Characteristics of Inhomogeneously Filled Double L-Septa Waveguides

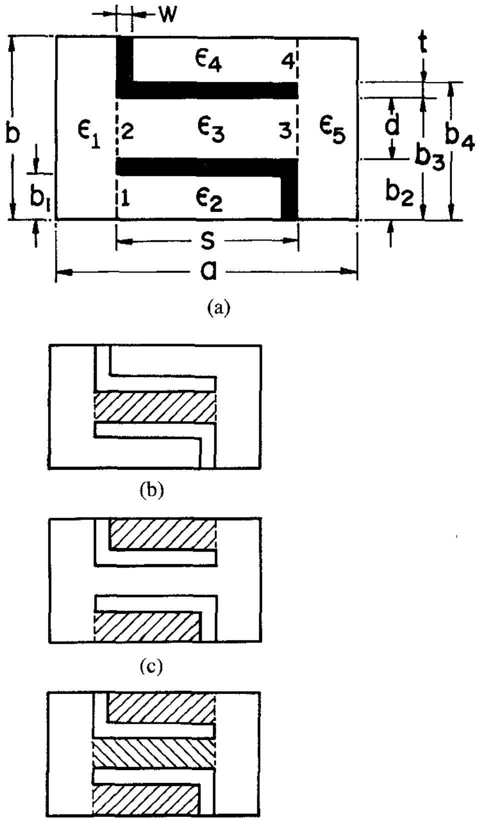
Pradip Kumar Saha and Debatosh Guha

Abstract—**Three types of inhomogeneous Double L-Septa Guides produced by selective dielectric loading of the different regions have been analyzed. The cut-off and bandwidth characteristics of these configurations are compared with inhomogeneous T-septa guide and homogeneous DLSG. From the study an optimum configuration with very large bandwidth emerges as a potential structure for practical implementation.**

I. Introduction

RECENTLY we have proposed a broadband rectangular waveguide having two L-shaped septa attached to the broad walls in antipodal configuration [1]. This Double T-Septa Guide (DLSG) is a variant of the previously reported Double T-Septa Guide (DTSG) which was suggested as a superior alternative to the Double Ridged Guide (DRG) [2], [3]. It was also shown that dielectric loading of the gap can improve significantly both the cut-off and bandwidth characteristics of DRG [4] and Double and Single T-Septa guides [5], [6]. Since the DLSG is an improvement over DTSG as shown in [1] and further improvements appear possible with dielectric loading, we have now analyzed an inhomogeneously filled DLSG (IDLSG), shown in Fig. 1(a).

An examination of the generalized structure in Fig. 1(a) shows that with selective dielectric loading of the five different regions of the DLSG, three types of inhomogeneous configurations may be considered as possible broadband waveguides. The first type—IDLSG-1 shown in Fig. 1(b)—has the central septa-gap (region 3) filled with a dielectric (ϵ_3), all other regions being air-filled. This configuration is a variant of the gap-filled inhomogeneous DTSG (referred to as IDTSG here) in [5]. In the second type — IDLSG-2 shown in Fig. 1(c) —two dielectric media support the septa by filling in the regions 2 and 4 (with $\epsilon_2 = \epsilon_4$) while the septa-gap and the trough regions are air-filled. One surmises that for low values of the dielectric constants ϵ_2 and ϵ_4, the blocks will provide mainly mechanical support for the septa and the characteristics of the IDLSG will be similar to those of the air-filled DLSG. This is true provided that the fields in the regions 2 and 4 are very weak. However, our calculations in connection with the power handling capability of DLSG show that these fields can be strong, even stronger than the field in the central gap, for certain septa dimensions. In such cases the dielectric filling of the regions 2 and 4 is likely to have significant effects. Further, in this configuration an L-septum can be fabricated by simply metallizing two faces of a dielectric block. The third type, shown in Fig. 1(d) is a combination of the above two types, having dielectrics filling the regions 2, 3 and 4.



(a)
(b)
(c)
(d)

Fig. 1. (a) Inhomogeneously filled Double L-Septa Guide. (b) IDLSG-type 1: $\epsilon_1 = \epsilon_2 = \epsilon_4 = \epsilon_5 = 1$; $\epsilon_3 > 1$. (c) IDLSG - type 2: $\epsilon_1 = \epsilon_3 = \epsilon_5 = 1$; $\epsilon_2 = \epsilon_4 > 1$. (d) IDLSG - type 3: $\epsilon_1 = \epsilon_5 = 1$; $\epsilon_2 = \epsilon_4 > 1$; $\epsilon_3 > 1$.

