Mechatronics Engineering Aspects of VHF band Antenna Design of Industry 4.0 Applications

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Abstract

The message of this research is to demonstrate the power of mechatronics engineering synergy using a basic antenna design as a case study for radar systems researchers.
The paper focuses on space & commercial aircraft' Very High Frequency (VHF) communication 'Dipole-Fed Corner Reflector' (DFCRA) antenna design while it collects relevant articles describing recent modern perspectives in antenna design for metric-wave Cyber-Physical System (CPS) applications. Areas of interest include but are not limited to mechatronics engineering synergy of antenna design techniques optimization such as weight reduction, size optimization, and phased array characteristics.

Introduction

Relation between the Antenna design and Mechatronics

This paper outlines antenna design requirements, advantages, and key performance metrics in case of a comprehensive mechatronics design and not a standard mechanical construction or electrical engineering design. The antennas and structures employed in WIFI, WLAN communications, radar, and other CPS sensing systems are having smart framework usually. The VHF Omni Range (VOR) system and the Instrument Landing System Localizer use 108-118 MHz air navigation beacons. VOR employs VHF radio waves (108-117.95MHz) with 50 kHz channel spacing, while ATC uses 118–137MHz and emergency uses 121.5MHz, VHF Antenna Systems fulfil requirements of Air Traffic Organizations. The DFCRA antenna is used to navigate destinations, and targets, and communicate with aircraft in ATC's region.

Methods and Materials

Traditional antenna design radiation pattern such as gain, half power beamwidth, and low sidelobes will be extended with mechatronics engineering parameters such as wind resistance and expensive material use. In this example, mechanical and material requirements confront well-known antenna features. Gain shows an antenna's directivity. A high-gain antenna radiates most of its power in one direction, while a low-gain antenna spreads it out. A high-gain antenna has better signal quality, but it must be carefully created, maintained, and installed to work with other antennas. Standardized CPS antennas are the key requirement and such the antenna impedance match to the transmitter or receiver is the most significant standard criterion. Matching the antenna's input impedance to 50 Ω ensures maximum power transfer from the RF circuitry to the antenna with little reflection. The reflected energy creates the Standing Wave Voltage Ratio (SWVR). A perfect match in case of $z_L -$ load impedance; $z_0 -$ output impedance is obtained when $z_L = z_0$ in $r = \frac{Z_L - Z_0}{Z_L + Z_0}$

Dipole-Fed Corner Reflector Antenna is a basic structure of directional antenna that use at VHF and UHF frequencies popularly.

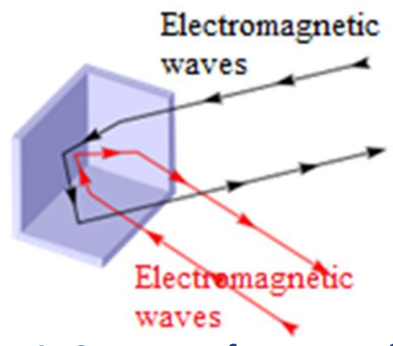

Figure 1. Concept of corner reflector

Technical requirements:

- 127.5 MHz centre frequency and a dipole-fed centre point between the two arms.
- A dipole must be fed by a balun if it's fed by a coaxial or other unbalanced transmission line.
- Iimpedance to 50 Ω.
- Reflections don't accumulate in phase like a parabolic reflector, but dimensions are chosen to maximum gain. Less optimum than a parabolic reflector, but easier to build.
- Figure 2 shows top, end, and side antenna sketches. Adding a reflecting corner to a dipole makes it directional. This antenna's radiating element is usually a dipole or folded dipole. Reflector length: 707.0 mm, width: 1.587m, angle: 158.2°; Dipole length: 1.093m, diameter: 23.51mm.

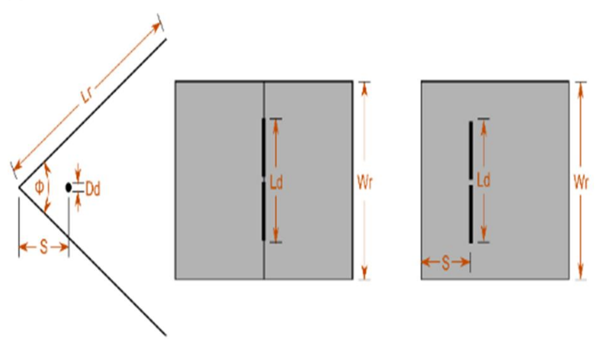

Figure 2. Sketches of the designed antenna

Findings

The radiation pattern follows theory, with a single main lobe and similar E- and H-plane beamwidths. The antenna's bandwidth has negligible gain change. The usual radiation pattern and main beam gain vs. frequency is depicted for a 13 dB corner reflector. Table 1 describes total gain & Figure 3 displays an example.

