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HYBRID CT-BEM METHOD ANALYSIS OF UNSCREENED SLAB LINES

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Abstract—A hybrid method of boundary element method (BEM) combined with conformal transformation (CT) is presented to calculate the capacitance of the unscreened slab lines. Conformal transformation transforms the infinite boundary boundary-value problem with the unscreened slab line into a finite boundary one that can be solved by the BEM, then the capacitance of the unscreened slab line is obtained by the BEM. Three representative computational examples, unscreened cylindrical single-bar slab line, unscreened rectangular single-bar slab line and unscreened cylindrical-bar coupled slab line, are given to validate the accuracy and efficiency of the CT-BEM hybrid method.

1. INTRODUCTION

Unscreened slab lines consisting of conductor bars and parallel conductor plates are widely used as microwave components (filters and couplers) and as connecters of a variety of electrical equipment. Under a quasi-TEM approximation, the field of the transverse cross-section of unscreened slab line is governed by two-dimensional static field equation. The accurate determination of the per-unit-length capacitance of unscreened slab line presents a great practical interest in several respects, the computation of the capacitance of unscreened slab line has been the focus of much research, and various numerical methods have been presented to calculate the capacitance of the unscreened slab lines in the past decades [1–21].

The boundary element method (BEM) is very popular for the electrostatic problems with linear and homogeneous media, and has been widely used to calculating various electrostatic field boundary-value problems. Because in BEM the boundary of the considered field domain is discretized with finite elements, therefore, only finite boundary problem can be handled directly. In order to calculate the capacitance of unscreened slab line by the BEM, the infinite boundary of the unscreened slab line must be truncated [3]. To overcome this problem, in this paper, a hybrid method of BEM combined with conformal transformation (CT) is presented to calculate the capacitance of the unscreened slab lines. Conformal transformation transforms the infinite boundary boundary-value problem with the unscreened slab line into a finite boundary one that can be handled directly by the BEM. Comparisons between the results obtained by the hybrid method and the available numerical published data fully validate the accuracy and efficiency of the CT-BEM hybrid method.

2. CALCULATION PROCEDURE AND RESULTS

2.1. Unscreened Cylindrical Single-bar Slab Line

The technique is best illustrated by means of an example, and one chosen here is an unscreened slab line shown in Figure 1(a) [4, 6, 8, 11, 12], which is composed of a cylindrical metallic bar of diameter D placed between two parallel grounded metallic planes with separation distance a. For calculating the capacitance of unscreened cylindrical single-bar slab line, Stracca et al. [4] used the moment method (MM) with a point-matching technique, Pan [6] presented the equivalent eccentric coaxial line technique, Costamagna and Fanni [8] used the conformal mapping, and Zheng et al. [11, 12] presented the multipole theory (MT) method. No exact conformal transformation is known for the cylindrical single-bar configuration shown in Figure 1(a), but two parallel grounded planes may be transformed into two circular boundaries, and the circular bar boundary may be transformed into a hollow circular boundary of radius

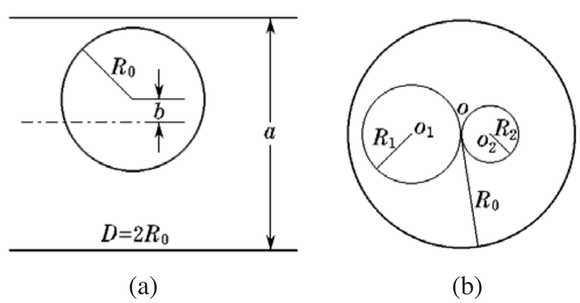

Figure 1. Unscreened cylindrical single-bar slab line.

R_0 by means of the following transformation.

$$\begin{cases} Z = R_0^2/(x - jy) \\ j = \sqrt{-1} \end{cases} \tag{1}$$

Figure 1(b) is the structure obtained by the transformation of Eq. (1), where $R_1 = R_0^2/(a - 2b)$, $R_2 = R_0^2/(a + 2b)$, $D = 2R_0$. Figure 1(b) is a boundary-value problem easily calculated by the BEM. The numerical results are given in Table 1. It can be seen from Table 1 that the results obtained by the CT-BEM hybrid method agree well with the accurate data reported in the literature.

