Design of Rectangular Dielectric Resonator Antenna for Artificial Neural Network

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ABSTRACT

This paper represents a study of simulation of a Dielectric Resonator Antenna (DRA) based on its rectangular shape for Artificial Neural Network (ANN). The DRA is intended to be used as the radiating element of a transmitting array of active integrated antennas; its input impedance must exhibit a proper resistive load at the fundamental resonance frequency, as well as a dominant reactive behavior, either inductive or capacitive, at higher harmonics. The design procedure is performed by exploiting Artificial Neural Networks (ANN), to find the resonator geometry starting from the desired resonance frequency, and a finite element based numerical tool for the electromagnetic characterization of the antenna. The ANN can be employed in a designed RDRA over a short range of frequency of 5.68-5.9 GHz. After simulation this network can give a broad acceptance of simulated data of input and output dimensions of DRA with the possible original existence of the corresponding dimensions.

Keywords – Artificial Neural Network, Dielectric Resonator Antenna (DRA), Far Field, Gain, Bandwidth.

I. INTRODUCTION

The field of wireless communications has been undergoing a revolutionary growth in the last decade. This is attributed to the invention of portable mobile phones some 15 years ago. The success of the second-generation (2G) cellular communication services motivates the development of wideband third-generation (3G) cellular phones and other wireless products and services, including wireless local area networks (WLAN), home RF, Bluetooth, wireless local loops (WLL), local multi-point distributed networks (LMDS), to name a few. The crucial component of a wireless network or device is the antenna.

In this era of wireless communications, low-profile and small-size antennas are highly preferable for mobile devices, such as cellular phones, notebook computers, personal digital assistant (PDA), etc. Very soon, our cities will be flooded with antennas of different kinds and shapes. On the other hand, for safety and portability reasons, low power, multi-functional and multi-band wireless devices are highly preferable. All these stringent requirements demand the development of highly efficient, low-profile and small-size antennas that can be made imbedded into wireless products.

In the last 2 decades, two classes of novel antennas have been investigated and extensively reported on. They are the microstrip patch antenna and the dielectric resonator antenna (DRA). Both are highly suitable for the development of modern wireless communications.

The use of a dielectric resonator as a resonant antenna was proposed by Professor S. A. Long in the early 1980's. Since the Dielectric Resonator Antenna (DRA) has negligible metallic loss, it is highly efficient when operated at millimeter wave frequencies. Conversely, a high-permittivity or partially metallized dielectric resonator can be used as a small and low-profile antenna operated at lower microwave frequencies. Low loss dielectric materials are now easily available commercially at very low cost. This would attract more system engineers to choose dielectric resonator antennas when designing their wireless products.

In the last decade, a considerable attention has been focused on dielectric resonator antennas (DRAs) as an alternative to microstrip ones [1-6]. DRAs represent a relatively novel application of dielectric resonators (DRs). These resonators are unshielded and rely, for field confinement within their boundaries, on a very high difference between their own permittivity and the permittivity of the outer medium. The low-loss, high permittivity dielectrics used for DRs ($\mathbf{10 \leq \varepsilon r \leq 100}$), ensure that most of the field remains within the resonator, so leading to high quality factor *Q*. If the permittivity constant is not too high and the excited mode presents strong fields at the resonator boundaries, the *Q* drops significantly inasmuch part of the stored energy is radiated in the environment. Since dielectric losses remain low and the size of the DR are small with respect to the free-space wavelength, these radiators provide small and high efficiency antennas.

DRAs are used in different applications as they exhibit several attractive features like small size, high radiation efficiency, light weight, simple

structure, better performance when used in phased array configurations (since they can be packed more tightly) [7-10]. Furthermore, consisting of 3D structures, DRAs show more degrees of freedom for their geometrical definition and shape [11].
The open literature presents various shapes for DRAs, such as cylindrical (CDRA), rectangular (RDRA), hemispherical (HDRA) and ring or annular DRA (ADRA). Many studies on DRAs have been devoted to radiation efficiency, radiated field characteristics and to enlarge the impedance bandwidth, but less attention has been given to their harmonic tuning and hence to their use in active integrated antennas (AIAs). Recently several contributions have been presented where harmonic tuning techniques have been proposed for Ku-band rectangular and cylindrical dielectric resonator antennas [12-14].

