TRIPLE BAND GPS TRAP LOADED INVERTED L ANTENNA ARRAY

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Abstract --- Modernization of the GPS system that is currently underway will require future GPS antennas to operate at three separate frequency bands centered around 1176 MHz (L_5 band), 1227 MHz (L_2 band), and 1575 MHz (L_1 band). A compact, low profile, Right Hand Circularly Polarized (RHCP), four-element antenna array of trap loaded inverted L elements capable of providing good gain coverage at all three frequency bands over the required bandwidth is described in this paper.

Key Words: GPS, Triple Band Antenna, Inverted L Antenna Array, Trap Loading, Circularly Polarized Antenna

1 INTRODUCTION

As part of the modernization effort of the Global Positioning System (GPS), a new GPS frequency designated as L_5 and located at 1176.45 MHz with a 20 MHz bandwidth will be available for civilian users of GPS [1,2]. A "Safety of Life" navigation signal at the L_5 frequency will enable precision approach navigation on a world-wide basis and provide mitigation against interference. GPS Block IIF satellites scheduled for launch at the beginning of 2005 will carry this new signal. The L_5 signal will be in addition to the existing GPS signals—at L_1 located at 1575.42 MHz and at L_2 located at 1227.60 MHz—that are currently used by both civilian and military users. The signals at L_1 and L_2 have a 20 MHz bandwidth with a proposed extension to 24 MHz to cover the new military signal, M-code, that will also be inserted into GPS Block III F satellites [3].

This paper describes a four-element, "trap loaded" inverted L antenna array that covers all three GPS frequency bands for the modernized GPS system. Inverted L antennas are compact, low profile transmission line types of antennas that have been used in various forms for missiles [4], and vehicular communication systems [5]. Trap loading has previously been used by amateur radio operators for increasing the bandwidth of monopole and dipole antennas operating in the HF and VHF bands [6] and more recently in a dual frequency GPS quadrafilar helix antenna developed at the MITRE Corporation [7]. A trap loaded Planar Inverted F Antenna (PIFA), a variant of the inverted L antenna, has also recently been designed for operation at 900 MHz (cellular systems) and 1800 MHz (personal communications systems) [8,9].

2 ANTENNA DESIGN

Figure 1 shows a picture of the right hand circularly polarized, four-element, trap loaded inverted L antenna array that was designed to operate at the three frequency bands of the modernized GPS system. The antenna is about 4.7" square with a height of 0.87". A Rohacell foam layer (dielectric constant of 1.07) was used for supporting the four inverted L elements of this array as shown in the picture.

