Design of a Planar Omnidirectional Antenna for Wireless Applications

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Abstract—Omnidirectional antennas are of great utility for many 802.11b,g,a applications. Often conventional designs do not offer high enough gain (efficiency) at microwave frequencies to satisfy system designers. This paper reviews conventional designs and presents a novel microstrip antenna design which achieves performance superior to conventional solutions at microwave frequencies.

Omni-Directional Antennas
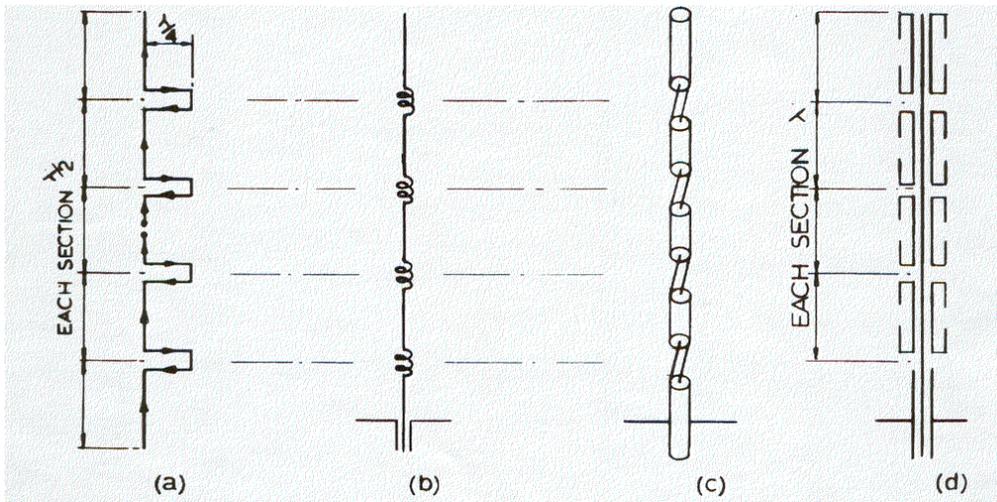
Figure 1–1 Common approaches to the design an omnidirectional antenna[1]

Growing interest in 802.11b, 802.11g and 802.11a applications has precipitated the need for omnidirectional antennas at 2.4-2.5 GHz and 5.15-5.35 GHz. Figure 1–1 illustrates a number of approaches researchers have taken in the past. These designs are called collinear dipole arrays.

The first antenna design (a) is known as a Franklin array. It uses small U-shaped sections of wire to provide a phase shift to maintain in-phase current along vertical sections of wire.

The opposing currents on each of the phase shifting sections minimizes radiation. In (b) meanderline phase reversal is used to create in-phase currents along the vertical radiating sections. The method illustrated in (c) uses half-wavelength sections of coaxial transmission line which have their inner and outer conductor connections reversed at each junction. This reversal causes the current on the outer conductor of each segment to be in phase and radiate an omnidirectional pattern. This type of antenna is often called a COCO antenna for coaxial collinear antenna. The geometry of (d) is an alternative form of (c).

Moment Method Radiation Pattern Calculation for $1.74\lambda_0$ Length
5 Element COCO Antenna 256 Pulses 2.45 GHz Directivity = 5.62 dB
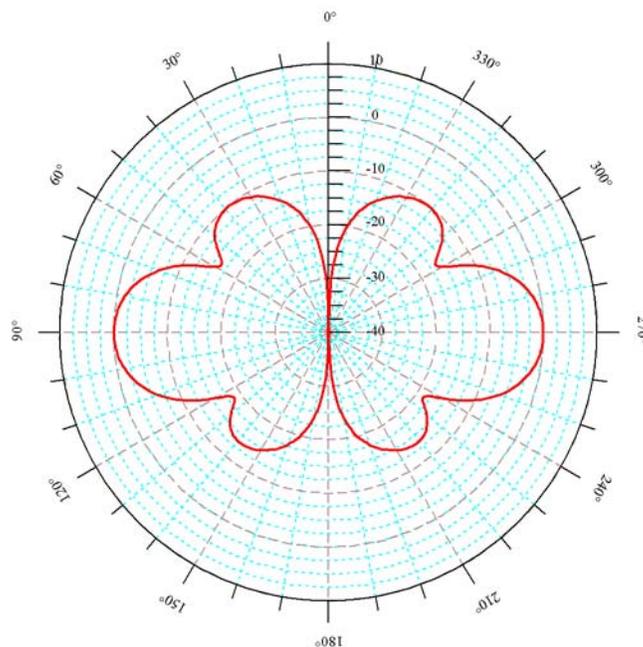
Figure 1–2 Radiation pattern of a 5 element COCO antenna computed with the Method of Moments (normalized).

