COMPUTER-AIDED TUNING OF MICROWAVE FILTERS

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Abstract

LCX synthesis and pattern search optimisation techniques are used to construct a very effective algorithm for computer aided tuning of microwave filters. Intercavity couplings and resonator detunings of the short-circuited network under test are worked out from the measurement of the phase of the reflection coefficient. The technique proves to be successful in tuning a 6-pole filter having both elliptic attenuation peaks and group delay equalisation and looks very promising for properly aligning channel filters of manifold multiplexers.

Introduction

Tuning of microwave filters becomes a very difficult task especially when the transfer function possesses the maximum allowable number of transmission zeros, that is the number of poles diminished by two. This situation is very often handled, in dual-mode cavity filters, with the so-called Pfitzenmaier (or partially reflex) configuration, and usualy corresponds to filter having both elliptic attenuation peaks outside the passband and group delay equalisation over most of the passband.

Tuning techniques presented in the past |1|, |2|, though providing a mean of measuring in-situ a number of intercavity coupling, do not seem to offer a comprehnsive approach to the problem of tuning microwave filters.

Theoretical outline

A basic concept is, however, introduced in |1|: the measurement method is an indirect technique (in that the significant parameter measured is the reflection coefficient of the short-circuited network and not a commonly interpreted s-parameter), and what is effectively measured are the 0/180 degree phase crossing, identified respectively as the zeros and he poles of the input admittance.

This fundamental identification is justified by the low-loss nature of the microwave filter which makes the short-circuited network almost purely LC, and leads to the general consideration that from the measurement of the phase of the reflection coefficient we are able to detect the singularities of the short-circuited network.

If this network is minimum phase (that is all the cavities are directly connected only) then the knowledge of the singularities (in the following intended to be brought down to their low-pass counterparts) enables the complete reconstruction of the measured network by means of a suitable LCX (lossless network including constant reactances) ladder synthesis technique |3|. In particular this can be done not only in terms of admittance inverters (corresponding to intercavity couplings) but also of constant sussceptances in parallel to capacitors (see for example |4|) that correspond to detuned conditions of the resonant cavities (fig. 1).

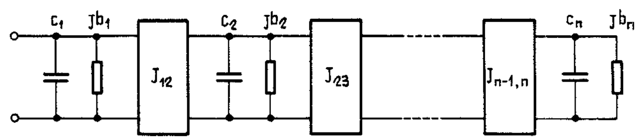

Fig. 1 - Low pass LCX network corresponding to short-circuited direct coupled filter

The algorithm just described has been implemented on a desktop computer governing a measurement set-up such as the one depicted in fig. 2, ands is able to give, for a set of directly coupled cavities under test, both the intercavity couplings (and hence the way for adjusting uncorrect irises or coupling screws) and the detunings of each cavity (given in MHz off centre frequency) providing a very convenient mean for tuning-up the structure under test (in the event of a direct coupled filter, the whole filter).

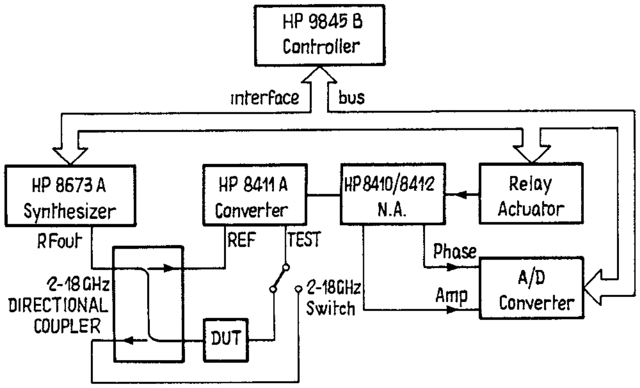

Fig. 2 - Block diagram of the test set-up

When the filter possesses extra couplings (the case of maximum interest in practice) the network is not minimum phase and the LCX ladder synthesis can no longer be used but the obstacle may be circumvented with the use of an optimisation technique.