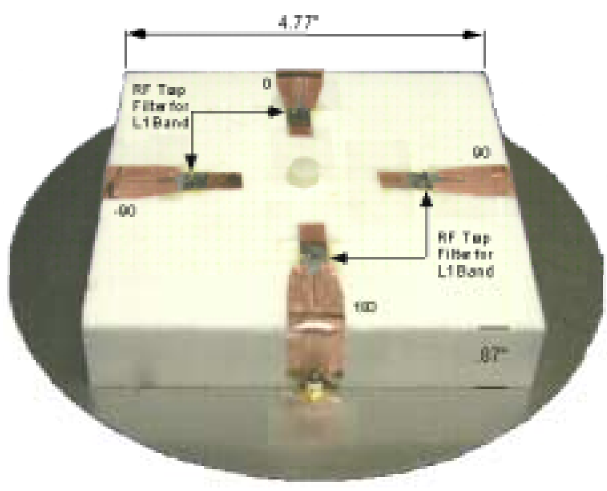

Figure 1: GPS Triple Frequency Trap Loaded, Inverted L Antenna Array

A single inverted L antenna typically has an elliptically polarized far field pattern, with both vertical and horizontal polarization components provided by the short vertical element and the much longer horizontal element. To achieve Right Hand Circular Polarization (RHCP) over a large portion of the upper hemisphere, as needed for receiving signals from the various GPS satellites, the four inverted L antenna elements of this array are arranged around a square at 90° intervals as shown in Figure 1 and excited with the equal amplitudes but with a relative phase difference of 0°, -90°, -180°, and -270° (or +90°). This type of phase distribution between the array elements was obtained by means of a compact microstrip feed network consisting of a 180° "rat race" hybrid, the two outputs of which were each connected to compact, surface mounted 90° hybrids. This type of feed excitation provides good RHCP gain for the inverted L antenna array over much of the upper hemisphere allowing it to acquire GPS satellites at elevation angles as low as 10°. Acquisition of the low elevation GPS satellites allows for a lower RMS position error in range. The input impedance of the inverted L antenna can be brought to resonance by adjusting the horizontal length "l" and the vertical height "h", such that $h + l \approx \lambda /4$, where λ is the wavelength [4,5]. The antenna array can be made to resonate in the L_1 GPS frequency band by placing an RF trap tuned to 1.5754 GHz at an appropriate position along the horizontal arm of each of the four inverted L elements of the array. The trap load presents a very high impedance in the L_1 band at the point in the antenna where the filter is placed. The trap filter used in the antenna consisted of a 2.2 picofarad capacitor in parallel with a 2.8 nanohenry, high "Q" inductor. These values for the filter inductance and capacitance were selected through experimental measurements of VSWR to bring the antenna into resonance as close as possible to 1.5754 GHz, the center frequency of the L_1 band, as shown in Figure 2. The 2.2 picofarad capacitor combined with the additional the gap capacitance between the two segments of the antenna line where the trap filter is placed result in a total capacitance of 3.6 picofarads. This is the capacitance value calculated from using the formula to achieve parallel resonance at the design frequency of 1.5754 GHz.

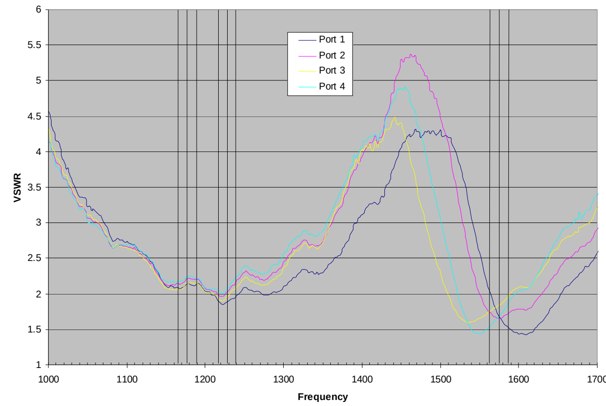

Figure 2: Measured VSWR of Triple Frequency GPS Trap Loaded Inverted L Antenna Array

The antenna at this juncture can be treated as a section of a microstrip line for the purpose of this evaluation [10]. The gap in the microstrip line can be represented as a series capacitance between two parallel capacitances. The trap filter also acts as an inductive load at the L_2 and L_5 bands for the remaining length of the antenna since these frequencies are below the resonant frequency of the trap filter. The inductive loading shortens the length of antenna that is needed beyond the filter to achieve resonance in these two lower frequency bands. To compensate for the inductive loading introduced by the trap filter, the length of the antenna arm beyond the trap load filter is adjusted through VSWR measurements to bring the antenna into resonance in the L_2 and L_5 frequency bands. Our investigations indicate that an additional trap load for the L_2 frequency is not needed since the resonance provided by the antenna arm extension beyond the L_1 trap filter was broad enough to cover both the L_2 and L_5 bands. Since the inductor in the trap load filter has a finite Q, the small resistance associated with the inductor broadens the resonance enough to achieve near resonance conditions in both the L_2 and the L_5 bands. The performance of this antenna was independently verified through a Method of Moment analysis using the NEC electromagnetic code.

3 EXPERIMENTAL RESULTS

Figure 2 shows the measured Voltage Standing Wave Ratio (VSWR) for this antenna array. Notice the second dip in the VSWR curve centered around 1.575 GHz. This is caused by the presence of the L_1 trap filter. The first dip in the VSWR curve is broad enough to provide a VSWR of slightly greater than 2:1 in both the L_5 and L_2 frequency bands. Figures 3a, 3b, and 3c show the measured input resistance and reactance in the three GPS frequency bands of interest. Notice that the reactance is low and the input resistance is between 30 and 40 ohms across all three bands obviating the need for a broadband matching network. Figures 4a, 4b and 4c show the measured RHCP (Right Hand Circular Polarization) and LHCP (Left Hand Circular Polarization) far-field radiation patterns. These are shown in red and blue respectively. These radiation patterns were measured with the antenna mounted at the center of a 51" diameter rolled edge ground plane. The patterns were measured in a near-field antenna range using a spherical scanning technique. This antenna has a good RHCP axial ratio at elevation angles above 30°. The gain does not fall off rapidly as the elevation angle decreases as in most GPS microstrip patch type antennas. The objective "Percentage Gain Coverage (P_G)" requirement for GPS antennas is that it provide a gain of better than -3.5 dBic over 95% of the solid angle coverage in the upper hemisphere between elevation angles of 90° and 10°. The measured percentage gain coverage P_G for the antenna described in this paper is 96% in the L_5 band, 97% in the L_2 band, and around 80% in the L_1 band. The lower RHCP gain in the L_1 band is caused by the frequency dispersion in the VSWR response of the four elements of the array. This can be seen from the results shown in Figure 2. P_G in the L_1 band can be improved to meet the specified gain coverage by designing the antenna with better mechanical tolerances and by re-tuning of the trap filter and its location in the four inverted L array elements. These measures should bring the four antenna elements into relative phase synchronism to achieve a better RHCP antenna gain across the L_1 band.

