Special Session on Recent Advances in Microwave Filter Design on Filpro (INVITED)

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Development of the filter synthesis software FILPRO were started about 30 years ago in DOS, Pascal. It had accumulated a vast amount of knowledge on filter synthesis and circuit transformations. It is still in DOS, hence not operating in new windows versions. Therefore it is no more available commercially. However it is still a very useful tool (on Win-98) which can cope with difficult and complex filter design problems. Some design examples will be presented in this talk and some as separate papers in this session.

SUBJECTS OF THIS TALK:

1) Dimensional Design of Microstrip and Dual Mode Waveguide Quadruplet Filters

***Abstract*—** A simple dimensional design procedure is developed for microstrip/stripline quadruplet and dual mode waveguide (circular or rectangular) quadruplet filters by starting with direct BP synthesis of a lumped quadruplet with inverter couplings, K14, K12, K23 and K34 (Fig. 1a). K14 is the cross-coupling inverter which creates a symmetric pair of finite transmission zeros (FTZ's) if the sign of K14 is opposite of the other inverters while a complex TZ is created if K14 has the same as the other inverters leading to linear phase (flat delay) responses.

A microstrip quadruplet is formed by converting the shunt arm parallel LC resonators into open circuited half wavelength transmission line resonators (OCTL) (Fig. 1.b). Then the filter is scaled by inserting inverters at source and load ends so that the OCTL resonators will have the desired characteristic impedance (Fig. 1.c). Then parallel coupled line (PCL) sections are formed by using the half length OCTL pieces coupled by inverters to form a microstrip quadruplet (Fig. 1.d).

For waveguide (WG) type realization, first the dual of the OCTL quadruplet is formed converting the OCTL resonators into SCTL resonators (Figs. 2.a, b, c). Then the circuit is scaled by inverters so that the SCTL resonators will be equivalent to the WG resonators with desired cross-sectional dimensions (Fig. 2.d). Then the SCTL resonators are replaced by their WG equivalents (Fig. 2.e). Thus a quadruplet is formed with four WG resonators (WG1, WG2, WG3 and WG4) coupled by inverters K14, K12, K23 and K34, with K14 being the cross-coupling inverter. Actually the resonator pair WG1 and WG2 will be realized as dual modes (vertical and horizontal modes) of a single WG (named as Left WG) by inserting a perturbation element which is simulated by the coupling inverter K12. Similarly the pair WG3-WG4 will be realized as dual modes of the Right WG created by the perturbation element simulated by the inverter K34 (Fig. 2.e). Hence the name dual mode WG filter. The inverters at terminations and the inverter K14 coupling the vertical mode resonators WG1 and WG4 are all realized as horizontal irises while the inverter K23 which couples the horizontal mode resonators WG2 and WG3 is realized as a vertical iris. Thus, the inverter pair K14 and K23 are actually realized as cross-type iris coupling the two WG's (Fig. 2.f). When the inverters K14, K23 and the inverters at terminations are replaced by their iris equivalents the lengths of WG1 and WG2 will change. Since they should have identical lengths for realization as a single WG, the lengths of WG1 and WG2 are equated by brute force and mode tuning reactive elements are inserted which can tune the vertical and horizontal modes to get the same electrical lengths. The same problem exist for resonators WG3 and WG4 which is solved by using mode tuning reactances in the similar way. This way a circuit model of a dual mode quadruplet is obtained with desired dimensions. Comparing with EM field model of the classical dual mode resonator filters (Fig. 2.f), it is seen that the inverters K12 and K34 correspond to the mode conversion perturbation elements while the tuning reactances correspond to the mode tuning screws. Hence a one-to-one correspondence is formed between the circuit model and EM fields model which simplifies design considerably. Some dual mode filters that are used as channel filters of diplexers and OMUX (output multiplexers for satellite applications) will be presented as a separate paper in this session.

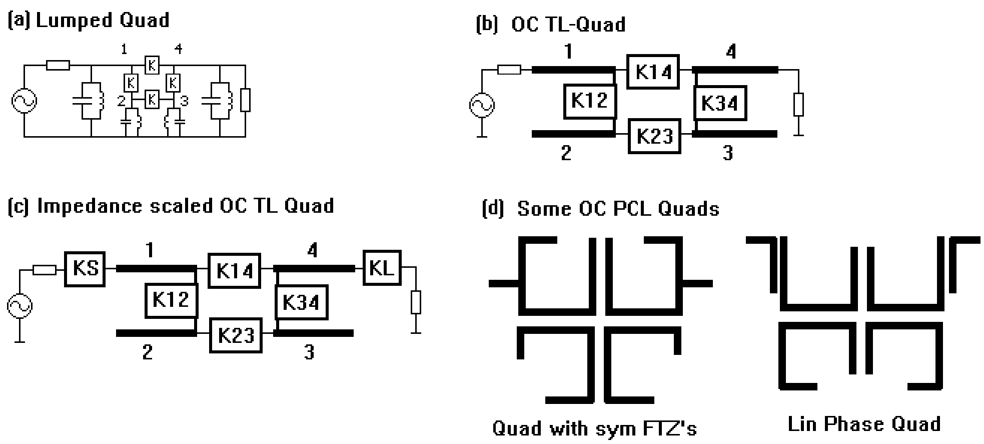

Fig. 1. Microstrip type parallel coupled line quadruplet design stages.

