ 0 & 1 \end{bmatrix} \tag{24}$$

Here L/2 represents half of the CPW length. The ABCD matrix of the whole unit cell can be calculated from (23) and (24) as:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{CPW} * \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{inter\text{-}digital\ capacitor} * \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{CPW} \tag{25}$$

From (25), parameter A can be calculated and (21) can be written as:

$$\cosh \alpha L \ \cos \beta L \ + \ j \sinh \alpha L \ \sin \beta L \ = M + jN + \frac{1}{j2Z_0\omega C}(O + jP) \tag{26}$$

where

$$M = \cosh \alpha_{CPW} L \ \cos \beta_{CPW} L \tag{27}$$

$$N = \sinh \alpha_{CPW} L \ \sin \beta_{CPW} L \tag{28}$$

$$O = \sinh \alpha_{CPW} L \ \cos \beta_{CPW} L \tag{29}$$

and

$$P = \cosh \alpha_{CPW} L \ \sin \beta_{CPW} L \tag{30}$$

In (26) α represents the attenuation constant and β represents the phase constant of the Bloch wave propagating on the unit cell whereas α_{CPW} and β_{CPW} are attenuation and phase constants, respectively, of the host CPW. From (26) the real and imaginary parts can be separated which gives:

$$\cosh \alpha L \ \cos \beta L \ = \cosh \alpha_{CPW} L \ \cos \beta_{CPW} L \ + \frac{\cosh \alpha_{CPW} L \ \sin \beta_{CPW} L}{2Z_0\omega C} \tag{31}$$

and

$$\sinh \alpha L \ \sin \beta L \ = \sinh \alpha_{CPW} L \ \sin \beta_{CPW} L \ - \frac{\sinh \alpha_{CPW} L \ \cos \beta_{CPW} L}{2Z_0\omega C} \tag{32}$$

The unknowns in (31) and (32) are α and β of the Bloch wave. Solving for α and β gives:

$$\alpha = \frac{1}{L} \cosh^{-1}\left(\frac{\sqrt{Q^2 + (R + 1)^2} + \sqrt{Q^2 + (R - 1)^2}}{2}\right) \tag{33}$$

and

$$\beta = \frac{1}{L} cos^{-1}\left(\frac{\sqrt{Q^2 + (R + 1)^2} - \sqrt{Q^2 + (R - 1)^2}}{2}\right) \tag{34}$$

where Q and R are the right hand sides of (31) and (32), respectively. The key idea when designing a ZOR antenna is to determine the frequency at which equation (34) is equal to zero. Since the propagation constant is inversely proportional to the wavelength, when equation (34) is zero, the wavelength at that frequency is equal to infinity. At this frequency, the antenna looks infinitely long electrically. In the next section, the expressions derived here for the interdigital capacitor loaded CPW will be used to design a ZOR-RFID antenna.
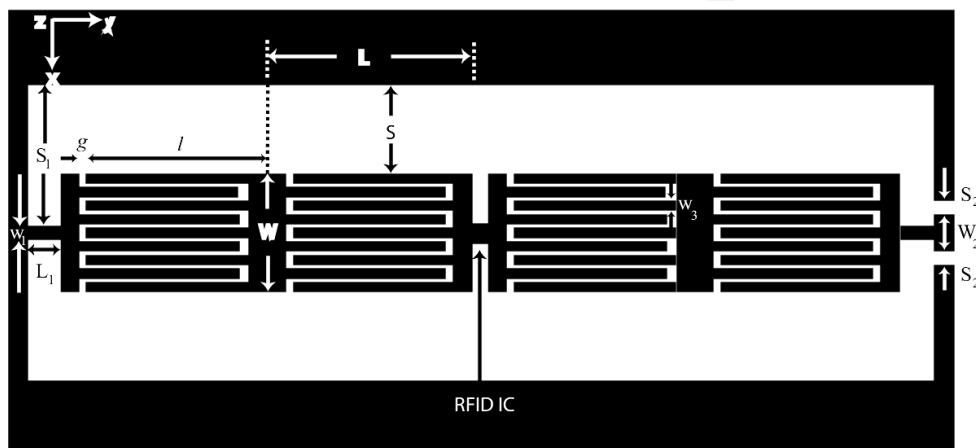
Figure 7. Layout of proposed ZOR RFID antenna with capacitor loaded CPW [30]