We have determined theoretically the cut-off and bandwidth characteristics of these three types of inhomogeneous structures. The results show promise for very large bandwidth even for moderate values of the dielectric constants.

For analyzing the generalized structure in Fig. 1(a) and determination of the eigenvalue equations of the HE and

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EH type hybrid modes, we use the Ritz–Galerkin technique. The lengthy derivation follows closely that used for the IDTSG in [5] and is not presented here.

II. Numerical Results

The first few modes of IDLSG are HE type hybrid. We denote the lowest mode by He_1 and its normalized cut-off wavelength by λ_{c1}/a. The next two modes in the spectrum are the cross-polarized trough modes which are similar to the eigenvalue spectra of DRG [7] DTSG [2], [3], DLSG [1] and IDTSG [5]. The next and the first higher order bandwidth determining HE mode is designated HE_2 and the corresponding normalized cut-off wavelength λ_{c2}/a. The computation of λ_{c1}/a and λ_{c2}/a was carried out by solving the HE eigenvalue equation for the three types of IDLSG described above. The theoretical characteristics of these proposed structures are as follows.

A. Gap-Filled IDLSG-1 (Fig. 1(b))

Fig. 2(a) and (b) show the cut-off and bandwidth characteristics, respectively, for a particular value of the dielectric constant ϵ_3 of the septa-gap together with the corresponding characteristics of air-filled homogeneous DLSG. The basic nature of λ_{c1}/a increasing monotonically with s/a, observed with homogeneous DLSG, remains the same with dielectric loading of the gap. And as expected from the earlier results of inhomogeneous DRG [4] and T-septa guides [5], the gap loading in the IDLSG-1 increases λ_{c1}/a substantially, by as much as 65%. There is considerable increase in the modal separation as well, particularly for small values of d/b and for small values of s/a below the bandwidth peaks of the air-filled DLSG. The gap loading shifts the bandwidth peaks to lower values of the septa width. The magnitude of this shift increases initially if the dielectric constant ϵ_3 is increased, as shown in Fig. 2(c). These features are also observed with IDTSG [5]. But, unlike IDTSG, this shift toward lower s/a does not continue with increased loading. For $\epsilon_3 = 10$, for example, the bandwidth peak shifts back slightly toward a higher value of s/a. While the λ_{c1}/a values are nearly equal for the IDLSG-1 and IDTSG (the two curves for $d/b = 0.1$ in Fig. 2(a) are indistinguishable), the bandwidth peaks of the former are only slightly higher, as can be seen from the bandwidth curves of IDTSG for $d/b = 0.1$ and 0.15, included in Fig. 2(b) for comparison. However, it is the large bandwidth for values of s/a beyond the peaks that makes the IDLSG-1 more attractive than IDTSG.

B. IDLSG-2 with Dielectric-Supported Septa (Fig. 1 (c))

The cut-off and bandwidth characteristics of this configuration for a low dielectric constant of $\epsilon_2 = \epsilon_4 = 2.05$ are shown in Fig. 3(a) and (b), respectively. Both the λ_{c1}/a and $\lambda_{c1}/\lambda_{c2}$ have been presented for very thin septa ($w/a = 0.005$, $t/b = 0.01$) because, as discussed above, the L-shaped septa can be fabricated by partly metallizing strips of dielectric in this configuration. An examination of the characteristics in Fig. 3(a) and (b), the four different curves for $d/b = 0.1$ in particular, brings out the following features of the dielectric backing of the septa and the effect of the septa thickness.

(i) The dielectric loading in IDLSG-2 also increases λ_{c1}/a, though only marginally, for the same septa thickness. With the same dielectric in the gap IDLSG-1 produces much larger increase in λ_{c1}/a.

(ii) The bandwidth peaks are, however, slightly lower and shifted toward higher values of s/a in comparison with those of the air-filled DLSG. IDLSG-1 has appreciably higher peaks for the same dielectric constant.

