ISSN 2229-5518

Increasing Coding Efficiency of Chipless RFID Tag for IoT Applications

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Abstract

The latest research is being done in designing chipless radio frequency identification (RFID) tags and coming up with innovative encoding schemes to increasing the coding efficiency. This has been further triggered by cropping up of the Internet of Things (IoT) Applications. This research work will look at enhancing the coding capacity by analyzing the tag capacity. In order to come up with a best solution, the strips of various widths are analyzed by varying the amplitude and applying amplitude shift keying technique. The substrates selected for the analysis are Kapton (a polyimide film) which remains stable at higher temperatures, Polyethylene terephthalate and paper. Resonators are designed and the frequency range selected for our research was from 3.10 GHz to 10.60 GHz with minimum width. It is further ensured that the designed tags have easy printability and are flexible. From the analysis, it is shown that the paper based tags, organic and decomposable in nature, provide a less costly solution which can be widely deployed. This is of great usage when we are talking about implementing them in the internet of things (IOT) devices which are highly dependent on identifications.

Keywords

Radio Frequency Identification, chipless, Internet-of-Things

1.1. Introduction

Internet of things is defined as a network in which every networked element can be accessed at any time and place through any route in physical or virtual domain. It comprises of smart devices which includes tablets, smart phones, hand-held-devices, smart terminals etc. IoT [1] has a broad range of applications and the trend of using them is growing at a much faster rate.

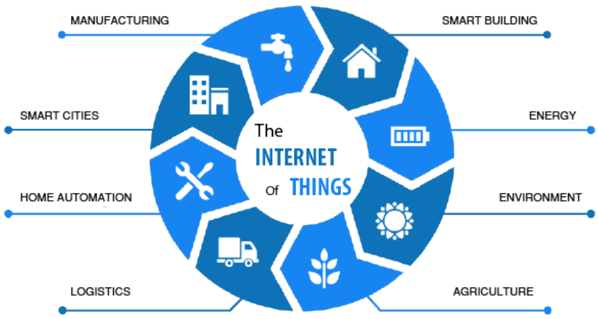

Figure 1.1: Internet of Things (IoT) (Source: Avance Smart Home)

IoT is being used extensively in manufacturing, smart cities, home automations, logistics [13], smart buildings, energy sector, environment and agriculture, just to name a few. In order to implement the IoT solutions [2], the network has to be managed remotely in a ubiquitous manner. Over the years we have seen the penetration of wireless sensor networks which act as a medium of communication and provide with management capabilities using wireless sensor nodes or smart nodes. In order to identify these smart nodes, what is needed are the radio-frequency identification (RFID) tags [4]. In this technology, the digital data is encoded inside the tag which are detected by the reader through radio waves [9]. The radio waves are used as a communication medium to transmit this information.

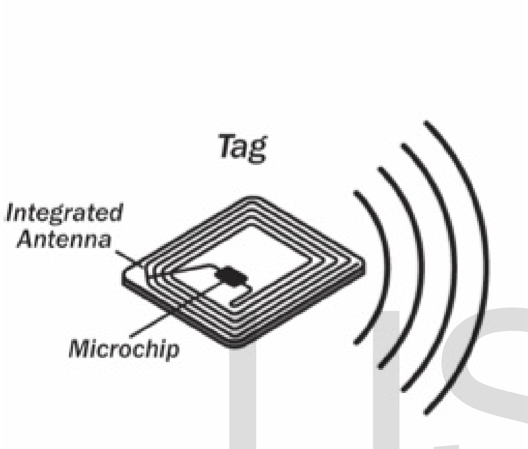

Figure 1.2: RFID Tag
(Source: http://itlaw.wikia.com/wiki/RFID_tag)

If we look at the diagram, we can see that a typical RFID tag [8] comprises of the following;

- Microchip
- Integrated Antenna
- Transponders (mounted on object to be monitored consisting of scatterer and encoder)
- Tag

The silicon chip is used as an encoder and the transmission of signals is achieved through the scatterer/antenna. The silicon chip is used for encoding of the information via the process of modulation.

Figure 1.3: Backscattering Principle
(Source: https://www.researchgate.net/publication/322436111_Design_and_analysis_of_C_shaped_chipless_RFID_tag)

As can be seen in the figure above, there is a reader antenna for the RFID at the one end and the function of this is to read the information via the radio communication channel from the tag antenna [12] of the RFID tag. The stimulus is initiated by reader side being electromagnetic in nature. This way the detection and the transmission of information takes place.

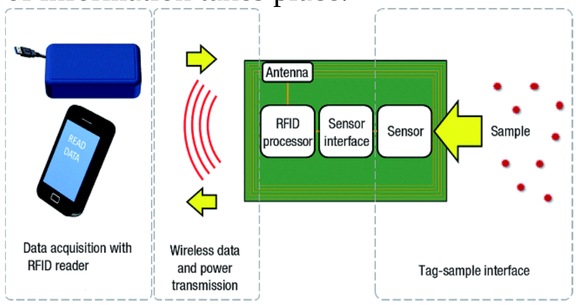

Figure 1.4: RFID-based tag operating principle
(Source: https://pubs.rsc.org/en/content/articlehtml/2017/ra/c7ra07191d)

These chipless tags (RFID) have very less cost and can be easily printable. Furthermore, they are very light in weight and exhibit great energy efficiency in addition to sustaining higher pressures and temperatures. This helps in embedding them on various IoT devices or applications easily [3] [5]. In short, they act like sensor nodes as is the case with the wireless sensor networks.