5.1. Zeroth order resonance

The layout of the proposed ZOR RFID antenna is shown in Fig. 7 [30]. The port of the antenna is located in the middle of the antenna with series capacitance down each arm. The operating principle of this antenna is based on the capacitive input impedance of the passive RFID ASIC. At resonance, the interdigital capacitors are supporting a wave propagating along the antenna. Since the input impedance of the ASIC is also capacitive the ASIC also supports wave propagation along the antenna in a manner similar to the interdigital capacitors [30]. During this process, the ASIC harvests the required power to perform the desired tasks and communicate while simultaneously supporting the wave propagating on the antenna.

The first step in the design process is to determine what capacitance is required to equate β to zero at the desired operating frequency such that the antenna looks infinitely long. For discussion, the non-zero frequency at which β becomes zero is known as the zeroth order resonance (ZOR) frequency [26], [30]. For simplicity a lossless ($\alpha = 0$) CPW line is assumed and then from (31) the required capacitance can be calculated to achieve ZOR at a particular design frequency as:

$$C = \frac{\cosh \alpha_{CPW} L \ \sin \beta_{CPW} L}{2\omega_r Z_0(1 - \cosh \alpha_{CPW} L \ \cos \beta_{CPW} L \ )} \tag{35}$$

Since we are interested in designing a ZOR antenna for the passive UHF RFID band, 915 MHz is taken as the operating frequency and from (35) the required capacitance can be calculated as C = 2.64 pF.

The unit cell shown in Fig. 7 was simulated in ADS 2009 with design parameters L = 17.56 mm, W = 8.82 mm, w_3 = 0.36 mm, S = 7.96 mm and H = 1.524 mm. A Rogers TMM4 (ε_r = 4.5 and tan δ = 0.002) was used as a substrate. For the lossless case the attenuation constant of the CPW and loss tangent of the substrate was assumed to be zero and a perfect conductor was considered. The capacitance of the unit cell was extracted [10] to be $C_{extracted}$ = 2.4 pF which is close to the required capacitance for ZOR at 915 MHz. The dispersion characteristics are plotted in Fig. 8. It can be noted that the attenuation constant decreases monotonically and becomes zero after 944 MHz. Similarly the propagation constant remains zero and after 944 MHz it increases monotonically. Thus 944 MHz can be taken as ZOR frequency for the given unit cell which comes within 3.2% of the required resonance frequency of 915 MHz. More discussion on this is reported in [30].