The study has been carried out by exploiting artificial neural networks (ANNs), for the inversion of the formula relating the fundamental resonance frequency and the geometrical parameters of the resonator, and a finite elements based numerical tool (the commercial software HFSS), for the electromagnetic characterization of the antenna.

II. DIELECTRIC RESONATOR ANTENNA (DRA)

A Dielectric Resonator Antenna (DRA) is a radio antenna which is mostly used at microwave frequencies and higher, that consists of a block of ceramic material of various shapes, the dielectric resonator, mounted on a metal surface, a ground plane. Radio waves are introduced into the inside of the resonator material from the transmitter circuit and bounce back and forth between the resonator walls, forming standing waves. The walls of the resonator are partially transparent to radio waves, and radio power is radiated into space.[15]
An advantage of dielectric waveguide antennas is they lack metal parts, which become lossy at high frequencies, dissipating energy. So these antennas can have lower losses and be more efficient than metal antennas at high microwave and millimeter wave frequencies. Dielectric waveguide antennas are used in some compact portable wireless devices, and military millimeter-wave radar equipment. The antenna was first proposed by Long, et al, in 1973.
Dielectric resonator antennas (DRA) offer the following attractive features:

- Generally the dimension of a DRA is of the order of $\frac{\lambda_0}{\sqrt{\epsilon_r}}$, where λ_0 is denoted as the free-space wavelength and ϵ_r is the dielectric constant of the resonator material. Thus, by choosing a high value of $\epsilon_r(\epsilon_r \approx 10-100)$, the DRA's size can be significantly reduced.
- No inherent conductor loss is present in the dielectric resonators, which leads to high radiation efficiency of the antenna. This kind of feature is especially becomes attractive for millimeter (mm)-wave antennas, where the loss can be high in the metal fabricated antennas.
- DRAs also offer simple coupling schemes to nearly all kinds of transmission line which used at microwave and mm-wave frequencies. This makes them suitable for integration into different planar technologies. The coupling between the planar transmission line and a DRA can be easily controlled by varying the position of the DRA with respect to that line. So the DRA's performance can be easily optimized experimentally.
- A DRA's operating bandwidth can be varied over a wide range by suitably choosing resonator parameters.
- Each mode of a DRA has a unique internal and associated external field distribution. Therefore, different radiation characteristics can be obtained by exciting different modes of a DRA.

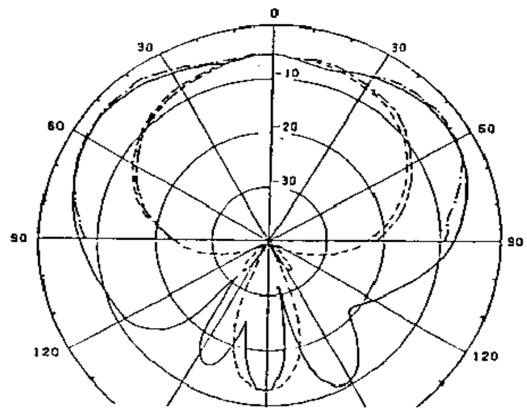


Fig.1 Radiation pattern of the DRA above the finite size ground plane (ref. IEEE)

The use of a dielectric resonator as a resonant antenna was firstly proposed in 1983. Due to the absence of metallic loss, the dielectric resonator antenna (DRA) is highly efficient when it is operated at millimeter (mm) wave frequencies. Also with the use of high dielectric constant material, the DRA can be used as a small and low profile antenna when operated at low microwave frequencies. Low cost dielectric materials are now easily available commercially: encouraging more antenna engineers to design communication systems with DRAs. Some reasons for using the DRA are its inherent merit of having no metallic loss, small physical size, easily tunable, and the large degree of design freedom in choosing the parameters. The characteristics of the major low order modes can be adequately approximated by keeping the low order terms of the multi-pole expansion for the field distribution. The radiation pattern of the DRA would ultimately depend on the field distribution inside the DRA.

