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# Dockon's CPL™ Technology:
# Microstrip Compound Antennas for Commercial Use

**CONTENTS**



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## Introduction

The purpose of this document is to familiarize the reader with recent developments in the area of electrically small (ELS) compound antenna science. Compound antennas are those in which ***both*** the TM and TE modes are excited in order to achieve performance benefits in higher bandwidth (lower Q), greater radiation intensity/power/gain, and greater efficiency for ELS antennas than previously thought possible.

In the late 1940s, Wheeler and Chu were the first to examine the properties of ELS antennas. Through their work, several numerical formulas were created to describe the limitations of antennas as they decrease in physical size. One of the limitations of ELS antennas which is of importance is that they have large radiation quality factors, Q, in that they store, on time average more energy than they radiate [1,5,3,6,2]. Because ELS antennas have high radiation Q, the smallest resistive loss in the antenna or matching network leads to very low radiation efficiencies typically between 1-50% [4]. Since then, it has generally been accepted by the science world that ELS antennas have narrow bandwidths and poor radiation efficiencies. As a result, much of the modern day achievements in wireless communications systems utilizing ELS antennas has come about from rigorous experimentation and optimization of modulation schemes and on air protocols. The ELS antennas utilized commercially today reflect the narrow bandwidth, low efficiency attributes which Wheeler and Chu first established.

In the early 1990s, Dale M. Grimes and Craig A. Grimes claimed to have mathematically found certain combinations of TM and TE modes operating together in ELS antennas that exceed the low radiation Q limit established by Wheeler and Chu's theory [8]. These claims sparked much debate and led to the term "compound field antenna" in which ***both*** TM and TE modes are excited opposed to a "simple field antenna" where either the TM or TE mode is excited alone [8]. The benefits of compound field ELS antennas have been mathematically proven by several well respected RF experts including a group hired by the U.S. Naval Air Warfare Center Weapons Division in which they concluded evidence of radiation Q lower than the Wheeler-Chu limit, increased radiation intensity, directivity (gain), radiated power, and radiated efficiency [9].

ELS compound field antennas have proven to be complex and difficult to physically implement, due to the unwanted effects of element coupling and related difficulty in designing a low loss passive network to combine the electric and magnetic radiators. A commercially available, reliable design for ELS compound field antennas has not existed until now. Dockon's CPL™ technology offers a solution to the commercial market for reliable, cost effective, electrically small or large compound field antennas.

## History and Theory

The basis for the increased performance of ELS compound field antennas in bandwidth, efficiency, gain, and radiation intensity derive from the effects of energy stored in the near field of an antenna. In RF antenna design, it is desirable to transfer as much of the energy presented to the antenna into radiated power as possible. The energy stored in the antenna's near field has

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historically been referred to as reactive power and serves to limit the amount of power that can be radiated. When discussing complex power, there exists a real and imaginary (often referred to as 'reactive') portion. Real power leaves the source and never returns whereas the imaginary power oscillates about a fixed position (within a half wavelength) of the source and interacts with the source affecting the antenna's operation. The presence of real power from multiple sources is directly additive whereas multiple sources of imaginary power can be additive or subtractive (canceling). The benefit of a compound antenna is that it is driven by both TM (electric dipole) and TE (magnetic dipole) sources which allows engineers to create designs utilizing reactive power cancelation that was previously not available in simple field antennas.

## Complex Poynting Theorem

In developing the background of compound antennas, it is necessary to mention the historical discussion of limitations in the mathematical tools used to generate the majority of the wave solutions used in many design books and software simulators. Much analysis of radiated power fields is based upon the complex Poynting theorem. This theorem is directly derived from the Maxwell's equations and is stated in the form: $\oint \mathbf{N}_c \bullet d\mathbf{S}$. The theorem has generated several key formulas which generations of antenna designers have accepted as RF design tenets. Specifically, the tenet of most importance to the modern world is that electrically small (ELS) efficient antennas cannot be built [11]. This statement is not true and the reasoning lies in the inability of the complex poynting theorem to describe multi-modal antennas such as compound field antennas. Research by C.A. Grimes and D.M. Grimes proves that what most RF design authors refer to as the reactive (or imaginary part of the complex power) power obtained from the complex poynting theorem is actually misrepresented because it is not in time phase quadrature with the real power [11]. The Grimes research further proves that the complex poynting theorem is inadequate for antenna analysis because it disregards a third important number in the analysis of sinusoidal time varying fields. This third number represents vital information about phase angle $\xi$ in multimodal radiation fields (compound fields) and has been discarded by countless RF design authors mostly unbeknownst to them. Without this phase angle information, there is no certainty that the imaginary term in complex power is in time quadrature with real power and so there is no certainty that it is actually the reactive power.