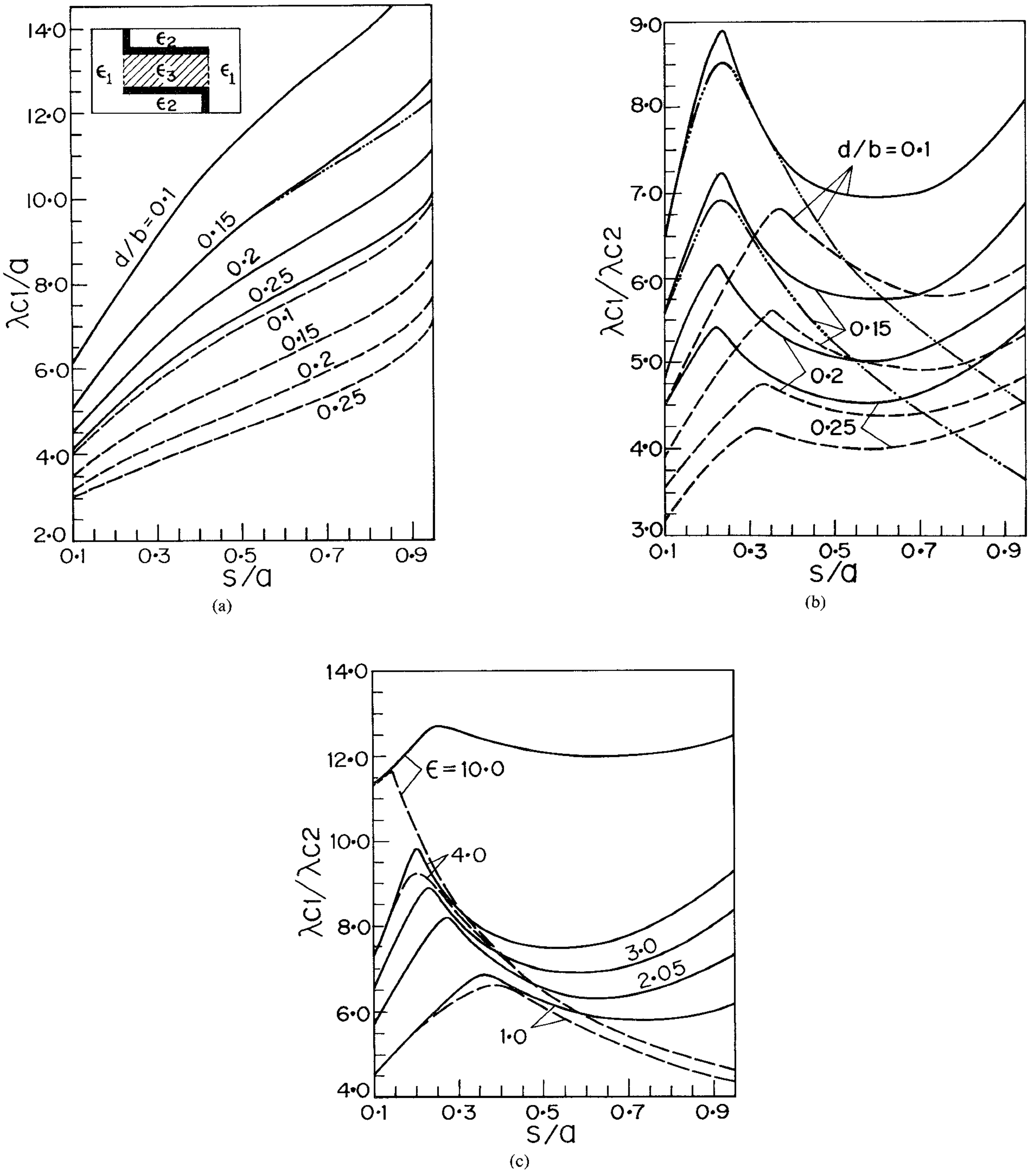
(iii) The IDLSG-2 bandwidth falls off monotonically with increasing s/a beyond the peaks. Similar variation is observed with IDTSG but for IDLSG-1 and DLSG, the nature of bandwidth variation is different in this region.

(iv) When the septa are made thinner, both the λ_{c1}/a and $\lambda_{c1}/\lambda_{c2}$ of IDLSG-2 improve significantly. It may be mentioned that such improvement is also obtained with homogeneous T-septa and L-septa guides. This improvement in IDLSG-2 is accompanied by a further shift of the bandwidth peaks to higher values of s/a in addition to that produced by the dielectric loading.

Calculations show that, as expected, if $\epsilon_2 \gtrsim 1$, the characteristics of the IDLSG-2 and air-filled DLSG are almost identical. The latter necessarily requires sufficiently thick septa for mechanical rigidity and fabrication of the structure will not be easy. On the other hand, if the septa are fabricated by very thin metallization of strips of dielectric like expanded polystyrene, the IDLSG-2 can be a significant improvement over the air-filled DLSG in respect of both the characteristics as well as ease of fabrication.