Table 1. Comparison of normalized capacitance of cylindrical single-bar slab line (C_∞/ε).

D/a	$b = 0$			$b/a = 0.05$		$b/a = 0.1$	
	CT-BEM	Ref. [4]	MT [11]	CT-BEM	MT [12]	CT-BEM	MT [12]
0.1	2.4684	2.4691	2.4691	2.4810	2.4819	2.5191	2.5200
0.2	3.3923	3.3946	3.3946	3.4171	3.4174	3.4928	3.4946
0.3	4.3446	4.3487	4.3487	4.3883	4.3910	4.5236	4.5266
0.4	5.4363	5.4362	5.4369	5.5063	5.5105	5.7472	5.7521
0.5	6.7605	6.7611	6.7613	6.8876	6.8941	7.3413	7.3486
0.6	8.4814	8.4811	8.4814	8.7313	8.7428	9.6985	9.7130
0.7	10.913	10.913	10.914	11.503	11.521	14.279	14.303
0.8	14.862	14.867	14.863	16.855	16.877	-	-

2.2. Unscreened Rectangular Single-bar Slab Line

Figure 2(a) shows an unscreened slab line [1, 13], which is composed of a rectangular metallic bar symmetrically placed between two parallel grounded metallic planes with separation distance a. For calculating the capacitance of unscreened rectangular single-bar slab line, Riblet [1] presented a series expansion method based on the conformal mapping, and Lucido et al. [13] presented the Neumann series solution based on the image theory. By the following conformal transformation

$$\begin{cases} Z = (W_0^2 + t^2)/4(x - jy) \\ j = \sqrt{-1} \end{cases} \tag{2}$$

The infinite boundary boundary-value problem is transformed into a finite one that can be handled directly by the BEM. Figure 2(b) is the structure obtained by the transformation of Eq. (2), where $R_c = (W^2 + t^2)/4a$. Figure 2(b) is a boundary-value problem easily calculated by the BEM. The numerical results are given in Table 2. It can be seen from Table 2 that the characteristic impedance obtained by the CT-BEM hybrid method agree well with the accurate data reported in the literature.

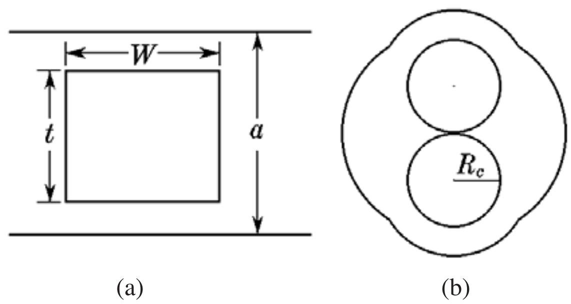

Figure 2. Unscreened rectangular single-bar slab line.

Table 2. Comparison of the characteristic impedance of rectangular single-bar slab line (Ω).

t/a	0.1	0.1	0.5	0.5	0.9	0.9
$W/(a-t)$	0.1	0.2	0.1	0.2	0.1	0.2
Present work	145.75	123.38	83.397	76.036	43.312	41.271
Riblet [1]	145.62	123.29	83.255	75.928	43.077	41.054

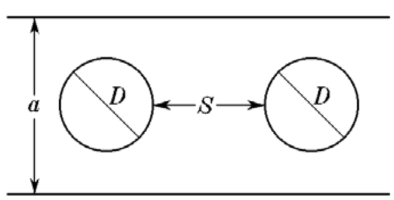

Figure 3. Unscreened cylindrical-bar coupled slab line.

2.3. Unscreened Cylindrical-bar Coupled Slab Line

Unscreened cylindrical-bar coupled slab line which is shown in Figure 3 has been described and studied by many authors [2, 5, 7, 9–12]. This coupled line can be excited in the two ways: "even mode" excitation or "odd mode" excitation, i.e., in-phase or opposite-phase, equal-amplitude excitations. For calculation of the capacitance of unscreened cylindrical-bar coupled slab line, Levy [2] used the approximate solution based on the conformal transformation, Fikioris and Tsalamengas [5] used the Carleman-Vekua method, Tailu and Olesen [7] presented the hybrid image-mode-moment method, Costamagna and Fanni [9] presented the Schwarz-Christffel conformal transformation, Abramowicz [10] presented an improved coupling coefficient method, and Zheng et al. [11, 12] presented the multipole theory method. Table 3 and Table 4 give the results obtained by the CT-BEM hybrid method. It can be seen from Table 3 and Table 4 that the numerical values obtained by the CT-BEM hybrid method agree well with the accurate data reported in the literature.