The time dependent Poynting theorem has been mathematically proven and is also derived from the Maxwell's equations stated in the form: $\oint \mathbf{N}(t) \bullet d\mathbf{S}$. Researchers have used Hansen's method to generate all the possible electromagnetic fields that can originate within a specific space and compared the power expressions derived from the two Poynting theorems. The conclusion is that the time dependant Poynting theorem accurately describes all possible electromagnetic fields and is the appropriate tool for antenna analysis.

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## Radiation Q

The theory behind ELS compound antennas involves proof of exceeding mathematical bandwidth limits of ELS antennas related to radiation Q. Q is a value used to describe any oscillating system, from bridges to antennas and is a measure of energy stored in the system versus energy radiated. Most RF engineers use the following definition for $Q = \frac{2\omega W}{P}$ where $W$ is the time average energy stored in the network, and $P$ is power dissipated in the network [19]. The radiation Q of an ELS antenna is of great importance because of its definite assessment of antenna performance. A high Q value means a great amount of reactive energy is stored in the near field which produces unwanted characteristics of high ohmic losses, narrow bandwidth, and large frequency sensitivity [19]. An antenna's component Q is inversely proportional to its bandwidth, and so RF designers prefer the lowest possible Q in many ELS antenna applications in order to achieve greater bandwidth. A fundamental lowest possible Q value for ELS antennas was first established by Wheeler and Chu in the late 1940s which has been widely accepted ever since. Hansen further developed the theory of lowest Q limit for ELS antennas and derived a relationship between physical size and Q in which Q grows rapidly to the third power as radiansphere radius is decreased [2]. However these derivations of lowest Q limit only applies to ELS antennas that excite either the TM or TE modes separately (simple field antennas). New research by several experts including D.M Grimes and C.A. Grimes show that ELS antennas exciting both TM and TE modes (compound field antennas) are capable of Q values lower and bandwidths greater than simple field antennas by a factor of $(ka)^2$ [8] ($k$ is the wave number and $a$ is the radius of the radiansphere). This has profound implications to ELS antenna design.

# Available Practical Designs of Compound Antennas

ELS compound antenna theory offers several important advancements to RF antenna applications: greater bandwidths, higher radiation intensity, higher directivity/gain, greater radiated power, and greater efficiency. Before Dockon's CPL™ technology, there has proven to be a lack of practical implementation in compound antenna theory. ELS compound antennas' benefits rely on the ability to cancel inductive/capacitive reactive power via two radiating elements, an electric (TM) and magnetic (TE) dipole. These two radiating elements are fed by a single source which requires its impedance to be matched to the electric and magnetic dipoles. In order for an ELS compound antenna to be useful, proper input impedance, input current phase and magnitude need to supplied over a wide frequency range. Some matching networks have been proposed, however none of them allow the combined electric and magnetic radiator to operate efficiently over a wide frequency band [4]. Moreover, those that do exist, do not offer commercially viable application typical in areas of cost, manufacturability, size, and reliability.

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# Introducing Dockon's Microstrip CPL™ Technology

Dockon's Compound PxM Loop (CPL™) technology is a commercially viable compound antenna design framework based on microstrip methodologies. Through several supporting patent pending technologies, Dockon's CPL™ designs are able to provide affordable compound antennas with performance characteristics previously thought impossible. The CPL™ technology includes several key components which overcome the previously stated barriers to practical design of compound antennas.

## *Colocated Magnetic Loop, Electric Dipole*

The CPL™ technology includes colocating a series resonant electric dipole to a small magnetic loop. In this orientation, the electric dipole (TM source) is located along the $\hat{z}$ axis and the magnetic loop (TE source) is in the same plane, the yz plane (see Figure1). The research at the U.S. Naval Air Warfare Center concurs this configuration for the electric dipole and magnetic loop [9]. The dipole moments must be orthogonal to each other in order to prevent the two radiating elements from operating as two independent elements.