The chipless RFID tags can have two types;

- Retransmission based
- Backscattering based

In case of the retransmission based ones, the size is generally more and there is a requirement of monopole antennas. However, backscattering based tags are smaller in size and consist of more than one resonators. It should be further noted that in case of backscattering signals, the data is encoded in time, frequency and amplitude/phase. If we are interested in enhancing the efficiency in terms of coding,

we have to look at various techniques used for the amplitude variations.
The coding capacity of the tags can be enhanced by using amplitude shift keying technique and coming up with a combination of more identifications ID's. This will also lead to the enhancement of the data rates. By using different substrates, the amplitude shift keying techniques can be applied on the respective tags and their results analyzed. This can lead to identifying the technique which is most suitable and can help in achieving higher data rates with increased coding capacities.

With these embedded tags [14], the IoT allows immediate response in the light of provided information. The info can be assessed on the internet and then decision making can be done remotely without having to get in touch in the physical world.

The RFID tags [17] can be distinguished in terms of the power and the way they are modulated. In case of power, it can be categorized as;

- Active Tags
- Passive Tags

Active tags have longer reading range and comprise of an on board battery. However, the cost of these tags is more. Passive tag price is less as compared with active ones as they do not have the baggage of carrying a power supply. Hence it depends on our application and requirements considering if the price is important or the range we are aiming at is crucial. The passive tags are generally deployed widely.

Similarly, in addition to being active or passive, the tags can also be classified based on their modulation techniques. As we know that the reflected signals properties differ from the signals (incident) due to their scheme of modulation. Because of the difference, the reader can interpret the encoded messages. Based on this, the embedded tag on an IoT device [16] or any object can be;

- Chip based
  - Scatterer
  - Encoder
- Chipless [6].

The tags can be implemented/embedded in many objects, like;

- Passports
- Currency Notes
- Cards for Toll Collection
- Clothes
- Vehicles
- Shoes
- Helmets

These RFID Tags should be considered as the replacement for the old barcode mechanisms. RFID's are also being used effectively for spying purposes because of their size and effectiveness in terms of transmitting data in real time so that immediate actions can be taken.

Figure 1.5: RFID Tags implementations/embedding in objects
(Source: http://www.stallionglobal.com/en/ecm/products/detail.aspx?pId=29)

The main thrust for the researchers is to explore technique that can increase the coding efficiency of RFID Chipless tags [15]. Furthermore, what we are looking at is the enhancement of the bit rates from the existing 24-bit to more i.e. highest among the previously done research work. Additionally, we are also looking at the tags which are environment friendly and support green electronics [7] by the use of different substrates.

1.2. Working Concept

In case of wireless communications, we cannot use the broadband antennas for the generation of signatures and the coding efficiency cannot be increased simply by using amplitude shift keying technique. Hence in order to trigger the RFID tag, circular polarization is needed. The equation used for circular polarization is;

$$\mathbf{E}(x, y, z, t) = E_o e^{j(\omega t - kz)}\hat{\mathbf{x}} + E_o e^{j(\omega t - kz + \pi/2)}\hat{\mathbf{y}}$$

Where,

D	=	Tag's maximum Dimension
λ	=	Wavelength

And is calculated using the equation;

$$d = (2D^2)/\lambda$$

The backscattered signal is observed which carries the information (selectivity, velocity, phase, amplitude, and resonance tag). Similarly, the capacity (encoding bits) relies on total number of resonators which are used. For us to increase the number of data bits, the number of resonators has to be increased while keeping in view the weight and the compact size of the resonator. The use of these methods can lead to the enhancement of the capacity and the option to tag more objects.

In our research we will analyze the amplitude of the received signal with the use of more than six resonators, which were previously used in the past studies design for using the tags in the credit cards. The amplitude of the receiving signals will be changed by the use of resistive strips. They will provide us with the "bridging" resistance, which otherwise will be infinite. They function in a way that they intervene in the path of the current thus reducing the height of the pulses. Amplitude variations will be observed for the number of scatterers with the use of these "bridging" resistance strips. The coding capacity will be calculated using the equation;

$$C = \mathrm{Log}_2 \{[(\Delta M_1)/(dM_1) + 1]\,[(\Delta M_2)/(dM_2) + 1]\,[(\Delta M_3)/(dM_3) + 1]\,[(\Delta M_4)/(dM_4) + 1]\,[(\Delta M_5)/(dM_5) + 1]\,[(\Delta M_6)/(dM_6) + 1]\,[(\Delta M_7)/(dM_7) + 1]\}$$

Where;

C	=	Coding Capacity
M	=	Magnitude
dM	=	Magnitude Resolutions

If we look closely, we can see change in the magnitude peaks because of resistive strip. By using the above equation, we take the difference of varying amplitude values of adjacent peaks with the application of flat strip and then the absence of it. The difference between the max/min amplitudes is calculated to validate the design.

