# MEASUREMENT SYSTEMS TO DISPLAY $\text{Re}(Z_{s.t.})$ OF SINGLY TERMINATED FILTERS

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## Abstract

Two measurement systems to display the real part of singly terminated filters are presented. Both systems utilize test equipment standard to most microwave laboratories. The theory of operation and measurement errors are discussed for both systems.

## Introduction

Tuning a singly terminated filter without annulling or without a complementary filter has been avoided in the past for lack of a simple measurement system. To overcome this difficulty, foreshortened doubly terminated filters have been suggested in place of singly terminated filters because of their convenience of tuning(1). With the appearance of contiguous multiplexers comprised of singly terminated cross coupled filters(2), a measurement system to align the component filters of a multiplexer is required. The techniques to be described are also of significant value in alignment of broad band contiguous multiplexing filters. This paper describes two measurement systems utilizing standard test equipment. They display the $\text{Re}(Z_{s.t.})$ thus allowing singly terminated filters to be properly aligned for equal ripple $\text{Re}(Z_{s.t.})$.

A singly terminated filter differs from a doubly terminated filter in that the former is designed for equal ripple real immittance while doubly terminated filters are designed for equal ripple transmission. The input impedance of a generalized singly terminated filter in the bandpass domain is illustrated in Figure 1-a. Combining two filters in a series diplexer configuration yields the contiguous diplexer characteristics plotted in Figure 1-b. The real part is approximately one over the combined passbands, while the reactive parts cancel in the crossover region. The residual reactive part is annulled with an appropriate reactive network.

Tuning a contiguous diplexer for return loss may lead to some difficulty. There will be interaction of the component filters in the crossover region. One might inadvertently mistune one channel to the benefit of its neighbor and vice versa. Aligning the component filters prior to combining will eliminate the detuning interaction between filters.

## Description of Measurement Systems

A simple measurement system to display $\text{Re}(Z_{s.t.})$ is shown in Figure 2. The theory of operation is explained referencing Figure 1. Visualize replacing channel 2 with a square law detector having an input impedance of 1+j0. The detected output, $P_0$, is proportional to $|i|^2$ where $|i|$ is the magnitude of the current flowing in terminal A. Also, replace the one ohm termination on channel 1 with a detector identical to that replacing channel 2. Assuming a lossless filter, its output is proportional to the power dissipated between terminals A-A', $P_d$. That impedance across A-A' is $R(\omega)+jX(\omega)$. Therefore, $P_d = |i|^2 \cdot R(\omega)$. The ratio of the detected power at the output of channel 1, $P_d$, to the detected power across B-B', $P_0$, is

$$P_d/P_0 = |i|^2 R(\omega)/(|i|^2 * 1) = R(\omega).$$

Thus, with the simple ratio meter setup shown in Figure 2, the real part of the input impedance of a filter may be measured. A ratio of zero dB displays a real part of one while the ripple level is

$$\text{ripple} = 10*\log(R(\omega))\ \text{dB}.$$

Note that the measurement does not depend upon the generator output level nor upon its source impedance.

The actual display of a practical filter with dissipation loss will be distorted. The lossy filter may be replaced with a lossless filter and a matched frequency dependent pad whose attenuation characteristic is $\alpha(\omega)$ dB. The detected output power is now

$$P_d = |i|^2 R(\omega) * 10^{\frac{\alpha(\omega)}{10}}.$$

The ratio A/B now has the distorted display shown by dotted lines in Figure 2-c. The distortion can be calibrated out by annulling the filter with a reactive network across terminals B-B' and measuring the dissipation loss of the annulled filter. The dissipation loss can then be marked on the scope face as the zero dB reference line. Alternatively, the dissipation loss of the filter may be computed and drawn on a scope face overlay. Final alignment of the filter is then possible.

The test setup of Figure 3 measures $R(\omega)$ independent of the filter dissipation loss. Again channel 2 is replaced by a matched square law detector. The incident and the reflected power is monitored with the aid of a dual directional coupler and detectors. It is clear that

$$P_i = P_r + P_d + P_o$$

where:

$P_i$ = incident power
$P_r$ = reflected power
$P_d = |i|^2 * R(\omega)$
$P_o = |i|^2 * 1$

rearranging terms

$$P_i/P_o - P_r/P_o = R(\omega) + 1$$

yields the result that the measurement of $R(\omega)$ is independent of the dissipation loss of the filter. By analysis one can demonstrate that the $Re(Z_{s.t.})$ is negligibly perturbed by moderate dissipation loss. Tuning of a singly terminated filter using this setup requires alignment to an equal ripple response very similar to the procedure to align doubly terminated filters using a reflectometer setup.

