A Novel Design of Reconfigurable Active Integrated Oscillator Feedback Antenna with Electronically Controllable for WiMAX/WLAN Applications

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***Abstract* ─** A novel reconfigurable active oscillator feedback antenna for WiMAX/WLAN applications is presented. By using a rectangular ring with a pair of protruded Γ-shaped strips in the active feedback antenna, two new resonances can be achieved. Also, the proposed rectangular ring with a pair of protruded Γ-shaped strips radiating patch has a major advantage in providing tighter capacitive coupling to the line, in comparison to the known radiating patch. In order to generate DC isolation in the RF path we use a pair of gap distances in the microstrip loop. Also, by using the [S] parameters of the active element a novel design of the microwave oscillator is performed. Simulated and experimental results obtained for this antenna show that the proposed Active Integrated Antenna (AIA) has a good return loss and radiation behavior within the WiMAX/WLAN frequency range.

Index Terms - Oscillator feedback antenna, reconfigurable active integrated antenna, WiMAX/WLAN systems.

I. INTRODUCTION

In multi-band wireless communication systems, one of key issues is the design of a compact active antenna while providing wideband characteristic over the whole operating band. It is a well-known fact that active feedback presents really appealing physical features such as simple structure, small size and low cost. Because of all these interesting characteristics, multi-band feedback oscillator antenna is expected to become a key device for the next generation multi-band and multi-mode wireless radios [1] and growing research activity is being focused on them [2-4]. Various switching based techniques have been proposed to achieve multi-band performance. Some of the topologies use separate oscillators [2] to obtain multi-band response, while others use distinct resonators [3] or matching networks [4] to achieve the same. An alternative switched resonator technique is discussed, wherein, oscillator's negative resistance is controlled by modifying microstrip line resonator's length using a diode based electrical switch. The technique is utilized to realize a dual-band oscillator.

In the last few years there have been rapid developments in Wireless Local Area Network (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX) applications. The 2.4/5.2/5.8 GHz (2.4–2.84/5.15–5.35/5.725–5.825 GHz) and 2.5/3.5/5.5 GHz (2500–2690/3400–3690/5250-5850 MHz) bands are demanded in practical WLAN and WiMAX applications, respectively. During the last year, there have been various antenna designs which enable antennas with low profile, lightweight, flush mounted and WiMAX devices. These antennas include the Planar Inverted-F Antennas (PIFAs) [5], printed monopole antennas [6], the chip antennas [7] and the planar monopole antennas [8]. However, up to now, a printed antenna that has Γ-shaped notch configuration has not been reported.

In this paper we propose a novel frequency reconfigurable active integrated oscillator feedback antenna with the capability to switch between WLAN and WiMAX modes. The antenna

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which uses a switchable slotted structure for reconfigurability has a simple structure and smallest size in comparison to antennas reported in literature [9]-[10]. In the proposed structure based on Electromagnetic Coupling (EC), a rectangular ring with a pair of protruded Γ-shaped strips in the microstrip transmission line is used to perturb two resonance frequencies at 2.4 GHZ (WLAN) and 3.5 GHz (WiMAX). This structure has a major advantage in providing tighter capacitive coupling to the line, in comparison to the known radiating patch [9]. In the proposed configuration a pair of gap distances are playing important roles in the radiating characteristics of this antenna, because it can adjust the electromagnetic coupling effects between the interdigital radiating patch and the microstrip transmission line [10]. Also, the implemented dual-band oscillator exhibited output power level of -16.21 dBm at frequency of 2.399 GHz and -23.09 dBm at frequency of 3.488 GHz, for various diodes bias conditions.

II. SYSTEM DESIGN CONCEPT

According to the feedback oscillator antenna in classification of active antennas, a two or three-terminal negative-resistance device can be connected directly to the terminals of a single antenna element or an array of elements. In this case, DC power is converted to radiate RF power. Oscillator antennas have been discussed for applications such as low-cost sensors, power combining and synchronized scanning antenna arrays [11].