1.3. Research Problem

The already available RFID tags are inflexible and their printability is difficult. There is a need to come up with paper-based decomposable organic tag for its wide scale tracking. In the evolving and emerging fields of internet of things (IoT) and green electronics, there is a need to develop RFID tags which are flexible [18] in nature, exhibit easy printability, and are decomposable and organic in nature with enhanced tracking capabilities.

These features are not existent at present. Additionally, the coding efficiency is also not much and needs to be improved. The coding efficiency needs to be enhanced and can only be achieved by having a chipless RFID tag with the adoption of unique amplitude shift keying encoding technique.

1.4. Purpose of Study

Chipless RFID tag having unique amplitude shift keying encoding technique will be presented in this research work. The researcher will enhance the coding efficiency regarding the RFID tag capacity. The amplitude variations of the backscattered RFID signal will be used for encoding the data. The amplitude shift keying technique will be applied using 3 substrates namely Kapton, Polyethylene terephthalate and paper. The aim is to design tags that will be flexible and will offer easy printability.

1.5. Objectives

Following objectives will be achieved through this research work.

- Chipless RFID tag design having unique encoding technique i.e. ASK.
- Enhancement of coding efficiency regarding tag capacity.
- Rhombic shaped broadband radiator's selectivity problem analyzation and Dual polarized rhombic shaped resonators design.
- Data encoding capacity will be increased.
- Environmental friendly tag suitable for green electronics and IoT applications will be realized.

1.6. Research Questions

Following are the research questions.

- How can a chipless RFID can be designed using some unique ASK encoding technique?
- How can the coding efficiency be enhanced regarding the tag capacity?
- How will the polarized rhombic shaped resonators be designed?
- How will the data encoding capacity be increased?
- How will the environmental friendly tag suitable for green electronics and IoT applications be realized?

2.1. Research Methodology

The tag design having similar dimensions will be analyzed for 3 substrates. In addition to achieving flexibility, the main purpose will be to come up with cost and energy efficient tags which will have better data encoding capacity. All tags will be designed and simulated in CST STUDIO SUITE®. CST STUDIO SUITE®.

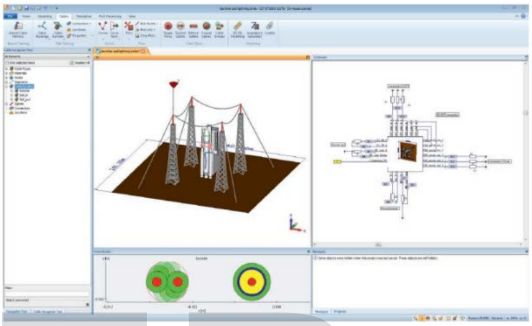

Figure 2.1: CST Studio Suite®

2.2. RFIF Tag Design

The proposed designed-simulated RFID tag comprises of seven resonating structures. Dual rhombic loops are designed and have the same dimensions for the three substrates.

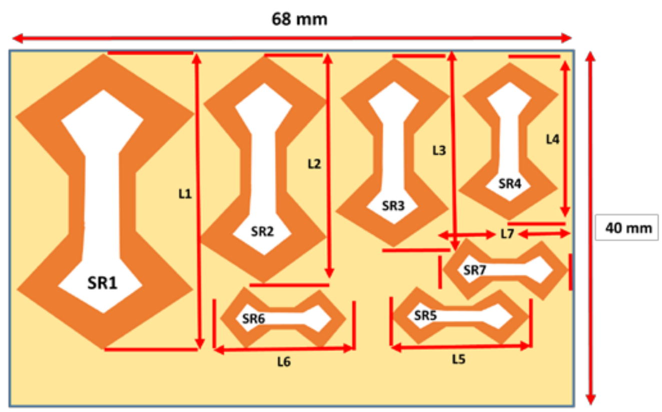

Figure 2.2: Designed Seven Resonators Tag

The overall dimension of RFID tag design are (68 x 40 mm^2) as follows:

- Length = 68 mm
- Width = 40 mm

International Journal of Scientific & Engineering Research Volume 10, Issue 7, July-2019
ISSN 2229-5518

- Scatterer Section (SR1) with Length (L1) = 40.20 mm
- Scatterer Section (SR2) with Length (L2) = 31.88 mm
- Scatterer Section (SR3) with Length (L3) = 26.00 mm
- Scatterer Section (SR4) with Length (L4) = 21.83 mm
- Scatterer Section (SR5) with Length (L5) = 17.71 mm
- Scatterer Section (SR6) with Length (L6) = 14.89 mm
- Scatterer Section (SR7) with Length (L7) = 12.37 mm

2.3. Kapton Substrate

Kapton® substrate (polyimide film) is mostly used as dielectric substrate owing to its high temperature resistance. The figure below shows the tag designed using Kapton.

