Experimental Study of Sleeve Antennas Using Variable Capacitors

Kengo Nishimoto, Ryosuke Umeno, Nobuyasu Takemura,
Toru Fukasawa, Masataka Ohtsuka, Shigeru Makino
Mitsubishi Electric Corporation
5-1-1 Ofuna, Kamakura-shi, 247-8501 Japan, Nishimoto.Kengo@bp.MitsubishiElectric.co.jp

Abstract

We propose two types of broadband sleeve antennas using variable capacitors. In the sleeve antenna, CRB(Current Rejection Band: the band within which the leakage current on the feeder is suppressed) becomes wider with an increase in the antenna width. Therefore, when the broadband characteristic is required, the sleeve antenna becomes large. In the proposed antennas, CRB can be adjusted by changing the capacitances of the variable capacitors. We show these characteristics by experiments, and broadband impedance adjustments are achieved. The radiation patterns of the proposed antennas almost correspond to that of a half-wavelength dipole antenna.

1. Introduction

A sleeve antenna consists of the monopole with a quarter wavelength and the sleeve conductor covering a coaxial feeder [1], [2]. The monopole and sleeve conductor are connected with the inner and outer conductors of the coaxial feeder, respectively. The sleeve conductor has two functions. One is the radiation of electromagnetic waves, and the other is the rejection of the leakage current on the outside of the outer conductor of the coaxial feeder. The sleeve antenna has no need for an additional balun for unbalanced feed, and its radiation pattern is similar to that of a dipole antenna. Instead of the coaxial feeder, we can use a microstrip line. In this case, the sleeve antenna is constructed on a dielectric substrate [3]∼[5].

The leakage current on the feeder can be suppressed only near the frequency where the length of the sleeve conductor is a quarter wavelength. In the planar sleeve antenna, CRB(Current Rejection Band: the band within which the leakage current is suppressed) becomes wider with an increase in the antenna width [6]. Therefore, when the broadband characteristic is required, the antenna width becomes large. The multi-band sleeve antennas having different lengths of sleeve conductors have been investigated [4], [5], but the sleeve antennas which can make broadband adjustments have not been reported.

To attain the broadband characteristics, we propose two types of planar sleeve antennas having variable capacitors. The sleeve conductors and the ground conductor of the feed line compose coplanar strips lines, and variable capacitors are embedded on the coplanar strips lines in series (series type) or in parallel (parallel type). In the proposed antennas, CRB can be adjusted by changing the capacitances of the variable capacitors. We show these characteristics by experiments, and broadband impedance adjustments are achieved. The radiation patterns of the proposed antennas almost correspond to that of a half-wavelength dipole antenna.

2. Theory

Figure 1 illustrates planar sleeve antennas with variable capacitors. These antennas are fed by microstrip lines, and GND indicates the ground plane of the microstrip line. We assume GND to be infinite to the downside of the figure. The sleeve conductors and GND compose coplanar strips lines. Variable capacitors are embedded on the coplanar strips lines in series (series type) or in shunt (shunt type). Fig.1(a) and Fig.1(b) show the series and shunt type antenna, respectively. When the impedances of the coplanar strips lines are infinite at CC', the leakage current flowing on GND below CC' can be suppressed.

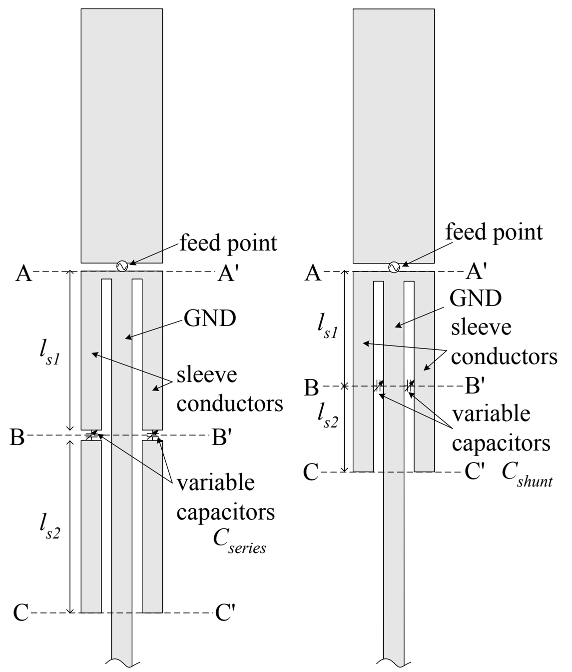
We assume that the coplanar strips lines have no loss. In the series type, to make the impedances of the coplanar strips lines infinite at CC', the capacitance of the variable capacitor is derived as

