Compact Oscillator Feedback Active Integrated Antenna by Using Interdigital Coupling Strip for WiMAX Applications

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Abstract **─** A novel active feedback antenna for WiMAX applications is presented. By using an interdigital coupling strip in the active feedback antenna two new resonances can be achieved. Also the proposed interdigital radiating patch has a major advantage in providing tighter capacitive coupling to the line in comparison to known radiating patch. In order to generate DC isolation in the RF path, we use a pair of gap distances in the microstrip loop. 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 frequency range.

Index Terms **─** Active integrated antenna, interdigital strip, oscillator feedback structure, and WiMAX applications.

I. INTRODUCTION

Recently, the needs for active integrated antennas (AIA) have been growing significantly for mobile communication systems, such as, worldwide interoperability for microwave access (WiMAX), wireless local area network (WLAN), global positioning satellite (GPS), et al. Active integrated antennas (AIA) can provide some effective solution to various problems, such as higher transmission loss, limited source power, and reduced antenna efficiency. AIA have many advantages of reducing device size, low weight, and low fabrication cost for receiver front-end modules [1, 2]. Various techniques of active antennas, such as injection locking, cavity control, varactor tuned antenna, and oscillation feedback loop, have been presented [2]. Although the technique of using an oscillation feedback loop has improved bandwidth, gain, phase noise performance in radiated signals, simultaneously providing good power added efficiency (PAE), it still has the problem of containing design complexity and fabrication cost [1].

In the last few years, there have been rapid developments in worldwide interoperability for microwave access (WiMAX) applications. The 2.5 GHz / 3.5 GHz /5.5 GHz (2500–2690 MHz / 3400–3690 MHz / 5250–5850 MHz) bands are demanded in practical WiMAX applications. During the last years, there are various antenna designs, which enable antennas with low profile, lightweight, flush mounted, and WiMAX devices. These antennas include the planar inverted-F antennas (PIFAs) [3], planar monopole antenna

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[4], and the printed dipole antennas [5]. In WiMAX communication systems, one of the 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 the active feedback presents really appealing physical features, such as simple structure, small size, and low cost. Because of all these interesting characteristics, active feedback are extremely attractive to be used in WiMAX applications and growing research activity is being focused on them [6, 7].

In this study, based on electromagnetic coupling (EC), an interdigital coupling strip in the microstrip transmission line is used to perturb two resonance frequencies at 3.5 GHz (WiMAX) and 4.2 GHz (C-band). The proposed interdigital radiating patch is shown in Fig. 1 (a). This structure has a major advantage in providing tighter capacitive coupling to the line in comparison to known radiating patch. In the proposed configuration a pair of gap distances are playing important role 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.

II. ANTENNA DESIGN AND CONFIGURATION

The proposed passive antenna fed by a 50 Ω feed line is shown in Fig. 1, which is printed on an FR4 substrate of thickness 0.8 mm, and permittivity 4.4. The numerical and experimental results of the input impedance and radiation characteristics are presented and discussed. The Ansoft simulation software high-frequency structure simulator (HFSS) [8] is used to optimize the design and agreement between the simulation and measurement.

Figure 2 shows the measured and simulated return loss and insertion loss characteristics of the proposed antenna shown in Fig. 1. The fabricated antenna has the frequency band of 3.27 GHz to over 4.38 GHz with two resonance frequencies around 3.53 GHz and 4.23 GHz. In order to understand the performance of the proposed structure in the WiMAX frequency band, the simulated current distributions on the radiating patch of the proposed antenna, are presented in Fig. 3. As shown in Fig. 3, at the resonance frequency (3.5 GHz), the current mainly concentrates on the C-shaped strips edges and also it can be seen that the electrical current does change its direction along these strips [5].

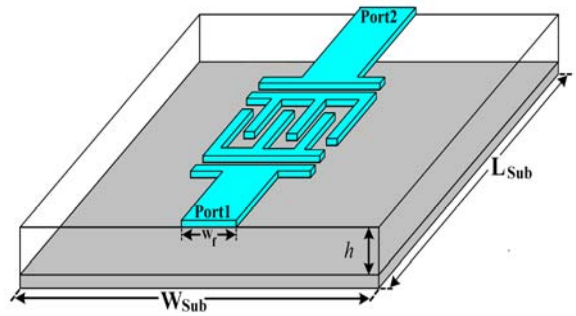

Fig. 1. The proposed antenna by using an interdigital coupling strip (W_{Sub} = 12 mm, L_{Sub} = 18 mm, W_f = 2 mm, and h = 0.8 mm).