In the microstrip antenna, resonant modes are excited by an inductance–capacitance (L-C) circuit of the resonant antenna. The passive antenna can be expressed by a series inductor-capacitor (LA-CA), as shown in Fig. 1 [3]. Figure 1 also shows the schematic of a Clapp oscillator circuit [4]. Two capacitors, C_{gs} and C_{ds}, are connected in series in the network of a Clapp oscillator circuit of Fig. 1. The resonant frequency of a Clapp oscillator circuit is mainly given by the elements of CA and LA of the conceptual equivalent circuit of the antenna. The passive antenna has two resonant frequencies: 2.4 and 3.5 GHz. Based on the resonant frequencies, the proposed active integrated antenna can be excited at similar resonant frequencies.

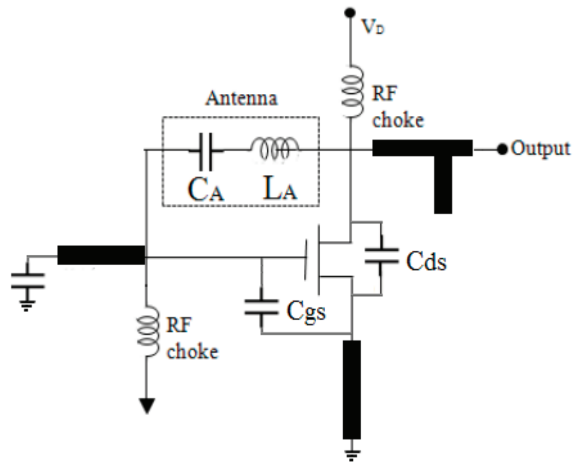
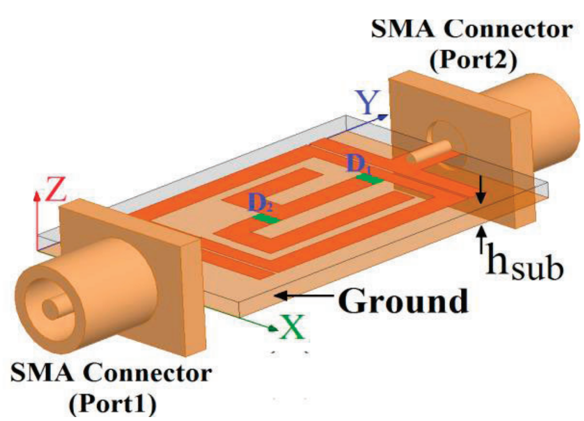


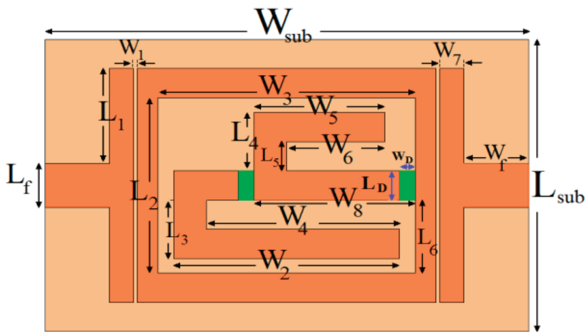
Fig. 1. Schemetice of active integrated antenna having Clapp oscillator circuit.

III. RECONFIGURABLE ANTENNA DESIGN

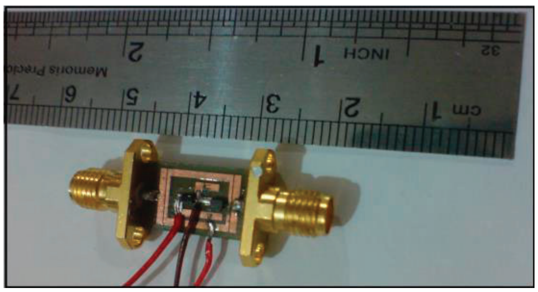
The proposed passive reconfigurable antenna fed by a 50-Ω feed line is shown in Fig. 2, which is printed on a FR4 substrate of thickness 0.8 mm and permittivity of 4.4. The numerical and experimental results of the input impedance and radiation characteristics are presented and discussed. The parameters of this proposed antenna are studied with parametric study process by changing one or two parameters at a time and fixing the others. The Ansoft simulation software High-Frequency Structure Simulator (HFSS) [12] is used to optimize the design and agreement between the simulation and measurement is obtained.