C. IDLSG-3 (Fig. 1(d))

For the type-3 configuration we present, in Fig. 4, only the bandwidth characteristics for $d/b = 0.1$ with the gap dielectric constant ϵ_3 as the parameter. The regions 2 and 4 are loaded with a fixed dielectric of $\epsilon_2 = \epsilon_4 = 2.05$. Then the curve for $\epsilon_3 = 1.0$ is obviously the IDLSG-2 bandwidth of Fig. 3(b). If the gap dielectric constant ϵ_3 is increased, the bandwidth peaks shift to lower values of s/a, just as in the case of type 1. Further, as the difference $(\epsilon_3 - \epsilon_2)$ increases, the overall bandwidth curve becomes more and more like that of IDLSG-1. If the characteristics of Fig. 2(b) and 4 are compared, we observe that the type-3 peaks are marginally higher, but beyond the peaks the IDLSG-3 bandwidth is comparable to IDLSG-1 only when ϵ_3 much larger than ϵ_2. In making this comparison it is to be kept in mind that the type 1 bandwidth characteristics, shown in Fig. 2(b) and (c), are for thick septa ($w/a = 0.1$, $t/b = 0.05$) while the type-3 curves are for very thin septa ($w/a = 0.005$, $t/b = 0.01$). And we have already noted that decreasing the



(a)

(b)

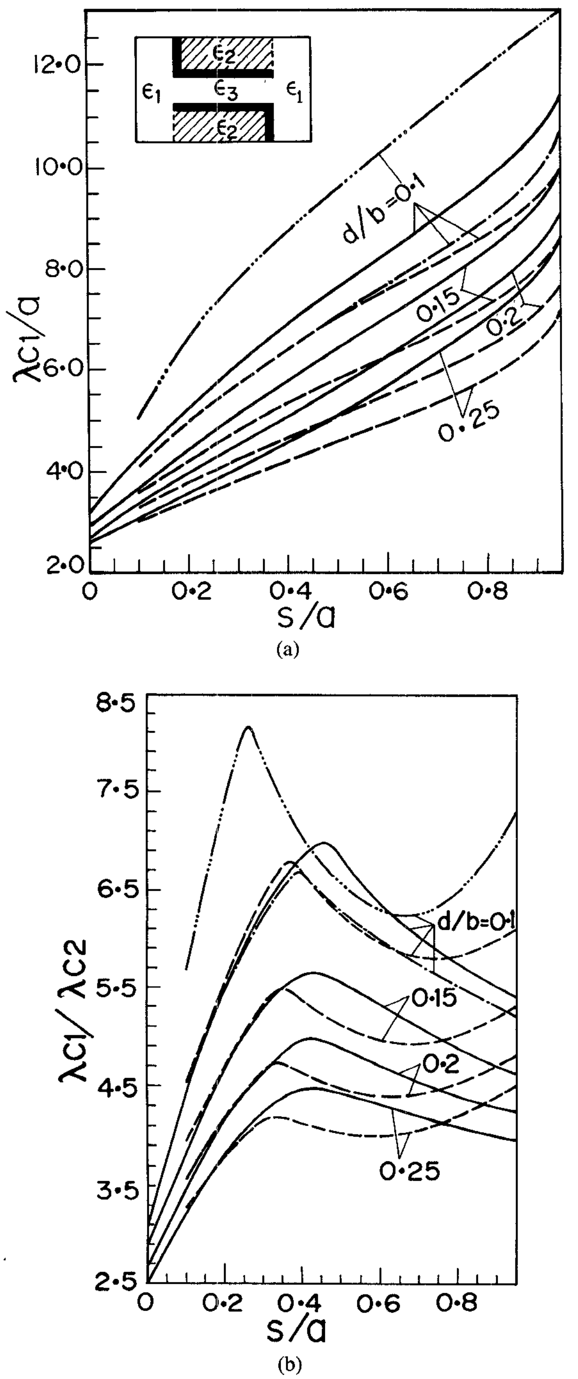
(c)