Table 3. Comparison of the normalized odd-mode capacitance of unscreened slab line (C_{oo}/ε).

D/a	S/a	Present work	Levy [2]	Chisholm [2]	Costamagna [9]	Zheng [11]
0.354	0.176	7.5422	7.5528	7.5347	7.5506	7.5378
0.400	0.226	7.5386	7.5404	7.5347	7.5397	7.5352
0.436	0.280	7.5551	7.5501	7.5347	7.5472	7.5553
0.462	0.338	7.5340	7.5371	7.5347	7.5347	7.5339
0.482	0.398	7.5368	7.5339	7.5347	7.5366	7.5362
0.498	0.462	7.5462	7.5436	7.5347	7.5464	7.5461
0.510	0.528	7.5524	7.5514	7.5347	7.5525	7.5523
0.518	0.596	7.5373	7.5371	7.5347	7.5384	7.5383
0.534	0.806	7.5352	7.5359	7.5347	7.5369	7.5368
0.544	1.168	7.5322	7.5285	7.5347	7.5322	7.5320
0.400	0.080	11.192	11.288	11.078	11.241	11.213
0.400	0.120	9.4843	9.5317	9.4595	9.5140	9.5317
0.400	0.160	8.4964	8.5419	8.4935	8.5167	8.5087
0.400	0.200	7.8449	7.8652	7.8478	7.8594	7.8539
0.400	0.240	7.3821	7.3982	7.3863	7.3924	7.3885
0.400	0.400	6.3882	6.3914	6.3903	6.3905	6.3894
0.400	0.600	5.8809	5.8848	5.8862	5.8856	5.8852
0.400	0.760	5.6908	5.6946	5.6949	5.6947	5.6946

Table 4. Comparison of the normalized even-mode capacitance of unscreened slab line (C_{oe}/ε).

D/a	S/a	Present work	Levy [2]	Chisholm [2]	Costamagna [9]	Zheng [11]
0.354	0.176	3.9123	3.9153	3.9142	3.9137	3.9112
0.400	0.226	4.5061	4.5080	4.5093	4.5052	4.5044
0.436	0.280	5.0360	5.0320	5.0281	5.0344	5.0337
0.462	0.338	5.4724	5.4718	5.4731	5.4731	5.4728
0.482	0.398	5.8454	5.8446	5.8497	5.8465	5.8463
0.498	0.462	6.1705	6.1721	6.1648	6.1728	6.1727
0.510	0.528	6.4382	6.4380	6.4257	6.4404	6.4403
0.518	0.596	6.6428	6.6424	6.6404	6.6427	6.6426
0.534	0.806	7.0723	7.0710	7.0727	7.0741	7.0740
0.544	1.168	7.3813	7.3806	7.3855	7.3833	7.3832
0.400	0.080	4.1611	4.1553	4.1646	4.1657	4.1635
0.400	0.120	4.2740	4.2626	4.2631	4.2641	4.2624
0.400	0.160	4.3527	4.3516	4.3578	4.3587	4.3573
0.400	0.200	4.4414	4.4444	4.4483	4.4489	4.4478
0.400	0.240	4.5235	4.5358	4.5340	4.5346	4.5336
0.400	0.400	4.8305	4.8263	4.8273	4.8273	4.8268
0.400	0.600	5.0816	5.0819	5.0826	5.0821	5.0819
0.400	0.760	5.2119	5.2130	5.2134	5.2131	5.2130

3. CONCLUSION

The present work presents a hybrid CT-BEM method for determining the capacitance of the various configuration unscreened slab lines, and the CT-BEM procedure to obtain the capacitance of unscreened slab lines has been described. An extensive comparison with the exact data reported in the literature shows the accuracy and efficiency of the CT-BEM hybrid method. The salient advantage of the CT-BEM method is that the infinite field domain boundary-value problem with the infinite boundary can be transformed into a finite boundary one that can be handled directly by the BEM, and the electrostatic field boundary-value problem with the infinite boundary can be solved by the BEM.

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