III. ARTIFICIAL NEURAL NETWORK (ANN)

Artificial Neural Networks (ANNs) are non-linear mapping structures based on the function of human brain. They are powerful tools for modeling, especially when the underlying data relationship is unknown. ANNs can identify and learn correlated patterns between input data sets and corresponding target values. After training, ANNs can be used to predict the outcome of new independent input data. ANNs imitate the learning process of the human brain and can process problems involving non-linear and complex data even if the data are imprecise and noisy. Thus they are ideally suited for the modeling of some data which are known to be complex and often non-linear. ANNs has great capacity in predictive modeling i.e., all the characters describing the unknown situation can be presented to the trained ANNs.

An ANN is a computational structure that is inspired by observed process in natural networks of biological neurons in the brain. It consists of simple computational units called neurons, which are highly interconnected. ANNs have become the focus of much attention, largely because of their wide range of applicability and the ease with which they can treat complicated problems. ANNs are parallel computational models comprised of densely interconnected adaptive processing units. These networks are fine-grained parallel implementations of non-linear static or dynamic systems. A very important feature of these networks is their adaptive nature, where “learning by example” replaces “programming” in solving problems. This feature makes such computation models very appealing in application domains where one has little or incomplete understanding of the problem to be solved but where training data is readily available. Work on artificial neural networks has been motivated right from its inception by the recognition that the human brain computes in an entirely different way from the conventional digital computer. The brain is a highly *complex, nonlinear and parallel computer* (information-processing system). It has the capability to organize its structural constituents, known as *neurons,* so as to perform certain computations (e.g., pattern recognition, perception, and motor control) many times faster than the fastest digital computer in existence today. Consider, for example, human *vision*, which is an information processing task [16-19]. It is the function of the visual system to provide a *representation* of the environment around us and, more important, to supply the information we need to *interact* with the environment. To be specific, the brain routinely accomplishes perceptual recognition tasks (e.g., recognizing a familiar face embedded in an unfamiliar scene) in approximately 100-200 ms, whereas tasks of much lesser complexity may take days on a conventional computer. The following definition of a neural network can be offered for an adaptive machine:

A neural network is a massively parallel distributed processor made up of simple processing units, which has a natural propensity for storing experiential knowledge and making it available for use. It resembles the brain in two respects:

- *Knowledge is acquired by the network from its environment through a learning process.*
- *Interneuron connection strengths, known as synaptic weights, are used to store the acquired knowledge.*

The procedure used to perform the learning process is called a *learning algorithm*, the function of which is to modify the synaptic weights of the network in an orderly fashion to attain a desired design objective.
The modification of synaptic weights provides the traditional method for the design of neural networks. Such an approach is the closest to linear adaptive filter theory, which is already well established and successfully applied in many diverse fields [20-22].

IV. BENEFITS OF NEURAL NETWORKS

It is apparent that a neural network derives its computing power through, first, its massively parallel distributed structure and, second, its ability to learn and therefore generalize.
The use of neural networks offers the following useful properties and capabilities:

1. *Nonlinearity*.
An artificial neuron can be linear or nonlinear. A neural network, made up of an interconnection of nonlinear neurons, is itself nonlinear. Moreover, the nonlinearity is of a special kind in the sense that it is *distributed* throughout the network. Nonlinearity is a highly important property, particularly if the underlying physical mechanism responsible for generation of the input signal (e.g., speech signal) is inherently nonlinear.

2. *Input-Output Mapping*.
A popular paradigm of learning called *learning with a teacher or supervised learning* involves modification of the synaptic weights of a neural network by applying a set of labelled *training samples* or *task examples*. Each example consists

of a unique *input signal* and a corresponding *desired response*. The network is presented with an example picked at random from the set and the synaptic weights (free parameters) of the network are modified to minimize the difference between the desired response and the actual response of the network produced by the input signal in accordance with an appropriate statistical criterion. In a nonparametric approach to this problem, the requirement is to "estimate" arbitrary decision boundaries in the input signal space for the pattern-classification task using a set of examples, and to do so *without* invoking a probabilistic distribution model. A similar point of view is implicit in the supervised learning paradigm, which suggests a close analogy between the input-output mapping performed by a neural network and nonparametric statistical inference [23].

3. *Evidential Response*.
In the context of pattern classification, a neural network can be designed to provide information not only about which particular pattern to *select*, but also about the *confidence* in the decision made. This latter information may be used to reject ambiguous patterns, should they arise and thereby improve the classification performance of the network.