In this case the set of measured singularities is the desired objective, and the pattern search optimisation algorithm |5| distorts a starting network (usually the tuned filter) modifying couplings and introducing detunings to force its singularities to match the objective. Fast running analysis routines are mandatory and cases for 2 resonators and for 4 and 6 resonators plus extra couplings have been covered. Losses can be easily accounted for and adjusted parameters can be excluded as long as the tuning procedure proceeds.

Experimental remarks

Since the singularities of the network under test are derived from a phase measurement, a key issue is the acquisition of a reliable reference. This is made difficult by the input coupling (either a probe or an iris) which causes a shift of the reference plane. The problem is here solved in conjunction with the measurement of the input coupling itself (that is the external Q of the input cavity) through a revisitation of Ginzton's phase method |6| originally developed for slotted-line measurements and here readapted to network analyser reflectometry. The phase method states that the external Q of a strongly overcoupled cavity is directy proportional to the phase slope of the reflection coefficient at resonance, the resonance being defined as the frequency at which a maximum of the phase slope occurs.

In the method described by this work the input cavity is measured first, and, by taking the derivative of the phase, the resonant frequency and the external Q are determined. The phase reference is taken so that the measured phase at resonance be exactly 180 degrees.

Each cavity of the filter to be tuned is first individually brought near its operating (tuned) condition using a particular mounting technique (here called "stand-alone" arrangement). The method has proven to be very effective and exploits throughly on 2 resonators the LCX synthesis capability described earlier.

A practical example will better clarify the whole tuning process. The filter to be tuned is a 6-pole 14 GHz advanced design prototipe having Butterworth behaviour in the passband amplitude response, elliptic peaks outside the passband and complete delay equalisation |7|. The transfer function possesses a pair of immaginary zeros and a pair of real zeros.

The six resonators are arranged in a dual-mode Pfitzenmaier configuration as depicted in the nodal representation of fig. 3.

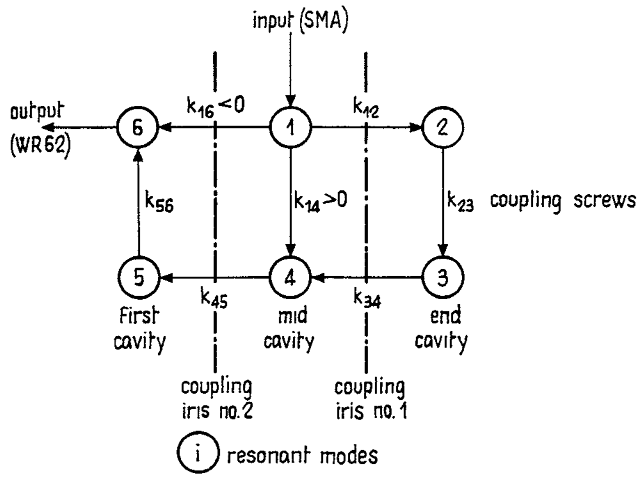

Fig. 3 - Nodal representation of the filter being tuned

Tuning of this network using the classical approach of minimising the return loss with almost inevitably result in a poor return loss and a bad delay equalization.

A step-by-step description of the tuning procedure is shown below (see fig. 3):

1) end cavity is tuned first setting properly tuning screws 2 and 3 and coupling screw k_{23}. Main arm (k_{12}) of coupling iris no.1 is used to access the cavity.

2) Mid cavity is put in stand-alone arrangement and accessed though SMA input coupling, then:
   - 2a) input external Q is correctly adjusted (within $\pm$ 2%) and phase reference is acquired;
   - 2b) using LCX synthesis modes 1 and 4 are tuned and extra coupling k_{14} is set.

3) Mid and end cavities are joined and accessed through SMA input coupling. Step 1 and 2 make the resultant set of 4 poles and 3 zeros be quite near their correct locations. A pattern search optimisation cycle is performed, each time computing actual detunings of modes 1,2,3,4 (and checking couplings if wanted).
The final result is reported in fig. 4 where measured values of poles, zeros and detunings are shown as given in the printout of the HP9845B calculator. Coupling values are correct within ± 1%.

