Frequency and Beam Reconfigurable Antennas for MMMB Communication Systems

Chang Won Jung

Graduate School of NID Fusion Technology, Seoul National University of Science and Technology, 172, Seoul, Korea
changwoj@snut.ac.kr

Abstract

In this paper, four reconfigurable antennas are presented for multi-mode multi-band (MMMB) communication systems. Each antenna is able to reconfigure diverse operational frequency bands or beam directions depending on the states of embedded switches, which are implemented using pin diodes or RF-microelectro-mechanical system (RF-MEMS) switches.

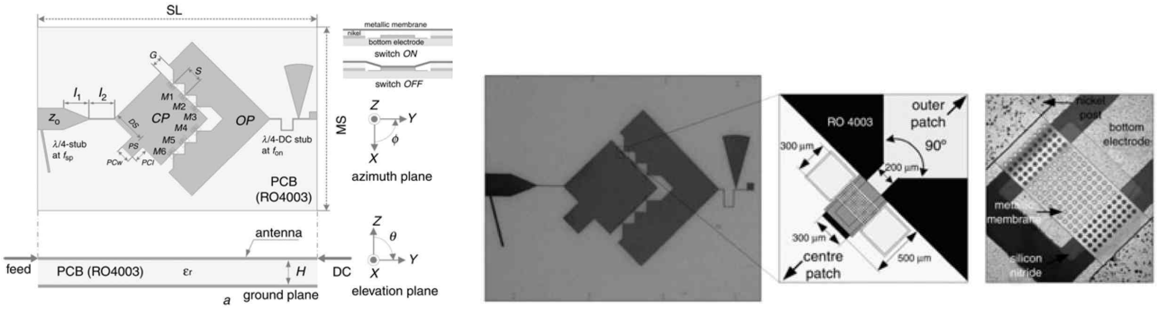
Keywords : Frequency Reconfigurable Antenna (FRA), Beam Reconfigurable Antenna (BRA), Multi-Mode Multi -Band (MMMB), RF-MEMS switch, PIN doide, Varactor

1. Introduction

The development of an antenna operating over multiple frequency bands of diverse communication services has been one of the main issues in multi-mode and multi-band (MMMB) RF systems [1-2]. Single antenna elements with single feed port that can operate over multiple frequency bands have mainly been implemented using wideband or multiband antenna techniques [1-2]. However, those antenna techniques have low radiation efficiency inherently compared with the single antenna element for single band operation[1-2]. Also, wideband antennas generally have higher-mode beams within operational frequency bands, and it is not desired in omni-directional communication environments [2]. To cover multiple frequency bands with better radiation efficiency and with better radiation pattern, frequency reconfigurable antennas have recently been introduced even though they suffer from radiation losses by using RF switches, such as diodes, FETs, and MEMS (micro electro mechanical system) switches [3-6]. In other issues of the antenna segment, the wireless systems include a large number of techniques that attempt to enhance the received signal, suppress all interfering signals, extend beam coverage, and steer multiple beams [3]. Methods of the improving those performances are usually categorized as using the adaptive array antenna or the switchable single antenna element [3-4]. Recently, the size of the adaptive array antenna has to be reduced due to the space limitation of the mobile applications, and actually it is difficult to realize. Therefore, the switchable single element antenna with beam steering capability is required for the practical implementations [3-4]. Also, the single antenna element is more suitable for integrating into small mobile devices since the method has advantage of simplicity, small size and easy radiation handling [3-4]. In this paper, we present four reconfigurable antennas for multi-mode multi-band (MMMB) communication systems [4-6]. Two frequency reconfigurable antennas (FRA) have been designed using RF-MEMS switches and diodes for the military and the commercial applications. Also, two beam reconfigurable antennas (BRA) have also been introduced. Each antenna can reconfigure diverse beam directions depending on the state of embedded switches.

