SUSPENDED RESONATORS FOR FILTERS- REDUCED λ_g EXCITATION OF EVANESCENT CAVITIES USING HIGH DIELECTRIC CONSTANT FEEDLINES

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Abstract - **A structure consisting of dielectric-loaded feed lines (such as surface wave lines similar to Goubau lines) and below-cutoff air-filled cavities can be used to form essentially L-C sections. The capacitance is due to electric field coupling from the feed line dielectric medium into the below-cutoff section. The inductance results from combining the inductors in the inductive tee-equivalent circuit for such below-cutoff sections. Dielectric loading is used to shorten the guide wavelength at the input to the evanescent section, increasing the effective input inductance. The dielectrically-loaded feed lines can comprise microstrip, CPW, CPS, Goubau lines (surface wave structures), waveguide, etc. The resulting resonant elements are usable at frequencies below 1 GHz, with small dimensions. If connected to the common ground plane, these L-C sections act as a transmission zero. If "floated", i.e. connected in the "hot" line rather than to the ground plane, the sections form bandpass circuits (transmission poles). The air-filled below-cutoff sections (evanescent mode) are placed in a supporting low-dielectric constant medium (air, Teflon or similar), with the open end in proximity to the dielectric portion of the feed line, and are thus termed "suspended". The individual L-C sections can be coupled together using microstrip, surface wave line, CPW, CPS, finline, waveguide, etc. Such combinations can be chosen to implement Chebychev, Butterworth, quasi-elliptic, etc. responses. These applications will be covered later.**

I. INTRODUCTION

In an interesting paper [1], Katehi et al present the possibility of exciting a resonant cavity micromachined into a silicon substrate. This cavity supports a dominant mode resonance for the particular cross section and length employed. In [1], the operating frequencies were in X-band. In this paper, we present the possibility of exciting mechanically similar cavities, but at much lower frequencies. The cavities will operate as evanescent mode inductors, and will be shown to resonate when combined with capacitance effectively resulting from electric field coupling between the open end of the evanescent section and the high dielectric constant material forming a portion of the lines feeding the evanescent section. Particular examples will be presented for operation as low as 1000 MHz. The resonance effect results from what will be called the ***"Equivalent Frequency"*** principle, by which it is recognized that a below-cutoff section is below cutoff, not to a given frequency, but to the wavelength of energy incident upon it. Eq. (4-1) illustrates that the reactance of the below cutoff section is dependent on the ratio of the ***wavelength of the incident energy*** (λ_g) to the ***cutoff wavelength for the section*** (λ_c). Thus, shortening that incident wavelength through the use of dielectric loading enables the below cutoff section to be effectively closer to cutoff and thus more easily excited. The ***tee-equivalent series inductance*** is increased (see Eq. 4.1), enabling resonance with a smaller capacitor for a particular resonant frequency. The basic structure and principle of the suspended resonators are illustrated in Figs. 1 to 4. In this paper, the below-cutoff sections are round, but any shape would work (e.g. rectangular, elliptical, etc.). The equivalent circuits are also shown in these figures, with the values of the elements shown. Inductances stem from the single mode tee-equivalent circuit of [2] and are presented in Figs. 3 and 4 as Eqs. (4-1) to (4-3), with the capacitance value given in (4-4), derived from image theory and contained in an Appendix to be presented at the Conference. The closed cup suspended above the ground plane provides a series resonant circuit and thus a transmission pole, while the cup directly connected to the ground plane implements a transmission zero. The combinations of series and shunt resonant circuits can be used to implement the usual variety of bandpass and bandstop filter circuits, with the shunt circuit used

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for additional transmission zeros, as required by the desired topology.

II. THE SURFACE WAVE LINES

The feed lines used for exciting the evanescent resonators are termed "Goubau like" in honor of G. Goubau who first described the phenomenon whereby RF energy propagates close to an isolated, dielectric-coated conductor [3]. In this paper, we use a microstrip-like configuration, but with the ground plane far from the isolated conductor. This conductor is supported on a high-dielectric constant substrate, and so most of the energy is bound by the dielectric, with the wavelength set by the dielectric constant of the substrate. The relatively high dielectric constant (> 10) essentially eliminates radiative losses from the line and thus ensures low-loss transmission of energy. The configuration is illustrated in Figs. 1, 2 and 5, with typical impedance data in Fig. 6. It can be seen that as the distance of the line to the ground plane decreases, the line approaches microstrip. However, as the line moves away from the bottom, the impedance is primarily a function of the ratio of the enclosure width W2 to the line/dielectric width W1 and energy is essentially bound by the conductor and retained in the dielectric layer. It has been found that the line Z0 displays essentially the same dependence on H for a wide range of W2, and is thus primarily a function of the ratio W2/W1, for H > W1. Thus, Fig. 6 can be used in the design of interconnecting lines for implementing various filter topologies, as well as for excitation of the resonators.