## Error Considerations

The simple measurement system has fewer sources of errors than the loss independent system. The measurement errors in the simple system are predominately associated with the VSWR of the detectors assuming the detectors are matched for frequency and power sensitivity. It can be shown that the error in the simple system is approximately

$$\Delta R(\omega) \approx \pm 2 (\Gamma_1 + \Gamma_2) \cdot R(\omega)$$

where $\Gamma_1$ and $\Gamma_2$ are the magnitude of the reflection coefficients of the two detectors. A $\Gamma$ of .005 corresponds to an error in the displayed real part of $\pm .02 * R(\omega)$. The largest contributors to errors in the second measurement system are the finite directivity of the dual directional coupler and the reflection coefficient of the $P_0$ detector. For example, the computed error is approximately $\pm .05 * R(\omega)$ for 40 dB coupler directivity and $\Gamma_d = .005$. Those errors associated with the detector characteristics can be made negligibly small by selecting detectors for frequency and amplitude tracking. However, deviation from square law on the order of 1% effects an additional 3% error in the display of $R(\omega)$. It is interesting to note that the same 1% error from square law effects only 0.1% error in the display of $R(\omega)$ on the simple measurement system.

## Experimental Results

Using the simple measurement system described above, N=4 and N=6 elliptic function dual mode waveguide filters were aligned. The input impedances of the filters were verified by measurement on an H.P. automatic network analyzer. The ANA data of an N=4 filter is plotted in Figure 4. The ANA data verifies the theory of operation of the simple measurement system.

## Conclusions

Two measurement systems to display the real part of singly terminated filters have been described. Both systems utilize standard test equipment available in most microwave laboratories. The predominate errors associated with equipment limitations have been described. Finally, the simple measurement system was verified with measured data.


## Acklowledgement

This paper presents the results of one phase of a program to develop a contiguous 5 channel waveguide multiplexer. The individual dual mode filters were fabricated in circular waveguide. The work was performed at and sponsored by TRW Systems, Redondo Beach, California.


## References


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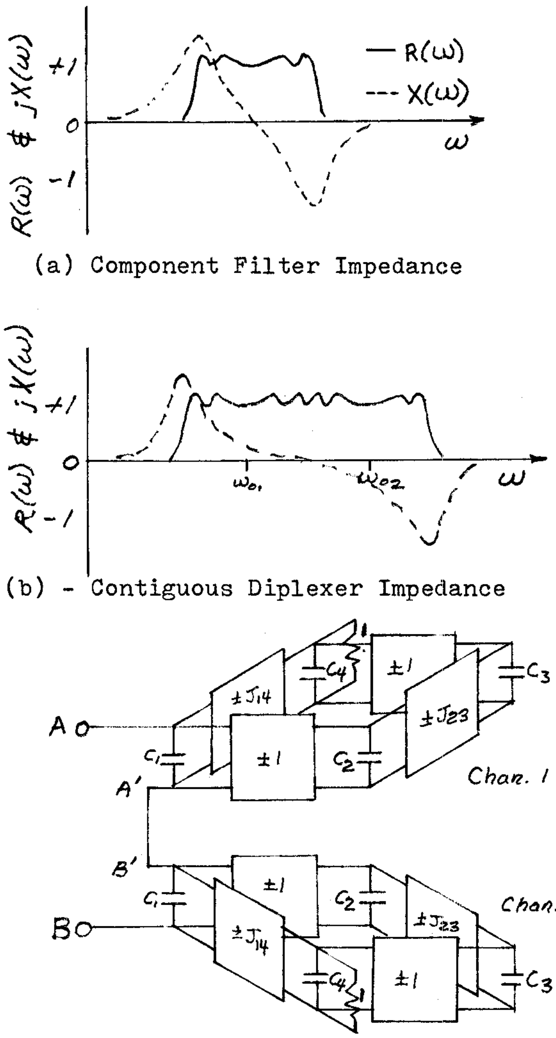
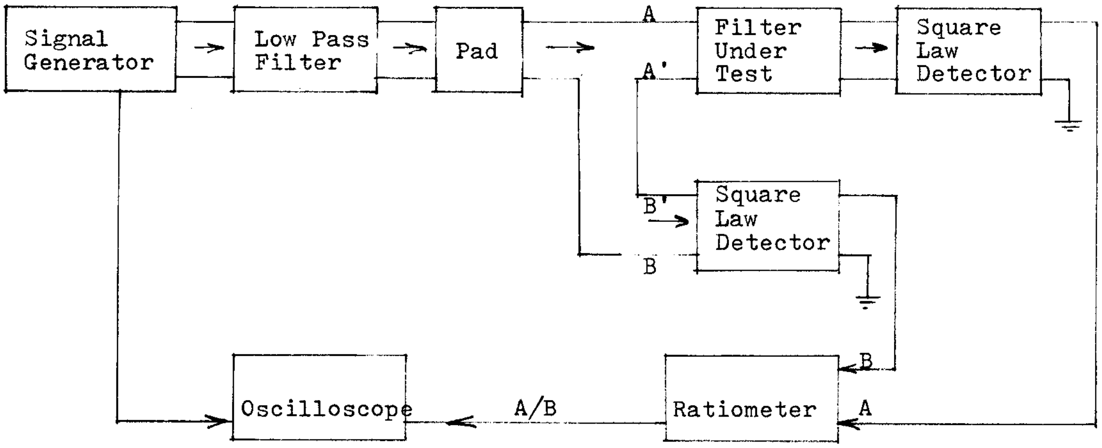