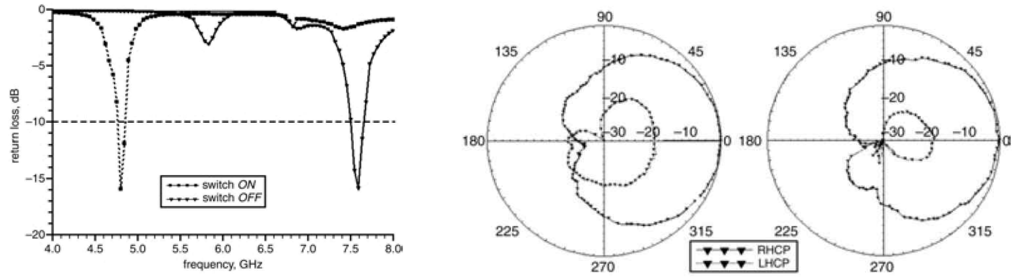
2. Frequency Reconfigurable Antennas

The topology of the first FRA based on a patch antenna with MEMS switches is shown in Figure 1 (a) [5]. The substrate is chosen to be Rogers's RO4003. Six MEMS switches (M1-M6) switches are used to connect two patches (CP and OP). When the metallic membrane is in down-state (switch ON state), resulting in an increase of the effective aperture and thus providing a lower frequency of operation, 4.8 GHz. On the other hand, a higher frequency of operation, 7.6 GHz, is achieved when the metallic membrane is in up-state (switch OFF state). The capacitive series MEMS switches with a bridge structure are used as shown in Fig. 1 (b). The pull-down voltage of the MEMS switch is about 30 V. Fig. 2 (a) shows the measured return loss for the reconfigurable patch antenna with the MEMS switches. The return loss is less than 10 dB at both frequency bands, 4.8 and 7.6 GHz. The measured radiation patterns are shown in Fig. 2.(b). In both switch ON and OFF states, the axial ratio is less than 3 dB in the main direction. The measured peak gain is 6.6 dBi at 4.8 GHz (ON state) and 5.5 dBi at 7.6 GHz (OFF state).



(a) (b)

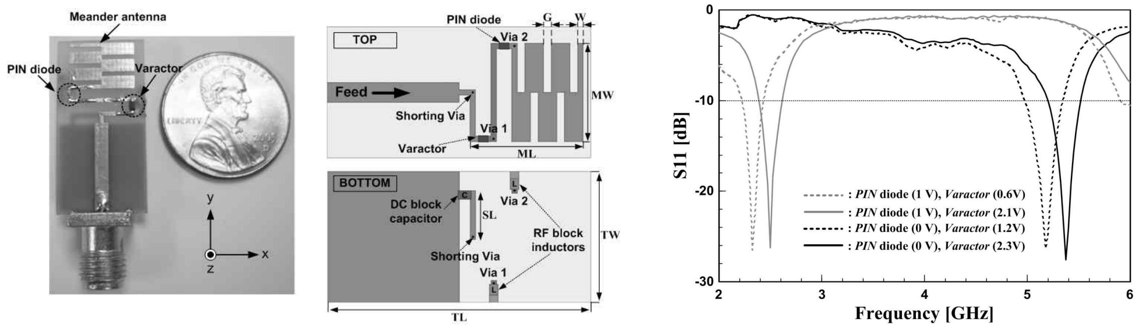
Figure 1: (a) Geometry of reconfigurable patch antenna, (b) Photograph of fabricated antenna prototype and RF-MEMS switch



(a) (b)

Figure 2: (a) Measured return loss of antenna with RF-MEMS switches, (b) Radiation pattern (y-z plane; elevation plane) of antenna with RF-MEMS switches

In the case of the second FRA, a PIN diode and a varactor are incorporated into the meander antenna for the macro-micro frequency tuning [6]. The photograph of the proposed antenna and the geometries of the top/bottom sides are also schematically shown in Figure 3 (a). The antenna is printed on an FR-4 substrate. The overall dimension of the radiator is approximately ML = 10 mm x MW = 8 mm. The measured reflection coefficients (S11) of the antenna are shown in Figure 3 (b). The figure shows the macro-micro frequency tuning capability of the antenna. The PIN diode in the antenna is used for the wide range tuning of operation frequency (macro-tuning) between wireless service bands of WiBro and WLAN applications, 2 and 5 GHz. When 0 V is applied to the PIN diode (*off*-state), the antenna operates at high frequency band, 5 GHz. When 1 V is applied to the PIN diode (*on*-state), the antenna operates at low frequency band, 2 GHz. The varactor in the antenna is used for the narrow range tuning of frequency (micro-tuning) between channels in each service band (2.3 ~ 2.5 GHz or 5.15 ~ 5.35 GHz). By using the varactor, the antenna can constantly tune the operation frequency from 2.3 GHz to 2.5 GHz for the *on*-state of the PIN diode and from 5.15 GHz to 5.35 GHz for the *off*-state of the PIN diode. It is also noted that the bandwidth of the antenna is immune to the varactor tuning and the on/off conditions of the PIN diode.