$$C_{series} = \frac{-\tan(\beta l_{s2})}{Z_0\omega(1-\tan(\beta l_{s1})\tan(\beta l_{s2}))} \tag{1}$$

where l_{s1} is the distance from AA' to BB' and l_{s2} is the distance from BB' to CC'. Z_0 is the characteristic impedance of each coplanar strips line, ω is the angular frequency and k is the wave number. In the shunt type, the capacitance where the impedances of the coplanar strips lines are infinite at CC' is derived as

$$C_{shunt} = \frac{1-\tan(\beta l_{s1})\tan(\beta l_{s2})}{Z_0\omega\tan(\beta l_{s1})} \tag{2}$$

At the desired frequency, the leakage current can be suppressed by changing the capacitances of the variable capacitors according to Eq.(1) or (2). The series and shunt variable capacitors are considered to be the transmission lines which have variable negative length and variable positive length, respectively. Therefore, the sleeve length ($l_{s1}+l_{s2}$) of the shunt type is shorter than that of the series type.



(a) Series type antenna (b) Shunt type antenna

Fig. 1: Planar sleeve antennas using variable capacitors

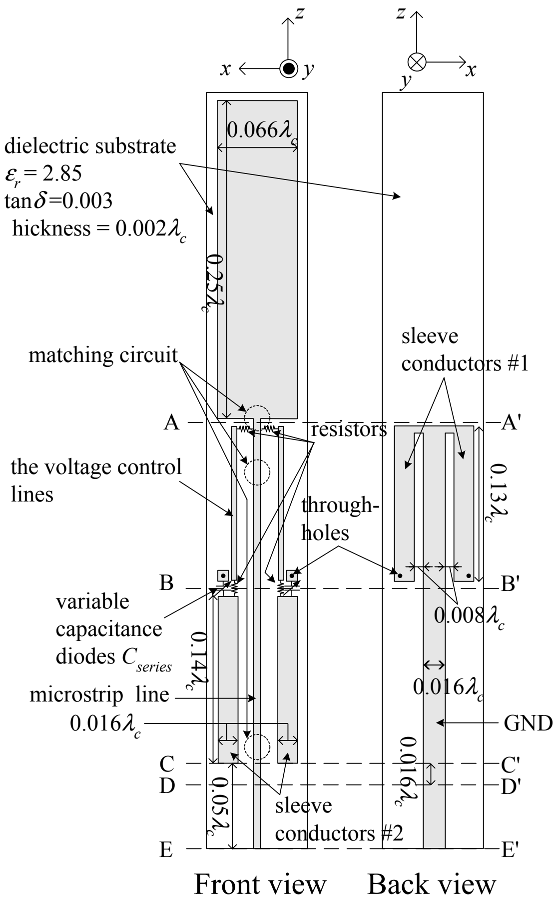


Fig. 2: Experimental model of the series type antenna

3. Series Type Antenna

A. Experimental Model

Figure 2 illustrates the experimental model of the series type antenna. In the figure, λ_c is the center wavelength of a design. The antenna is constructed on a dielectric substrate (ϵ_r = 2.85, $\tan\delta$ = 0.003, thickness = $0.002\lambda_c$). The sleeve conductors are divided into sleeve conductors #1 and #2, and they are connected by variable capacitance diodes. Through-holes connect the diodes and the sleeve conductors #1. The reverse bias voltages of the diodes are fed through the microstrip line. The voltage control lines of the diodes connect the strip conductor of the microstrip line and the sleeve conductors #2. The resistors at both ends of the voltage control lines cut off the high frequency current. The voltage control lines hardly affect the antenna characteristics because it is very close to the sleeve conductors #1.

The experiments are performed on UHF. The antenna illustrated in Fig.2 is set in a dielectric cover. The impedance matching circuit which consists of lumped elements and an open stub is inserted in the antenna.