4. *Contextual Information*.
Knowledge is represented by the very structure and activation state of a neural network. Every neuron in the network is potentially affected by the global activity of all other neurons in the network. Consequently, contextual information is dealt with naturally by a neural network.

5. *Fault Tolerance*.
A neural network, implemented in hardware form, has the potential to be inherently *fault tolerant*, or capable of robust computation, in the sense that its performance degrades gracefully under adverse operating conditions. In order to be assured that the neural network is in fact fault tolerant, it may be necessary to take corrective measures in designing the algorithm used to train the network [25].

6. *VLSI Implementability*.
The massively parallel nature of a neural network makes it potentially fast for the computation of certain tasks. This same feature makes a neural network well suited for implementation using Very-Large-Scale-Integration (VLSI) technology. One particular beneficial virtue of VLSI is that it provides a means of capturing truly complex behavior in a highly hierarchical fashion [26].

7. *Uniformity of Analysis and Design*.
Basically, neural networks enjoy universality as information processors. We say this in the sense that the same notation is used in all domains involving the application of neural networks. This feature manifests itself in different ways:

- Neurons, in one form or another, represent an ingredient *common* to all neural networks.
- This commonality makes it possible to *share* theories and learning algorithms in different applications of neural networks.
- Modular networks can be built through a *seamless integration of modules.*

8. *Neurobiological Analogy*.
The design of a neural network is motivated by analogy with the brain, which is a living proof that fault tolerant parallel processing is not only physically possible but also fast and powerful. Neurobiologists look to (artificial) neural networks as a research tool for the interpretation of neurobiological phenomena. On the other hand, engineers look to neurobiology for new ideas to solve problems more complex than those based on conventional hard-wired design techniques [27-31].

V. LITERATURE REVIEW

A first wave of interest in neural networks (also known as ‘connectionist models’ or ‘parallel distributed processing’) emerged after the introduction of simplified neurons by McCulloch and Pitts in 1943 (McCulloch & Pitts, 1943).They proposed a model of “computing elements” called Mc-Culloch-Pitts neurons, which performs weighted sum of the inputs to these elements followed by a threshold logic operation. Combinations of these computing elements were used to realize several logical computations. The main drawback of this model of computation is that the weights are fixed and hence the models could not learn from examples which are the main characteristic of the ANN technique which later evolved.

Hebb (1949), proposed a learning scheme for adjusting a connection weight based on pre and post synaptic values of the variables. Hebb’s law became a fundamental learning rule in neuron-network literature. Rosenblatt (1958), proposed the perceptron models, which has weight adjustable by the perceptron learning law. Widrows and Hoff (1960) and his group proposed an ADALINE (Adaptive Linear Element) model for computing elements and LMS (Least Mean Square) learning algorithm to adjust the weights of an ADALINE model.

When Minsky and Papert published their book Perceptrons in 1969 (Minsky & Papert, 1969) in which they showed the deficiencies of perceptron models, most neural network funding was redirected and researchers left the field. Only a few researchers continued their efforts, most notably

Teuvo Kohonen, Stephen Grossberg, James Anderson, and Kunihiko Fukushima.

The interest in neural networks re-emerged only after some important theoretical results were attained in the early eighties (most notably the discovery of error back-propagation), and new hardware developments increased the processing capacities. This renewed interest is reflected in the number of scientists, the amounts of funding, the number of large conferences, and the number of journals associated with neural networks. Nowadays most universities have a neural networks group, within their psychology, physics, computer science, or biology departments.

Hopfield (1982), gave energy analysis of feedback neural networks. The analysis has shown the existence of stable equilibrium states in a feedback network, provided the network has symmetrical weights. Rumelhart et al. (1986), showed that it is possible to adjust the weight of a multilayer feed forward neural network in a systematic way to learn the implicit mapping in a set of input-output patterns pairs. The learning law is called generalized delta rule or error back propagation.

Artificial neural networks can be most adequately characterized as 'computational models' with particular properties such as the ability to adapt or learn, to generalize, or to cluster or organize data, and which operation is based on parallel processing. However, many of the above mentioned properties can be attributed to existing (non-neural) models. Often parallels with biological systems are described. However, there is still so little known (even at the lowest cell level) about biological systems, that the models we are using for our artificial neural systems seem to introduce an oversimplification of the 'biological' models.