The Franklin antenna design of 1–1 (a) did not fit the required volume constraint and would be difficult to implement. The use of meanderline sections to produce required phase shifts as done in (b) is very frequency dependent and it has proven difficult to add enough sections to provide the required effective aperture, maintain the desired phase relationships, and produce an antenna which exceeds the required gain target of ≥ 5.0 dBi over the required bandwidth.

The most promising approach would appear to be: (c). A successful candidate antenna is fed from one end, which can be done in the case of a COCO antenna. Judasz and Balsley developed a COCO antenna that is fed from one end and they analyzed it using the Method

Moment Method Radiation Pattern Calculation for $1.74 \overline{\lambda}_0$ Length 5 Element COCO Antenna 256 Pulses 2.45 GHz Directivity = 5.62 dB

30 degrees

Approximated Directivity (30 degree BW) = 5.5 dB
MM Directivity = 5.62 dB

Normalized Power (dB)
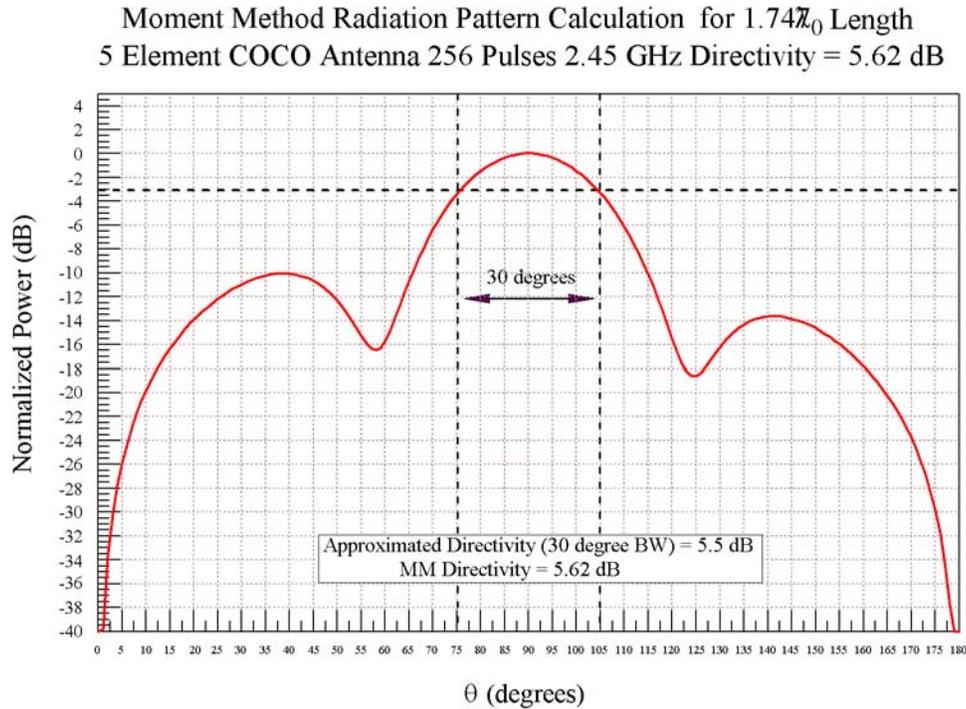
θ (degrees)

