With diagonal permittivity and permeability tensors given by

$$[\epsilon_r] = \begin{bmatrix} \epsilon_{r_{xx}} & 0 & 0 \\ 0 & \epsilon_{r_{yy}} & 0 \\ 0 & 0 & \epsilon_{r_{zz}} \end{bmatrix} \quad (4)$$

$$[\mu_r] = \begin{bmatrix} \mu_{r_{xx}} & 0 & 0 \\ 0 & \mu_{r_{yy}} & 0 \\ 0 & 0 & \mu_{r_{zz}} \end{bmatrix} \quad (5)$$

all that is required are the following modifications. In the evaluation of the $[S]$ matrix elements, all the dot products of the form $\vec{t}_{i,j} \cdot \vec{t}_{k,l}$ must be replaced by $\vec{t}_{i,j} \cdot \vec{t'}_{k,l}$ with

$$\vec{t'}_{k,l} = \frac{1}{\mu_{r_{xx}}} t_{k,l_x} + \frac{1}{\mu_{r_{yy}}} t_{k,l_y} + \frac{1}{\mu_{r_{zz}}} t_{k,l_z} = [\mu_r]^{-1} \cdot \vec{t}_{k,1} \quad (6)$$

where $\cdot$ is now the conventional matrix–vector inner product. Note also that the $1/\mu_r$ term in (18) of the above paper [1] must be removed since it is now effectively included in the dot product. The matrix retains its symmetry. The lower half and diagonal of the $[S]$ matrix is shown in (7), at the bottom of the previous page.

For the $[T]$ matrix elements, Min *et al.* [4] provide the required expressions, but since this conference publication may not be readily accessible, the extension will be given here. (It was derived independently by this author.) Terms of the form $I_{ij} = \vec{A}_i \cdot \vec{A}_j$ must be replaced by $I'_{ij} = \vec{A}_i \cdot \vec{A}'_j$ with $\vec{A}'_j = [\epsilon_{r_{xx}} A_{j_x} + \epsilon_{r_{yy}} A_{j_y} + \epsilon_{r_{zz}} A_{j_z}] = [\epsilon_r] \cdot \vec{A}_j$. The ϵ_r term in (19) of the above paper[1] must also be removed since it is now included in I'_{ij}. The lower half and diagonal of the $[T]$ matrix is shown in (8), at the bottom of the previous page.

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Comments on "Transitional Combline/Evanescent-Mode Microwave Filters"

Itzhak Shapir and Victor Sharir

In the above paper,[1] Levy *et al.* refer to the phenomenon of combline-filter bandwidth expansion (i.e., practical bandwidth versus theoretical TEM-analyzed bandwidth). Levy *et al.* explain that this phenomenon is mainly caused due to evanescent waveguide modes propagating through the structure, affecting the overall coupling coefficients and bandwidth. This explanation, known for many years, is only one among other explanations such as coupling between nonadjacent resonators, also known for many years. These explanations and derived equivalent models are not fully compliant with practical results and may be applicable only in limited frequencies and structural dimension.

In paragraph five of the above-paper,[1] Levy *et al.* claim to have investigated and disprove an explanation suggested by us which was recently published [1]. This explanation is based on deviation from quasi-static two-dimensional cross-sectional TEM-derived coupling coefficients, mainly caused due to the proximity of a ground plane to the open ends of the resonator array, significantly affecting the overall bandwidth. The effect of this ground plane, usually used to carry tuning elements, is not fully represented in traditional equivalent models and design formulas for combline-filter design and analysis.

However, Levy *et al.* investigated a structure with a large iris between the resonators, which is significantly different than the classic structure we have investigated. Therefore, the "disproval" of our explanation by Levy *et al.* has no practical validation.

Moreover, it is expected that evanescent waveguide modes should cause similar effects in interdigital filters, yet these filters' performance comply with their TEM analysis, a fact Levy *et al.* admit to be unable to explain in paragraph six of the above paper.[1] According to our explanation, this fact is obvious since in interdigital filters the resonator open ends hardly participate in the overall coupling. In addition, Levy *et al.* do not explain the dependence of that phenomenon on the spacing between resonators in paragraph four of the above paper,[1] while our explanation is consistent with this

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[1] R. Levy, H.-W. Yao, and K. A. Zaki, *IEEE Trans. Microwave Theory Tech.,* vol. 45, no. 12, pp. 2094–2099, Dec. 1997.

fact. Although they state that "... the observed BWR is theoretically confirmed," the only thing confirmed is the accuracy of the mode-matching technique in analyzing the full three-dimensional structure, which we do not doubt.