(a)



(b)



(c)

Fig. 2. Configuration of the switchable antenna: (a) side view, (b) top view and (c) fabricated scheme.

Figure 3 shows the simulated and measured return loss characteristics of the proposed antenna, as shown in Fig. 2. As shown in Fig. 3 in this structure, the rectangular ring with a pair of protruded Γ -shaped strips with two p-i-n diodes is used in order to electronically switch between the WLAN (2.4 GHz) and WiMAX (3.45 GHz) frequency bands.

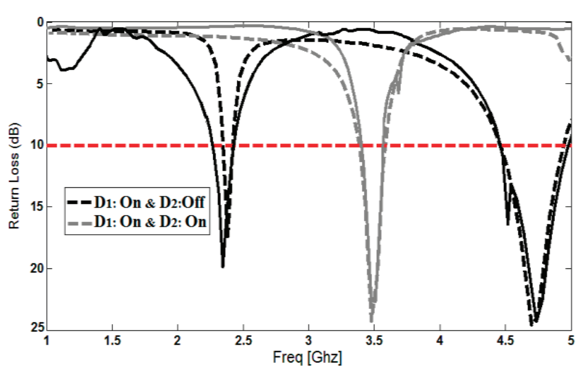


Fig. 3. Reflection coefficient of the antenna for various states of diodes (dashed line: simulated, solid line: measured).

For applying the DC voltage to PIN diodes, metal strips with dimensions of 1.5 mm × 0.6 mm were used inside the main slot. In the introduced design, HPND-4005 beam lead PIN diodes [13] with extremely low capacitance were used. For biasing PIN diodes, a 0.7 volt supply is applied to metal strips. The PIN diodes exhibit an ohmic resistance of 4.6 Ω and capacitance of 0.017 pF in the on and off states, respectively. By turning diodes on, the metal protruded Γ -shaped strips are connected to the rectangular ring radiating patch and become a part of it. The desired frequency band can be selected by varying the states of PIN diodes, which changes the total equivalent length of the strip.

In order to understand the phenomenon behind switching electronically between first and second resonance frequency, the simulated current distributions on the radiating patch of the proposed antenna for on and off statuses of the PIN diode are presented in Figs. 4 (a) and (b), respectively. As shown in Fig. 3 (a), at the first resonance frequency (2.4 GHz), the current mainly concentrates on the bottom edges of the protruded Γ -shaped strips and also it can be seen that the electrical current does change its direction along the bottom of the protruded Γ -shaped strips. Finally, the current mainly concentrates on the upper protruded Γ -shaped strips at the second resonance frequency (3.5 GHz), as shown in Fig. 4 (b).

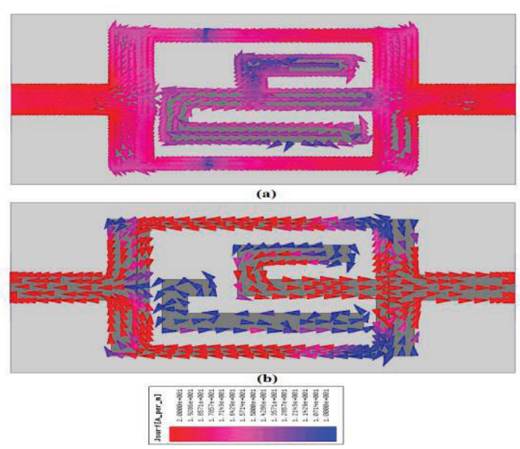


Fig. 4. Simulated surface current distributions on the radiating patch: (a) at the first resonance frequency (2.4 GHz) and (b) the second resonance frequency (3.5 GHz).

