

Distributed Impedance Matching Technique for Antenna Wireless Applications

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Abstract— an approach for developing impedance matching for antennas using the concept of current control and reactive loading is presented. This scheme is based on a modal analysis referred to as Characteristic Modes (CM) which is used to obtain physical insight about the antenna's behavior and to modify/improve the antenna's currents to achieve the desired goals. The scheme could be applied to obtain wideband impedance and radiation pattern behavior; however, the reactive loads may exhibit a non-foster behavior which requires active devices. If the wideband condition is relaxed, the technique can be applied to design multiband antennas for various applications where the loads can be foster (lumped elements). The technique was applied to a Universal Serial Bus (USB) and Radio Frequency Identification (RFID) antennas and yielded a much improved antenna performance.

Index Terms—antenna, reactive loading, impedance matching, RFID, characteristic modes theory.

I. INTRODUCTION

Antenna design is typically composed of three different, but related tasks to achieve the desired radiation pattern and frequency bandwidth: geometry and material definition, feed network design, and input impedance matching. Designing these major components simultaneously is difficult in most cases. Due to the great advances made with numerical computational techniques, brute force optimization is often used in the design of antennas. Unfortunately, most optimization methods do not provide any physical insight.

Characteristic Mode Theory [1] is one of the very few numerical methods that provide a great deal of physical insight because it allows us to determine the natural modes of the radiating structure. Since these natural current and radiation pattern modes satisfy certain orthogonally properties, they are referred to as Characteristic Modes. The key feature of these modes is that the total antenna current, input admittance and radiation pattern can be expressed as a linear weighted combination of individual modes. Using this decomposition method, it is possible to study the behavior of the individual modes, understand them and therefore control the antenna's behavior. In other words, controlling the currents induced on the antenna to achieve the desired input impedance and radiation pattern behavior over a given frequency band.

This paper discusses designing antennas by controlling the antenna currents over the desired frequency band to achieve the desired performance specifications for a set of constraints. Here, a systematic method based on the Theory of CM and reactive loading to achieve the goal of current control is developed. This technique can be used to match the antenna to the source connected to it as well as to achieve the desired

radiation pattern. The technique is much more general than the traditional impedance matching where the matching circuit is located at the feed point only. Another form of CM, namely; N-port CM (NCM) [8], is also used in this paper. NCM is similar to the CM introduced in [1]; however, it uses a N-port Z-matrix instead of a full MoM Z-matrix to solve for the generalized eigenvalue problem.

The overall goal is to provide a systematic approach for designing and/or improving the performance of an antenna (in principle, any geometry) using a reactive loading technique and the theory of Network Characteristic Modes (NCM). This modal analysis helps us to determine the required load(s) for any complex radiator system to expand the useful input impedance and whenever possible the radiation pattern bandwidth over a desired frequency band.

II. MULTIPORT REACTIVE LOADING AND INPUT IMPEDANCE MATCHING TECHNIQUE FOR ANTENNAS

Reactive loading refers to the use of reactive loads at various locations on the antenna structure, including the feed point. The loads are determined based on the desired behavior of the antenna currents. The technique starts by examining the modal behavior on the given antenna geometry aiming to find modes which can offer the desire behavior.

A. Universal Serial Bus (USB) Antenna

One of the applications which can benefit from this developed technique is the Universal serial bus (USB) dongle antennas. These antennas are in large demand for applications in WLAN, Bluetooth and LTE. These antennas are used to send and receive signals between devices. Such antennas should be of compact size, operate at dual and/or multiple bands and have sufficient frequency bandwidth.

