4) The power absorbed by a human adult standing at a distance of 20 cm from the antenna when its input power is 30 W (140 W) at 90 MHz (27 MHz) is the same as the power that would be absorbed from the exposure to 10-mW/cm^2 plane-wave irradiation.
5) For antennas of height $h>\lambda_0/4$, the current is perturbed quite appreciably from its free-space distribution when in near proximity to a biological body. Also, a nonsymmetric antenna-body configuration produces a nonsymmetric antenna current distribution.
6) The body may act as a director element when placed close to an antenna. This has been demonstrated in the case of an 80-MHz antenna-body system.

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Short Papers

On the Odd-Mode Capacitance of the Coupled Microstriplines

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***Abstract*—This short paper aims to recognize the correct decomposition for the total odd-mode capacitance of the coupled microstriplines and present an improved expression for the gap capacitances. The used procedure utilizes the results which were obtained earlier by the conformal mapping techniques.**

I. Introduction

In recent years, a number of papers have reported the use of single microstripline as an intermediate step for designing coupled microstriplines [2]–[5]. Garg and Bahl [5] successfully used an approach to obtain coupled capacitances by suitably dividing the total capacitance into a parallel plate and fringing ones. The design equations presented by Garg and Bahl [5] are believed to be the most accurate so far. However, in these equations the decomposition of the total odd-mode capacitance is not in accordance with electromagnetic field theory, in that the basic capacitances C_{10} and C_{12} in Fig. 1(a) are not functions of the applied voltage on any of the conductors [1]. Therefore, the even-mode capacitance must appear in the expression for the odd-mode capacitance Fig. 1(b).

II. Calculation of the Odd-Mode Capacitance

The breakup of the odd-mode capacitance into parallel plate fringing and gap capacitances is shown in Fig. 2. The odd-mode capacitance may be written as

$$C_o = C_p + C_f + C_f' + C_{ga} + C_{gd} \quad (1)$$

where C_p, C_f, and C_f' are the same as those given by Garg and Bahl [5]. C_{gd} may be calculated exactly using the results obtained for the corresponding coupled striplines shown in Fig. 3, except

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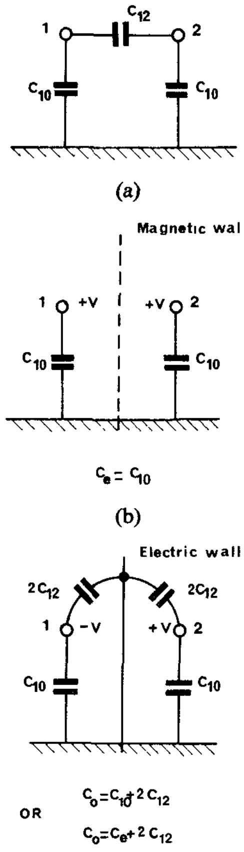

Fig. 1. The equivalent circuits of the symmetrical coupled microstriplines. (a) General. (b) Even mode. (c) Odd mode.

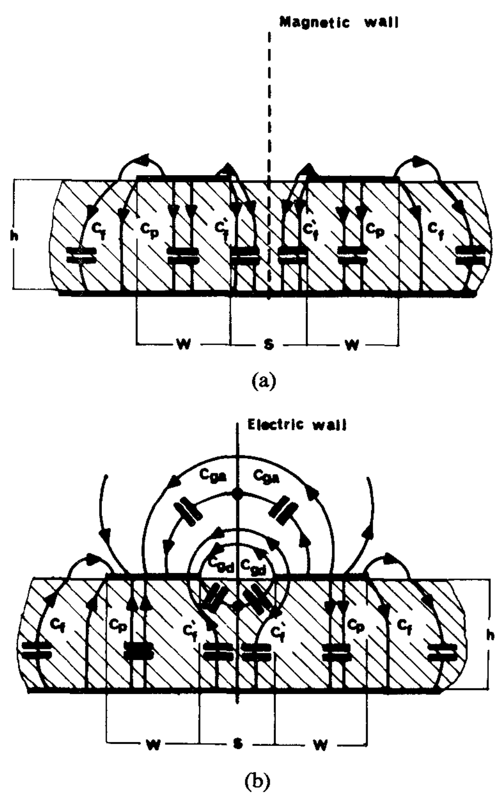

Fig. 2. Decomposition of total capacitance of coupled microstriplines in terms of various capacitances. (a) Even-mode capacitance. (b) Odd-mode capacitance.

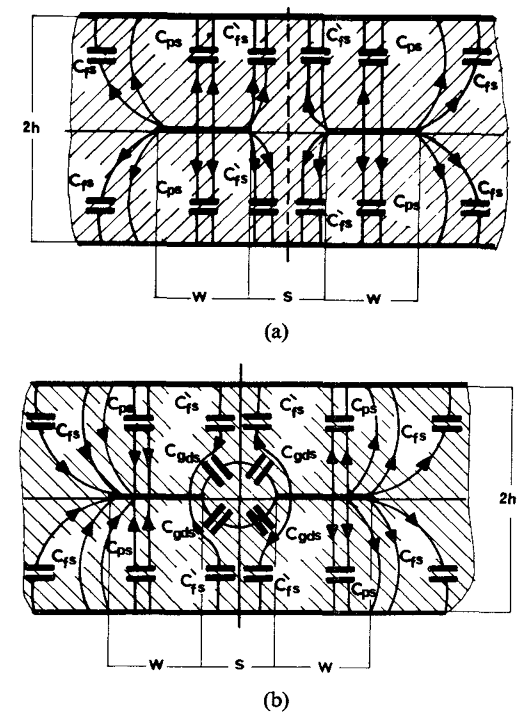

Fig. 3. Decomposition of total capacitance of coupled striplines in terms of various capacitances. (a) Even mode. (b) Odd mode.

