# Active Integrated Empty SIW Cavity Backed Slot Antenna for Increased EIRP

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***Abstract*—In this paper, a novel active integrated antenna (AIA) is proposed with improved effective isotropic radiated power (EIRP). The antenna element is an empty substrate integrated waveguide (ESIW) cavity backed slot antenna to achieve excellent gain performance while having a very small antenna footprint. The antenna is integrated with a low phase noise feedback oscillator which oscillates at 11 GHz. The proposed AIA provides very high EIRP owing to the integration of a high gain antenna (~9dBi) and the high RF power output (4.628 dBm) of the oscillator. The oscillator component has good DC to RF conversion efficiency of about 29%. The proposed AIA can be used for wireless power transfer and active wireless sensor tag or vital sign sensor designs.**

***Keywords—active integrated antenna, empty substrate integrated waveguide, feedback oscillator, slot antenna***

## I. INTRODUCTION

Active integrated antenna is a combination of active components and passive antenna module to form an integrated component which effectively reduces the system footprint. AIAs mostly have amplifier or oscillator integrated to the antenna. Some amplifying AIAs have been reported so far which combine amplifier (low noise or power amplifiers) with antenna subsystems [1]. An antenna combined with an oscillator is known as self oscillating AIA which does not require additional source for the generation of the RF power. Self oscillating AIAs are essential components in modern RF and microwave systems for the design of wireless power transfer and charging modules [2]. An AIA based sensor tag design has been reported which can sense and transmit permittivity information of some loaded dielectric material to a reader module [3]. AIAs have also been reported for use in other applications like vital sign sensing [4]. One of the key aspects in the performance of an AIA is its EIRP. Several techniques have been used to increase the EIRP of the AIAs but most of them use bulky antenna structures to boost EIRP of the same. An active reflectarray has been proposed which provide excellent EIRP although at the cost of increased system space [5]. Another important aspect in the design of AIAs is to minimize the phase noise, for which several techniques like the use of metamaterial [6] and phase locked loop (PLL) [7] have been proposed. Hence there is a need for low profile AIA which provides good EIRP, which can be achieved by designing low profile high gain antennas and oscillator with good RF power output and low phase noise. Recently, a low profile high gain antenna design has been proposed based on empty SIW cavity backed slot [8]. This antenna is a good candidate for the design of low profile AIA. In this work, an AIA consisting of a cascade of feedback oscillator and an ESIW cavity backed slot antenna has been proposed which provides moderately high EIRP while requiring small space. The oscillator also has good phase noise performance owing to the feedback loop and high quality factor of the empty SIW cavity. The layout of the proposed structure is shown in Fig. 1. The proposed design has been simulated using ADS and HFSS.

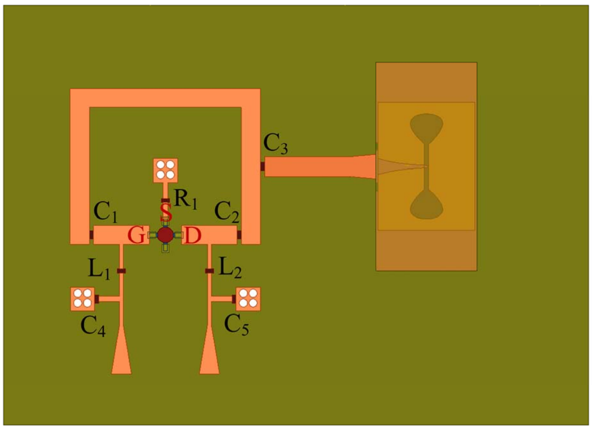


Fig. 1: Layout of active integrated antenna ($C_1$=$C_2$=$C_4$==$C_5$=47 pF, $C_3$=470 pF, $L_1$=$L_2$=27 nH, $R_1$=50 Ohm).

## II. DESIGN OF AIA

### A. Antenna module

The antenna section is based on empty SIW cavity. Empty or air filled SIW has been proposed in [9] which offers significant reduction in dielectric loss component. The antenna design is based on the one proposed in [8]. A figure of eight dumbbell shaped slot is backed by an empty SIW cavity. Owing to the absence of dielectric inside the cavity the efficiency of the overall antenna increases and is more than normal SIW cavity backed slot antennas. The exploded 3D view of different layers of the antenna is shown in Fig. 2. This antenna is used in the feedback loop path of the oscillator section of the AIA. Owing to its intrinsically high gain and compact size the empty SIW cavity backed antenna is a suitable choice for this design.