(a) Component Filter Impedance

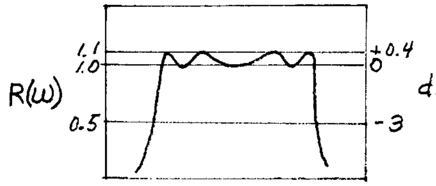
(b) - Contiguous Diplexer Impedance

(c) - Series Junction Diplexer

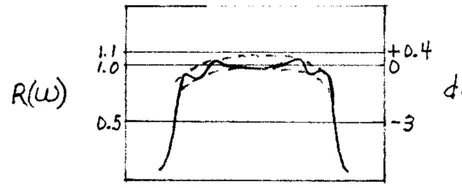
Figure 1 - $Z_{s.t.}$ and Series Junction Equivalent Circuit of Contiguous Diplexer




(a) - Measurement System




(b) - Lossless Filter Response




(c) - Response of Filter With Loss

Figure 2 - Simple Measurement System to Monitor R(ω).

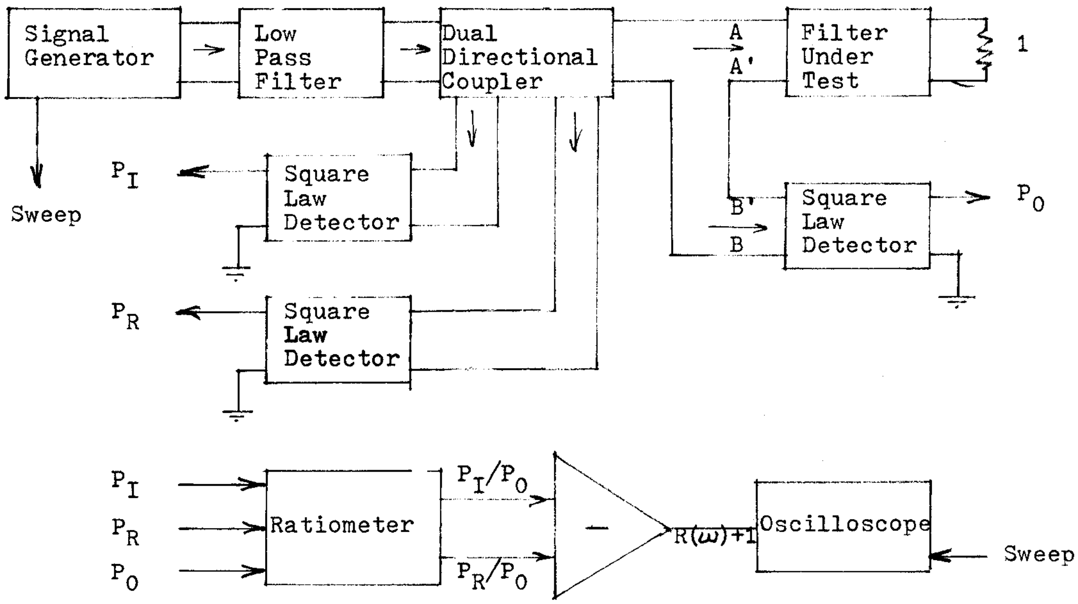



Figure 3 - Measurement System to Monitor R(ω).
Display Independent of Insertion Loss

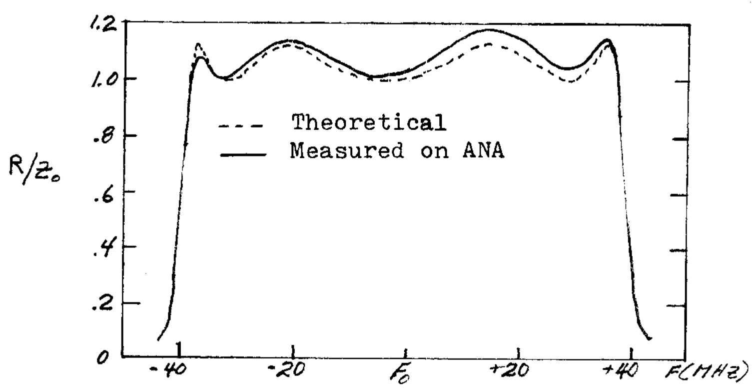



Figure 4 - Plot of ANA Data for Filter Tuned on Simple Measurement System