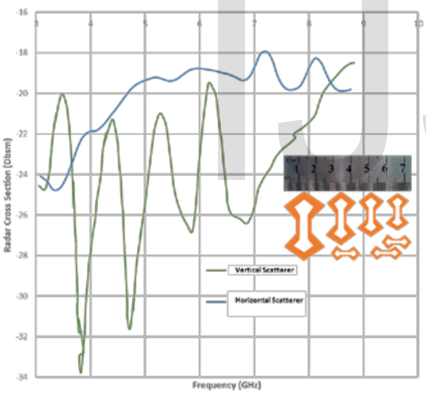

Figure 2.3: Resonating peaks, Kapton substrate without resistive strip

The thickness of the material is taken as 170 µm having permittivity, the ability of a substance to store electrical energy, of 3.40.

	Resonating Frequency (RF) in GHz						
Substrate	RF1	RF2	RF3	RF4	RF5	RF6	RF7
Kapton	3.48	4.35	5.20	6.18	7.00	8.00	8.50

Table 2.1: Resonating Frequencies – Kapton Substrate

The table above shows the resonating frequencies of the scatterers. The larger scatterer SR1 has the resonating frequency of 3.48 GHz, SR2 being 4.35 GHz, SR3 being 5.20 GHz, SR4 being 6.18 GHz, SR5 being 7.00 GHz, SR6 being 8.00 GHz and SR7 being 8.5 GHz.

2.4. Polyethylene Terephthalate Substrate

Polyethylene Terephthalate substrate is the most common thermoplastic polymer resin of the polyester family. The thickness of the material is taken as 90 µm having permittivity, the ability of a substance to store electrical energy, of 2.60.

	Resonating Frequency (RF) in GHz						
Substrate	RF1	RF2	RF3	RF4	RF5	RF6	RF7
Polyethylene Terephthalate	3.60	4.70	5.60	6.75	7.80	9.00	9.20

Table 2.2: Resonating Frequencies - Polyethylene Terephthalate Substrate

The table above shows the resonating frequencies of the scatterers. The larger scatterer SR1 has the resonating frequency of 3.60 GHz, SR2 being 4.70 GHz, SR3 being 5.60 GHz, SR4 being 6.75 GHz, SR5 being 7.80 GHz, SR6 being 9.00 GHz and SR7 being 9.20 GHz.

2.5. Paper Substrate

Paper substrate is used considering the green environment. The thickness of the material is taken as 200 µm having permittivity, the ability of a substance to store electrical energy, of 3.0.

	Resonating Frequency (RF) in GHz						
Substrate	RF1	RF2	RF3	RF4	RF5	RF6	RF7
Paper	3.40	4.20	5.20	6.20	7.00	8.10	8.50

Table 2.3: Resonating Frequencies – Paper Substrate

The table above shows the resonating frequencies of the scatterers. The larger scatterer SR1 has the resonating frequency of 3.40 GHz, SR2 being 4.20 GHz, SR3 being 5.20 GHz, SR4 being 6.20 GHz, SR5 being 7.00 GHz, SR6 being 8.10 GHz and SR7 being 8.50 GHz.

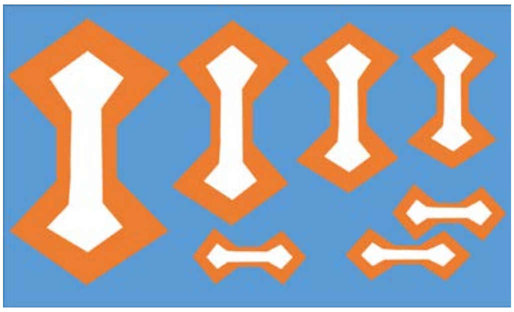

Figure 2.4: Tag using Paper Substrate

The designed substrate with paper is shown in the above figure.

3.1. Design

In order to do the analysis, now we have to add the resistive strip on all the resonators. It is also important to avoid any kind of coupling between the resonators to avoid any interference. As we can see in our design, there is not a standard equal spacing between the resonators. There exists a minimum distance of 0.75 mm between the first and the second resonator in order to achieve the decoupling between the adjacent resonators. This is a sufficient distance separating the resonators. Similarly the distance between subsequent resonators is varied so that no electromagnetic interference takes place. The resistive strips of different widths and dimensions are applied for horizontal and vertical resonators for the implementation of amplitude shift keying technique. The width of the resistive strips are varied for vertical scatterers SR1 to SR4 and for horizontal scaterers from SR5 to SR7. This results in amplitude variations as shown in the table below for SR1 between minimum and maximum and producing the corresponding data bits of the particular substrate tag.

Substrate	Max Amplitude (SR1) dB	Min Amplitude (SR1) dB	Data Capacity of Tag
Kapton	-20.11	-24.32	17
Polyethylene Terephthalate	-19.78	-24.12	25
Paper	-20.99	-24.84	27

Table 3.1: Amplitude Variations (Max-Min) and Data Capacity [11]

Resultantly we see the amplitude variations of the resonating peaks as the resistive strip is varied at different positions. It should also be noted that when we applied the resistive strip on any specific resonator, it also causes an effect on the amplitude of its neighboring peaks. Following the same pattern, the amplitude variance analysis is carried out for all the resonators from SR1 to SR7. Figure below shows the change of amplitude between maximum and minimum for scatterer SR1.