### B. Active oscillator section

To provide self oscillating characteristic of the AIA, a feedback oscillator is designed with the antenna in its

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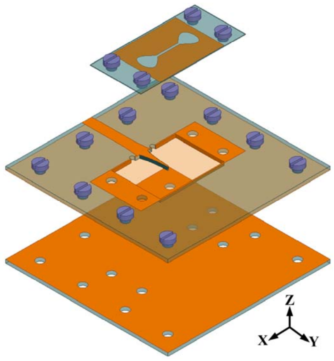
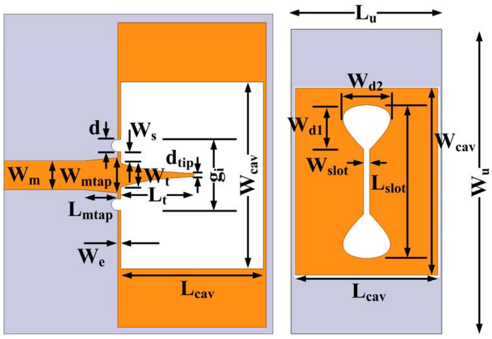
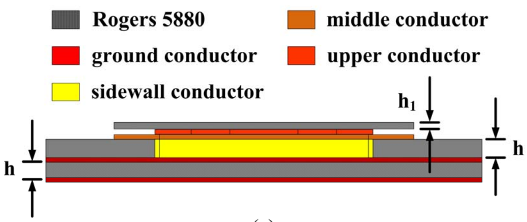



(a)




(b)




(c)

Fig. 2: (a) 3D view of multiple layers of the antenna, (b) layout of middle and top layers with dimensions, all dimensions in mm ($W_m$=2.44, $W_{mtap}$=3, $L_{mtap}$=3, $W_t$=2, $L_t$=6.15, $d_{tip}$=0.3, d=1, $W_e$=0.25, $g_i$=5, $W_s$=1, $W_{cav}$=15.7988, $L_{cav}$=12, $W_{d1}$=3.762, $W_{d2}$=3.995, $W_{slot}$=0.5, $L_{slot}$=12.9996, $W_u$=25.7988, $L_u$=12.5), (c) cross sectional view of antenna structure, all dimensions in mm (h=0.787, $h_1$=0.127).

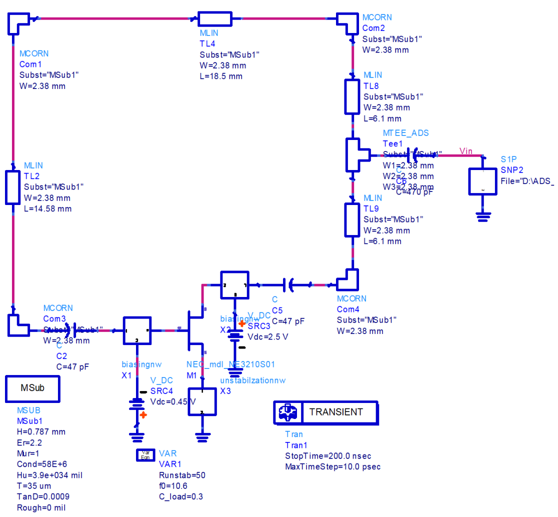


Fig. 3: Circuit schematic of active integrated antenna.

feedback path. GaAs pHEMT NE3210S01 has been used for this design. The ADS circuit schematic is shown in Fig. 3. The oscillator is designed using common source configuration with feedback loop between gate and drain terminals. The antenna S-parameter has been simulated by HFSS and the data is fed to the circuit simulator. The pHEMT is biased to -0.45 V at the gate terminal and 2.5 V at the drain terminal. The transistor is made unstable by introducing a resistor $R_1$ of 50 Ohm. Both the antenna and the oscillator section has been designed using RT/Duroid 5880 ($\varepsilon_r$=2.2, tanδ=0.0009, height=0.787mm) substrate. The length of the feedback path consisting of the antenna is chosen such that it satisfies Barkhausen criterion for oscillation. The feedback oscillators are more stable and thus provide low phase noise performance.

## III. Simulation Results and Discussion

The antenna structure is simulated using full wave EM simulator HFSS. The reflection coefficient of the antenna is shown in Fig. 4. The 10 dB return loss bandwidth of the

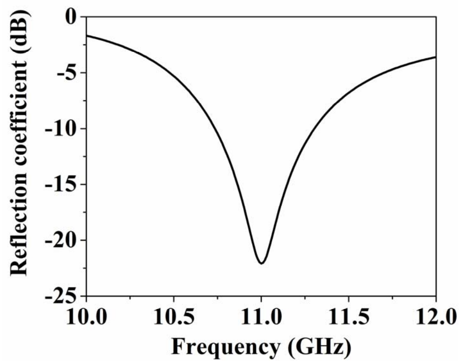



Fig. 4: Reflection coefficient variation with frequency.