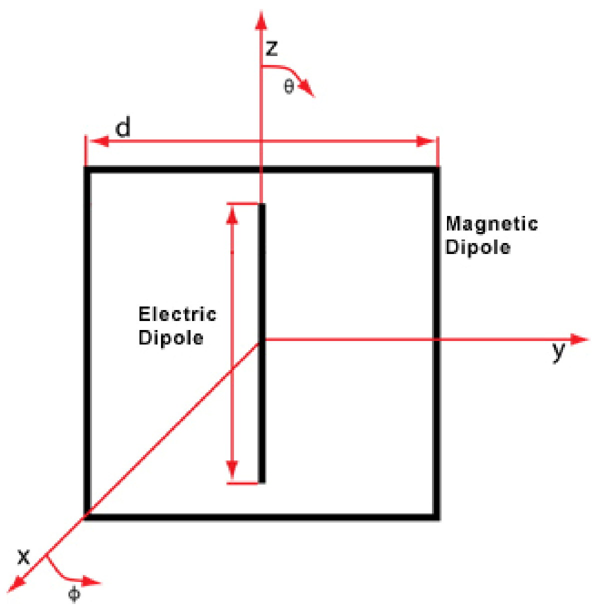


Figure 1: CPL™ design concept with electric dipole along z axis, magnetic loop in yz plane

## *Wide Bandwidth: Dockon's Innovative RF Splitter & Phase Tracker*

It has been proven that if the electric and magnetic radiating elements are driven with in-phase current, they operate independently, an undesirable characteristic [9]. Additionally, for zero reactive power, the magnitude ratio of input current supplied to each element was theoretically proven to be [9]:

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$$A = \frac{|I_L|}{|I_D|} = \sqrt{\frac{R_D}{R_L}} = \frac{L_D}{kS} = \frac{\frac{L_D}{\lambda_0}}{2\pi\left(\frac{d}{\lambda_0}\right)^2}$$

Where:

- $R_D$, $R_L$ is the radiation resistance in the TM electric dipole and TE magnetic loop respectively.
- $L_D$ is the length of the electric dipole
- $\lambda_0$ is the free space wavelength
- $d$ is the length of one side of a theoretically closed square loop.
- S is the loop area ( $d^2$ )
- $k$ is the wave number $= \frac{2\pi}{\lambda_0}$

Satisfying these two contraints over a wide frequency band of operation requires innovation as currently available microstrip techniques would often limit CPL™ antennas' performance. These two constraints have been satisfied within Dockon's patent pending CPL™ technology via two innovations: a low loss, high isolation RF combiner/splitter for multi-element arrays and a phase tracker. The RF combiner/splitter and phase tracker, both passive devices, allow CPL™ antennas to maintain proper current magnitude ratio and phase quadrature over very wide bands of operation from a single power source.

The Dockon phase tracker can be conceptually illustrated as a series of varying inductance and capacitance adjusting with frequency. The phase tracker always maintains proper quadrature between the electric and magnetic radiating elements over very wide frequency ranges.