VI. DRA MODEL

The model of rectangular dielectric resonator antenna is designed with the use of software named as Ansoft HFSS. The required tools for getting help to construct the appropriate dielectric resonator antenna with probe feed are previously installed in this software. After constructing the required figure, it have to give the proper excitation according to the requirement, by which after simulation it is very easy to get the radiation pattern from the far field report and the frequency vs. dB rectangular plot from terminal solution data report. The following figures are of constructed DRA using software and the corresponding simulated graph and pattern for the particular dimensions of the configured DRA which is a rectangular in shape.

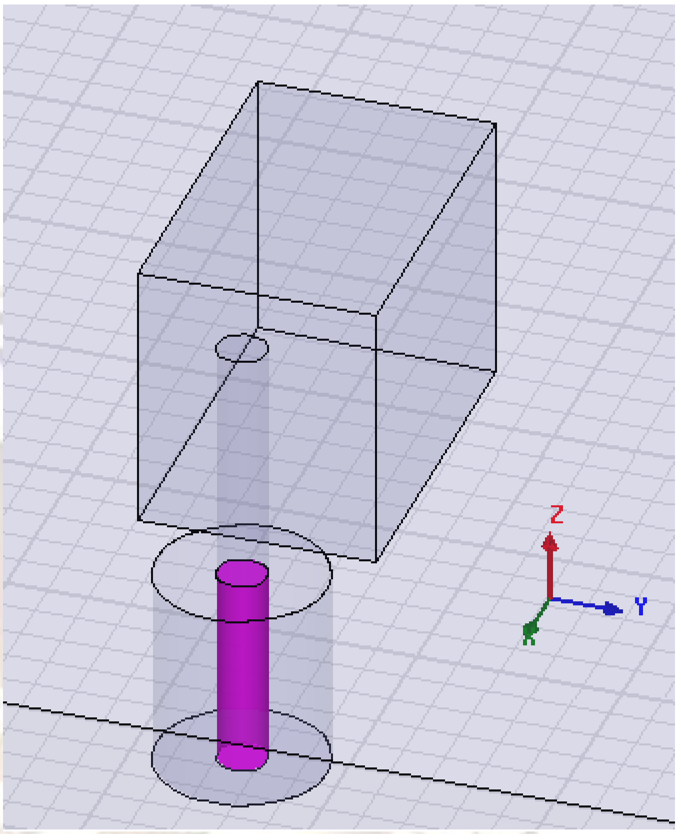


Fig 2. Constructed Rectangular Dielectric Resonator Antenna using Ansoft HFSS

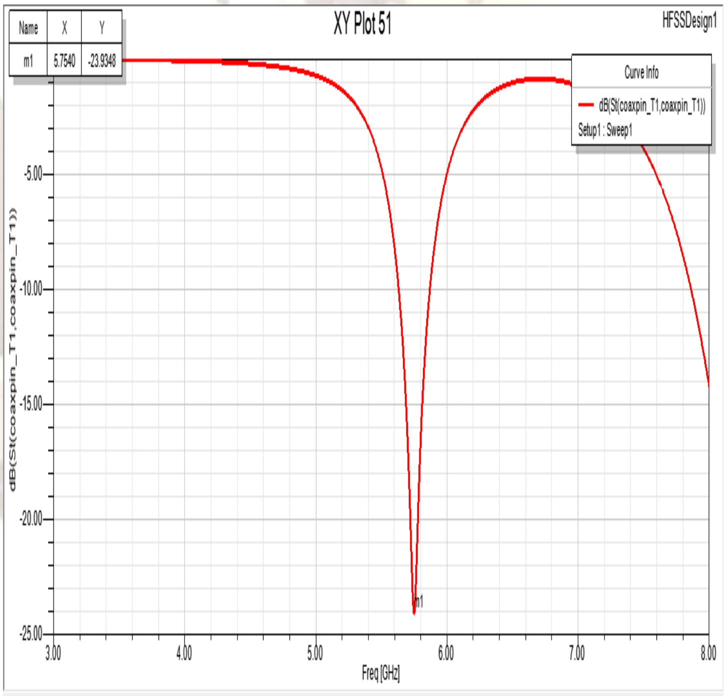
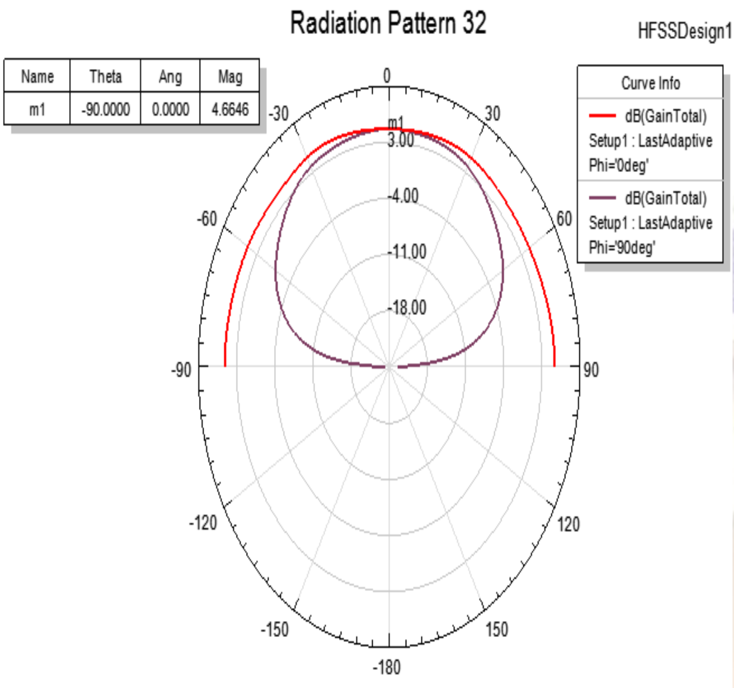


Fig.3. Simulated Output of Frequency vs. dB Graph from Rectangular Plot.

Fig.4. Simulated Output of Radiation Pattern from Far Field Report.



VII. DISCUSSIONS

After doing many more programming and simulation process of the corresponding designed DRA structure by using the Ansoft HFSS software, it is very easy to predict that after making the proper dimensions of the input parameters like the length, breadth, height of rectangular dielectric resonator antenna, probe height and probe offset position, its became easier to get the proper gain of the radiation pattern, bandwidth and the frequency in the desired range in between 5.68 GHz and 5.9 GHz. After giving a desired input values for different parameters