Figure 1–3 Rectangular plot of Figure 1–2. The pattern directivity is 5.62 dBi computed with pattern integration and the approximate directivity of a 30 degree beamwidth is 5.5 dB.

of Moments (MoM).[2] Their MoM analysis was implemented and it was determined that a 5 element COCO antenna would have a directivity of 5.62 dB (Figure 1–2) using pattern integration. This directivity would allow for 0.5 dB loss in the design and still achieve the desired ≥ 5.0 dBi gain target. As a check, a graph computed by Pozar which relates the directivity of an omnidirectional pattern (without sidelobes) to its 3 dB beamwidth was used to estimate the COCO directivity from the computed pattern.[3] The pattern directivity obtained is approximately 5.5 dB.

The predicted pattern as presented in Figure 1–2 is plotted on a rectangular graph in Figure 1–3. The half power beamwidth is 30 degrees.

The COCO antenna does not have a $50\,\Omega$ driving point impedance and requires a quarter wave matching section. This adds to the complexity of the design and decreases manufacturability.

A COCO antenna was fabricated, matched and measured. A typical result for the radiation pattern of a 2.45 GHz COCO antenna is found in Figure 1–4. The gain of the antenna was lower than expected at 2.9 dBi. The average 3 dB beamwidth is 31 degrees which
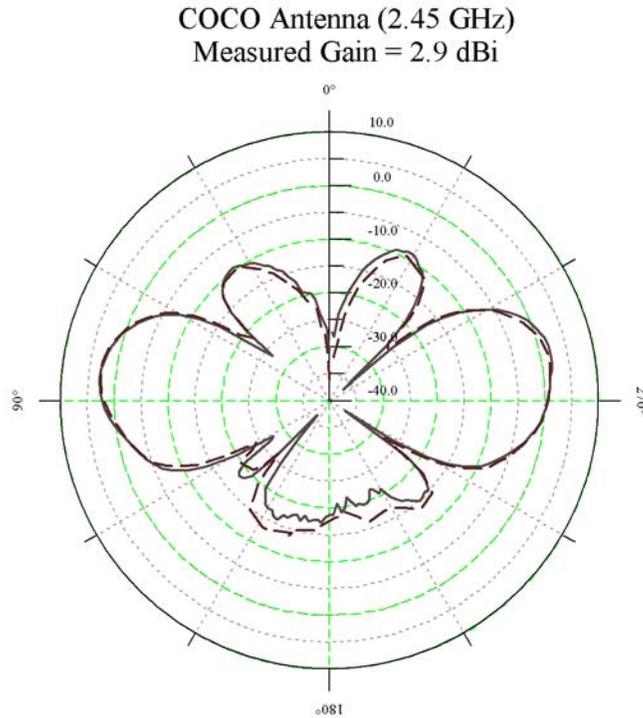
Figure 1–4 Measured $\phi = 0°, 90°$ radiation patterns of 5 section COCO antenna at 2.45 GHz. The maximum gain is 2.9 dBi with a 31° average 3 dB beamwidth

is close to the beamwidth (35°) expected for a directivity of at least 5.0 dBi. The moment method predicted 5.62 dBi if the COCO antenna has an efficiency of 100%. The antenna was losing at least 2.72 dB because of its efficiency. COCO prototypes were made from very low loss coaxial transmission lines of different diameters. The unacceptable efficiency losses were not from the matching network and were only weakly affected (≈ 0.5 dB) by using the lowest loss coaxial cable obtainable. When a COCO antenna is used at low frequencies it has a high efficiency, but when used in microwave applications its efficiency degrades. The origin of these losses is not understood. This inability to meet gain requirements caused us to reject the COCO as a practical omnidirectional design in the microwave region. Thus all of the designs presented in Figure 1–1 were rejected as candidates for an omnidirectional antenna solution.