For the lossy case the attenuation constant of the CPW was calculated using (19) and the loss tangent was taken as tan δ = 0.002. The conductivity was defined as σ = 5.8 x 10^7 S/m with a conductor thickness of 35 μm. The dispersion characteristics for the lossy case were also presented in Fig. 8. A similar response for both the lossy and lossless case is shown except for the fact that the phase constant is non-zero below the ZOR point and similarly the attenuation constant is non-zero after the ZOR point. Here the ZOR point is taken as the point at which α = β and it coincides with the lossless ZOR point [26],[30].
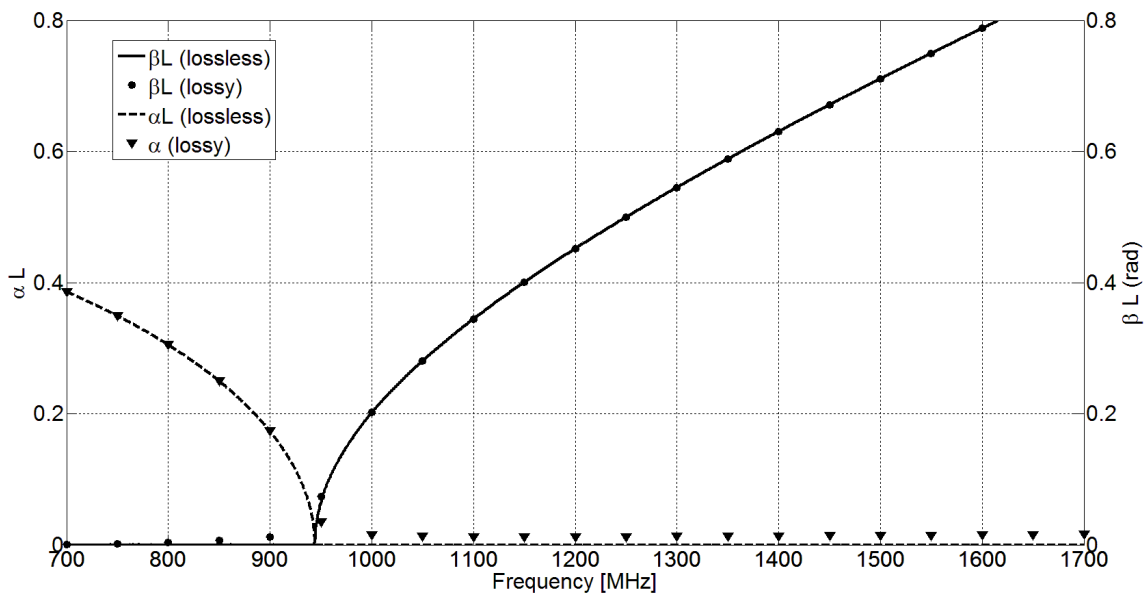
Figure 8. Dispersion diagram of lossless and lossy interdigital capacitor loaded CPW

5.2. Zeroth order resonator RFID antenna measurements

Again, the proposed ZOR RFID antenna with the capacitor loaded CPW is shown in Fig. 7. The antenna is composed of four series connected unit cells, where each unit cell has a layout similar to the image in Fig. 6. The proposed antenna has a 50 ohm CPW at one end and a high characteristic impedance short circuit line on the other end similar to [26] and [30]. The Higgs-2 by Alien Techonologies [29] RFID ASIC was used and attached at the port of the antenna (at the center). The Higgs-2 has an input impedance of Z_{in} = 13.73 + j142.8 Ω at 915 MHz. The antenna was designed on a Rogers TMM4 substrate with ε_r = 4.5, tan δ = 0.002 and a substrate thickness of H = 1.524 mm. The design parameters of the proposed ZOR RFID antennas are given in Table 1 and [30].

A wider central strip was used to obtain the required series capacitance as shown in Fig. 7 and the gap between the central conductor and reference conductors on either side was made as large as possible so that the parasitic shunt capacitance could be made as small as possible. This ensured a dominant series capacitance created by the interdigital capacitance and the input impedance of the passive UHF RFID ASIC connected to the antenna port. Furthermore, this will simplify the ABCD matrix representation of each unit cell.

The ZOR RFID antenna shown in Fig. 7 was simulated in Ansoft HFSS v.13. The simulated input resistance, reactance and reflection coefficient are shown in Fig. 9, Fig. 10 and Fig. 11, respectively. The fabricated prototoype ZOR RFID antenna is shown in Fig. 12 [30].

C	2.4 pF	w_3	0.66 mm
W	8.82 mm	S_1	12.17 mm
L	17.56 mm	S_2	0.35 mm
S	7.96 mm	L_1	5 mm
w_1	0.4 mm	l	16.2 mm
W_2	3 mm	g	0.36 mm