IV. MULTI-BAND OSCILLATOR DESIGN

Transistor oscillators can be designed using either bipolar or GaAs MESFET devices [14-15]. Using the [S] parameters of the active element, the design of the microwave oscillator is performed using our full-scale computer simulation program. The stability of the device can be checked by two stability factors K and |Δ|. The mathematical equations for K and |Δ| are [14]:

$$\Delta = S_{11}S_{22} - S_{21}S_{12}\,, \tag{1}$$

$$K = \frac{1-|S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2|S_{21}S_{12}|}\,. \tag{2}$$

The stability of the used transistor at the frequencies of 2.4 GHz and 3.5 GHz is calculated through calculation of the stability factor K and Δ [16]. The transistor is potentially unstable at the operated frequencies 2.4 GHz and 3.5 GHz (i.e. K=0.5718 and K=0.656, respectively). The stability circle at the gate-to-drain port is calculated by (3) and (4). In this design the gate-to-drain port is the terminating port.

$$R_S = \left|\frac{S_{12}S_{21}}{S_{11}^2 - \Delta^2}\right|, \tag{3}$$

$$C_S = conj\left(\frac{(S_{11}) - \Delta.conj(S_{22})}{|S_{11}|^2 - |\Delta|^2}\right). \tag{4}$$

Any Γ_T in the shaded stability circle region produces $|\Gamma_{in}|>1$ (i.e. a negative resistance at the input port). We select an arbitrary point in mentioned region, at this point $\Gamma_T = 0.9\angle -165^\circ$ and the associated impedance is $Z_T = -j7.5\Omega$. This reactance can be implemented by an open-circuited 50Ω line of length 0.226λ. With Z_T connected, the input reflection coefficient is found to be $\Gamma_{IN} = 12.5\angle -160^\circ$ and the associated impedance is $Z_{IN} = -50 - j3.5\Omega$. The load matching network is designed using (5)-(9), that is $Z_{IN} = 21 - j2.1\Omega$.

$$\Gamma_{in} = S_{11} + \frac{S_{12}S_{21}\Gamma_T}{1 - S_{22}\Gamma_T}\,, \tag{5}$$

$$\Gamma_S = \Gamma_{in}^*\,, \tag{6}$$

$$Z_{in} = Z_0\frac{1-|\Gamma_S|^2 + 2j|\Gamma_S|\sin(\theta_{\Gamma_S})}{1+|\Gamma_S|^2 - 2|\Gamma_S|\cos(\theta_{\Gamma_S})}\,, \tag{7}$$

$$Z_L = \frac{real(Z_{in})}{3} - jimag(Z_{in})\,, \tag{8}$$

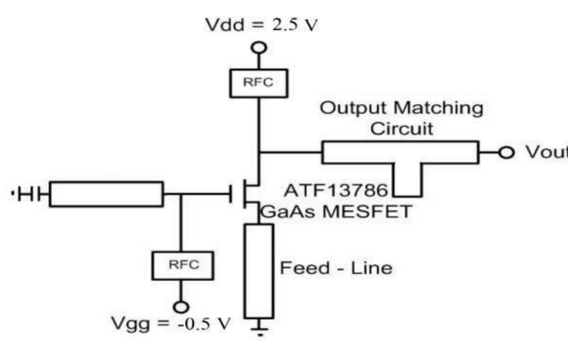
$$Y_{in} = \frac{50}{Z_L}\,. \tag{9}$$

The terminating circuit is designed to get maximum reflection coefficient at the transistor output. The analytical design of the terminating circuit and the output matching circuit are performed using the developed computer program [4]. As a result of the developed program and the optimization process described elsewhere [5], the lengths and widths of the termination and matching circuits are:

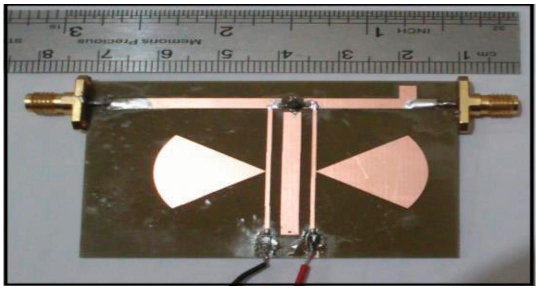
Terminating circuit: Length of open circuit series line (50 Ω)=32.4569 mm and width of open circuit series line =3 mm.

