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Frequency-tunable open-ring microstrip antenna with optimally-positioned varactors for radiated-power *in situ* measurements

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This paper presents a novel frequency-tunable open-ring microstrip antenna for radiated-power measurements in a real environment. In order to elevate the probing up to a few tens of meters, the antenna must have light-weight, narrow-bandwidth, and broad side-beam characteristics. An open-ring microstrip antenna is a good candidate for satisfying these requirements. Varactors are attached to tune the operation frequency, but the conventional position, which is in the vicinity of the ring-opening, shows a much lower gain and poor cross-polarization level. This paper proposes a superior position for the varactors, which is the upper-edge of the left and right sides of the ring. The reflection coefficient (S_{11}) in the simulation and experiment demonstrated that the resonant frequency can be increased by increasing the supply voltage. The proposed tunable antenna can be utilized in the probing apparatus to measure the radiated power.

1. Introduction

As wireless communication services with low radiation power are developed, the restriction of high-power radiation devices and facilities, such as base stations, satellite stations, and digital broadcasting stations, is becoming increasingly important [1]. Currently, the electromagnetic field strengths are measured near the ground in order to protect the worker from exposure to the base stations [2,3]. The exact heights are 1.1 m, 1.5 m, and 1.7 m in [3]. Meanwhile, equivalent isotropically radiated power (EIRP) [4] is recommended to protect the other wireless communication devices and facilities by restricting the radiated power from high-power microwave stations [5,6].

Fig. 1 shows a sketch of a measurement system of EIRP parameters in a real environment; the system comprises a probing apparatus, motor-driven elevating support, motion device, and controlling computer. The probing apparatus is mounted on the elevating support, and the detector and battery are integrated together with the antenna.

For the *in situ* measurements, as sketched in Fig. 1, the near-field or Fresnel field measurement method [7,8] is recommended in order to avoid the multi-path effect. Additionally, the EIRP is related to the maximum radiated power to be measured. Therefore, the probing apparatus should be elevated up to a few tens of meters, which requires a light-weight antenna. A broadside beam is also necessary in order to minimize errors from the alignment, as shown in Fig. 1. For these requirements, an open-ring microstrip antenna is a good candidate [9,10].

To measure the selected frequency channel in spite of interference from another microwave station, two solutions can be considered. One is to use a multi-band antenna, as reported in [11], and to select the desired frequency channel using a spectrum analyzer. However, this solution requires a long RF-cable running from the ground to the probing apparatus. The other solution is to use an antenna with a narrow bandwidth and to tune the frequency. A probing apparatus adopting this frequency-tunable antenna does not need a long RF-cable or spectrum analyzer, and thus the measurement system is easy to install and operate in a real environment.

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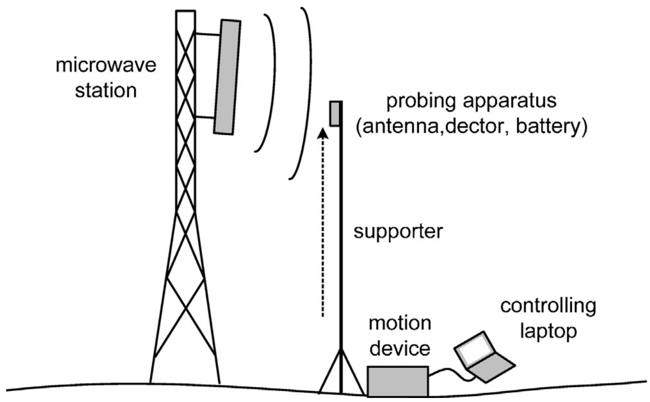

Fig. 1. Sketch of an measurement system of EIRP in a real environment.

To achieve the frequency-selective characteristics, a significant amount of research on the frequency-tuning of antennas has been reported. Research indicates that a technique using a voltage-tuning varactor has certain advantages, including easy integration and a low bias level [12,14]. This frequency-tuning can be understood in terms of capacitance loading [12]. The conventional position of a varactor is the end of the microstrip [13,14]. However, when this position is applied to open-ring geometry, the gain is quite low, as will be discussed later.

This paper presents a novel frequency-tunable open-ring microstrip antenna for radiated-power *in situ* measurements. In particular, the optimum position for the varactor has been proposed.

2. Antenna geometry

Fig. 2 shows the geometry of the varactor-loaded open-ring microstrip antenna. The square ring has sides measuring $L = 12$ mm, with a uniform width of $W = 2$ mm. This dimension of 12 mm × 12 mm is only 2.6% of the square patch, which has a lateral length of 75 mm at 1.3 GHz, and is smaller than that of the configuration proposed in [13,14]. The gap between the two ends of the ring is $S = 1$ mm. The ring is printed on a dielectric layer with a relative permittivity of $\varepsilon_r = 2.2$ and a thickness of 0.508 mm. A 5.0-mm-thick air layer is placed between the ground plane and dielectric layer. The ground plane measures 100 mm × 100 mm. The coaxial-feeding pin of a SMA connector is connected directly to the microstrip. The feeding position is offset by 2.3 mm from the center of the ring for impedance matching.