B. Leakage current

Figure 3 shows the leakage current when the bias V_R changes. In the figure, the vertical axis is $|I_l/I_f|$, where I_l is the leakage current at DD' of GND and I_f is the feed current. And, f_c is the center frequency of a design. The current is measured by a shielded loop antenna. The microstrip line is connected with a coaxial cable at EE'. Then, the coaxial cable is extended to the downside of the figure and gets into the microwave absorbers. Table 1 shows the correlation between the bias V_R and the capacitance C_{series}. In the table, $\omega_c = 2\pi f_c$. Note that the frequency where the leakage current is suppressed increases with V_R in Fig.3. Namely, CRB can be adjusted by changing V_R.

Table 1: Correlation between V_R and C

V_R	C [F]
$0.05V_0$	$0.0195/\omega_c$
$0.12V_0$	$0.0097/\omega_c$
$0.27V_0$	$0.0056/\omega_c$
$0.53V_0$	$0.0029/\omega_c$
V_0	$0.0019/\omega_c$

C. Input Impedances

Figure 4 shows the input impedances at DD'. This figure shows the impedances on the frequency bands where the leakage current is almost suppressed. Note that VSWR<2.2 is achieved from $0.76f_c$ to $1.24f_c$ (48% bandwidth). When V_R increases (C_{series} decreases), the resonant frequency of the antenna as well as the frequency where the leakage current is suppressed increases, because the electrical lengths of the

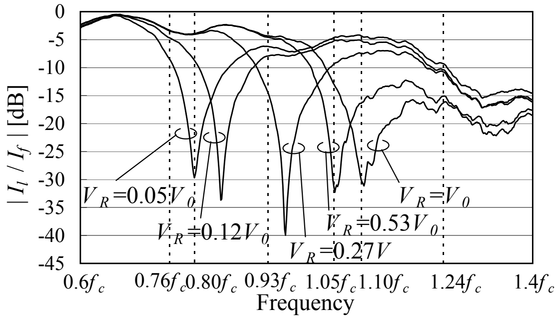


Fig. 3: Frequency versus $|I_l/I_f|$

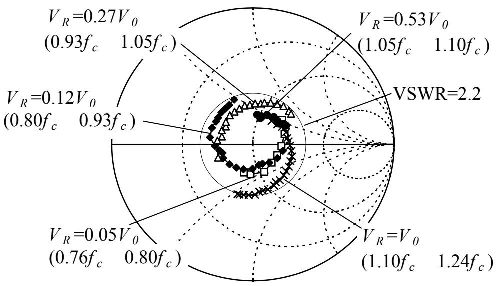


Fig. 4: Measured input impedances at DD' ($Z_0 = 75\Omega$ at the center)

sleeve conductors become shorter. Therefore, the proposed sleeve antenna has an advantage in that the impedance matching is easy to realize even if the desired frequency changes.

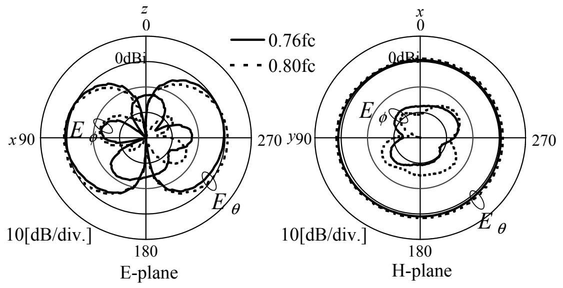
D. Radiation Patterns

Figure 5 shows the measured radiation patterns in E-plane(zx plane) and H-plane(xy plane) at $V_R = 0.05V_0 \sim V_0$. This figure shows the patterns at the frequencies where the leakage current is almost suppressed. We find that these radiation patterns are similar to that of a half-wavelength dipole antenna.