Omnidirectional Planar Microstrip Antenna (OMA)

The ideal antenna solution would have several properties: 1) $50\,\Omega$ driving point impedance (i.e. no balun or matching transformer) 2) 5.0 dBi or greater gain over the desired bandwidth. 3) Be compact, low cost and readily manufacturable.

Planar microstrip antennas are generally low cost. A geometry for a planar microstrip omnidirectional antenna introduced by Bancroft and Bateman is presented in Figure 1–5.[4] [5]
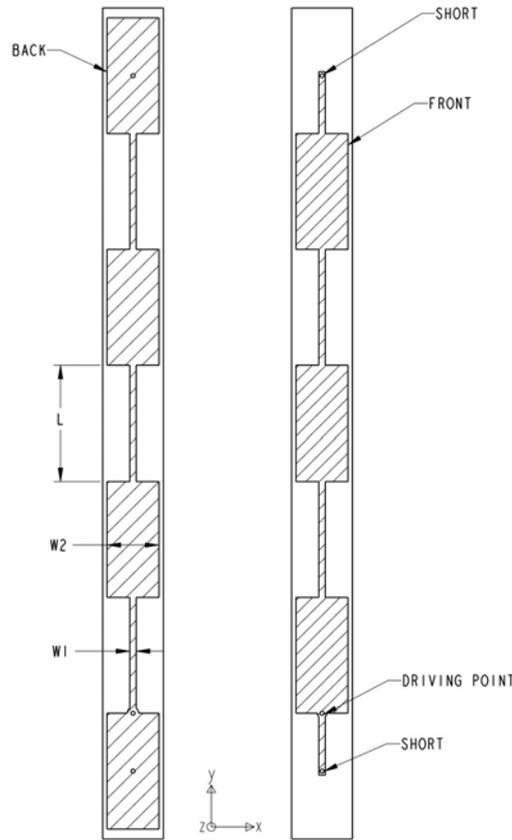
Figure 1–5 Geometry of an omnidirectional microstrip antenna (OMA).

The idea in a nutshell is to create alternating sets of $50\,\Omega$ microstrip transmission lines. Each section is one-half wavelength long at the frequency of operation. Each groundplane section was initially set to be about 5 times the conductor width of the microstrip transmission line and later optimized for driving point impedance. An electrical short is placed on either end of the antenna in the center of a section. The shorts are one-quarter wavelength from a dividing section. When a wave travels from the driving point to the short it has a phase shift of 90 degrees. The short then shifts the phase of the current by an additional 180 degrees. The reflected wave has another 90 degree phase shift when it arrives at the driving point (for a total of 360 degrees) and matches the phase at the driving point of the outgoing wave.

