# A Compact Airborne Co-Aperture Cavity-backed Spiral Antenna Design

Chu Pi*[1]
Leihua Electronic Technology Institute, AVIC, Wuxi, China

## ABSTRACT

This paper describes a design of novel wideband co-aperture cavity-backed spiral antenna for airborne passive direction finding (DF) applications. Due to the restricted installation locations and rigorous environmental conditions, the design integrates two separate bands of cavity-backed spiral antennas into a common radome which can effectively reduce radar cross section (RCS) and the difficulty of mounting on airframe. The antenna design is modeled and optimized by using commercial electromagnetic software. Simulation results reveal good performance from 2 to 40GHz which can be considered as an excellent candidate to replace the original discrete aperture design. The proposed antenna will be supplied in amplitude and/or phase-tracking sets of typical airborne electronic warfare (EW) systems

**Keywords:** Compact; Airborne; Co-aperture; Millimeter-wave (MMW); Cavity-backed Spiral Antenna

## 1. INTRODUCTION

To meet the expanding challenges of electronic warfare, telemetry and many other defense or civil applications, spiral antenna [1][2] stand out due to its inherent characteristics of broad frequency bandwidth and circular polarization, as shown in Fig.1. This type of antenna is extensively used as stand-alone element or elements of arrays for detection of threat signals having various polarizations in EW receiver systems. Besides that, it can also be applied in fixed-beam arrays, scanning arrays, as feeding source for parabolic or shaped dishes [3].

Figure 1. Cavity-backed spiral antenna and arrays.

Millimeter spectrum is often used in the active radar based precision-guided weapons. MMW seeker technology is developing rapidly, especially in recent decades, therefore challenges faced by EW systems are increasing. As depicted in Fig.2, conventional airborne radar warning receiver (RWR) or electronic support measures (ESM) systems employs two discrete bands of cavity-backed spiral antennas, namely E/J band and K band, to receive signals from diverse emitters [4].

[1]*pichu1987pp@icloud.com; ppaimama@126.com

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Figure 2. Convectional antenna design with discrete apertures.

In order to further enhance the stealthy performance of aircraft and reduce mounting difficulty, integration of two cavity-backed spiral antennas with different operational bands is presented in this paper. The K band antenna is squeezed into the E/J band cavity and commonly housed in a single radome by introducing certain deformation on the spiral radiator. As a result, the reduced antenna aperture also causes acceptable deterioration on impedance matching and radiation pattern.

## 2. DESIGN AND IMPLEMENTATION

Typical EW receiver systems require wideband, low-profile, circularly polarized and try to avoid the dedicated omnidirectional radiation pattern [5]. Antenna performance will directly affect specifications of the entire system, since it is located at the most front-end of the chain as demonstrated in Fig.3. The selection of ideal antenna type comes down to balance the fundamental factors which normally include size, weight, cost, and reliability.

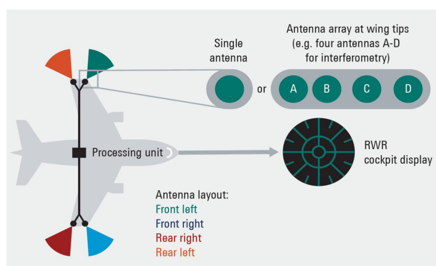



Figure 3. Functional system block diagram of typical EW receivers.

Spiral antennas are inherently circularly polarized radiators with relatively constant input impedance and radiation patterns over broad frequency bands. Its working bandwidth is determined by the fine precision of the feeding region (high frequencies) and overall spiral aperture size (low frequencies). The function and principle of operation are determined by three main cavity-backed spiral antenna components — the spiral radiator, backing cavity and balun transformer.

### 2.1 Spiral radiator design

The spiral is a planar structure that is typically fabricated by a two-start spiral etched on certain substrate. The frequency band of radiation is limited by the physical dimensions of the spiral. The most popular configurations are the Archimedean and the dual equiangular spirals.

In this work, spiral radiator selects the conventional Archimedean form which will be etched on RT duroid substrate with tapered matched terminations. Archimedean spiral has a constant arm width and separation between arms through the entire aperture. The geometrical parameters of Archimedean spiral can be calculated by using the empirical formulas given by [6]. More accurate values will be obtained from simulations.