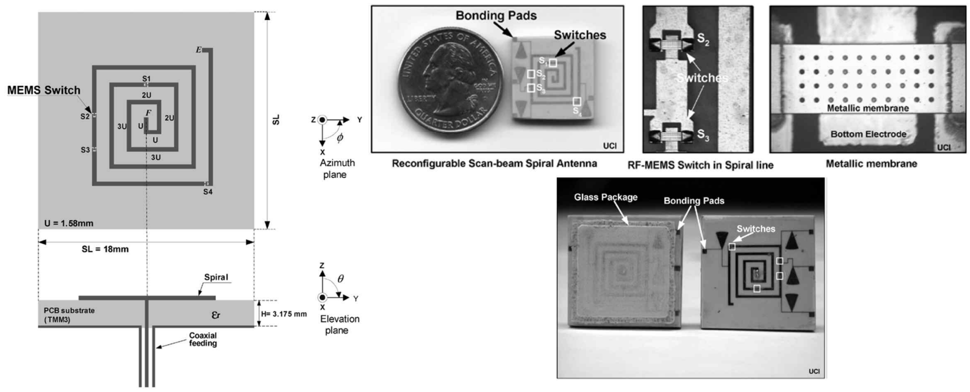


(a) (b)

Figure 3: (a) Proposed macro-micro frequency reconfigurable antenna, (b) Measured reflection coefficients (S11)

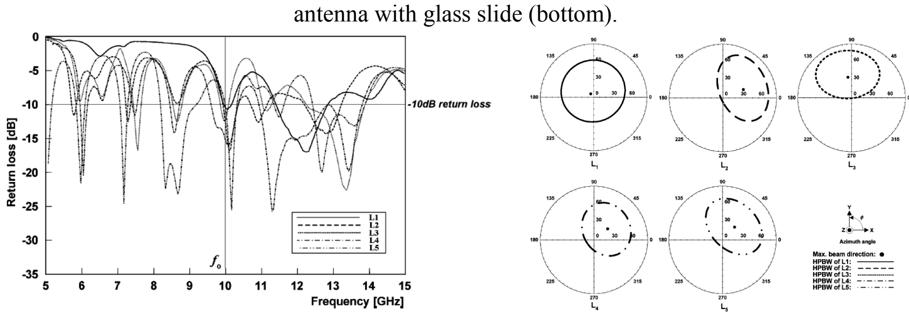
3. Beam Reconfigurable Antennas

The topology of the first BRA based on a single-arm rectangular spiral antenna integrated with RF-MEMS switches is shown in Figure 4 [4]. The spiral antenna consists of five sections that are connected with four RF-MEMS switches ($S_1 \sim S_4$). The spiral arm lengths ($L_1 \sim L_5$) is determined as the distance from the feeding point, F, to the last RF-MEMS switch in the off state ($S_1 \sim S_4$). The location of switches has been determined such that the axial ratio and gain of the antenna are optimum at operation frequency, 10 GHz [4]. The antenna we propose in this paper can provide five different radiation directions using four RF-MEMS switches. The optimum spiral arm lengths ($L_1 \sim L_5$) are obtained from the plot of axial ratio and gain at the maximum beam direction for the desired polarization (RHCP) [4]. The return loss of the antenna measured using a vector network analyzer in the frequency band from for different arm lengths as shown in Figure 5 (a). The return loss is below 10 dB at the operating frequency (10 GHz) for any of the selected spiral lengths. The half power beam width (HPBW) area and maximum beam direction of the spiral lengths ($L_1 \sim L_5$) in the vertical direction of the azimuth angle is presented in Figure 5 (b). Summary of maximum beam direction, axial ratio, gain and HPBW of selected spiral arm length (L1 ~ L5) are shown in table 1.



(a) (b)

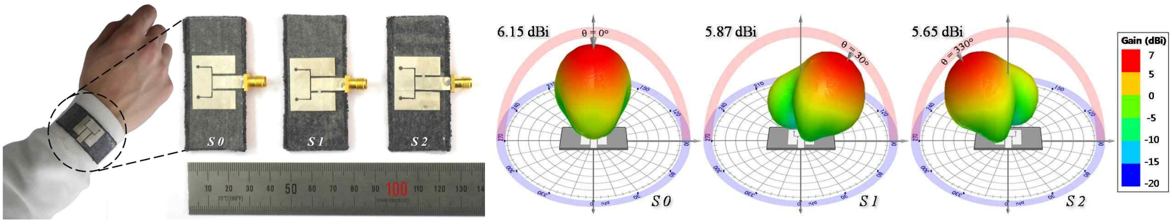
Figure 4: (a) Top and side view of spiral configuration and its feeding, (b) Spiral antenna with its dc biasing network (upper left), microscopic picture of the fabricated RF-MEMS capacitive switch (upper center and right) and the packaged antenna with glass slide (bottom).