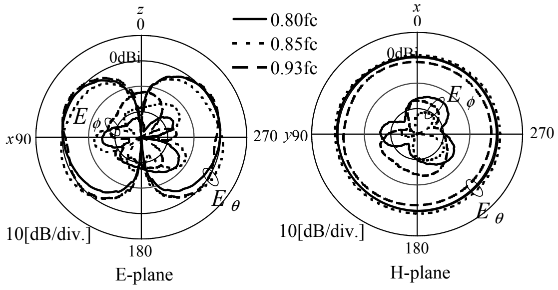
4. Shunt Type Antenna

A. Experimental Model

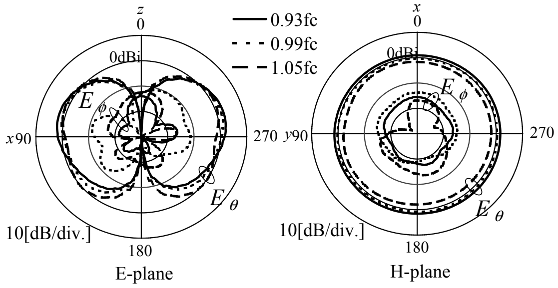
Figure 6 illustrates the experimental model of the shunt type antenna. Shunt variable capacitance diodes are embedded on the coplanar strips lines composed by the sleeve conductors



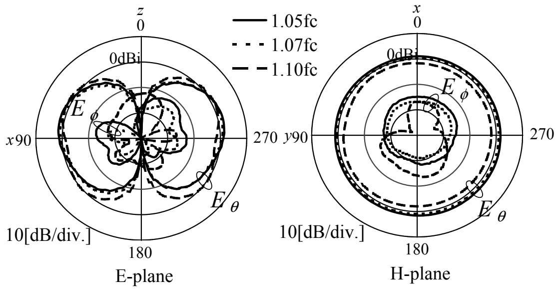
(a) $V_R = 0.05V_0$



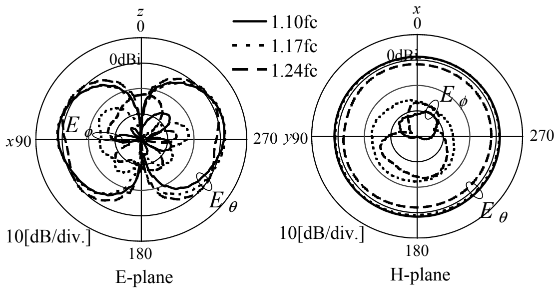
(b) $V_R = 0.12V_0$



(c) $V_R = 0.27V_0$



(d) $V_R = 0.53V_0$



(e) $V_R = V_0$

Fig. 5: Measured radiation patterns

and GND. The diodes are connected to the sleeve conductors and GND by through-holes. The bias voltages of the diodes are fed through the microstrip line. The voltage control lines of the diodes connect the strip conductor of the microstrip line and the diodes. The resistors at both ends of the voltage control

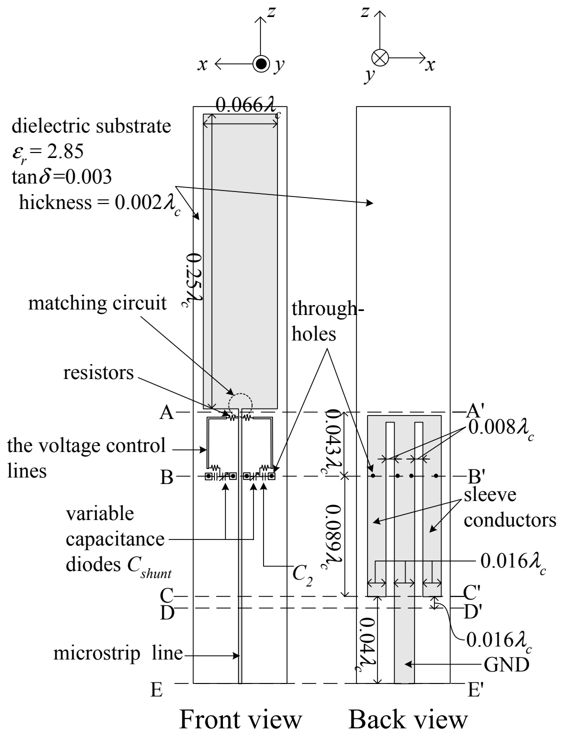


Fig. 6: Experimental model of the shunt type antenna

lines cut off the high frequency current. Moreover, capacitors (C_2) are set for DC cut.

The experiments are performed on UHF. The antenna illustrated in Fig.6 is set in a dielectric cover. The impedance matching circuit which consists of lumped elements is inserted in the antenna.