Fig. 2. (a) Normalized cut-off wavelength λ_{c1}/a versus s/a with d/b as parameter of IDLSG − 1. $b/a = 0.5$, $\epsilon_1 = \epsilon_2 = 1$, $\epsilon_3 = 3.0$, $w/a = 0.1$, $t/b = 0.05$. ________ IDLSG − 1 -------- DLSG ($\epsilon_3 = 1$) —···—···— IDTSG (b) Bandwidth characteristics $\lambda_{c1}/\lambda_{c2}$ versus s/a with d/b as parameter of IDLSG − 1. $b/a = 0.5$, $\epsilon_1 = \epsilon_2 = 1$, $\epsilon_3 = 3.0$, $w/a = 0.1$, $t/b = 0.05$. ________ IDLSG − 1 ---------- DLSG ($\epsilon_3 = 1$) —···—···—IDTSG (c) $\lambda_{c1}/\lambda_{c2}$ versus s/a of IDLSG − 1 with ϵ_3 as parameter. $d/b = 0.1$, other parameters as in Fig. 2(a). ________ IDLSG − 1 ----- IDTSG

septa thickness enhances the bandwidth. Thus for very large bandwidth as well as easy fabrication, the IDLSG-3 configuration with thin metallized septa on dielectrics of low permittivity and septa-gap loaded with high value of ϵ_3, appears to be the best choice.

IV. CONCLUSIONS

Inhomogeneously filled Double L-Septa Guides in three different configurations have been evaluated theoretically for the cut-off wavelength and bandwidth of the lowest



(a)

(b)

Fig. 3. (a) λ_{c1}/a versus s/a of IDLSG-2 with d/b as parameter. $b/a = 0.5$, $\epsilon_1 = 1$. IDLSG-1: $\epsilon_3 = 2.05$, $\epsilon_2 = 1$ IDLSG-2: $\epsilon_2 = 2.05$, $\epsilon_3 = 1$ Thin septa: $w/a = 0.005$, $t/b = 0.01$ Thick septa: $w/a = 0.1$, $t/b = 0.05$ IDLSG-2 (Thin) -·-·-·- IDLSG-2 (Thick) — ···—···— IDLSG-1 (Thick) ------- DLSG (Thick). (b) $\lambda_{c1}/\lambda_{c2}$ s/a of IDLSG-2 with d/b as parameter. All parameters and denotations are as in Fig. 3(a).

hybrid mode. In one configuration, considerable improvement in both these features results from dielectric loading of the septa gap. The second configuration in which the L-shaped septa can be made by metallization of dielectric strips, should be easier to fabricate and can be looked upon as a modified and improved DLSG. The attractive features of these two configurations are combined in the third structure in which the septa are made by metallization of

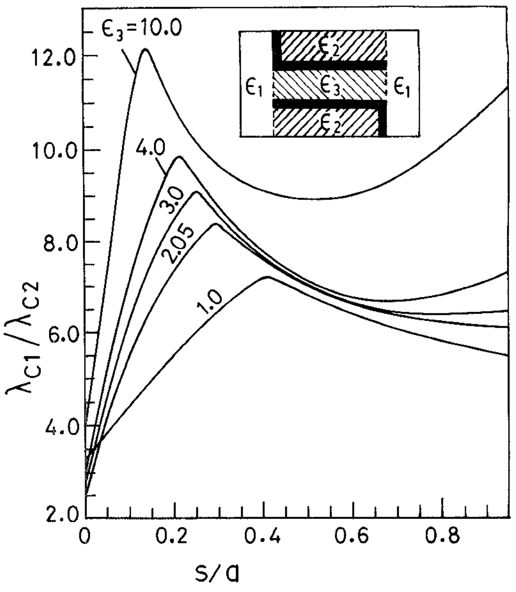


Fig. 4. Bandwidth characteristics of IDLSG-3 with ϵ_3 as parameter. $b/a = 0.5$ $\epsilon_1 = 1$, $\epsilon_2 = 2.05$ $w/a = 0.005$, $t/b = 0.01$.

strips of low dielectric constant and the septa gap is filled with a high permittivity material.

With further theoretical and experimental studies it should be possible to design and fabricate most of the commercially available double ridged waveguide components in DLSG and IDLSG, the choice depending on bandwidth requirement and suitability. Structurally the configuration IDLSG-2 is closest to the DRG and can provide an improved alternative transmission medium for passive broadband devices. The transition to standard rectangular waveguide, would, however, be a little more complex. The septa width s may first be tapered to the base width w so that the structure reduces to a waveguide with two antipodal single ridges of width w. The height b_2 of these ridges is then tapered to zero. In presence of dielectric loading in IDLSG, the dielectrics will also have to be tapered suitably along with the septa.

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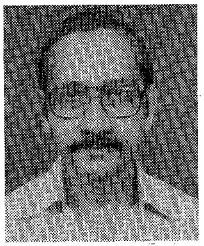

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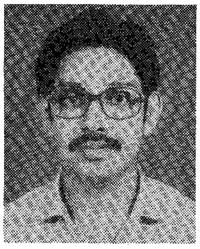

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