A more in-depth explanation of the theory behind this planar antenna is illustrated in Figure 1–6. The top figure is a side view of a microstrip transmission line. The electric field shown is for an electromagnetic wave travelling to the right. A snapshot is taken just as the
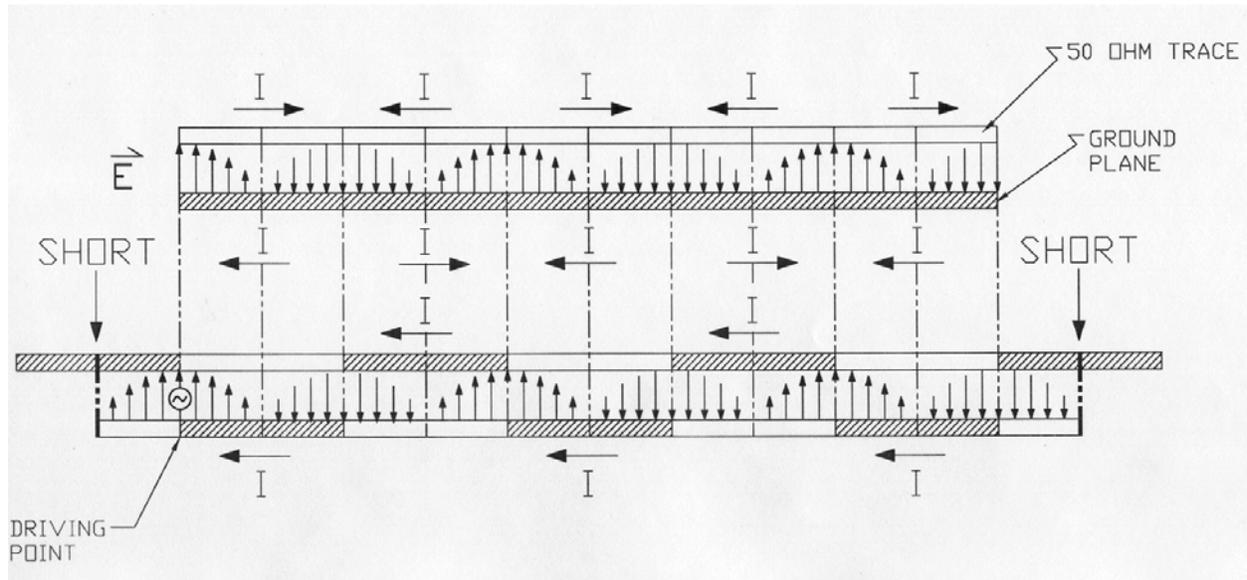
Figure 1–6 The upper figure is of the electric fields and currents on a microstrip transmission line (viewed from the side). The lower figure is the transmission line with half-wavelength inverted sections which produce in phase currents on the groundplane sections of the antenna. A pair of shorts are placed at electric field minimums at each end to form a closed resonator.

wave reaches the open end of the transmission line. We note the current maxima occur at the electric field minima and are reversed every half-cycle.

The bottom figure of Figure 1–6 shows the microstrip transmission line as if it were cut into half-wave sections, each section flipped with respect to one another and connected back together. Only the currents on the wide sections (microstrip T-line groundplanes) are shown, which are all in phase with one another.

The field structure at each microstrip section reversal interface doesn't match the dominant quasi-TEM mode of a microstrip line and so a discontinuity is encountered. The electric field is maximized at each discontinuity which encourages radiation. A pair of shorts one-quarter wavelength from each end allows the desired field configuration to exist as a resonant structure.

In the limit as the radiating elements (groundplane widths) are decreased, they approach the microstrip conductor width, the antenna then becomes a non-radiating twin lead transmission line. This provides a way to modify the driving point impedance by changing the width of each radiating element. This was done to match the antenna to a $50\,\Omega$ driving point impedance.

