Reconfigurable RF-MEMS Antennas

— Frequency and Polarization Tuning Technologies —

[#]Kazushi Nishizawa, Kyosuke Mochizuki, Yasuhiko Urata, Tamotsu Nishino,
Tatsuhiko Suzuki, Hiroaki Miyashita, Yoshihiko Konishi,
and Takashi Katagi
Mitsubishi Electric Corporation
325, Kami-machiya, Kamakura, 247-8520 Japan
Nishizawa.Kazushi@dp.MitsubishiElectric.co.jp

Abstract

This paper presents two types of reconfigurable RF-MEMS antennas, which are loaded in part with switches. The former antenna is capable to operate at multiple frequencies by changing its patch size. The latter can switch between orthogonal dual-polarization by changing slotted shape on it. The feasibility and effectiveness of these antennas are verified by experimental results.

Keywords : Reconfigurable Antennas RF-MEMS Switch Frequency Tuning Polarization Tuning

1. Introduction

Reconfigurable antennas with tunable performances for various applications (e.g., communication and radar systems) have been studied by many research organizations in the first decade of this century [1], [2]. These antennas generally have switching functions in order to change the antenna size and structure. As known RF switches, there are PIN diodes, FET, RF-MEMS switches, and so on. Among them, the RF-MEMS switches especially can be integrated with the antenna as a monolithic unit by using a MEMS process. These also have advantages as low power consumption and low transmission losses. Accordingly, the reconfigurable antennas with the RF-MEMS switches (called "reconfigurable RF-MEMS antennas" or "RRMAs") are excellent in not only having the high performances but also mass production and cost reduction.

In the research and development of RRMAs, RECAP (REConfigurable Aperture Program) project contributed greatly [3]. The project was carried out by DARPA (Defense Advanced Research Projects Agency) from 1999 to 2002. The RRMA in [3] has an ultimate structure. In short, because it is composed of the set of conductor fragments, which are interconnected electrically through the RF-MEMS switches, its performances can be arbitrarily tuned by changing the state of the switches. However, because of the complex structure, there are a lot of problems which should be overcome in order to design it actually. This is why various wired antennas and patch antennas provided with the switches have been examined due to their easy structure after 2003 when RECAP ended [4], [5]. By the way, as the tunable technologies of RRMAs, there are the following three types: namely, a frequency tuning (FT), a beam scanning (BS), and a polarization tuning (PT). FT and BS technologies can serve a frequency band expansion and multiple directions of scanning in radar systems, respectively. On the other hand, PT contributes toward improving target identification performances in radar and quality of communication services. Since the number of researching RRMAs with FT is more than that of BS, FT is a higher feasible technology. Additionally, because reported examples of PT are very few, PT is a challenging technology.

Judging from this trend, we take up two types of tunable technologies, i.e., FT and PT. At first, our aim is the feasibility study of the RRMA with the RF-MEMS switches made in MELCO. The RRMA with FT, which can operate at multiple bands by changing its size, is suitable patch antenna to reach the goal. The second aim of this study is to challenge the development of a new PT technology including our original idea. In a patch antenna with a "U"-shaped slotted line, this technology can achieve the switching between dual orthogonal-polarization by turning the direction of "U" around electrically.

In this paper, the above two RRMAs are actually manufactured in the MEMS process, and the results of the experiments are described to verify those feasibility and effectiveness. The

geometry and design of the RRMA with FT are described in Section 2, and those of the RRMA with PT in Section 3, respectively. In each section, the measurement results of a prototype are also presented. In addition, the detail of the RF-MEMS switch used here is described in Section 2.

2. Frequency Tunable Patch Antenna

2.1 Geometry and Operating Principle

The geometry of the RRMA with FT is shown in Fig. 1. Each strip conductor is arranged in symmetry on both sides along the E-plane of the patch antenna and it is connected to the main body of antenna with multiple RF-MEMS switches at even intervals. As a fundamental operation, the effective resonant length of the patch antenna changes by switching the state of ON/OFF, and then the operating frequency changes electrically. Especially, this antenna can have a lot of operating frequency bands corresponding to the number of combinations between ON and OFF states.