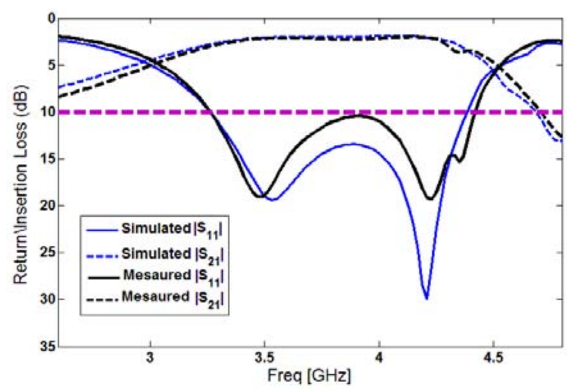

Fig. 2. Measured and simulated return loss and insertion loss characteristics for the passive microstrip antenna.

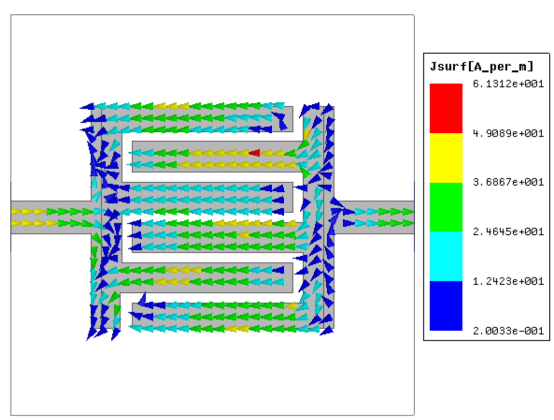

Fig. 3. Simulated surface current distributions on the radiating patch for the proposed passive antenna shown in Fig. 1, at 3.5 GHz.

The measured peak antenna gain against frequency in the range of 3.2 GHz – 4.3 GHz, are plotted in Fig. 4, showing small variations of less than 1 dBi.

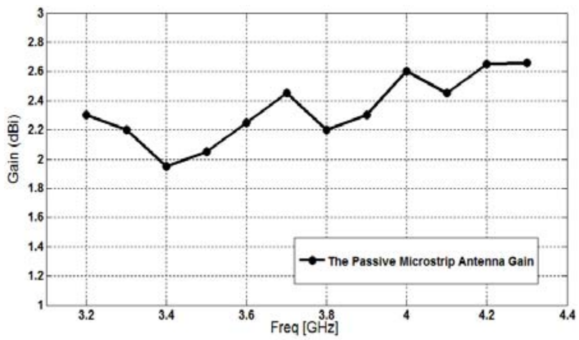

Fig. 4. Measured peak antenna gain versus frequency for the fabricated antenna in the 3.2 GHz – 4.3 GHz band.

III. OSCILLATOR DESIGN

Transistor oscillators can be designed using either bipolar or GaAs MESFET devices [9, 10]. 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 $|\Delta|$. The mathematical equations for K and $|\Delta|$ are as given in [10],

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

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

The stability of the used transistor at the frequency of 3.5 GHz is calculated through calculation of the stability factor, K and Δ. The transistor is potentially unstable at the operated frequency 3.5 GHz (i.e., $K = 0.656$) and the stability circle at the gate-to-drain port is shown in Fig. 1. In the notation of Fig. 1, 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 $\Gamma_T = 0.9\ \angle{-165}\ ^{o}$, and the associated impedance is $Z_T = -j7.5\ \Omega$. This reactance can be implemented by an open-circuited 50 Ω line of length 0.226 λ. With Z_T connected, the input reflection coefficient is found to be $\Gamma_{IN} = 12.5\ \angle{-160}\ ^{o}$, and the associated impedance is $Z_{IN} = -50-j3.5\ \Omega$. The load matching network is designed using equations (5) to (9), that is $Z_{IN} = 21-j2.1\ \Omega$,

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

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

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

$$Z_L = \frac{Real(Z_{in})}{3} - j\,Imag(Z_{in}), \tag{8}$$

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

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 [9]. As a result of the developed program and the optimization process described elsewhere [10] the lengths and widths of the termination and matching circuits are:

Terminating Circuit: Length of the open circuit series line (50 Ω) = 19.25 mm, and width of the open circuit series line = 3.2 mm.

Load matching circuit: Length of series line (50 Ω) = 1.525 mm, width of series line = 3.2 mm, length of open single shunt stub = 8.05 mm, and width of open balanced shunt stub = 3.2 mm.

In this paper, we simulated and manufactured microwave oscillator for wireless applications by using advance design system (ADS) simulator [11]. The presented miniature packaged oscillator with the matching circuit is shown in Fig. 5.