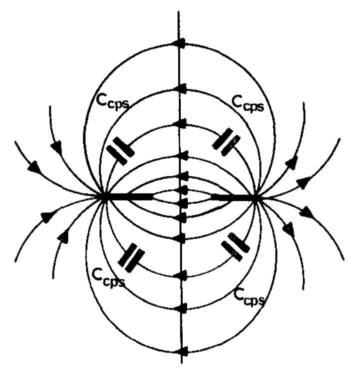

Fig. 4. The total capacitance of the coplanar strips.

that the spacing between the two ground planes is $2h$. The value of C_{gd} is obtained from the following relation:

$$C_{gd}=\tfrac{1}{2}(C_{os}-C_{es}) \tag{2}$$

where C_{os} and C_{es} are the odd- and even-mode capacitances of the corresponding coupled striplines [6]

$$C_{(o,e)s}=\frac{\epsilon_r}{c30\pi}\frac{\mathrm{K}(k_{o,e})}{\mathrm{K}(k'_{o,e})} \tag{3}$$

where $\mathrm{K}(k_{o,e})$ and $\mathrm{K}(k'_{o,e})$ are the elliptic function and its complement and c is the velocity of light in free space and

$$k_{o,e}=\begin{cases}\tanh\left(\frac{\pi}{4}\frac{W}{h}\right)\Big/\tanh\left(\frac{\pi}{4}\frac{W+S}{h}\right), & \text{for odd mode}\\ \tanh\left(\frac{\pi}{4}\frac{W}{h}\right)\cdot\tanh\left(\frac{\pi}{4}\frac{W+S}{h}\right), & \text{for even mode}\end{cases} \tag{4}$$

and

$$k'^2_{o,e}=1-k^2_{o,e}. \tag{5}$$

TABLE I
COMPARISON OF ODD-MODE IMPEDANCES FOR $\epsilon_r = 9.6$

$\frac{W}{h}$	$\frac{S}{h}$	Bryant and Weiss	Coats	R. Garg and I.J. Bahl	This method
0.2	0.05	37.5	36	38.3	35.7
	0.2	53.4	52	52.9	51.8
	0.5	67	67	66.6	66.5
	1.0	78.7	77.5	79	78.1
0.5	0.05	29.6	28	30	28.5
	0.2	39.9	39	41.2	39.3
	0.5	49.7	49	50.1	49.4
	1.0	57.7	57.7	57.9	57.7
1.0	0.05	24.7	23.5	24.9	23.9
	0.2	31.6	31.5	32.3	31.3
	0.5	38.1	38	38.1	38.1
	1.0	43.2	42	42.3	43.5
2.0	0.05	19.6	18	19.1	19.2
	0.2	23.7	23	23.8	23.7
	0.5	27.4	27	27.1	27.6
	1.0	30.1	29.5	29.6	30.5

Accurate and simple expressions for the ratio $K(k)/K(k')$ are available in the literature [7].

The capacitance C_{ga} represents the gap capacitance in air. It may be calculated by using the results from the capacitance of the corresponding coplanar strips (cps) of width W and spacing S and with air as a dielectric, and then subtracting the contribution due to the fringe capacitance in air. This contribution may be considered rigorously using the dielectric filling fraction defined by Wheeler [8]. However, a value which simplifies the final expression for the odd-mode capacitance may be estimated as follows:

$$\Delta C_f(\text{air}) \simeq C_f - C_{fs} \tag{6}$$

and the expression for the gap capacitance C_{ga} may then be written as

$$C_{ga} = C_{cps} - (C_f - C_{fs}) - (C_f' - C_{fs}') \tag{7}$$

where C_{cps} is the capacitance of the corresponding coplanar strips shown in Fig. 4. Owyang and Wu [9] give the following equations for C_{cps}:

$$C_{cps} = \epsilon_0 \frac{K(k')}{K(k)} \qquad k = \frac{S/h}{S/h + 2W/h} \qquad k'^2 = 1 - k^2 \tag{8}$$

where $K(k')$ and $K(k)$ have already been given. A direct substitution from (3) and (6) into (1) gives the following simple expression for C_o:

$$C_o = C_{cps} + \tfrac{1}{2} C_{os}. \tag{9}$$

III. RESULTS AND CONCLUSION

A typical set of calculations for $\epsilon_r = 9.6$ using (1)–(5) are compared with the values of Bryant and Weiss [10], Coats [11], and Garg and Bahl [5] in Table I. It is observed that the agreement is quite good.

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