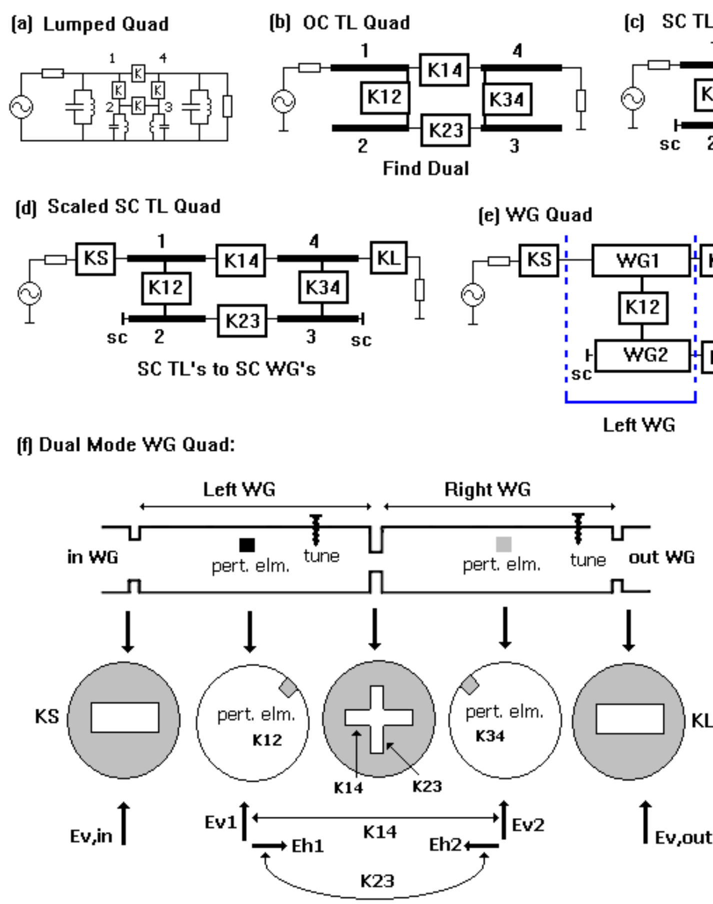

Fig. 2. Dual mode waveguide quadruplet design stages.

2) Selective Linear Phase Cross Coupled Dielectric Resonator Filters for IMUX applications

Circuit transformations are developed and placed into Filpro for converting cascade coupled N-resonator filters into cross-coupled (folded) N-resonator filters. Cross-couplings are adjusted for either creating finite jw-axis and/or s=σ+jw plane transmission zeros to get selective linear phase filters. For IMUX (input multiplexers of satellites) applications dielectric resonators are used. Filters may involve has both vertical and diagonal cross couplings to satisfy extreme delay ripple requirements. An example will be presented as a separate paper in this session.

3) A novel approach for designing miniature corrugated waveguide lowpass filters with wide rejection bandwidth

Recent publications on miniaturized corrugated waveguide (WG) LP filters with wide rejection bandwidths for use in satellite applications rely on designing a band stop (BS) block with reduced height waveguides augmented by impedance matching blocks at input and output. A new approach is formulated in Filpro which can design both BS block and impedance matching blocks as a single unit. In this approach first a TEM mode commensurate length distributed element LPF is synthesized by placing N transmission zeros (TZ) at infinity and N+1 Unit Elements (UE) with a very high quarter wavelength frequency fq to get small longitudinal dimension. The TZ's at infinity appear as series arm SC stubs after extraction of the TZ's. Hence the resulting circuit involves N+1 UE's interleaved by N series SC stubs. The number of UE's and TZ's are selected to get both minimum size for the filter and also to set the required stopband rejection level. Then the UE's and SC stubs are converted into WG UE's and WG SC stubs with desired WG cross-sectional dimensions, **a** and **b**. The stopband is shaped by spreading the TZ's into the targeted stopband by adjusting their lengths. Then both heights **b** of the UE's and lengths of SC stubs are optimized to get both a very high skirt slope and a very high stopband rejection level over a very wide stopband (14 GHz-to-40 GHz with 60 dB rejection level) while preserving the passband return loss. A design example will be presented as a separate paper in this session.

4) Comparison of Exponential, Linear, Collin and Klopfenstein Tapers.

Impedance tapering is widely used in many applications like couplers, baluns, mixers, power dividers, etc. However their utility are limited by their computational complexity and difficulties in obtaining their ABCD parameters for displaying insertion loss and return loss responses. Among the four types of tapers mentioned in the heading only Exponential tapers has neat analytical solutions which lends itself for displaying insertion loss readily. Linear tapers are preferred due to ease of manufacturing. Collin and Klopfenstein tapers offer wider passbands with controllable return loss levels. These four types of tapers are programmed into Filpro by splitting them into a large number of uniform line pieces so that the insertion and return loss responses can be plotted for comparison.