IV. ACTIVE INTEGRATED ANTENNA DESIGN

The presented active feedback antenna is shown in Fig. 6, which is printed on an FR4 substrate of thickness 1.6 mm, permittivity 4.4, and loss tangent 0.018. The proposed active feedback antenna structure consists of an interdigital coupling strip for radiating element, a microstrip loop, and an amplifier with DC bias circuit and matching circuit for active part. The width of the 50 Ω microstrip line is fixed at 3.2 mm, as shown in Fig. 6. The matching circuit to the left and right of the device controls the degree of feedback [10]. 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 measured phases of the amplifier and passive antenna into consideration [12, 13]. The proposed antenna is connected to a 50 Ω SMA connector for signal transmission. Figure 7 presents the photograph of a realized active integrated antenna on an FR-4 substrate with the SMA connector.

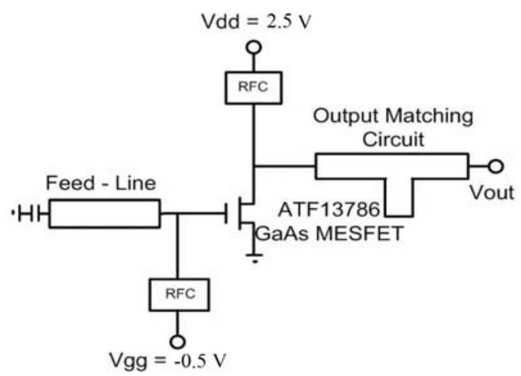

Fig. 5. Circuit layout of the proposed oscillator.

Figure 8 shows the measured return loss. The measured return losses of the active antenna shows gains of 14.3 dBi, 8.3 dBi, 4.4 dBi at each resonance frequency with the bias condition of VG = –0.2 V, VD = –0.3 V and ID = 8 mA. The magnitude of S_{11} decreases with the increase of the operating frequency. The resonant frequencies of the active antenna are correspondingly shifted by the amount of the parasitic parameters, which are caused by the transistor parameters and the layer of the active antenna. The parasitic components of the circuit pattern, printed on the substrate with copper conductors, may affect the resonant frequency, and changing the total length of the antenna. Owing to such structural errors, measured resonant frequencies are shifted from 3.5 GHz to 3.58 GHz and from 4.2 GHz to 4.31 GHz. The shift of the operating resonant frequencies becomes larger at higher operating frequency. These results may be caused by the growing effect of the added impedances at higher frequencies.

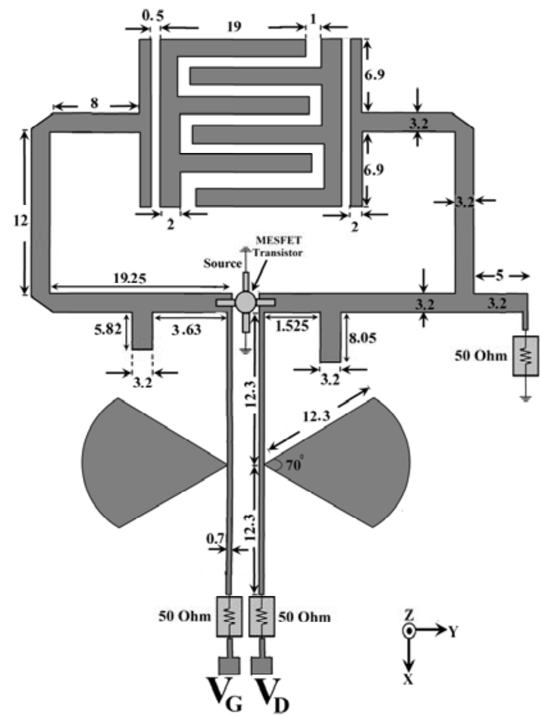

Fig. 6. Configuration of the proposed active integrated antenna with GaAs MESFET.

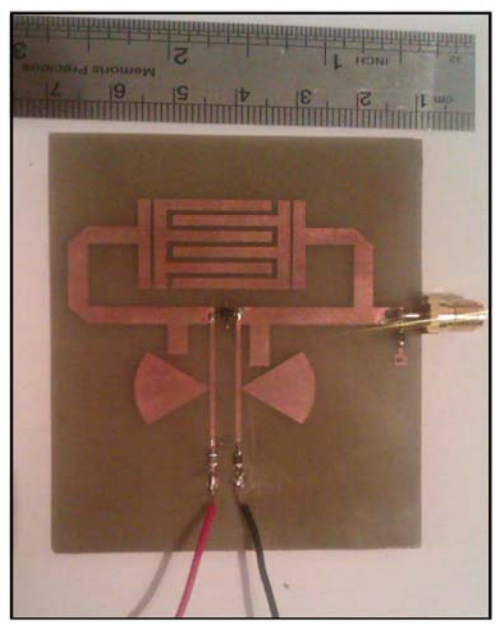

Fig. 7. Photograph of the realized active integrated antenna.