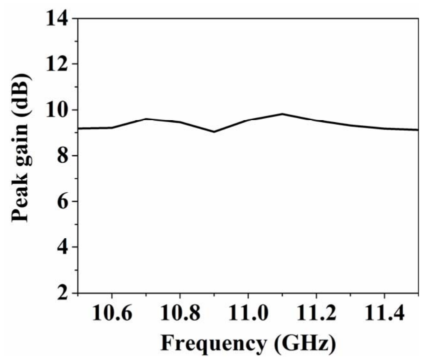



Fig. 5: Antenna peak gain variation with frequency.

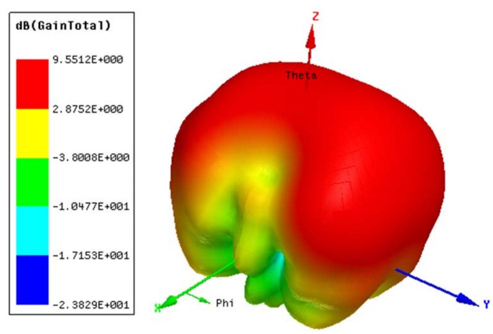
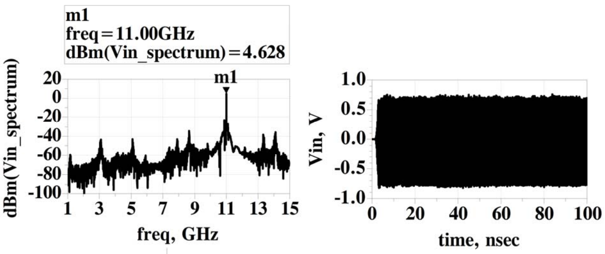



Fig. 6: 3D radiation pattern of the antenna at 11 GHz.




(a) (b)

Fig. 7: (a) Input signal spectrum to antenna, (b) time domain response.

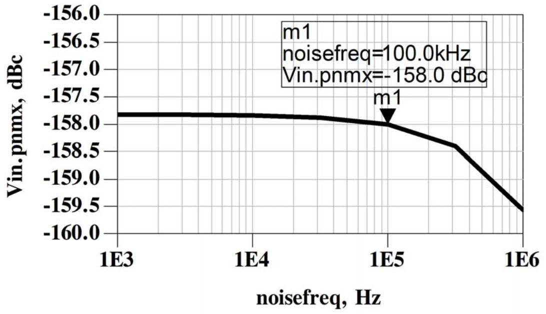



Fig. 8: Simulated phase noise performance at 11GHz center frequency.

antenna is 5.46% having center frequency at 11GHz. The proposed antenna provides ~9dBi gain throughout the band of interest. At 11 GHz the peak gain of the antenna is 9.55 dBi. The peak gain plot with frequency is shown in Fig. 5. The 3D radiation pattern of the antenna is also shown in Fig. 6. The pattern is directive and hence has greater gain. Finally, the circuit simulation is done using ADS. The spectrum and time domain responses of RF input signal going to the antenna terminal are shown in Fig. 7 (a) and (b). The oscillator produces 4.628 dBm output at 11 GHz frequency. The stable oscillation can be observed from the time domain response. The oscillator consumes 10 mW DC power and hence achieves about 29% DC to RF conversion efficiency. Since the proposed designed is not measured experimentally the EIRP can be calculated directly by adding the gain of the antenna and the RF output level. The calculated EIRP is 14.178 dBm which is quite high considering a single antenna element having small overall system footprint. The single sideband phase noise performance of the proposed AIA is shown in Fig. 8. The phase noise is as low as -158 dBc/Hz at 100 KHz offset.

## IV. Conclusion

A novel AIA has been proposed in this paper that makes use of empty SIW technology to design low profile high gain cavity backed slot antenna. Owing to reduction in dielectric loss of the antenna, there is significant increase in the efficiency and overall gain of the antenna. The proposed AIA has good EIRP and DC to RF conversion efficiency. The proposed AIA can be made tunable by incorporating varactor diodes in the oscillator section since the antenna supports an FBW of 5.46%, over which the gain is also quite flat. The tunable range can be further increased by increasing the bandwidth of the proposed antenna, which can be achieved by exciting hybrid modes by the use of different slots. The proposed AIA can be used for wireless charging system, wireless sensor tag design and vital sign detection applications.

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