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Evanescent Mode Bandpass Filters for Microwave Communication Systems – A review

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Abstract. This paper reviews some of the many published technical papers relating to the design of bandpass filters using Evanescent mode (waveguide below cut-off) technique. A small section of an evanescent mode closely represents lumped inductances. Resonators may be formed by introducing capacitive obstacles in the waveguide and this concept is being used in the design of tunable bandpass filters. Evanescent mode filters have drawn much attention to applications such as air-borne equipment and satellite systems due to the fact that they are light weight and smaller in size compared to conventional filters. We will follow the development of this methodology from the early investigations through the later applications and see how inductive strips in ridge waveguides would improve the performance of evanescent mode bandpass filters.

Keywords: Evanescent, Bandpass, Passband, Stopband, Ridge, Substrate, Waveguide.

1. Introduction

It was clear from the findings of G.F. Craven, & C.K Mok, in 1971, [1] that filters could be designed with evanescent mode waveguides (waveguide below cut-off) using resonators which are formed by the series inductance coupling and capacitive obstacles. It was recommended that capacitive screws or studs could be used for narrow band filters but a thin sheet of high permittivity dielectric is more suitable for broadband applications. The lumped circuit concept here was much useful in the design of bandpass filters. The greatest advantage over conventional filters being its light weight and considerable reduction in size and cost.

2. Design Developments

In 1972, C.K. Mok et al [2] incorporated susceptance loading midway between cavities and it was shown that by replacing conventional capacitive tuning screws with quartz-rod tuning elements, the losses were comparable to conventional waveguides but the volume (size) of filters were reduced by 25 to 40%. Where losses are not so important, it may be traded for further reduction in volume.

In 1981, a five section, 7 GHz evanescent mode bandpass filter was designed by G. Ramakrishnan and D.K. Banerjee [3] wherein tuning screws have been used as capacitive elements. A three section bandpass filter at a center frequency 7 GHz had a passband of 55MHz and over this band, the VSWR was 1.05 and insertion loss, 0.9 dB. The group delay within the passband was 0.125 nanoseconds. The bandpass filter was used in the design of an upconverter for 7GHz band.

In 1983, Richard. V. Snyder et al [4] designed bandpass filter with wide stopbands using a stepped wall evanescent mode approach. This was applicable for center frequencies above 40GHz. Conventional evanescent designs suffer from close spacing of the first few capacitive pins and moreover, the mechanical problem affects the tuning time. Inductive Iris filters also become impractical due to the iris size, interaction and stopband flare above 20%. The stepped wall design has a series coupled evanescent dominant mode approach and is easy to tune, structurally simple, compact construction and offers high reliability. The stepped wall approach provides an end section transformation for coax connectivity.

In 1984, N.P. Akers et al [5] had designed a seven element evanescent mode bandpass filter at band using fixed stubs and capacitive screws for tuning. Eventhough the insertion loss was less than or equal to 1 dB, which was comparable to the predicted loss, the author concludes that improvements in insertion loss should be possible by replacing the metal resonators with suitable dielectric.

In 1986, A.M.K. Saad et al [6] designed a bandpass filter using evanescent mode waveguide sections as impedance K-inverters, while using serrated single or double ridge waveguide sections as series resonators. Introducing serrations in the ridge waveguide resonators reduces the ridge length and hence, losses and creates low pass structure in each resonator which improves the out of band response.

In 1988, K.S. Kong et al [7] designed an evanescent mode bandpass filter with non-touching E- Plane fins combined with a capacitive iris. Their point was that filters with capacitive screws were snot ideally suited for mass production and hence the capacitive screws were replaced with non touching E-Plane fins. The design of a Ka band two fin filter using RT/Duroid substrate was presented which has a ripple less than 0.8 dB and the passband was found to be 15%.

In 1992, Vladimir. A. et al [8] presented an evanescent mode filter based on T-septum waveguide technology. This technology was utilized to reduce the resonator cut-off frequency compared with standard ridge waveguide designs. The lengths of the coupling sections were reduced thus reducing the overall structure considerably. The 10GHz prototype manufactured was measuring only 18.4 mm in length.

In 1996, H. Baher et al [9] designed a evanescent filter with dielectric inserts at various points along the guide. A dielectric (Teflon) with permittivity of 2.1 was chosen resulting in a center frequency of 11.882GHz. The passband corresponds to 2% bandwidth with a minimum passband return loss of 15dB.