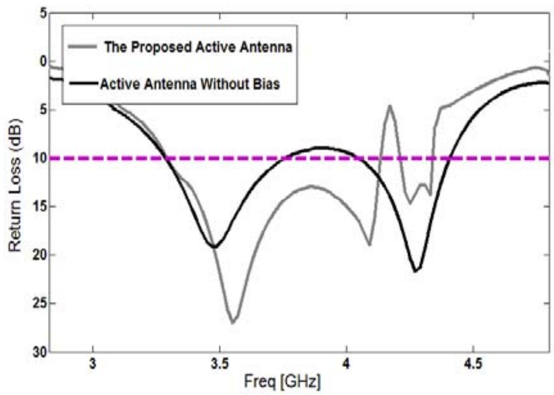

Fig. 8. Measured return losses of the active integrated antenna and the passive antenna.

The simulated radiation patterns including the co- and cross-polarizations for the E-plane (y-z plane) and H-plane (x-z plane) at the resonance frequencies are shown in Fig. 9. The simulated radiation patterns are calculated by using the gap-source technique with the commercial EM simulator HFSS, considering the complete active feedback antenna, which has same layout, except with an active transistor [9]. The received cross-polarizations in the E- and H-planes of the AIA are approximately 17 dB and 14 dB lower than the maximum co-polarized radiation, respectively. As seen in Fig. 3, the radiation pattern in the H-plane is asymmetrical due to the asymmetrical presence of the distributed oscillator-feedback circuitry. The obtained gain by the amplifier is of 11.2 dB. The designed feedback-antenna oscillator has stable oscillation and a clear spectrum at the frequency of 3.54 GHz, which is only a 0.2 % deviation from the design frequency.

Figure 10 shows the radiated output power from the fabricated active integrated antenna for the previously mentioned biasing conditions measured in anechoic chamber. The implemented oscillator exhibited output power level -33.09 dBm at frequency of 3.488 GHz. 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.

V. CONCLUSION

As presented above, the AIA is an interesting subject for WiMAX applications. In this paper, an active integrated antenna using an interdigital coupling strip antenna, are presented. In the proposed structure, based on electromagnetic coupling (EC), an interdigital coupling strip in the microstrip transmission line is used to perturbs two resonance frequencies at 3.5 GHz (WiMAX) and 4.2 GHz (C-band). The amplifier design based on the AIA concept has been shown to provide an efficient and successful method for designing high efficiency and compact systems. The obtained gain by the amplifier is 11.2 dB. The designed feedback-antenna oscillator has stable oscillation and a clear spectrum at the frequency of 3.54 GHz, which is only 0.2 % deviation from the design frequency.

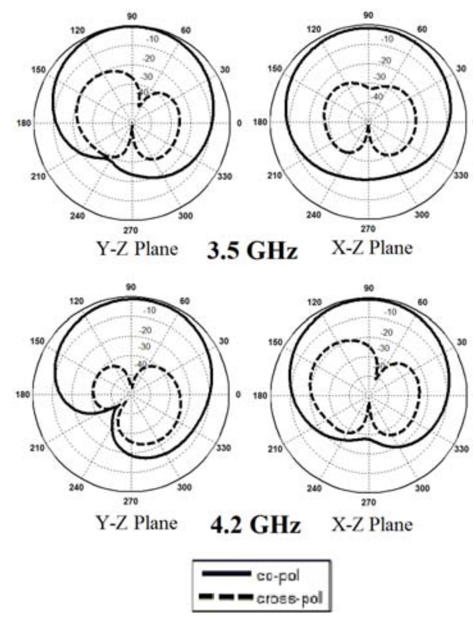

Fig. 9. simulated radiation patterns of the proposed antenna.

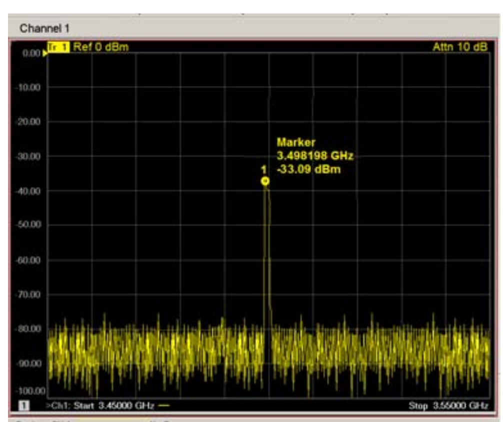

Fig. 10. Measured output power radiated from the proposed oscillator at 3.5 GHz.

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