2.2 RF-MEMS Switch

Here, we explain the details of the RF-MEMS switch which is loaded on RRMAs. Figure 2 shows the structure of the switch. It is adopted a cantilever structure to share the RF signal and the DC control signal lines, and also all parts of it are composed of the metal [6]. According to these structural features, it can be miniaturized and be loaded on the antenna. Additionally, the contact point and the cantilever have a characteristic of the same electrical potential and then there is almost no current flow on them. From this, the power consumption of this switch is extremely low. As taking notice, it is necessary that the RF signal does not pass through a bias line side to satisfy undesired radiation free. The plans for achieving it are described later.

2.3 Measurement Results

The prototype of the frequency tunable patch antenna was fabricated on a high-resistant Si wafer (ε_r = 11.9) in the MEMS process. Figure 3 shows the SEM photograph of the antenna structure before assembly. In order to suppress the decrease in the antenna performances, the bias lines, which supply the DC voltage to the pull-down electrode, are arranged to be orthogonal in the internal electric field of the antenna. Figure 4 shows examples simulated and measured |S11| of the antenna. The simulated resonant points at the frequency range correspond to the measured points. Consequently, the FT technology with MELCO-built RF-MEMS switches was established.

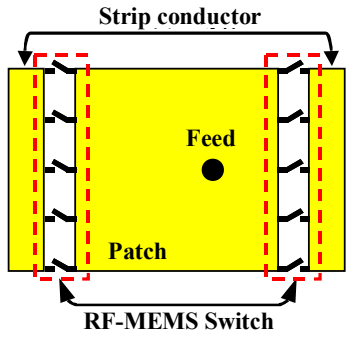

Figure 1: Geometry of the RRMA with FT.

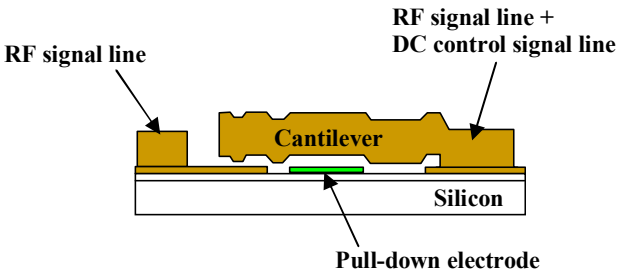

Figure 2: Geometry of the RF-MEMS Switch.

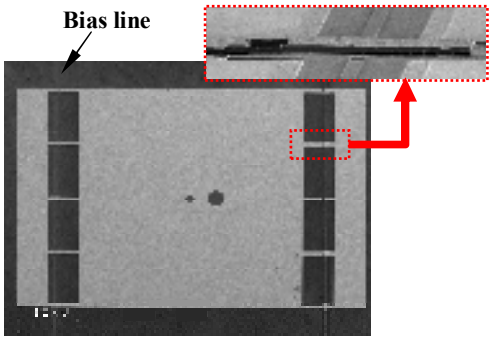

Figure 3: SEM Photograph.

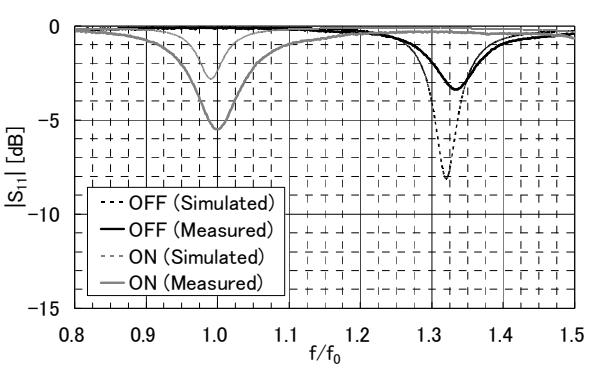

Figure 4: Simulated and Measured |S11|.

3. Polarization Tunable Patch Antenna

3.1 Geometry and Operating Principle

The geometry of the proposed polarization tunable patch antenna (RRMA with PT) is shown in Fig.5. A square, loop-shaped slotted line is arranged in the center of the square patch conductor, and therefore the patch conductor is divided into internal and external sections. RF-MEMS switches are mounted in the areas enclosed by the dotted circles shown in Fig. 5. In two apexes of the square line except those apexes with the switches, one apex is short-circuited between the internal and external conductors, the other is opened. When one switch is ON-state and the other is OFF-state, the U-shaped slotted line is formed on the patch conductor. When the RF signal is fed through feed pins, which is located at the center of the conductor, from the backside of the ground plane, the RRMA operates as a U-slotted patch antenna with the linear polarization performance.