Load matching circuit: Length of series line (50 Ω)=15.318 mm, width of series line =3 mm, length of open single shunt stub =1.51 mm and width of open balanced shunt stub =3 mm.

A series feedback is added to the source of the transistor using microstrip line to maximize the value of S11 of the oscillator operated at 2.4 GHz and 3.5 GHz. As the result of the gradient method optimization process in the ADS, the length and width of the microstrip line connected to the source of the transistor are 28.94 mm and 3 mm, respectively. Figure 5 shows the circuit layout and Fig. 6 shows |S11| in dB versus frequency for the deigned microstrip oscillator.



(a)



(b)

Fig. 5. Circuit layout of the proposed oscillator: (a) schematic and (b) fabricated oscillator.

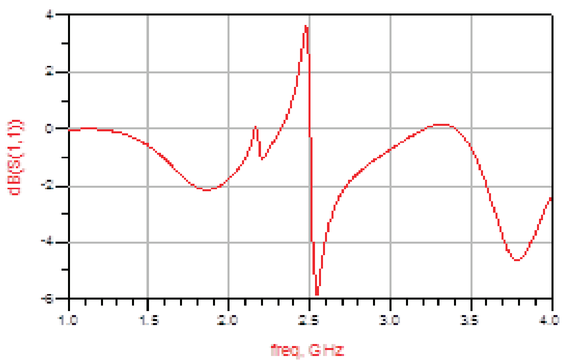


Fig. 6. |S11| (dB) versus the frequency.

V. RECONFIGURABLE FEEDBACK OSCILATOR ANTENNA MEASURMENT

A microwave oscillator presented in this work using a feedback antenna structure with a high-Q factor provides high power; high DC to RF conversion ratio. The feedback antenna dimension barely affects the dimension of the microstrip line located on the top of the substrate when applied to oscillators. In this structure, PIN diodes were used as the frequency selection switch to change effective length of the microstrip line resonator; which forms a part of the overall oscillator circuit. Biasing circuit for the diodes was designed in such a way that it didn't disturb the biasing voltage of the transistor. While forward bias included complete length, reverse bias incorporated length of the resonator just before the diode as a part of the overall oscillator. Nevertheless, negative resistance condition for oscillation was maintained at both the designed frequencies, thereby upholding oscillation at one frequency during forward biasing of D_1 and at another frequency in two diodes biasing case. The switch capacitance was taken into account while deciding resonators' lengths for the two frequencies. Dimensions of the resonators and the matching network were optimized using Agilent's Advanced Design System (ADS) in conjunction with the Electromagnetic (EMDS) Simulation tool to get the required oscillation frequencies for dual-band operation.

The presented active feedback antenna is shown in Fig. 7, which is printed on an FR4 substrate of thickness 0.8 mm, permittivity 4.4 and loss tangent 0.018. The proposed active feedback antenna structure consists of a rectangular ring with a pair of protruded Γ -shaped strips for radiating element, a microstrip loop, an oscillator with DC bias circuit and matching circuit for active part. The width of the 50-Ω microstrip line is fixed at 1.5 mm, as shown in Fig. 7. The matching circuit to the left and right of the device controls the degree of feedback. On the other side of the substrate a conducting ground plane is placed. In addition, to satisfy the oscillation-phase requirement, the microstrip loop is fixed to a suitable electrical length taking the calculated phases of the oscillator and passive antenna into consideration [16]. The proposed antenna is connected to a 50-Ω SMA connector for signal transmission.