Fig.1 depicts the reflection coefficient $|S_{11}|$ of the original and loaded antenna (both simulated), where the latter was designed using the CM technique in conjunction with NCM and the loading technique described above. Assuming $|S_{11}| < -10\text{dB}$ is considered acceptable (VSWR=2), the modified antenna impedance bandwidth is 16.25% at the lower band (2.4GHz); whereas, at the upper band (5.5GHz) is 28%. The maximum realized gain (includes impedance mismatch losses) using EM simulator was found to be 1.93dB and 1.91dB for lower and upper bands, respectively. To validate this proposed approach, the antenna was fabricated (see the insert in Fig.1). Fig.1 compares reflection coefficients $|S_{11}|$ of the original and loaded (simulated and measured) antenna. The realized gain patterns for the loaded antenna can be seen in Fig.2 at 2.4GHz

and 5.5GHz, respectively. Note that the antenna also exhibits good radiation efficiency. Using the well-known Wheeler Cap method, the efficiency was found to be (91.61%, 86.03%) at (2.5/5.5) GHz respectively. This can be considered to have superior performance when compared to other work found in the literature [2].

B. Radio Frequency Identification (RFID) Antenna

The other applications which can profit from this matching technique are Radio Frequency Identification (RFID) antennas. RFID is a technology that uses RF signals for the automatic identification of objects. This technology is currently used in many commercial applications such as inventory control, entry permission into buildings and contactless payment system. Typical passive RFID systems consist of a base station (Reader) and tag antenna. The reader transmits an RF signal, which is received by the tag and returned it back after adding the tag's information. The tag is an antenna and chip circuit where the chip is connected to the antenna terminal. The design of such antenna is very crucial as it controls the read range. Read range is defined as the maximum distance at which the RFID reader can detect the back-scattered signal from the tag [3].

Here we aim to design a simple UHF-RFID tag antenna. A key step in the design is the placement of reactive loads on the antenna structure and using an N-port CM to determine their values. Unlike the USB antenna, the loads here modify the antenna's input impedance so it is conjugate matched to the chip complex input impedance, thus increasing the reading-range at the desired frequency bands.

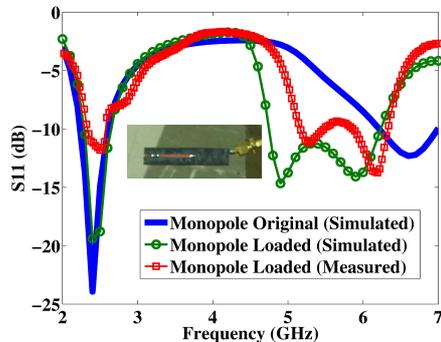


Fig.1: $|S_{11}|$ for original and loaded antenna (Simulation and Measurements)

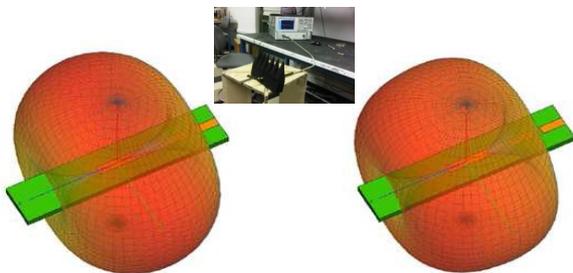


Fig.2 : Realized Gain pattern (EM Simulator) at 2.5GHz (left) and 5.5GHz (Right)



Fig.3 : UHF-RFID Loaded Antenna

Placing the loads on the antenna and performing the EM simulation, the input impedance can be obtained. The simulated impedance at 915MHz is $(11.0857+j143.073 \Omega)$, which is very close to the conjugate of the chip's input impedance. The theoretical read-range [3] of the loaded antenna is achieved at 915MHz where 13m of reading-range is obtained with a minimum reading distance of 9m over the frequency band using the setup shown in Fig.3. This is considered to be a good performance for such a small antenna. More details about the technique and its applications can be found in [4] which was a result of the MTT fellowship award.

III. CONCLUSIONS

A framework for designing antennas using the concept of current control and reactive loading is presented. The physical insight that CM offers is of great value because it allows us to understand how the modes interact (positively or negatively) yielding a much improved antenna design technique. More importantly, it allows the designer to use this information to modify the antennas and achieve the design goals. The load locations and values were determined using the analysis that CM/NCM provides where the simulated and measured data shows great agreement with the design specifications. The antennas designed here (USB and RFID) are simple and efficient. They also show superior performance compared to others found in the literature. The authors are sincerely grateful for the support that the MTT fellowship award offer which highly assist in making this work more valuable practically through conducting other measurements that led to extra validation to the proposed technique.

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