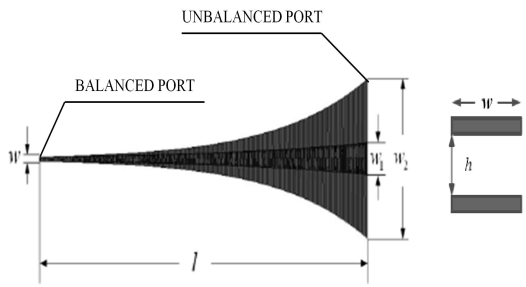
**2.2 Backing cavity design**

The spiral antenna inherently radiates energy in bidirectional beams perpendicular to its plane when both arms are fed in antiphase at the center. In order to achieve the unidirectional pattern with multi-octave bandwidth, a backing metallic cavity with radiation-absorbing material is necessary. Obviously, the influence of the cavity design on the match, gain, beamwidth, circular polarization and squint, all of which tend to limit the band of an essentially frequency-independent spiral radiator.

In this contribution, the height of absorbing material is approximately 84% of the cavity height, the inter-space between apertures and absorbing material will be filled with polystyrene foam.

**2.3 Balun transformer design**

The spiral radiator, being a balanced device, needs to be fed from a balanced transmission line. The addition of a balun transformer will be necessary once the interface to the antenna is in coaxial form. Considering the difficulties of manufacturing, a microstrip balun with nonlinear tapering is employed, as shown in Fig.4.




Figuer 4. Geometry of the tapered microstrip balun.

The initial geometrical parameters of the nonlinearly tapered microstrip balun is calculated by the empirical formulas in [6].

## 3. SIMULATION AND MODELLING

Based on the above antenna prototype, the FDTD based CST Microwave Studio is used to establish the simulation model. This integrated design consists of single co-aperture spirals with respective microstrip balun transformers, backing cavities and coaxial connectors. Fig.5 illustrates the integrated spiral aperture design and cross-section view of the proposed co-aperture cavity-backed spiral antenna.

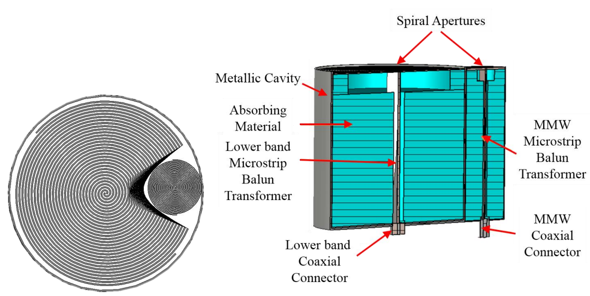



Figure 5. Co-aperture antenna simulation model.

As seen in the figure, E/J band spirals are dished towards the feeding region to incorporate the K band spirals closely. The spiral radiators employ two-arm Archimedean forms with tapered microstrip balun design. Besides, in order to minimize the coupling effect between antennas, the K band antenna is housed by a backing cavity of its own.

Both spiral radiators and balun transformers are printed on Teflon substrate with dielectric constant $\varepsilon_r$=2.2. The absorbing material used inside the cavity is with $\varepsilon_r$=1.5, $\tan\delta$=0.5 and polystyrene foam with $\varepsilon_r$=1.03 is selected to fill the remaining gap. Following antenna dimensions can be obtained from CST Microwave Studio as shown in the table below.

Table 1. STRUCTURAL Parameters of the Proposed Antenna Design.

| Name | Parameter | Value/mm |
|---|---|---|
| Balun length | $l$ | 40 |
| Number of spiral turns | $N$ | 15 |
| Balanced balun end linewidth | $w$ | 0.16 |
| Unbalanced balun end linewidth | $w_1$ | 1.62 |
| Ground plane linewidth | $w_2$ | 6.48 |
| Backing cavity height | $h$ | 41.5 |
| Balun substrate height | $h_1$ | 0.51 |
| Spiral substrate height | $h_2$ | 0.25 |
| Absorber height | $h_2$ | 35 |
| Backing cavity diameter | $D$ | 58.6 |
| E/J band spiral inner diameter | $D_{i\_E/J}$ | 2.1 |
| K band spiral inner diameter | $D_{i\_K}$ | 0.9 |
| E/J band spiral outer diameter | $D_{o\_E/J}$ | 44.2 |
| K band spiral outer diameter | $D_{o\_K}$ | 6.8 |

The simulated antenna features are depicted in the following Fig.6 to Fig.10 respectively.