In 2000, M. Lecouve et al [10] developed Genetic algorithm optimization for evanescent mode filter design. It consists of air filled waveguide with dielectric inserts along the guide. The genetic algorithm method does not use equivalent LC prototypes for low pass filters, and gives directly useful and optimum responses. A 2.54 dielectric permittivity was chosen and the bandpass edges were taken as 8.117GHz and 8.142GHz.

In 2001, Anatoly Kirilenko et al [11] designed and presented evanescent waveguide filters based on ridged waveguide sections. It was shown that insertion of additional inductive strips to ridge notches between ridge waveguide sections reduces the longitudinal filter size and achieving sufficient improvement in stopband characteristics. The results show that in the passband of 10.5 – 11.5GHz passband, the return loss was not worse than 25dB. Here the fact which required additional study is that the inductive strips introduced is parasitic in nature and may upset the phase conditions.

In 2001, Tao Shen and Kawthar. A. Zaki [12] investigated the length reduction of evanescent mode ridge waveguide bandpass filters. It was found that the filter length could be reduced by increasing the height of the waveguide and also found that the cut of frequency of fundamental mode has a considerable effect on the filter length. A five section, 10GHz filter of bandwidth 1 GHz and passband return loss of 20dB was designed. In the design, the waveguide was filled with a dielectric material of relative dielectric constant of value 6. Results show that more than 20% length reduction was achieved with increase of ridge waveguide height. It is also shown that increasing the height of the ridge waveguide has no effect on the spurious response of the filter.

In 2006, P. Soto et al [13] presented design methodologies for optimizing length, losses, power handling and spurious free out – of- band response. In order to overcome the manufacture errors, in this design, tuning screws were replaced by rectangular cross section teeth, which were design by computer aided tools. Here, the evanescent waveguide consists of ridge waveguides with rectangular metal inserts both in the upper and lower walls connected through below- cut off housing waveguide sections. A seven resonator bandpass filter was designed with a center frequency of 6.9664 GHz with a 249 MHz Bandwidth and a return loss of 23dB. However, it was found that there were several narrow spikes in the filter spurious-free stopband. These spikes were due to small shifts in the manufactured pieces composing of the final structure. It was suggested that better losses could be achieved by increasing the gap between ridges or the housing width in exchange for a longer filter.

In 2008, Xianrong Zhang et al [14] designed and presented a seven resonator evanescent mode bandpass filter. They used CST software to design the filter and the fabrication of the filter consists of seven posts and tunable screws along the waveguide. Results shows that from 7.55GHz to 8.25GHz, the insertion loss was lower than 0.45dB and the reflection was lower than -20dB. Conventional fine tuning screws were used in this design to shift down the center frequency, expand the pass band bandwidth and lower down the reflection in the passband.

In 2009, Lin- Sheg Wu [15] conducted a study on Cross Coupled Substrate Integrated Evanescent Mode Waveguide Filter. Two forth order direct coupled and cross coupled BPFs were studied in this paper with a center frequency 3.45GHz, bandwidth of 0.3GHz ad return loss of 20dB. The substrate considered here is LTCC ferro A6S which has s permittivity of 5.9. The evanescent mode coupling RSIW (Ridged Substrate Integrated Waveguide) sections are connected with a multilayer FSIW (Folded Substrate Integrated Waveguide) directly. The results show that the size of the filter is much smaller and have better spurious response characteristics than the conventional ones. In conclusion, it is found that if the monomode bandwidth of the multilayer FSIW is increased, the performance of the band pass filter can be further improved.

3. Conclusion

The design improvement of evanescent mode waveguide bandpass filters has been reviewed. Various techniques have been used to realise resonators with capacitive elements such as screws / posts, insertion of inductive strips alongside the waveguide, capacitive iris, stepped wall and ridge waveguide sections. The focus is to achieve filters with better stopband characteristics than the known analogues, low losses and reduction is size. Conventional evanescent designers suffer from close spacing of the first few capacitive pins and moreover, the mechanical problem affects the tuning time. Inductive Iris filters also become impractical due to the iris size, interaction and stopband flare above 20%.

Evanescent mode waveguide filters with dielectric inserts along the guide was tested for optimum responses but the design depends on the permittivity of the dielectric to suit various frequency bands. Later, it was found that evanescent waveguide bandpass filters based on ridged waveguide sections with insertion of additional inductive strips to ridge notches between ridge waveguide sections reduces the longitudinal filter size achieving sufficient improvement in stopband characteristics. Moreover, further studies show that Substrate Integrated Evanescent mode waveguides reduces the filter size and have better spurious response characteristics than the conventional ones.

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