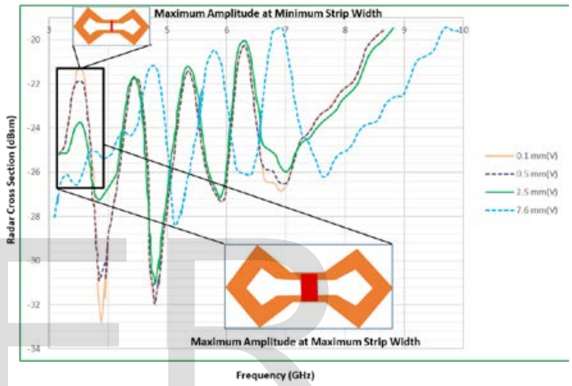

Figure 3.1: Simulation Result: Amplitude Shift Keying SR1 Vertical Scatterer (Kapton)

Here it is important to plot the radar cross section (a measure of how detectable an object is) vs the frequency for the horizontal scatterers SR5 to SR7.

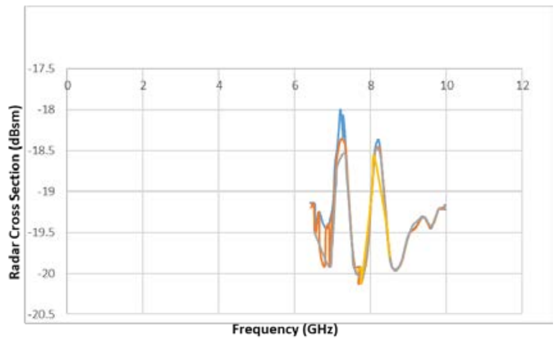

Figure 3.2: Simulation Result: Amplitude Shift Keying SR1 Horizontal Scatterer (Kapton)

We can observe in the above graph the deterioration of the amplitude and shift in the neighboring peaks response which depicts that as we change the thickness of the substrate, frequency behavior changes.

Testing environment consists of 2 antennas, 1 for reception of the signals & the other for transmission of the signals. The tag design is tested for prototypes using each substrate for analysis of the reliability parameters as shown below.

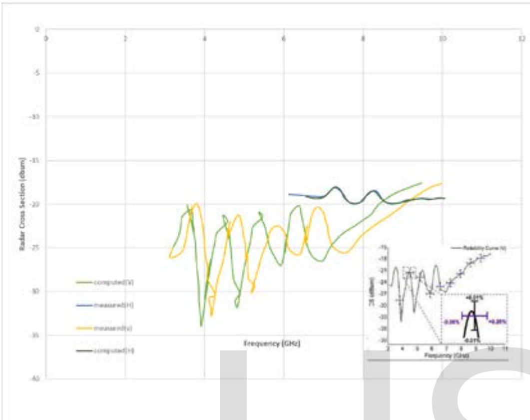

Figure 3.3: Reliability Graph (Measured-Cross Section)

A fully damped radar cross section (a measure of how detectable an object is) flats peak & width of resistive strip.

Substrate	SR1 (mm)	SR2 (mm)	SR3 (mm)	SR4 (mm)	SR5 (mm)	SR6 (mm)	SR7 (mm)
Kapton	7.4	4.8	3.8	0.4	0.4	0.4	0.4
Polyethylene Terephthalate	6.9	2.9	2.9	2.4	0.4	0.3	0.2
Paper	5.9	1.8	2.4	2.4	0.3	0.3	0.3

Table 3.2: Resistive Strips Widths

In case of max resistive strip width, resistance is found low. Width of resistive strip is mini, resistance high and it can be seen or proved by the below mentioned eqauation.

$R = (\rho L)/A$

Where.

R = Resistance

L = Resistive Strip Length

ρ = Resistivity

A = Cross Sectional Area of the Strip

3.2. Mathematical Equation

It is therefore found; capacity of tag increases when we introduce more amplitude levels by varying the resistive strip widths. Similarly, the level to which the neighboring peaks exhibit the variations, known as magnitude resolution, are dependent on the type of substrate which ultimately effects the data encoding capacity. The coding capacity can now be calculated for all the substrates using the equation;

$$C = \text{Log}_2 \{[(\Delta M_1)/(dM_1) + 1]\ [(\Delta M_2)/(dM_2) + 1]\ [(\Delta M_3)/(dM_3) + 1]\ [(\Delta M_4)/(dM_4) + 1]\ [(\Delta M_5)/(dM_5) + 1]\ [(\Delta M_6)/(dM_6) + 1]\ [(\Delta M_7)/(dM_7) + 1]\}$$

Where;

C	=	Coding Capacity
M	=	Magnitude
dM	=	Magnitude Resolutions

Now doing the mathematical calculations for the individual substrates, we can get the coding capacity. The table below shows the data values.