B. Leakage current

Figure 7 shows the leakage current when the bias V_R changes. In the figure, the vertical axis is $|I_l/I_f|$, where I_l is the leakage current at DD' of GND and I_f is the feed current. The method of measuring the current is the same as the series type. $C_{shunt} = 0.0184/\omega_c$[F] when $V_R = 0.16V_0$, and $C_{shunt} = 0.0042/\omega_c$[F] when $V_R = V_0$. Note that the frequency where the leakage current is suppressed increases with V_R in Fig.7.

The series and shunt variable capacitors are considered to be the transmission lines which have variable negative length and variable positive length, respectively. Therefore, the sleeve length of the shunt type is shorter than that of the series type. On the other hand, in the shunt type antenna, the frequency band where the leakage current is suppressed at a value of V_R is narrower than in the series type. Namely, the shunt type antenna is smaller than the series antenna, however the shunt type needs more switching times of V_R than the series type.

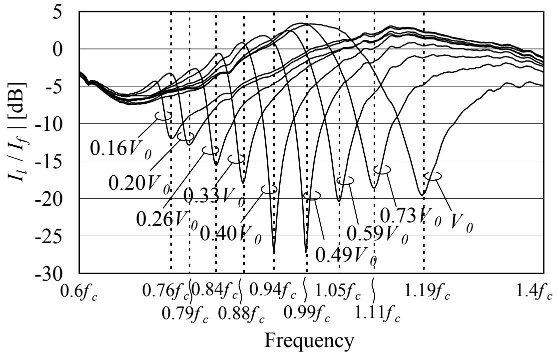
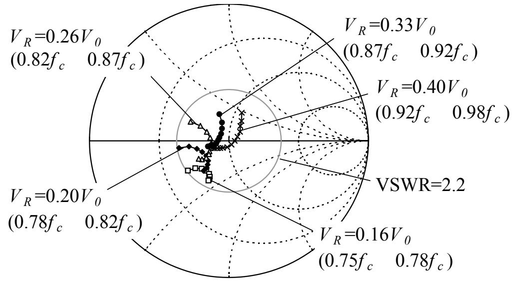
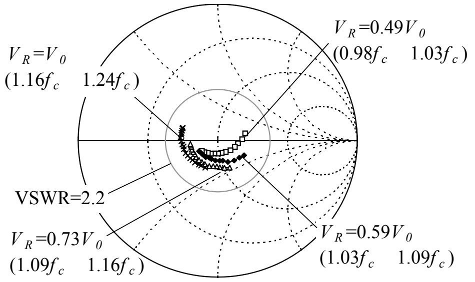


Fig. 7: Frequency versus $|I_l/I_f|$



(a) $V_R = 0.16V_0, 0.20V_0, 0.26V_0, 0.33V_0, 0.40V_0$



(b) $V_R = 0.49V_0, 0.59V_0, 0.73V_0, V_0$

Fig. 8: Measured input impedances at DD' ($Z_0 = 75\Omega$ at the center)

C. Input Impedances

Figure 8 shows the input impedances at DD'. This figure shows the impedances on the frequency bands where the leakage current is almost suppressed. Note that VSWR<2.2 is achieved from $0.75f_c$ to $1.24f_c$ (49% bandwidth). When V_R increases (C_{shunt} decreases), the resonant frequency of the antenna as well as the frequency where the leakage current is suppressed increases. Therefore, the proposed sleeve antenna has an advantage in that the impedance matching is easy to realize even if the desired frequency changes.

5. Conclusions

We have proposed two types of broadband sleeve antennas using variable capacitors. The sleeve conductors and the ground conductor of the feed line composing coplanar strips lines, the variable capacitors are embedded on the coplanar strips lines in series (series type) or in parallel (parallel type). CRB can be adjusted by changing the capacitances of the variable capacitors. We have shown these characteristics by experiments, and broadband impedance adjustments have been achieved. The bandwidths are 48% in series type and 49% in shunt type. The shunt type antenna is smaller than the series antenna, however the shunt type needs more switching times of V_R than the series type. Moreover, the radiation patterns of the proposed antennas are similar to that of a half-wavelength dipole antenna.

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