We believe that different mechanisms of coupling simultaneously affect the overall performance of microwave combline filters, but some may have negligible effect; thus, for different filter structures, different explanations may be more valid. Our explanation complies with most of the common standard-type combline filters for narrow and medium bandwidth, and the modified equivalent model is simple and easily updates the standard combline equivalent model. We do not accept the "religious" rejection of other explanations to this complicated phenomenon, as demonstrated by Levy *et al.* and other evanescent-mode filter masters.

To conclude, it is important to mention that our explanation and modified equivalent model were successfully adopted by others to achieve fast and accurate design procedure [2]. This proves the validity of our explanation and the practical value of our modified equivalent circuit.

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Authors' Reply

Ralph Levy, Hui-Wen Yao, and Kawthar A. Zaki

On the whole, we disagree with most of the arguments of Dr. Shapir and Dr. Sharir, but they raise some interesting points which deserve careful consideration, and we are grateful for the opportunity both to respond and to clarify certain aspects of the above paper[1] which may be subject to misunderstanding.

Perhaps the most revealing statement they make is that they do not doubt the accuracy of our mode-matching technique. Given this premise, we should then state that the above paper[1] did not attempt to propose equivalent circuits for either the combline or interdigital structures. We presented facts only, and discuss as the explanation for the well-established bandwidth expansion factor the phenomena of evanescent moding, which has been the most widely held cause by almost all of the filter experts with whom we have discussed this issue. We may consider the TEM mode model for combline filters as a quasi-stationary approximation, a technique which has been used in in many waveguide problems and often is the first term in accurate field-theory representations, e.g., see the discussion of the equivalent static method for solution of discontinuity problems as described in [1, pp. 153–160]. As stated in the above paper,[1] a pure TEM mode cannot exist in a combline filter, which is really a metallic-loaded rectangular-waveguide structure, any more than it can in any other type of waveguide, loaded or otherwise. It so happens that in the case of ground plane spacings b, which are much smaller than a wavelength, the TEM mode quasi-static approximation is a very good one.

It is not true that we only investigated structures with a large iris between the resonators. The vast majority of our results were with no irises, as stated in the above paper,[1] and they clearly demonstrate the dramatic increase in bandwidth or coupling coefficient as b/λ increases (see Figs. 6 and 7 in the above paper[1]).

We have doubts that the "end effect" theory proposed by Shapir and Sharir has any validity in explaining the major effects, as demonstrated rather clearly by Fig. 7 in the above paper[1]. This shows that while the bandwidth is subject to minor changes via end effects (variations with respect to g/b), these effects are masked by the enormously greater increase in coupling coefficients with increase in b/λ. Changes in the coupling coefficients will be expected when any change is made to a combline filter since, as stated repeatedly, it is a waveguide—not a TEM structure, and the calculations via even and odd TEM modes of the two-dimensional cross section cannot give a precise result. Combline filters are really quite complicated structures worthy of further study.

The equivalent circuit model proposed by the authors may indeed give good predictions of bandwidth expansion factors for certain parameter ranges, but no rigorous field-theory calculations were presented and it is possible that the equivalent circuit is, in reality, simply a convenient mathematical approximation which fits the measured results. It appears from the authors description that indeed the measured results were fitted to the equivalent circuit. There is no assurance that this equivalent circuit has physical validity. If it happens to fit the observed bandwidth expansions, then go ahead and use it, but beware that it may break down for parameters outside of its range of validity. It may be similar to the popular method of representing results in terms of polynomial approximations, which are subject to similar breakdown and, in reality, usually have no physical significance. Actually, one of us has proposed a study to elucidate the true physical equivalent circuit for both combline and interdigital structures, and we hope to report results in the near future.

The authors raise an interesting point regarding the smaller bandwidth expansion effects seen in interdigital filters. An explanation proposed by others is that, here, the lowest order waveguide modes tend to be suppressed, but this is perhaps too general a statement and an oversimplification. The effects should be investigated by careful studies in field theory, combined perhaps with circuit methods. We are open to the proposal of any equivalent circuit based on physical reality, which may or may not turn out to be similar to that proposed by the authors. Of course, it should be pointed out that the TEM model of the interdigital structure has unit element or transmission-line coupling, while the combline circuit has series short-circuited stub coupling, which is a vastly different situation.

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