Table 1. Design parameters of proposed ZOR RFID antenna

Next, to measure the read range of the prototype tag, an Alien Technologies ALR-9900 RFID reader was used [29] (with maximum output power of 1W). It was connected to a circularly polarized antenna with a gain of 6dBi and the RFID Tag was placed in an anechoic chamber. A read range of 3.4 m was determined with the RFID reader; however the *max read range* was not determined because the overall dimensions of the anechoic chamber were too small. An alternate method has been provided in [30] and [31] to predict the maximum achievable read range based on system power levels and measurements. This method uses the Friis transmission equation and the fact that a certain minimum power is required to activate the tag. Using this information the output power of the RFID reader was reduced until the reader could no longer detected the tag at 3.4 m. The required attenuation was 7 dB. Then the following equations were used to predict the maximum read range:
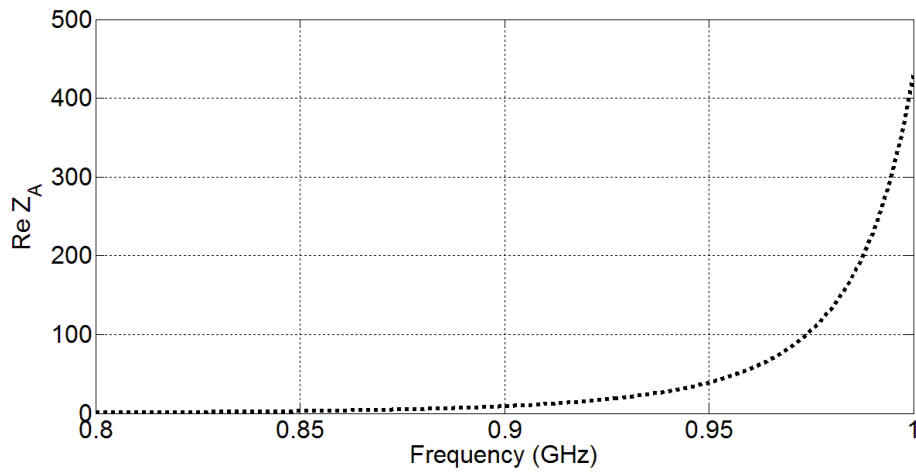
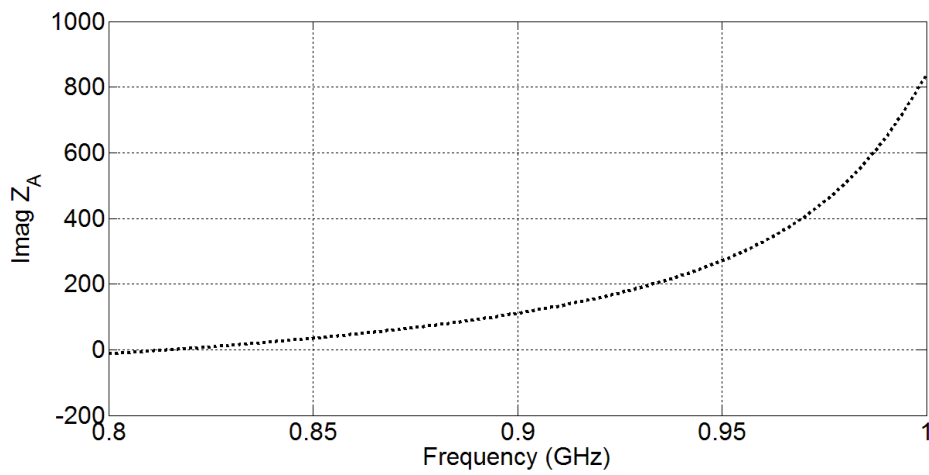**Figure 9.** Proposed ZOR RFID antenna input resistance

Figure 10. Proposed ZOR RFID antenna input reactance

$$P_{r_{min}} = \frac{P_{t_{max}} G_t G_r \lambda^2}{(4\pi R_{max})^2} \tag{36}$$
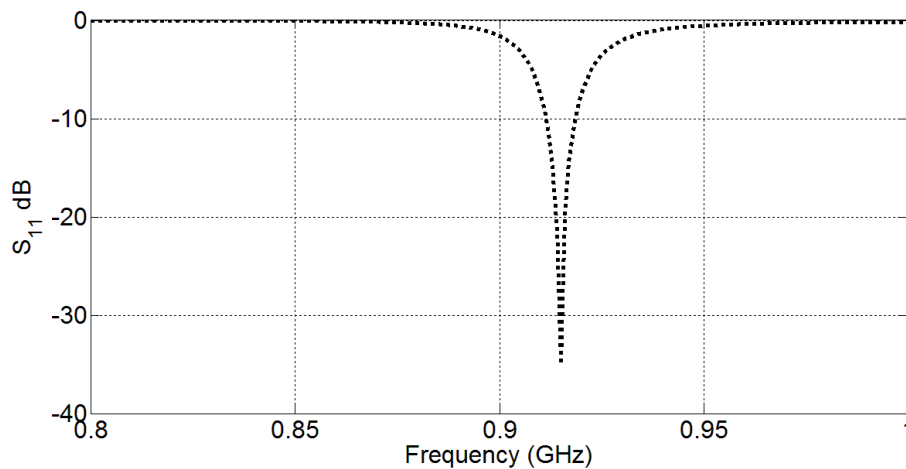
and