ABSRACTS OF PAPERS PROPOSED FOR PRESENTATION IN THIS SPECIAL SESSION:

1) Gökhan Boyacıoğlu, Bulent Alicioglu and Nevzat Yildirim, "Dimensional Design of Dual Mode Waveguide Filters", Aselsan Military Ind. Ankara.

Abstract— **In this paper, a simple and systematic design procedure is described for classical circular or rectangular waveguide dual-mode filters. The design procedure starts with cascade synthesis of lumped quadruplet version of the filter with inverter couplings. Then the LC resonators are converted into SC transmision line (SCTL) equivalents coupled by inverters. The whole circuit is impedance scaled by inverters at ports for realization of resonators as waveguides with desired cross-sectional dimensions. Then SCTL resonators are converted into waveguide resonators, forming a quadruplet with four waveguide resonators coupled by inverters. The resonators 1 and 4 (connected to input and output) are treated as simulating the vertical modes while the inner resonators (2 and 3) are simulating horizontal mode fields. The vertical and horizontal modes of the same waveguide are coupled by inverters K12 and K34 while the inverters K14 and K23 simulate couplings between the modes of the two waveguide resonators. Then all inverters are converted into constant reactances in between TL pieces. This stage causes electrical lengths of the waveguides simulating vertical and horizontal mode to differ. They are equated by introducing proper tuning reactances to complete the design. As examples, several diplexers and multiplexers will be described to be used in output multiplexers (OMUX) of a satellite payload.**

Index Terms - **Circular waveguide, design methodology, distributed parameter circuits, dual-mode filter, equivalent circuits, waveguide filters.**

2) O. Ozan Öztürk, Sacid Oruç, Bulent Alicioglu and Nevzat Yildirim, "Design of a Highly Selective Linear Phase Cross-Coupled Dielectric Resonators Filters", Aselsan Military Ind. Ankara.

Abstract— **In this paper, a highly selective linear phase filter is designed and implemented in cross-coupled form using dielectric resonators in Ku band to be used as channel filter in input multiplexer (IMUX) of a satellite payload. Extreme delay flatness is required: 1.5 nS delay ripple over 60 % of the passband and 12 nS near the band edges. The Initial design is carried out as 10 resonator symmetric cross-coupled filter with inverter couplings realizing four finite transmission zeros on the software Filpro. The delay ripple requirement of 1.5 nS within the passband is readily satisfied while the delay ripple near band edges needed optimization on the circuit simulator ADS. Then the circuit is transferred to EM simulator for converting coupling inverters into realizable forms. The positive inverters (mangetic couplings) are realized as irises while the negative inverters (electric couplings) are realized in ridged waveguide forms which is the main novelty of this paper. However when the inverters are converted into iris and ridge waveguide forms a tilt is observed in delay exceeding the delay ripple limits. The tilt is then corrected by modifying the filter by inserting diagonal cross-couplings also. Measured results confirm the theory.**

Index Terms **– Cross-coupled filters, filter synthesis, inverters, ridged waveguides, dielectric resonators, magnetic couplings, electric couplings.**

3) Metehan Çetin, Gokhan Boyacıoğlu, Bulent Alicioglu and Nevzat Yildirim, "A Miniaturized Corrugated Waveguide Low Pass Filter with High Selectivity and Wide Rejection Band", Aselsan Military Ind. Ankara.

(Patent Pending)

***Abstract*— In this paper, a simple methodology is developed for the design of miniature, highly selective corrugated waveguide lowpass filter (LPF). It has wide rejection bandwidth (14-40 GHz) with rejection level of more than 60 dB. It will be used in output multiplexer (OMUX) stages of a satellite payload. The recent publications on miniaturized corrugated waveguide (WG) LPF's rely on designing a band stop (BS) block with reduced height waveguides augmented by impedance matching blocks at input and output. In the new approach both BS block and impedance matching blocks are synthesized as a single unit. First a TEM mode commensurate length distributed element LPF is synthesized by placing N transmission zeros (TZ) at infinity and N+1 Unit Elements (UE) with a very high quarter wavelength frequency fq to get small longitudinal dimension. The number of UE's and TZ's are selected to get both minimum size for the filter and also to set the required stopband rejection level. The resulting circuit involves N+1 UE's**

interleaved by N series SC stubs. Then the UE's are converted into WG UE's and the SC stubs are converted into WG SC stubs with desired WG cross-sectional dimensions, a and b. The stopband is shaped by spreading the TZ's into the targeted stopband by adjusting their lengths. Then both heights b of the UE's and lengths of SC stubs are optimized to get both a very high skirt slope and high rejection in the stopband while preserving the passband return loss. Thus the design of the circuit model is completed. Then Electromagnetic (EM) model is formed on FEST3D for optimization and CST for full-wave simulation to display the final responses. EM simulation results are almost the same as the circuit simulations, satisfying all requirements. Total length is about 9 mm which is among the smallest ones in its class. Initial implementation trials are promising. Alternative production techniques are in progress.

Index Terms **–Waveguide filters, corrugated waveguide filters, distributed element filters, commensurate length filters, filter synthesis, Unit Elements, Transmission Zeros.**