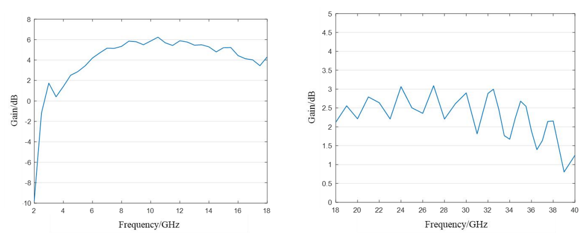



Figure 6. Realized gain of the antenna.

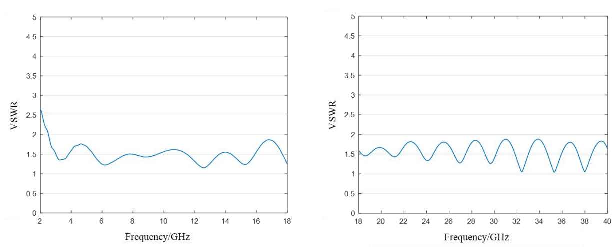
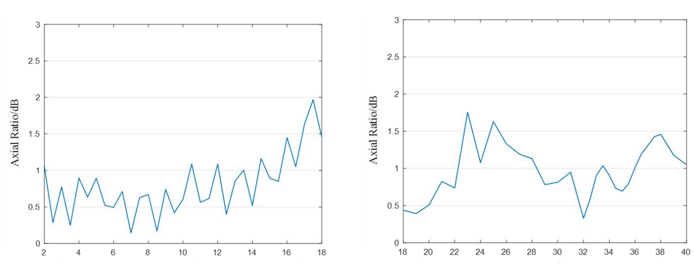



Figure 7. VSWR of the antenna.




Figur 8. Broadside axial ratio of the antenna.

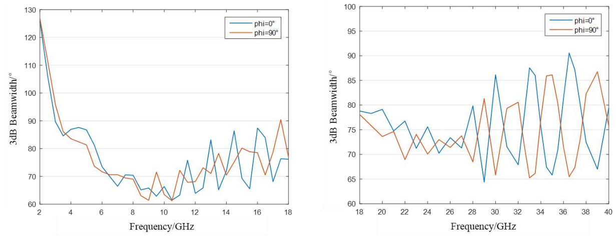



Figure 9. 3dB Beamwidth of the antenna.

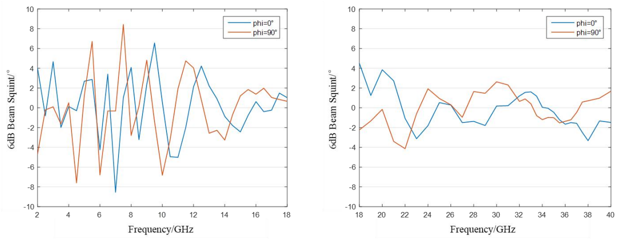
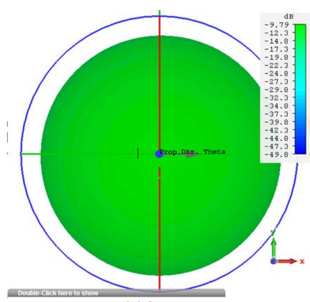


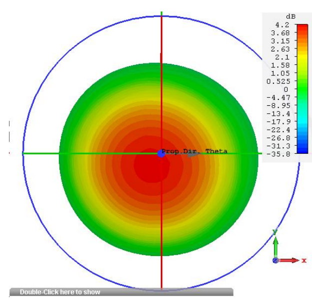

Figure 10. 6dB beam squint of the antenna.