For example, when Switch 1 (SW#1) is ON and Switch 2 (SW#2) is OFF, the U-shaped slotted line can be considered as open along the y-axis, as shown in Fig. 6 (a). In this case, the antenna radiates a linear polarization along the y-axis. Conversely, when SW#1 is OFF, and SW#2 is ON, the slotted line becomes transverse, and the linear polarization is radiated along the x-axis, as shown in Fig. 6 (b). However, when both switches are ON or OFF, it does not operate because the U-shaped line is not formed. Accordingly, when both switches change alternately their state electrically, the patch antenna becomes possible to switch between orthogonal dual-polarization without mechanically rotating itself. And furthermore, because the length of the slotted line between the edges on the open-side of the U-shaped line is shorter than the wavelength, the unwanted resonance does not occur from the slotted line at the operating frequency.

3.2 Antenna Design

The proposed RRMA is molded on the same Si wafer as shown in Section 2 (see Fig. 7). This antenna has some structural features. The patch conductor and the loop-shaped slotted line are squares to give the same performance between orthogonal dual-polarization. The same RF-MEMS switches as the one described in Section 2 was used. The number of switches is achieved by the minimal number (2 pieces) from which the antenna performances are not ruined. The bias lines are arranged in the slit on the external patch conductor for its insulation with the patch conductor. They also have the air-bridge structure on the way of them to prevent the conductor from dividing into parts. To avoid the propagation of RF signal into the bias line, an open stub and a single-layer chip capacitor are installed on the way of the line.

3.3 Measurement Results

The measured reflection performances at feed point are shown in Fig. 8. In both conditions described in Figs. 6 (a) and (b), these performances are almost corresponding. It is verified that, when switches do not work, it becomes a total internal reflection. The example of the radiation performances at f in Fig. 8 are shown in Figs. 9 (a) and (b). The former is the E-plane patterns in state of Fig. 6 (a), and the latter is that of Fig. 6 (b). Both patterns are corresponding, and additionally those of the H-plane patterns are also in agreement (These results will be shown at the oral session). As these results, it is confirmed that the function of polarization tuning is successfully realized by RF-MEMS switches operating correctly and with no mechanical rotation of itself. Because the measured and the simulated patterns are also corresponding, it is verified that the prototype is manufactured according to the design.

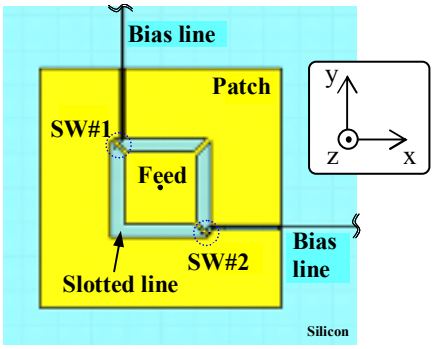

Figure 5: Geometry of the RRMA with PT.

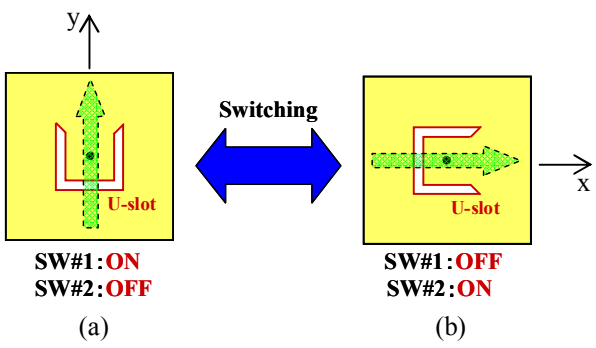

Figure 6: Direction of the Dual Polarizations.

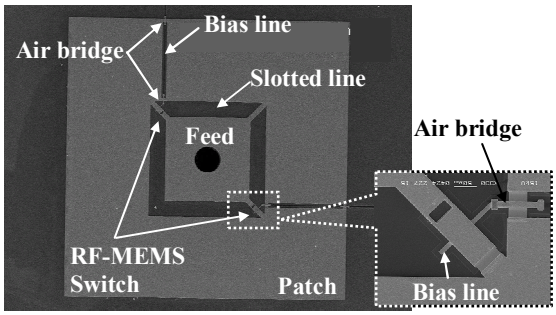

Figure 7: SEM Photograph.