Substrate	dM1 (dB)	dM2 (dB)	dM3 (dB)	dM4 (dB)	dM5 (dB)	dM6 (dB)	dM7 (dB)
Kepton	0.56	0.35	0.32	0.281	0.44	1.21	1.22
Polyethylene Terephthalate	0.53	0.12	0.13	0.34	0.51	0.09	0.08
Paper	0.49	0.80	0.07	0.08	0.14	0.06	0.03
Substrate	**Ma1 (dB)**	**Ma2 (dB)**	**Ma3 (dB)**	**Ma4 (dB)**	**Ma5 (dB)**	**Ma6 (dB)**	**Ma7 (dB)**
Kepton	- 20.10	-21.60	-22.15	-19.4	-17.50	- 18.22	- 18.43
Polyethylene Terephthalate	- 19.70	-21.10	-20.50	-19.62	-17.40	- 16.81	- 16.79
Paper	- 21.11	-22.42	-21.66	-20.50	-18.10	- 18.89	- 18.91
Substrate	**Mb1 (dB)**	**Mb2 (dB)**	**Mb3 (dB)**	**Mb4 (dB)**	**Mb5 (dB)**	**Mb6 (dB)**	**Mb7 (dB)**
Kepton	- 24.50	-25.00	-24.00	-24.20	-19.00	- 19.20	- 19.40
Polyethylene Terephthalate	- 25.00	-25.22	-24.10	-24.11	-18.67	-17.6	- 17.40
Paper	- 25.06	-26.05	-24.03	-24.05	-19.02	- 19.40	- 19.55

Table 3.3: Magnitude Resolutions of all Substrates

3. 2. 1. Kapton Substrate

Putting the values in the below equation;

$C = Log_2 \{[(\Delta M_1)/(dM_1) + 1] [(\Delta M_2)/(dM_2) + 1] [(\Delta M_3)/(dM_3) + 1] [(\Delta M_4)/(dM_4) + 1] [(\Delta M_5)/(dM_5) + 1] [(\Delta M_6)/(dM_6) + 1] [(\Delta M_7)/(dM_7) + 1]\}$

Where;

$(\Delta M_1)/(dM_1)$	=	(24.5-20.10)/(0.56)
$(\Delta M_2)/(dM_2)$	=	(25.0-21.6)/(0.35)
$(\Delta M_3)/(dM_3)$	=	(24.00-22.15)/(0.32)
$\Delta M_4)/(dM_4)$	=	(24.2-19.4)/(0.28)
$\Delta M_5)/(dM_5)$	=	(19.00-17.5)/(0.44)
$\Delta M_6)/(dM_6)$	=	(19.2-18.22)/(1.21)
$(\Delta M_7)/(dM_7)$	=	(19.40-18.43)/(1.22)

$C = Log_2 \{[(24.5\text{-}20.10)/(0.56) + 1] [(25.0\text{-}21.6)/(0.35) + 1] [(24.00\text{-}22.15)/(0.32) + 1] [(24.2\text{-}19.4)/(0.28) + 1] [(19.00\text{-}17.5)/(0.44) + 1] [(19.2\text{-}18.22)/(1.21) + 1] [(19.40\text{-}18.43)/(1.22) + 1]\}$

$C = (8.85) \times (10.7) \times (6.78) \times (18.1) \times (4.4) \times (1.8) \times (1.7) = Log_2\, 156461.2 = 17$ bits

Coding Capacity using Kapton substrate is calculated to be 17-bits. With 6 resonators in the previous research, it was 16 bits. Hence, 1-bit improvement achieved.

3. 2. 2. Polyethylene Terephthalate

Putting the values in the below equation;

$C = Log_2 \{[(\Delta M_1)/(dM_1) + 1] [(\Delta M_2)/(dM_2) + 1] [(\Delta M_3)/(dM_3) + 1] [(\Delta M_4)/(dM_4) + 1] [(\Delta M_5)/(dM_5) + 1] [(\Delta M_6)/(dM_6) + 1] [(\Delta M_7)/(dM_7) + 1]\}$

Where;

$(\Delta M_1)/(dM_1)$	=	(25.00-19.70)/(0.53)
$(\Delta M_2)/(dM_2)$	=	(25.22-21.10)/(0.12)
$(\Delta M_3)/(dM_3)$	=	(24.10-20.50)/(0.13)
$(\Delta M_4)/(dM_4)$	=	(24.11-19.62)/(0.34)
$(\Delta M_5)/(dM_5)$	=	(18.67-17.40)/(0.51)
$(\Delta M_6)/(dM_6)$	=	(17.60-16.81)/(0.09)
$(\Delta M_7)/(dM_7)$	=	(17.40-16.79)/(0.08)

$C = Log_2 \{[(25.00\text{-}19.70)/(0.53) + 1] [(25.22\text{-}21.10)/(0.12) + 1] [(24.10\text{-}20.50)/(0.13) + 1] [(24.11\text{-}19.62)/(0.34) + 1] [(18.67\text{-}17.40)/(0.51) + 1] [(17.60\text{-}16.81)/(0.09) + 1] [(17.40\text{-}16.79)/(0.08) + 1]\}$

$C = (11) \times (35.3) \times (28.6) \times (14.2) \times (3.49) \times (9.7) \times (8.6) = Log_2\, 45911066.4 = 25$ bits

Coding Capacity using Polyethylene Terephthalate substrate is calculated to be 25-bits, 4 bits' improvement from the previous research.