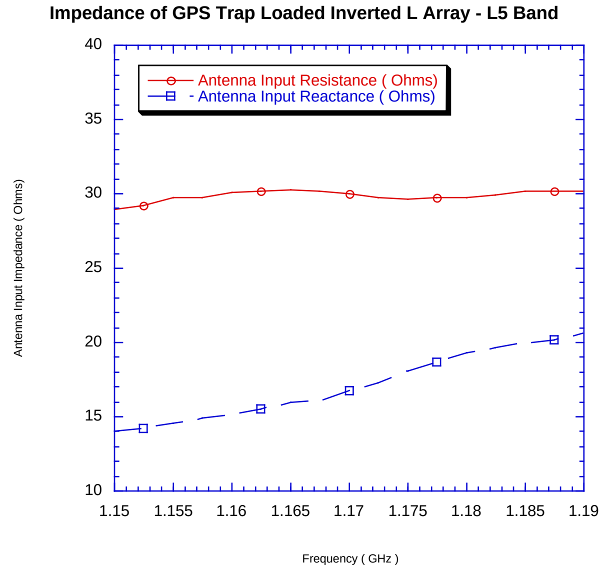

Figure 3a: Measured Input Impedance in the L_5 Band

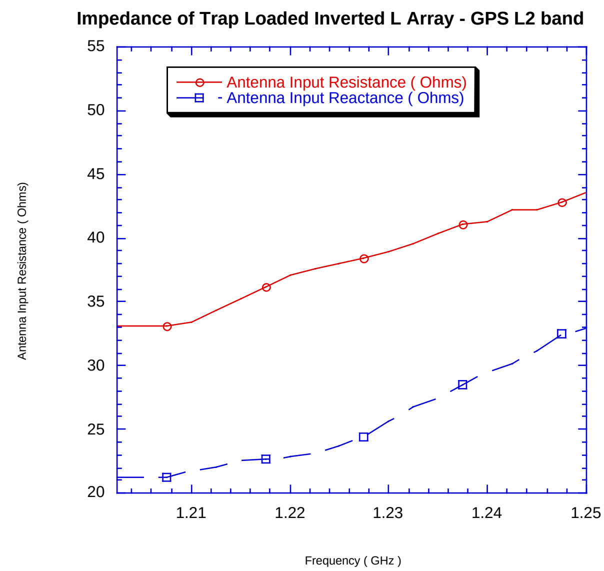

Figure 3b: Measured Input Impedance in the L_2 Band

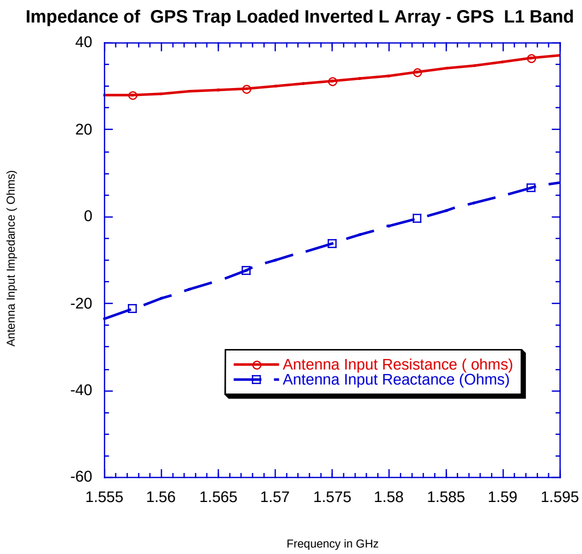

Figure 3c: Measured Input Impedance in the L_1 Band

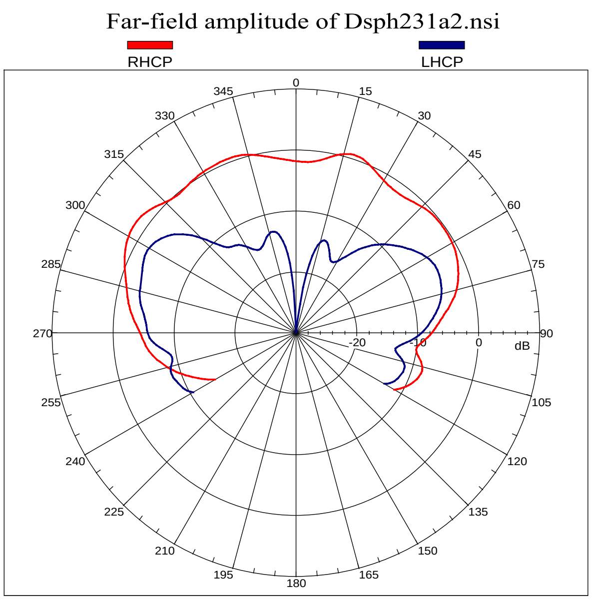

Figure 4a: Measured Antenna Pattern at 1176 MHz (Center Frequency of the L_5 Band)

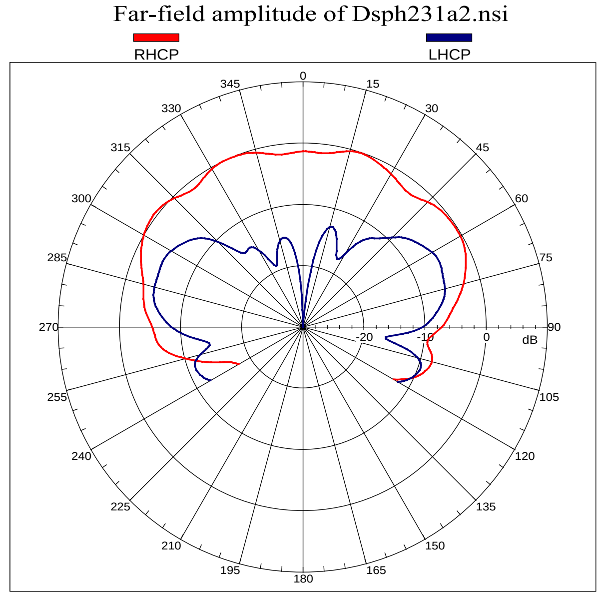

Figure 4b: Measured Antenna Pattern at 1227 MHz (Center Frequency of the L_2 Band)

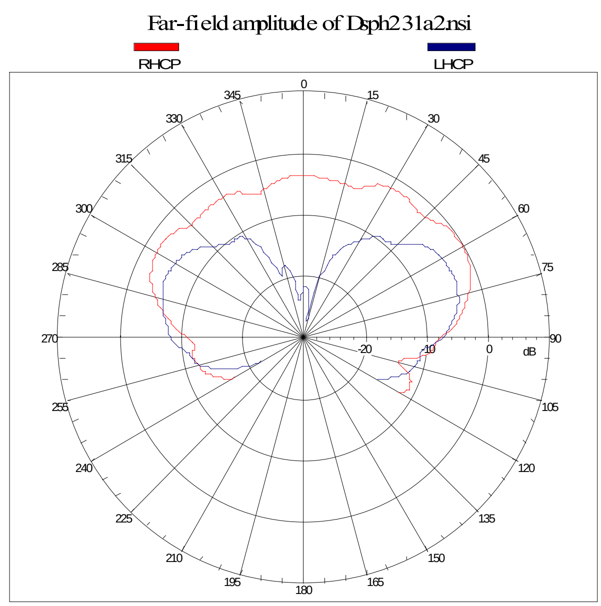

Figure 4c: Measured Antenna Pattern at 1575 MHz (Center Frequency of the L_1 Band)

CONCLUSION

As part of the modernization of the Global Positioning System, a third frequency, L_5 centered at 1176 MHz with a 20 MHz bandwidth, will soon be introduced. A signal at L_5 will be added to those in the existing two frequency bands, L_1 and L_2 centered at 1575 and 1227 MHz respectively, each with a 20 MHz bandwidth. The signal bandwidth in these last two frequency bands will be expanded to 24 MHz with the introduction of the new military M code signal that is also part of the GPS modernization effort. A four-element, right hand circularly polarized, trap loaded inverted L antenna array that provides good gain coverage at all three frequency bands is described in this paper. The antenna is easy to build and is excited by a microstrip 180° hybrid used in conjunction with two 90° hybrids to provide the required phase shift between the four array elements to generate right hand circular polarization. The array has a broad antenna pattern with a RHCP gain of better than --3.5 dBic over a major portion of the upper hemisphere down to an elevation angle of 10°. It therefore provides visibility to GPS satellites even at low elevation angles ensuring good position accuracy.

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