of DRA and probe, it's become prompt to get the required amount of output values for the parameters namely frequency, gain and bandwidth. Then after getting a huge amount of various output data according to its various input data, its next job is to compare the huge datasheet with the original existence of that various dimensions of rectangular dielectric resonator antenna. The data is collected in a table format of the following:

Table.1. Small Datasheet Collected by Ansoft HFSS (High Frequency Structure Simulator) Software

d/h	w/h	Δx	P	$f_{simulated}$	BW	Gain
1.82	1.08	0	2.9	5.798	0.129	4.8646
1.92	1.12	0	3.2	5.827	0.174	4.74
1.89	1.12	0.1	4.1	5.839	0.088	4.5676
1.82	1.08	0.1	4.7	5.738	0.188	5.5954
1.89	1.12	0.2	4.9	5.823	0.128	4.3842
1.41	0.92	0.3	5	5.744	0.125	4.776
1.57	0.99	0.4	6	5.688	0.181	4.3342
1.57	1.02	0.5	5.2	5.871	0.157	4.2301
1.48	0.94	0.6	6	5.721	0.109	4.0688

here,

d= length of DRA
w= breadth of DRA
h= height of DRA
Δx= probe offset position
P= probe height
$f_{simulated}$= simulated frequency
BW= bandwidth

VIII. CONCLUSION

After all such discussion it can be concluded that a huge set of data can be collected by using this Ansoft HFSS software, with the help of which an Artificial Neural Network model can be designed. By this ANN model we will able to establish the proper relationship between the input parameters and the output parameters of antenna. By the simulation process we can able to predict the output parameters namely frequency, bandwidth and gain of antenna correctly. This artificial neural network model will help us to design antenna with our desired parameters.

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