3. 2. 3. Paper

Putting the values in the below equation;

$C = Log_2 \{[(\Delta M_1)/(dM_1) + 1] [(\Delta M_2)/(dM_2) + 1] [(\Delta M_3)/(dM_3) + 1] [(\Delta M_4)/(dM_4) + 1] [(\Delta M_5)/(dM_5) + 1] [(\Delta M_6)/(dM_6) + 1] [(\Delta M_7)/(dM_7) + 1]\}$

Where;

$(\Delta M_1)/(dM_1)$	=	(25.06-21.11)/(0.49)
$(\Delta M_2)/(dM_2)$	=	(26.05-22.42)/(0.80)
$(\Delta M_3)/(dM_3)$	=	(24.03-21.66)/(0.07)
$(\Delta M_4)/(dM_4)$	=	(24.05-20.50)/(0.08)
$(\Delta M_5)/(dM_5)$	=	(19.02-18.10)/(0.14)
$(\Delta M_6)/(dM_6)$	=	(19.40-18.89)/(0.06)
$(\Delta M_7)/(dM_7)$	=	(19.55-18.91)/(0.03)

$C = Log_2 \{[(25.06\text{-}21.11)/(0.49) + 1] [(26.05\text{-}22.42)/(0.80) + 1] [(24.03\text{-}21.66)/(0.07) + 1] [(24.05\text{-}20.50)/(0.08) + 1] [(19.02\text{-}18.10)/(0.14) + 1] [(19.40\text{-}18.89)/(0.06) + 1] [(19.55\text{-}18.91)/(0.03) + 1]\} = 25$ bits

$C = (9.06) \times (5.5) \times (34.8) \times (45.3) \times (7.5) \times (9.5) \times (22.3) = Log_2\, 124812495.012 = 27$ bits

Coding Capacity using Paper substrate is calculated to be 27-bits through the use of 7 resonators, which is an improvement to the previous research done by the researchers who achieved 25 bits by using 6 resonators.

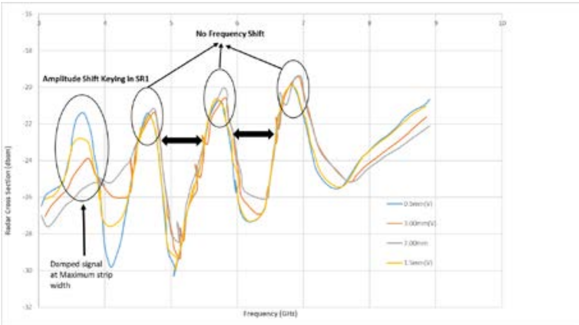

Figure 3.4: Simulation Result: Amplitude Shift Keying SR1 Vertical Scatterer (Polyethylene Terephthalate)

Figure above shows the amplitude shift keying of polyethylene terephthalate based tag and the figure below shows the radar cross section of the horizontal scatterers using polyethylene terephthalate substrate.

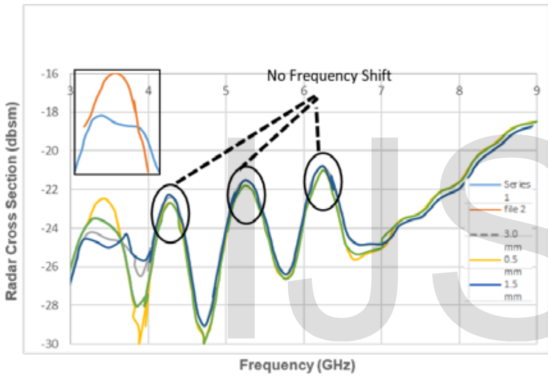

Figure 3.5: Simulation Result: Amplitude Shift Keying SR1 Horizontal Scatterer (Polyethylene Terephthalate)

As can be seen, the resistive strip's width and resonator's sizes are interlinked with each other. It is observed that as the strip widths decrease as the sizes of resonators decrease. The above figures also depict that by using polyethylene terephthalate tag and surrounding peaks are very minimally affected by noise, and hence the tag capacity has shown improvement. By using values provided in Table 4, shows capacity of polyethylene terephthalate comes out to be 25 bits.

Similarly, in case of paper substrate, resonating peaks damping is faster in comparison to other substratess, as shown in the figures below.

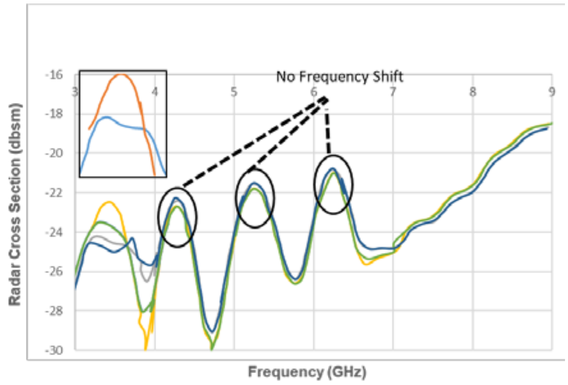

Figure 3.6: Simulation Result: Amplitude Shift Keying SR1 Vertical Scatterer (Paper)

The figures above depict none shift of frequency on the neighboring peaks due to amplitude variation in 1st scatterer.