4) First cavity is put in stand-alone arrangement and accessed through externally coupling iris. The same procedure as in steps 2a) and 2b) is repeated on modes 5 and 6.

5) First cavity is added to previously joined mid and end cavity and the whole filter is assembled. Access port is SMA input connector.
A final pattern search optimization cycle is performed. The parameters to be adjusted are all the screws (tuning and coupling) of first and mid cavities, the screws of the end cavity being left by then unchanged. Final detunings turn out to be below 1 MHz.

Measured zeros		**Theoretical locations**	
1	14.10304	1	14.1031
2	14.12509	2	14.1250
3	14.14677	3	14.1469

Measured poles		**Theoretical locations**	
1	14.08627	1	14.0861
2	14.11372	2	14.1138
3	14.13594	3	14.1362
4	14.16388	4	14.1640

Measured detunings (MHz)	
1	- 0.2
2	0.3
3	- 0.2
4	- 0.2

Fig. 4 - Measured parameters of resonators 1,2,3,4 assembled

The short circuit condition is now removed and the filter response is subsequently measured; no further adjustment of the screws is performed. The results is reported in fig. 5 and 6 and is considered to be quite satisfactory. Elliptic peaks are almost exactly placed and the Butterworth behaviour can be recognised by the rounded amplitude bandedges. Most of all the group delay is very well equalised and shows close resemblance (also in number of ripples) to the theoretical prediction. Such a result will hardly be attainable using a conventional tuning method.

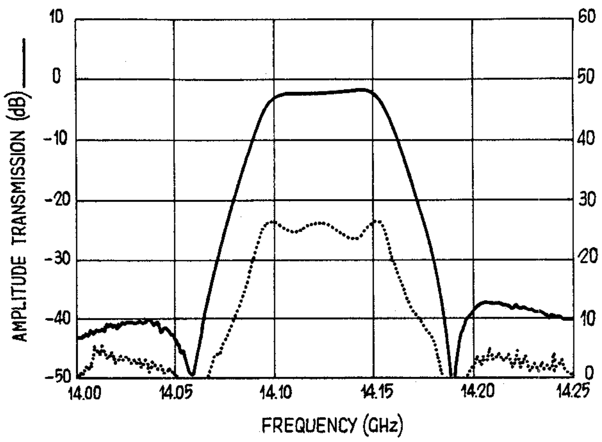

Fig. 5 - Measured return loss of the assembled filter

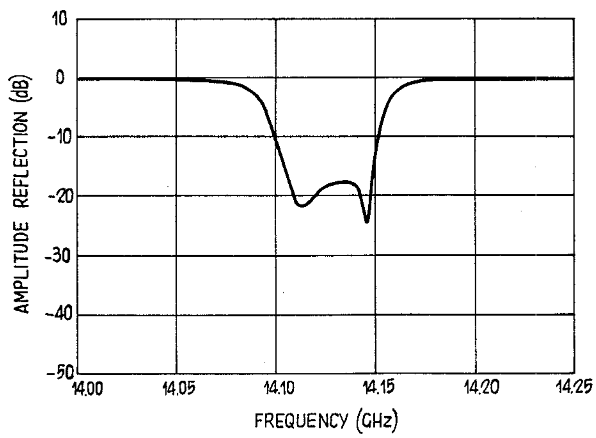

Fig. 6 - Measured transmission of the assembled filter

A slight asymmetry is still present but is believed to be due to unwanted additional couplings generated by small out-of-alignment-of field polarizations inside adjacent cavities and not attributable to uncorrectness of the tuning procedure.

Conclusions

A very general computed-aider tuning procedure able to handle filters having quite sophisticated transfer functions has been presented. Short circuit network under test can be characterised not only in terms of intercavity couplings but also of cavity detunings, and this feature makes the proposed procedure nearly ideally suited for aligning also channel filters of manifold waveguide multiplexers |8|, where some of the resonators must have a specified amount of detuning to let the whole structure operate correctly.

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