III. THE RESONATORS

As shown in Figs. 1 and 2, the resonators can be connected to implement either series or shunt resonant equivalent circuits. The effective inductance of the below cutoff section (round in this paper but also possibly rectangular, elliptical....any cross section with a separable wave equation and a high pass cutoff characteristic) results from the fact that the cutoff wavelength for the section is shorter than the signal wavelength. Without the reduction in signal wavelength resulting from dielectric loading, the effective series inductance in the equivalent circuit is lower and more resonating capacitance is required in either the series or shunt case for a particular resonant frequency. The equivalent series inductance is proportional to the square root of the substrate dielectric constant. Simulated and measured data is shown for a typical series and shunt case in Figs. 7 and 8. In the frequency range between 1 and 2 GHz, the effective unloaded Q for these resonators is about 400. The loss tangent for the dielectric material used is measured as .002, so the majority of the resonator loss is dissipation in the dielectric. It is intended to use ferroelectric dielectrics for implemention of electrically tunable resonators.

III. FILTERS AND CONCLUSIONS

At this time, only simple two and four pole filters have been built. The individual resonators are connected with lengths of the surface wave line, with each length representing an inverter, as required by basic synthesis. However, many topologies are possible, including cross-coupling of the bandpass resonators, individual transmission zeros placed with the bandstop resonators, etc. Two resonator networks are shown in Fig. 9 (one with TL and one with a lumped interconnect), with one possible higher order interconnection in Fig. 10. The filters will be separately reported at the conference and in a later paper.

IV. BIBLIOGRAPHY

1. J. Papapolymerou, J. Cheng, J. East,L. Katehi, "A Micromachined High-Q X-Band Resonator", MGWL, June 1997
2. R. Snyder, "New Application of Evanescent Waveguide to Filters", Trans MTT, Dec. 1977
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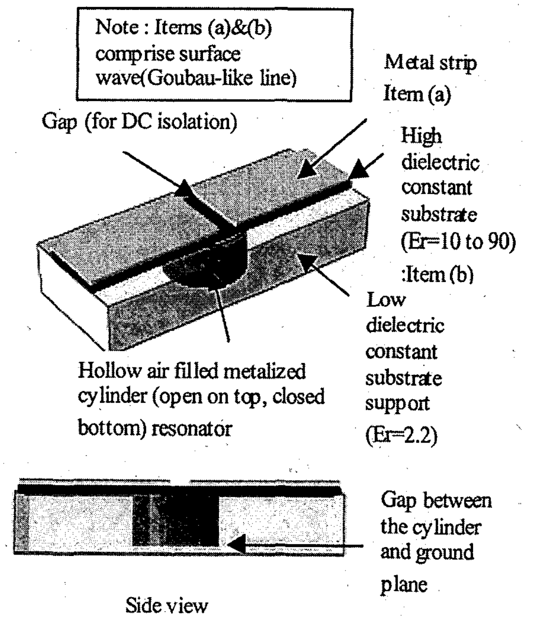

Fig. 1 Evanescent suspended bandpass resonator (Series transmission pole).

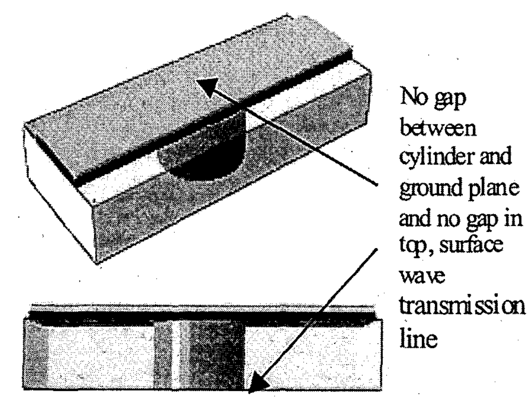

Fig.2 Evanescent suspended bandstop resonator (shunt transmission zero).

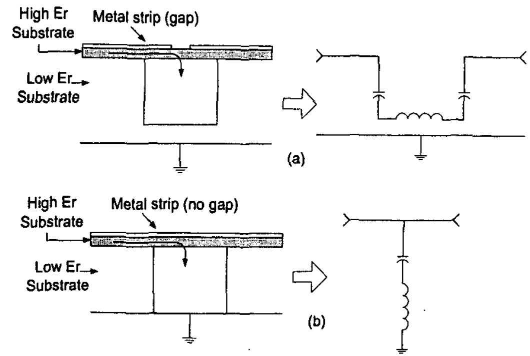

Fig.3. Equivalent circuit elements for both (a) bandpass and (b) bandstop cases; values of capacitance C given from (4-4).