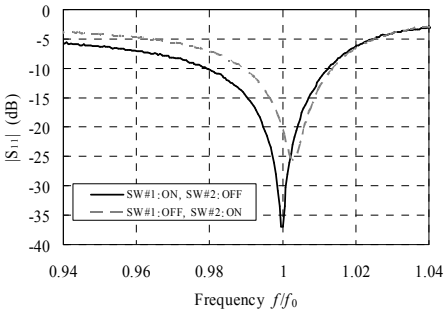

Figure 8: Measured |S11|.

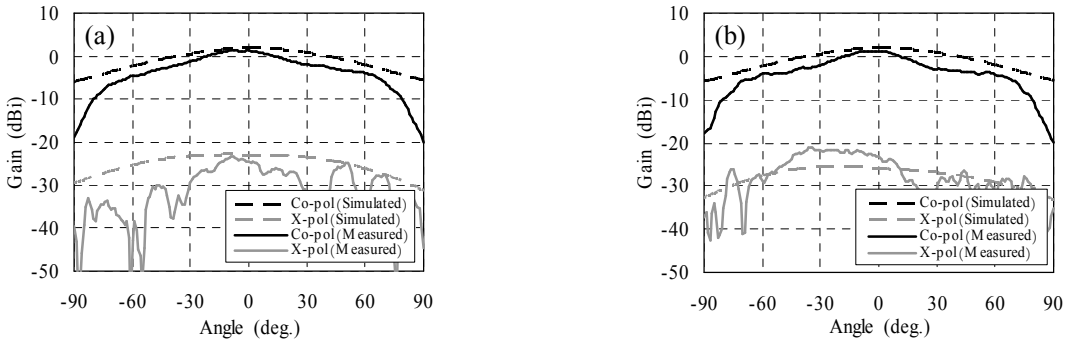

Figure 9: Measured and Simulated Radiation Patterns of E-plane.

4. Conclusion

As reconfigurable antennas which have some switches on the patch conductor, two types of the RRMAs have been proposed and furthermore the feasibility and effectiveness have been confirmed. One is the patch antenna of frequency tuning electrically. Multiple operating frequencies can be achieved with a lot of switches. This is, therefore, suitable for the usages as frequency bands sharing and wideband antennas. The other is the U-shaped slotted patch antenna which is capable of electrical switching orthogonal dual-polarization. Because of this ability, applications to the polarization diversity in communications and polarimetric radar can be expected in the future.

Acknowledgment

The authors would like to thank Dr. Y. Yoshida, Advanced Technology R&D Center, Mitsubishi Electric Corporation, Hyogo, Japan, for his development of the MEMS process.

References

[1] S. Onat, L. Alatan, and S. Demir, “Design of Triple-Band Reconfigurable Mictostrip Antenna Employing RF-MEMS Switches,” Proc. in 2004 IEEE Antennas and Propagation Society International Symposium, Monterey, July 2004.

[2] L. Petit, L. Dussopt, and J. Laheurte, ”MEMS-Switched Parasitic-Antenna Array for Radiation Pattern Diversity,” IEEE Trans. Antennas Propagat. , vol. 54, No. 9, pp. 2624-2631, Sept. 2006.

[3] http://www.ee.ucla.edu/~pbmuri/1999-review/potenziani/index.htm.

[4] D. E. Anagnostou, G. Zheng, M. T. Chryssomallis, J. C. Lyke, J. Papapolymerou, and C. G. Christodoulou, “On the Silicon-etched Reconfigurable Antenna With RF-MEMS Switches,” IEEE Antennas and Propagation Society International Symposium, Washington, July 2005.

[5] Chang won jung, Ming-jer Lee, G. P. Li, and Franco De Flaviis, “Reconfigurable Scan-Beam Single-Arm Spiral Antenna Integrated With RF-MEMS Switches,” IEEE Trans. Antennas Propagat., vol. 54, No. 2, pp. 455-463, 2006.

[6] T. Nishino, M. Miyazaki, Y. Yoshida, and M. Taguchi, “RF-MEMS from DC to Millimeter-wave,” IEEE Mediterranean Electrotechnical Conference 2006, pp. 297-300, 2006.