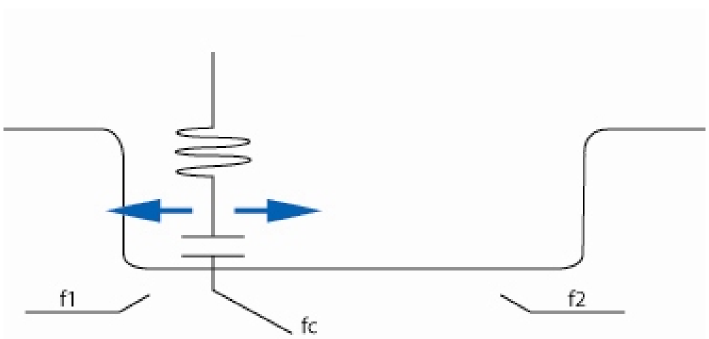


Figure 2: Variable Reactance of ¼ Wave Element Offers Wide Bandwidth Operation

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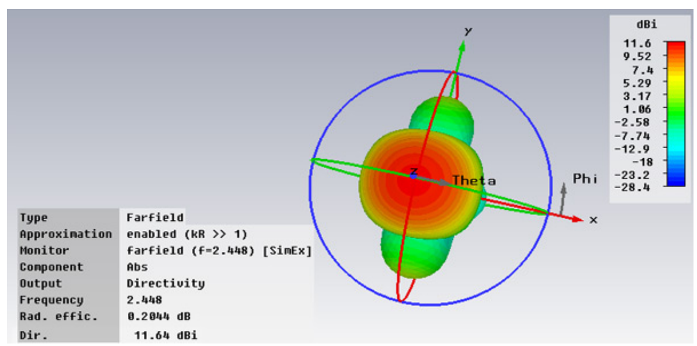
The Dockon RF combiner/splitter incorporates unique isolation on all ports allowing for near perfectly matched CPL™ antenna arrays to be created for use in very wide band operation. This provides unique operational and design characteristics:

- Near perfect impedance matching over very wide bandwidth for multi-element arrays
- Adjustable antenna patterns in wide bandwidth operation for high-coverage (omni) to high-directive (point to point) applications.
- Low-loss properties of the multi-element combiner/splitter increases directivity (gain)
- Dual linear polarization (horizontal and vertical) for overcoming multipath effects
- Wide band, multi-element spatial diversity for providing greater receiver sensitivity

## Custom and Standard CPL™ Antenna Designs

Dockon designs each CPL™ antenna solution specifically to exceed the demands of wireless performance. The CPL™ technology is broadly scalable across multiple frequency ranges in a variety of physical form factors and variations in shape, size, footprint and volume. CPL™ antenna technology is suitable for a variety of applications including: automotive, industrial, medical, mobile, internet/telecom, consumer electronics, aerospace and defense.

Dockon's design team utilizes well-known, highly advanced simulation, prototyping, measuring, and testing tools capable of providing its customers with the most optimized antennas for their applications. Base case reference designs are continuously being developed and published to Dockon's website, www.dockon.com/solutions/, which highlight the performance advantages of CPL™ antenna technology. Custom designs are developed by Dockon's well-experienced engineering staff quickly and efficiently.




Dockon utilizes advanced simulation tools to design and optimize CPL™ antennas

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## Conclusion

The breakthrough of Dockon's CPL™ antenna technology exceeds the demands for wireless antennas to be smaller, more powerful, wideband, and highly efficient. CPL™ antenna technology is based upon microstrip design techniques and represents the world's first commercial solution to over 20 years of academic research on compound antennas. This will allow Dockon's customers to greatly increase their differentiation advantage in the industry and simplify design processes. Unique features of CPL™ antennas include:

- Highly efficient – Compound fields
- Very wide bandwidth (low radiation Q) – Single elements and arrays
- Reactive power cancellation – Excites both electric (TM) and magnetic (TE) radiators
- Small size – 2D microstrip compound antenna
- Improved directivity for ELS designs – Backed by over 20 years academic research
- Available on many substrate materials including FR-4

Coupled with CPL™ antennas, new possibilities are available for efficient, resilient wireless communications. With greater RF antenna efficiency, transmitters are able to lower their power output saving valuable battery life. RF conversations between wireless devices will be more stable, reliable, and produce less RF pollution from re-transmit requests and increased noise from over-powered transmitters. In a world with increasing dependency and capacity requirements on wireless data delivery systems, it becomes crucial to optimize additional elements in these systems. CPL™ antennas will surely be an integral component of future RF design.

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## About Dockon

Dockon, Inc. is a wireless antenna company based in Reno, Nevada and the San Francisco Bay Area. After more than three years of research and development by former NASA Jet Propulsion Laboratory scientists, the CPL™ design methodology was invented allowing Dockon to offer the first commercially viable microstrip compound field antenna. The patent pending CPL technology allows Dockon to create customized antennas for our partners and customers that are smaller, produce more gain and efficiency, greater bandwidth, and easier manufacturability than any other antenna available on the market today. Our business model is to be a technology provider and development partner to firms that require sophisticated, customized antenna solutions for wireless devices and applications.

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