As shown in Fig. 2, one end of the varactor is connected to the ground through a soldering pad and shoring pin. The varactor model is an SMV1231 from Skyworks. Four geometries were investigated to find the optimal location at which to attach the varactor, as shown in Fig. 2(a)–(d). In the previous research [12–14], the varactor is located at the ring-opening as shown in Fig. 2(a), which is a general location that can be universally considered. The varactor location shown in Fig. 2(b) is offset from the ring-opening. Fig. 2(c) shows the location proposed in this paper. The varactor is positioned at the upper-edge of the left and right sides. The fourth position is the middle of the right and left sides, as shown in Fig. 2(d). Fig. 2(e) shows a side view with a DC-feeding configuration using a ZFBT-4R2GW-FT+ bias-tee (Mini-Circuits).

3. Optimum position of the varactor

The simulation was performed using CST software [15]. The varactor was replaced by an equivalent circuit. Because the parallel capacitance is zero, as reported by the vendor, the SMV1231 varactor was first modeled using a series RLC circuit, with a resistor of $R = 2.5\ \Omega$ and an inductor of $L = 0.7$ nH. The series capacitance, C, depends on the DC voltage.

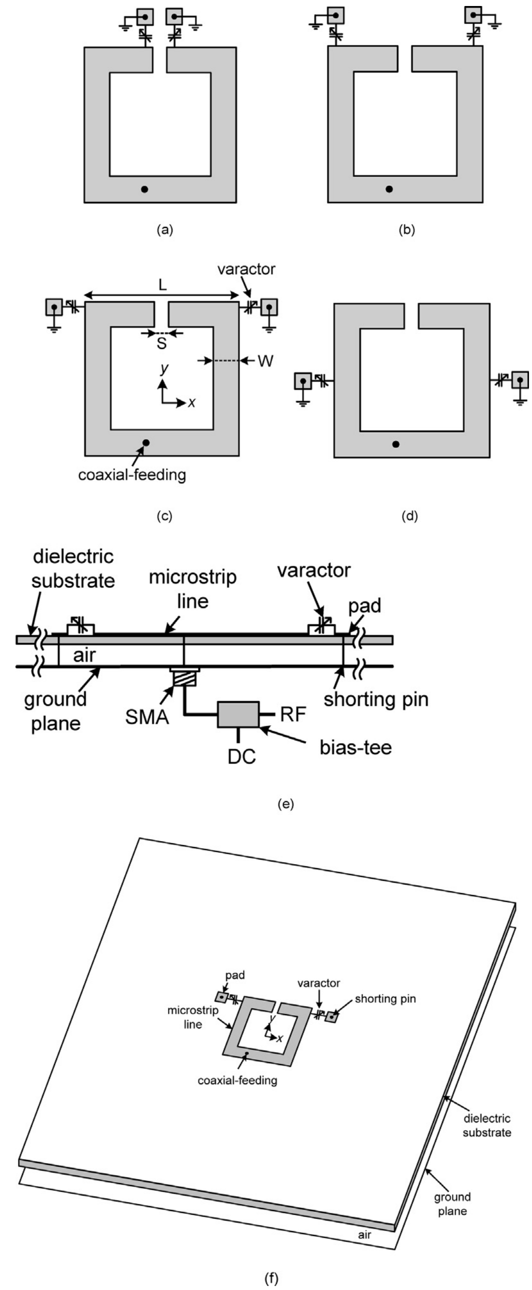

Fig. 2. The varactor-loaded open-ring microstrip antenna with different varactor positions: (a) ring-opening, (b) offset from the ring- opening, (c) upper edge of the left and right sides, (d) middle edge, (e) a side view, and (f) a perspective view.

Fig. 3 shows the simulated reflection coefficient (S_{11}) for different varactor locations. DC feeding voltages of 4 and 10 V are examined, and the corresponding capacitance values are 1.1 and 0.63 pF, respectively. The simulated resonant frequencies for all geometries shift upward as the DC voltage increases from 4 to 10 V.

It is also interesting to note that the resonant frequencies of Fig. 2(a)–(c) are similar, but those of Fig. 2(d) are much higher. The reason can be found in the current distribution, as shown in Fig. 4. The currents only exist between the two varactors, and thus the resonant path of the geometry in Fig. 2(d) is shorter than the others.

Related to the current distribution, Fig. 5, which shows the simulated gain according to the varactor position and DC voltage,