In view of the above results, the realized gain ranges from -10 to 6dBic, the VSWR is typically less than 2.5:1 over the majority of the band, axial ratio is less than 2dB at broadside, 3dB beamwidth is between 60o and 130o and 6dB beam squint is lower than ±9o.

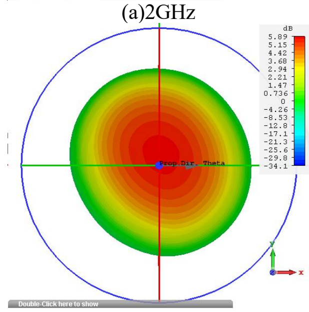
Antenna radiation property is crucial for achieving superior DF performance [7]. The simulated 3D radiation patterns at 2GHz, 6GHz, 12GHz, 18GHz, 24GHz, 32GHz, 36GHz and 40GHz are depicted in Fig.11 (a) to (h) accordingly.



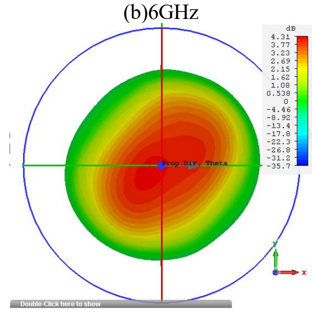
(a)2GHz



(b)6GHz



(c)12GHz



(d)18GHz

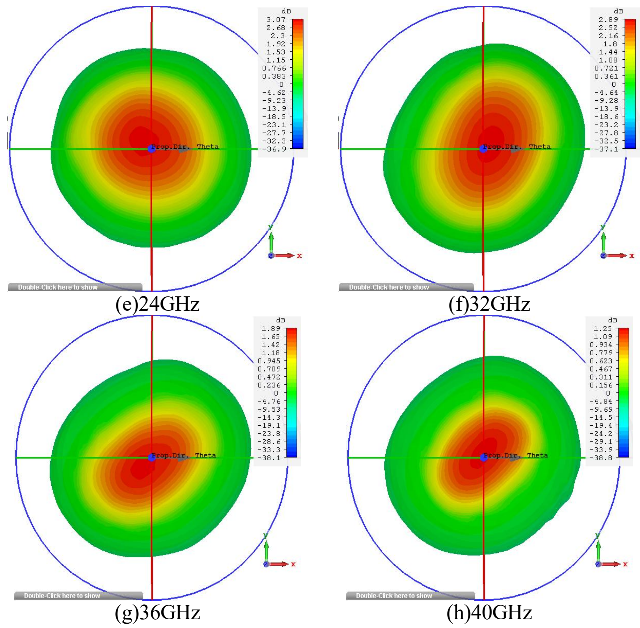



Figure 11. 3D radiation patterns of the antenna at various frequencies.

Seen from the figures, the deformation of spirals mainly degrades radiation patterns at lower frequency bands. Besides, the discontinuity introduced by dished spirals also leads to higher VSWR. It also destroys the structural symmetry which results in pattern distortion. This issue might be overcomed by introducing a highly resistive termination to last halfturn of the spiral.

## 4. CONCLUSIONS

Since the invention of the spiral antenna by E. M. Turner in 1954, spirals and other frequency independent antennas [8] [9] are irreplaceable components of various electronic warfare, communication, direction-finding systems, and atmosphere, ground or space exploration stations.

Airborne platforms especially unmanned aerial vehicles (UAVs) that feature low observability typically require sensors with reduced aperture. The demand for compact, low-cost antenna on aircraft is extremely strong especially in the MMW spectrum.

This paper describes a novel compact co-aperture spiral antenna design which covers the standard band 2~18GHz and an in-line MMW band 18~40GHz. Both apertures employ two-arm archimedean spirals with separate backing cavities and balun transformers. The overall antenna size is only Ø58.6mm×41.5mm (without coaxial connectors) which is almost equivalent to the original E/J band cavity-backed spiral antenna. Preliminary results obtained from full wave simulations reveal the proposed antenna is able to fulfill the system requirements, thus can be seen an excellent candidate to replace the original design for amplitude and/or phase comparison DF applications. The fabrication of antenna and its integral radome cover is still under progress.

## 5. ACKNOWLEDGMENT

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