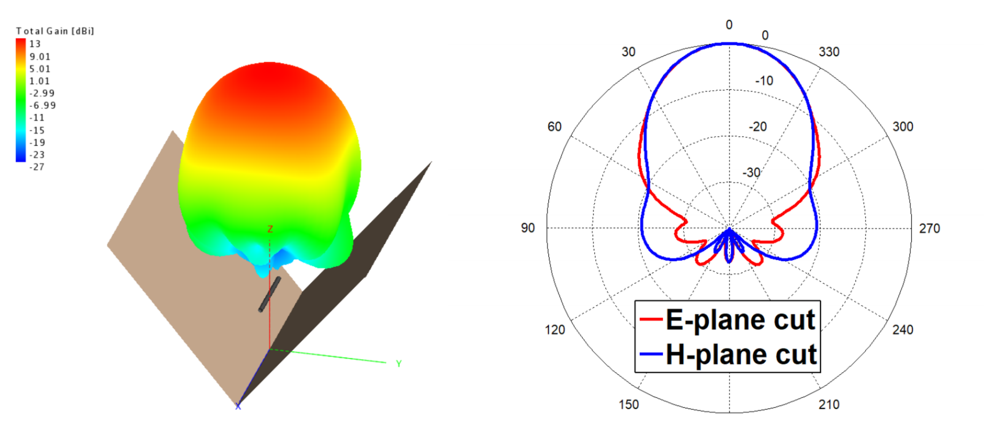

Figure 3. Total gain and radiation pattern

Table 1. Typical CRA Characteristics

Typical Characteristics					
Band width	Gain	Size	Impedance	Radiation	Polarization
<10%	>8 dBi	$\geq \lambda$	40Ω-100Ω	Directional	Linear (elliptical)

Higher bandwidth can be achieved with thicker biconical or cylindrical feed dipoles. The main disadvantage of the basic DFCRA design is that the reflector must be repositioned to avoid blocking the feed point. Table 2 highlights the major properties of Figure 3s' single and 2-element phased arrays. Table 3 shows DFCRA's radiation performance with 1, 2, 3, 5, and 7 elements.

Table 2. Summary of The Main DFCRA Characteristics

Antenna		Single Reflector-Exciter-Dipole			Linear Phased Array- 2 Element-Reflector			
Frequency	Element Spacing (m)	Length (m)	Width (m)	Tilt (deg)	Ground Plane Length (m)	Ground Plane Width (m)	Spacing (m)	Corner Angle (deg)
127.5 MHz	1.422	1.035	0.03456	90°	1.3806	2.7609	0.518	90°

Table 3. General Overview of calculated DFCRA Performances

Reflector [Aluminum]	Gain	Beamwidth	Sidelobe
Single element	6.97 dBi	80°	-19.7 dB
2 elements	10.2 dBi	50°	-17.2 dB
3 elements	12.7 dBi	20°	-11.9 dB
5 elements	14.2 dBi	20°	-12.1 dB
7 elements	15.7 dBi	10°	-11.8 dB

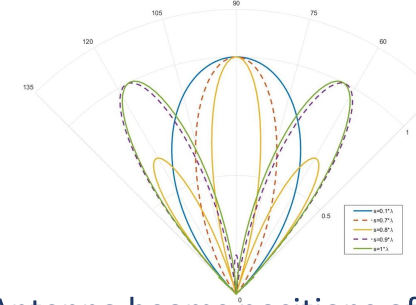

Figure 4. Antenna beams positions of DFCRA array

This antenna characteristics can be extended for complex mechatronics antenna design solution. It is important for saving material and reduce surface against strong wind. The idea is that use net as reflector type surface and compared it against solid reflector surface structure behavior. The size of the net as the single reflector is chosen for 10x10, 20x20, 30x30, 50x50 and 70x70 cm. Degradation of the antenna electrical parameters were analyzed with these net sizes and the results indicate that the DFCRA with an aluminum net size of 20x20 cm is optimum for mechatronics performance and gives synergy among dedicated requirements. The gain of the antenna is reduced from 10.2 dBi to 7.55 dBi while the beamwidth is 50° to ≈43° and the sidelobe levels are varies from -17.2 dB to 0.00228 dB. The wind load is 7.44 N at 50 km/h and this is reduced to 2.68 N at 30 km/h. Consequently, the mechatronic engineering design approach of the DFCRA array allows reduction of weight, antenna air resistance force, while the performance degradation is neglectable.

Discussion

The Industry 4.0 platform gives a more comprehensive picture of today's production process, mass customization, innovation ecosystems, better manufacturing speeds, increased quality, lower mistake rates, optimal efficiencies, and improved customer closeness. Antennas are needed for communication and sensing systems. This VHF antenna meets IoT and Cyber-Physical System specifications for mechatronics engineering.

Conclusions

It blends mechatronics with VHF antenna design for Industry 4.0. DFCRAs are used to communicate between ATC and aircraft and are a great example of optimized mechatronics engineering. The simulated antenna design approach is useful and can be applied to antenna maintenance demands too. VHF DFCRA design concepts should have advanced mechatronics engineering needs.

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