$$P_{r_{min}} = \frac{P_{t_{max}}}{\alpha} \frac{G_t G_r \lambda^2}{(4\pi R_{measured})^2} \tag{37}$$
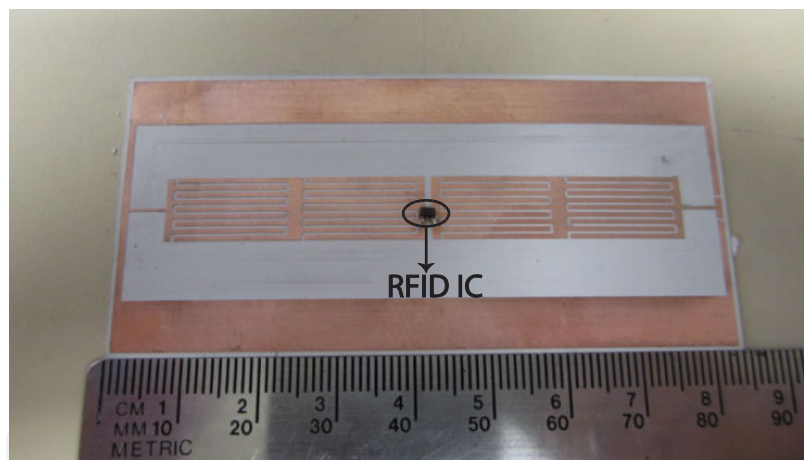
Since (36) and (37) both use minimum received power, they can be equated to produce

$$R_{max} = 10^{\alpha_{dB}/20} R_{measured} \tag{38}$$

Putting α = 7 dB and $R_{measured}$ = 3.4 m in (38) gives a predicted max read range of 7.6 m which meets or exceeds the performance of similar and large passive UHF RFID tags available on the market today.

Figure 11. Input reflection coefficient of proposed ZOR RFID antenna

Figure 12. Fabricated ZOR RFID antenna [30]

6. Conclusion

The expanding use of passive UHF RFID systems has increased the performance demands on readers, tags, software and manufacturing costs. Because of these new constraints, the desire for more compact and better performing tags is beginning to grow. In this chapter, a summary of passive UHF RFID systems has been presented with several of the key antenna design requirements mentioned. Following this introduction, background on left-handed

propagation, co-planar waveguides and interdigital capacitor loaded co-planar waveguides have been introduced and summarized. From these sections, the ZOR-RFID antenna for passive UHF RFID tags is presented. The operating principle behind the ZOR-RFID antenna is the use of interdigital capacitors along the length of the antenna to support wave propagation. Furthermore, the capacitive input impedance of the passive RFID ASIC attached to the port of the antenna supports propagation in a manner similar to the interdigital capacitors. This allows the ASIC to still harvest power and communicate while supporting wave propagation. Measurements show that a predicted 7.6 m read range is possible with this new antenna design. This read range is comparable to existing commercially available passive UHF RFID tags with similar overall sizes.

7. Future work

There are several different avenues of future work possible. The first topic of interest is to reduce the overall size of the ZOR RFID prototype antenna. This could be done by using resonator elements instead of the interdigital capacitors. Further development on printing the ZOR-RFID antenna on flexible substrates would be of great interest. Maybe the investigation of paper, LCP and Kapton substrates could be performed. Extending this work to develop a multi-band antenna would also be possible. This would allow this antenna design to be used in multiple countries.

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