(a) (b)

Figure 5: (a) Measured return losses of each spiral arm lengths, L1 ~ L5, (b) Measured half power beam width area and maximum beam direction in the vertical direction of the azimuth angle

The photograph of the fabricated second BRA (*S0, S1, S2*) and the antenna mounted on the human-wrist are shown in Figure 6 (a). The overall dimension of the antenna patch is 23.8 x 21.4 mm^2. The conductive part of the antenna is manufactured by the silver-paste. The antenna consists of an antenna patch part and an indirect transmission-line part. The antenna is fed by an indirect, and isolated from the transmission-line on the same plane. The antenna patch and indirect feed are designed to connect by using two artificial switches. The switch in ON-state means that the conductive line is connected between the indirect feed and the antenna patch (short). Also, the switch in OFF-state means that the conductive line is disconnected (open). There are three states (*S0*, *S1*, *S2*) by the configuration of two artificial switches. *S 0* denotes that both switches (1) and (2) are in OFF-state. *S 1* denotes only switch (1) is in ON-state, and *S 2* denotes only switch (2) is in ON-state. Figure 4 shows the simulated 3D radiation patterns (yz-plane). Summary of maximum beam direction, peak gain and HPBW by switch states are shown in table 2. The antenna structure is designed and analyzed using 3D EM field simulation tool, the SEMCAD X and HFSS [7].



(a) (b)

Figure 6: (a) The photograph of the fabricated antenna of each state (*S 0*, *1*, *2*) and the antenna mounted on the human-wrist, (b) Simulated 3D radiation patterns (*S 0*, *1*, *2*)

4. Conclusions

In this paper, four reconfigurable antennas are presented for MMMB communication systems. The first FRA using RF-MEMS switches capable of changing the frequency of operation while maintaining RHCP radiation with high frequency ratio (1.6:1) is presented. The antenna can be used in applications requiring frequency diversity with a high frequency ratio of the circularly polarized wave. The macro-micro frequency tuning antenna as the second FRA provides broad and fine frequency tuning capability at the same time. This *Macro-micro* tuning technology opens up the possibility of designing more efficient frequency reconfigurable antenna systems. Also, the first BRA provides steering beam capability using a single arm rectangular spiral. The antenna is fully integrated with MEMS switches fabricated in the same substrate. In addition the second BRA using a patch antenna with U-slot is introduced. It is found that operation frequencies of all the states (*S 0*, *1*, *2*) are identical, and overall HPBW of three states is 115°. This BRA using single patch antenna designed on the fabric substrate which is proven capability of integration with clothing.

Table I

Summary of maximum beam direction, axial ratio, gain and HPBW of selected spiral arm length (L1 ~ L5)

Spiral Arm Length	L/λo	Max. beam direction (degree)		Gain (dBi)	Axial ratio (dB)	HPBW (degree)
		Theta (Θ)	Phi (Φ)			
L_1	0.9	7	104	4	2.1	102
L_2	2.4	36	18	5.2	1.9	78
L_3	2.35	32	93	4.2	1.9	79
L_4	3.1	32	36	6.1	2.3	73
L_5	3.4	30	43	5	2	76

Table II

Summary of maximum beam direction, peak gain and HPBW by switch states (S0, S1, S2)

States		Max. beam direction (°)		Peak gain (dBi)	HPBW (°)
		Phi (Φ)	Theta (θ)		
S 0	SW (1): OFF SW (2): OFF	0	0	6.62	60
S 1	SW (1): ON SW (2): OFF	90	30	6.69	55
S 2	SW (1): OFF SW (2): ON	270	331	6.11	65

References

[1] Y. Shin, B. Kim, W. Kwak, and S. Park, "GSM/DCS/IMT-2000 triple-band built-in antenna for wireless terminals", IEEE Antennas Wire. Propag. Lett., Vol. 3, pp. 104–107, 2004

[2] M.J. Ammann and Z.N. Chen, "Wideband monopole antennas for multi-band wireless systems", IEEE Antennas Propag. Mag., pp. 146–150, 2003

[3] G.H. Huff and J.T. Bernhard, "Integration of packaged RF MEMS switches with radiation pattern reconfigurable square spiral microstrip antennas", IEEE Trans. Antennas Propag., Vol. 54, pp. 464-469, 2006

[4] C. Jung, M. Lee, G.P. Li and F. De Flaviis, "Reconfigurable scan-beam single-arm spiral antenna integrated with RF-MEMS switches", IEEE Trans. Antennas Propag., Vol. 54, pp. 455-463, 2006

[5] C. Jung, M. Lee and F. De Flaviis, "Reconfigurable Dual-Band Antenna with High Frequency Ratio (1.6:1) using MEMS Switches", IET Electronics Letters, vol. 44, Issue 2, pp.76-78, 2008

[6] C. Jung, Y.J. Kim, Y. E. Kim, and F. De Flaviis, "A Macro-micro Frequency Tuning Antenna for the Reconfigurable Wireless Communication Systems", IET Electronics Letters, vol. 43, Issue 4, pp. 201-202, 2007

[7] SEMCAD X by SPEAG, www.speag.com

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