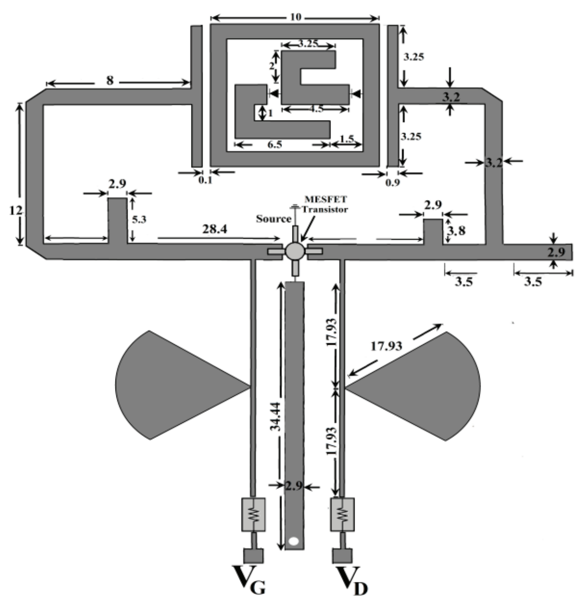
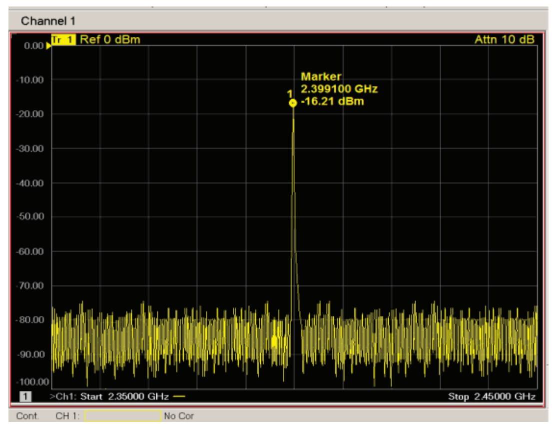


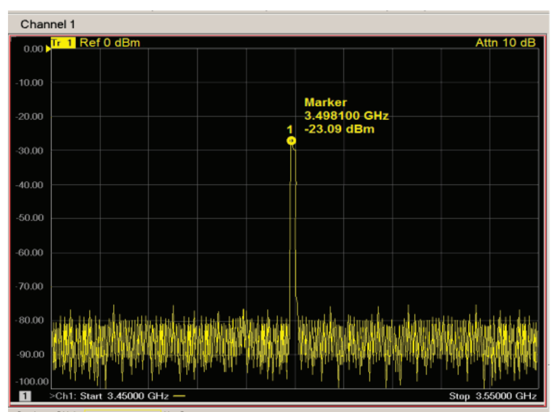
Fig. 7. Configuration of the proposed active integrated antenna with GaAs MESFET.

Conventionally, multi-band oscillators are realized by reconfiguring the frequency selective network [3-5]. Typically, a negative resistance cell is combined with a switch-controlled resonator. Distinct frequency selective circuit units are designed such that the negative resistance cell satisfies the necessary oscillating condition at their corresponding resonant frequencies. As shown in Fig. 7, the proposed multi-band oscillation scheme modifies the frequency selective network by varying only the microstrip length to select the desired frequency response, as depicted in the block diagram of Fig. 1 for dual-band case. At the network's input, two microstrip resonators of different lengths are connected in feedback through an electrical switch to define the required oscillating frequencies. Simultaneously, a dual-band output matching network is designed for optimum output power efficiency to a 50 Ω load at both the designed frequencies. The scheme is extendable to multi-band scenario using additional frequency selective circuits connected through electrical switches with appropriate multi-band matching network at the oscillator's output. A dual-band oscillator prototype was implemented using the proposed reconfigurable antenna scheme with single transistor. The common-source configuration of a GaAs MESFET Transistor (ATF13786) was used to generate appropriate negative resistances for dual-band oscillation at 2.4 GHz and 3.5 GHz [17]. The transistor was DC biased through a radial stub implemented using a high impedance (100 Ω) quarter wavelength (electrical length 90^0) microstrip line, which is further shunted by a low impedance (20 Ω) quarter wavelength open stub. Biasing voltages of VDS=2.5 V and VGS=-0.5 V were maintained at the drain and the gate terminals of the transistor. It is known that oscillations are achieved at those frequencies where the stability parameter (K) value is less than one. In order to meet this instability condition for oscillations at both the desired frequencies, a microstrip line was added to the transistor's source terminal. In effect, the microstrip incorporates an external positive series feedback to the network, thereby ensuring the required network destabilization.