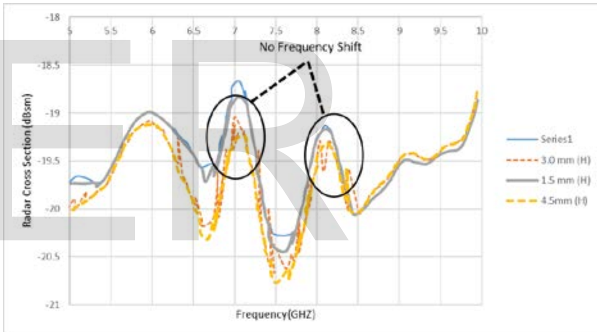

Figure 3.7: Simulation Result: Amplitude Shift Keying SR1 Horizontal Scatterer (Paper)

Using paper substrate, tag capacity is measured to be 27 bits.

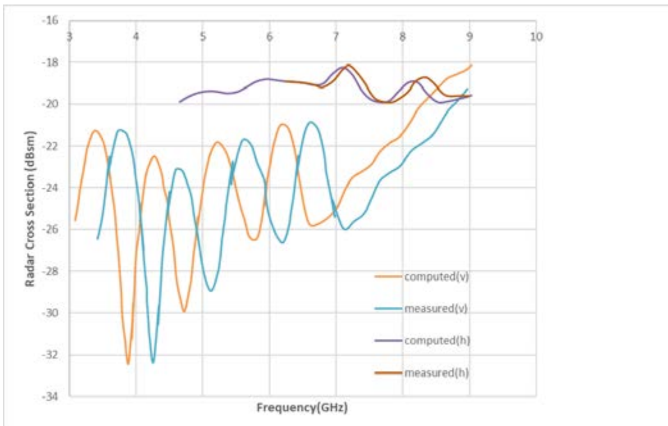

Figure 3.8: Paper Substrate (Measured-Computed Results Vertical/Horizontal)

The measured results for paper substrate with no resistive strip are shown in the above figure, which are in line with the computed values through the equation.

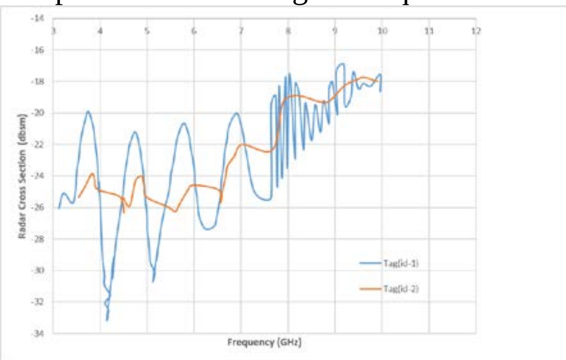

Figure 3.9: Coding Principle: Amplitude Shift Keying

Coding principles are based on amplitude shift keying technique. The tag identities for 2 varied combinations are shown below.

4.1. Research Summary

In this research work, the following has been achieved;

- We have analyzed the Broadband radiator's selectivity problem.
- Instead of using the on-off keying technique, ASK technique has been used.
- keeping chipless RFID Size same, data encoding capacity has been increased.
- Data coding for Kapton substrate has been increased from 16 bits to 17 bits.
- Data coding for Polyethylene Terephthalate substrate has been increased from 21 bits to 25 bits.
- Data coding for paper substrate has been increased from 24 bits to 27 bits.
- Environmentally friendly 27 bit tag is designed-realized.
- The scatterers were placed in a way to reduce the coupling effect to minimum value.
- Tag design with 3 substrates having the same encoding technique were verified.
- The realized tags provide flexibility.
- The cost of the tags is less.
- The size of the RFID Tag has been reduced from 70 mm x 42 mm to 68 mm x 40 mm
- The realized tags are easy to manufacture.
- Paper based substrate tag is found to be highly suitable for green electronics and IoT applications.

4.2. Contribution to Knowledge (Academic Contribution)

Through this research work, radiator's selectivity problem for broadband was looked into. Unique ASK technique will be applied. Keeping the size of chipless RFID small, the researcher will enhance the data encoding capacity. Additionally, environmental friendly tag will be realized which has not been done before.

4.3. Statement of Significance (Practical Contribution)

The research will lead to practical significance for future work which will emphasizes on the equipping tag with sensing capabilities using ASK and enabling them to secure a prominent position in the emerging fields of IoT and green electronics.

In this research work amplitude of received signal will be observed. ASK will be explored for Eight or more resonators. By doing this, the researcher will try to increase the overall capacity of the tag. The main purpose will be to make cost effective, energy efficient tags also having admirable data encoding capacity. The researcher will try to improve the following factors:

- Data Encoding Capacity
- Environment friendly Tag (Green electronics with paper substrate)
- Reduced Coupling effect

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