The lower illustration of Figure 1–6 shows a short at each end, placed $\lambda/4$ from the open
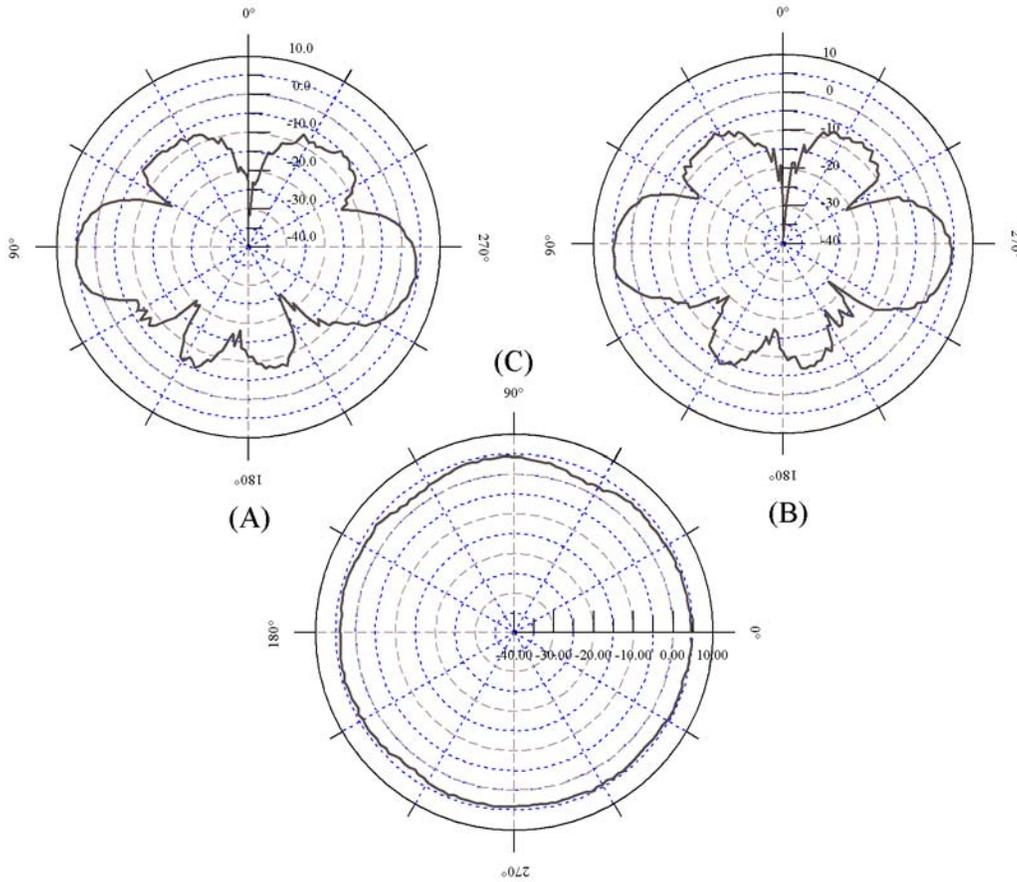
Figure 1–7 Measured radiation patterns of a seven section Omnidirectional Microstrip Antenna A) y–z plane, B) x–z plane, C) x–y plane

ends of the upper illustration, but the antenna as conceived in Figure 1–5 continues to have an extra wide half-section without a second conductor. This extra section helps to shield the antenna from the attached coax at the driving point. The second open section at the top maintains the symmetry of the antenna. The outer conductor of a coaxial transmission line is soldered above the short and terminates at a relief which has a hole for the center conductor. The center conductor protrudes through and connects to the upper trace to feed the antenna at the plane of the first transmission line flip from the bottom.

The currents on the two terminating quarter wave sections remain in phase with the half wave sections.

The 2:1 VSWR impedance bandwidth of the OMA element is 19.0% which is very good for an omnidirectional antenna. The pattern bandwidth is narrower at around 5–6%.

The radiation patterns of an OMA for 802.11b (2.45 GHz) are shown in Figure 1–7. The measured maximum gain is 5.61 dBi. The antenna is seen to be very efficient. The maximum directivity computed using FDTD is 6.03 dB.

Conclusion:

Conventional omnidirectional designs are not well suited to operation at microwave frequencies which include the 802.11b,a,g bands. This is due to their geometry or lack of performance. A microstrip omnidirectional antenna has been developed which is compatible with 802.11 applications and cost effective.

References:

[1] Johnson, Richard and Jasik, Henry (ed.),"Antenna Engineering Handbook," Second Edition *McGraw Hill*, 1984, pp. 27-14

[2] Judasz, Thierry, J. and Balsley, Ben, B., "Improved Theoretical and Experimental Models for the Coaxial Colinear Antenna," *IEEE Transactions on Antennas and Propagation*, VOL. 37 NO. 3 March 1989, pp. 289-296

[3] Pozar, D., "Directivity of Omnidirectional Antennas," *IEEE Antennas and Propagation Magazine (Antenna Designer's Notebook)*, Hal Shrank ed. VOL. 35 NO. 5 October 1993, pp. 50-51

[4] US Patent Pending, US Patent Application Serial Number 60/461,689

[5] Bancroft, R., and Bateman, B.,"An Omnidirectional Planar Microstrip Antenna," Submitted for publication on April 30, 2003 to *IEEE Transactions on Antennas and Propagation*