The proposed reconfigurable frequency oscillator feedback antenna is fabricated and tested. Figures 8 (a) and (b) show the radiated output power from the fabricated oscillator feedback antenna for the previously mentioned biasing conditions measured in anechoic chamber. The implemented dual-band oscillator exhibited output power level of -16.21 dBm, at frequency of 2.399 GHz and -23.09 dBm, at frequency of 3.488 GHz for diodes bias conditions. Second harmonics for both the cases were observed to be about 12 dB below the output power at fundamental frequencies. The output power is measured to be about 25.17 dBm, using an Agilent E4440A spectrum analyzer and a double-ridged horn antenna (gain 17 dBi) as a reference antenna placed at a distance of 2 m.



(a)



(b)

Fig. 8. Measured output power radiated from active feedback antenna: (a) at 2.39 GHz and (b) at 3.48 GHz.

The measured radiation patterns including the co-polarization and cross-polarization for the E-plane (y-z plane) and H-plane (x-z plane) at the resonance frequencies, are shown in Fig. 9. The received cross-polarizations in the E-plane and H-plane of the AIA are approximately 19 and 23 dB lower than the maximum co-polarized radiation, respectively. As seen in Fig. 9, the radiation pattern in the H-plane is asymmetrical due to the asymmetrical presence of the distributed oscillator-feedback circuitry.

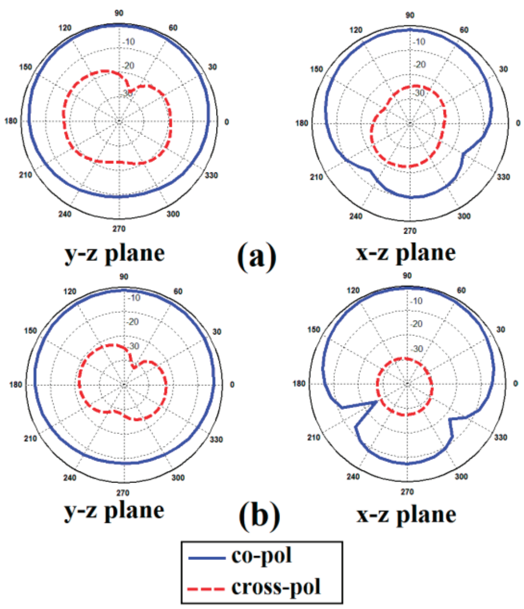


Fig. 9. Measured radiation patterns of the proposed antenna: (a) at 2.4 GHz and (b) at 3.5 GHz.

V. CONCLUSION

As presented above, a novel design of reconfigurable active integrated oscillator feedback antenna with electronically controllable is an interesting subject for for WiMAX/WLAN applications. By using a rectangular ring with a pair of protruded Γ-shaped strips in the active feedback antenna, two new resonances can be achieved. In the proposed structure, based on Electromagnetic Coupling (EC), an interdigital coupling strip in the microstrip transmission line is used to perturb two resonance frequencies at 2.4 GHz (WiMAX) and 3.5 GHz (C-band). The oscillator design based on the AIA concept has been shown to provide an efficient and successful method for designing high efficiency and compact systems. The implemented dual-band oscillator exhibited output power level of -16.21 dBm, at frequency of 2.399 GHz and -23.09 dBm, at frequency of 3.488 GHz for diodes bias conditions. Second harmonics for both the cases were observed to be about 12 dB below the output power at fundamental frequencies.

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