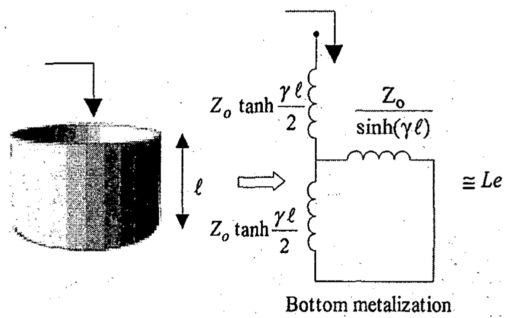

Fig. 4.(a) Metalized wall and bottom bellow-cutoff cross section. (b) *For a single-mod below cutoff, the equivalent circuit is short-circuited tee.*

$$Z_o \tanh\frac{\gamma \ell}{2} \qquad \frac{Z_o}{\sinh(\gamma \ell)} \qquad Z_o \tanh\frac{\gamma \ell}{2} \qquad \cong Le$$

$$L_e = Z_o \tanh\left(\frac{\gamma \ell}{2}\right) + \frac{Z_o^2 \tanh\left(\frac{\gamma \ell}{2}\right)}{Z_o \tanh\left(\frac{\gamma \ell}{2}\right) + \frac{Z_o}{\sinh(\gamma \ell)}} \quad (4\text{-}1)$$

Z_o (for round cross section sector with cut-off wave length of λc)

$$Z_o = \frac{377}{\sqrt{\left(\frac{\lambda_g}{\lambda_c}\right)^2 - 1}} \quad (4\text{-}2)$$

$$\gamma = \left(\frac{6.28}{\lambda_g}\right)\sqrt{\left(\frac{\lambda_g}{\lambda_c}\right)^2 - 1} \quad (4\text{-}3)$$

The values of Zo & from [2], and guide wavelength from the dielectric constant in the surface wave feed lines. Derivation of C an in Appendix to be presented at the talk.

$$C = \frac{2\pi \varepsilon_r \varepsilon_o r\sqrt{4d^2 + r^2}}{\sqrt{4d^2 + r^2} - r} \quad (4\text{-}4)$$

r = radius of cylinder, d = thickness of dielectric layer in surface wave line structure, C is effective total circuit static capacitance.

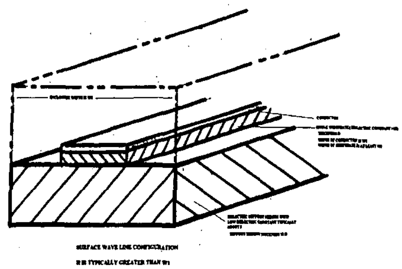

Fig. 5 Surface Wave Line Configuration
Enclosure width is W2, Line and dielectric widths are W1, high dielectric constant substrate thickness is d (er > 10), support thickness is H, er =2
For surface wave, H > W1

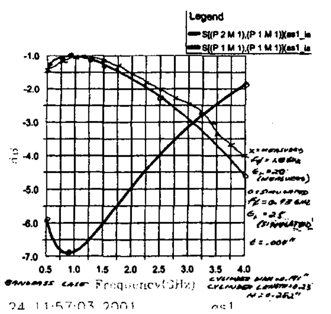

Fig. 7 Bandpass Case

F0=1.03 GHz (measured), 0.93 GHz (simulated)
Dielectric constant =25 in simulation, 20 actual
Substrate thickness is .004"

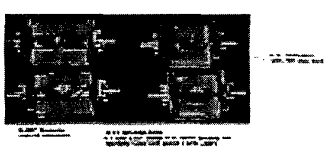

Fig. 9A Bandpass and Bandstop resonators

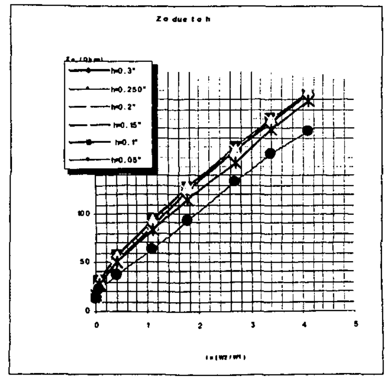

Fig. 6 Z0 vs. ln (W2/W1) for various values of H

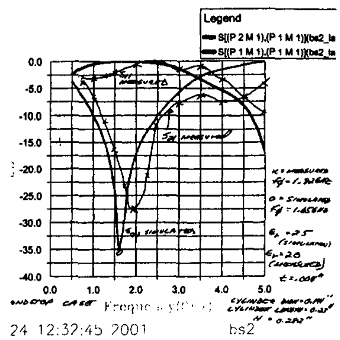

Fig. 8 Bandstop Case
F0=1.82 GHz (measured), 1.65 GHz (simulated)
Dielectric constant= 25 in simulation, 20 actual, .004" thick

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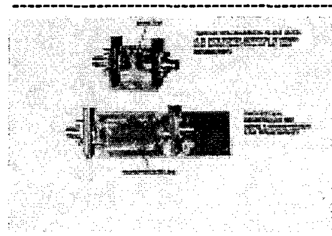

Fig. 9B Two resonator BP types...using either TL or lumped inverters

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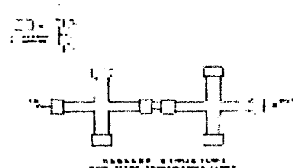

Fig. 10 One proposed multiresonator connection