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Short-Circuit Tuning Method for Singly Terminated Filters

MING HUI CHEN, MEMBER, IEEE

Abstract—**This paper describes a filter tuning method based upon the match of measured and computed input impedances for a short-circuited filter. Two singly terminated filters, an 8-pole Chebyshev filter, and a 6-pole pseudoelliptic function filter tuned by using this method have demonstrated excellent performance.**

Introduction

Singly terminated filters are the key elements in constructing a contiguous band multiplexer [1]. Due to the lack of a systematic tuning method for the singly terminated filter, the contiguous band multiplexer would be difficult to construct and tune. This may be why the contiguous band multiplexer is seldom used in a practical system.

The conventional filter tuning is based upon the return loss characteristics of a filter. Minimum reflection in the passband with correct center frequency and bandwidth is usually the criterion for tuning doubly terminated filters. Since the input port for a singly terminated filter is not matched over the entire passband due to the existence of passband reactance, the criterion of minimum reflection cannot be used for filter tuning. A method based upon the filter's short-circuit impedance, which has been used for the measurement of intercavity couplings [2], has been further developed for tuning singly terminated filters. This paper presents this filter tuning method, as well as the experimental results for two model filters tuned by using this method.

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The author was with COMSAT Laboratories, Clarksburg, MD 20734. He is now with the Antenna and Communication Laboratory, TRW Systems Group, Redondo Beach, CA 90278.

Network Model for the Filter

With the short-circuit filter tuning method, the tuning and coupling screws are set one by one according to the match of measured and computed input impedances for a short-circuited filter. Therefore, the correct network representation for the filter is extremely important. Consider a multiple-coupled cavity network [3], [4], whose currents and voltages are related by an impedance matrix Z as follows:

$$\begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_N \end{bmatrix} = Z \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_N \end{bmatrix} \tag{1}$$

with

$$Z_{ii} = \frac{1}{Q_u \times BW} + j\frac{2}{\pi \times BW}\left(\frac{\lambda_{0i}}{\lambda g_{0i}}\right)^2 \cdot \tan\left(\frac{\pi \lambda g_{0i}}{\lambda_g}\right), \qquad i = 1, 2, \cdots, N \tag{2}$$

$$Z_{ij} = jM_{ij}, \qquad i \neq j \tag{3}$$

where Q_u is the unloaded cavity Q, BW is the fractional bandwidth, and λ and λ_g are the free space and guide wavelengths, respectively.

When the cavity i is resonant, λ_{0i} and λg_{0i} are set according to the midband frequency of the filter; when i is not resonant, λg_{0i} and λ_{0i} are set according to a detuned frequency which may be measured in advance. The coupling coefficients, M_{ij}, the input resistance, R_1, and the output resistance, R_2, define the network as shown in Fig. 1 with the input at AA' and output at BB'. A short-circuited filter is a 1-port network with a short circuit at BB' and the input at

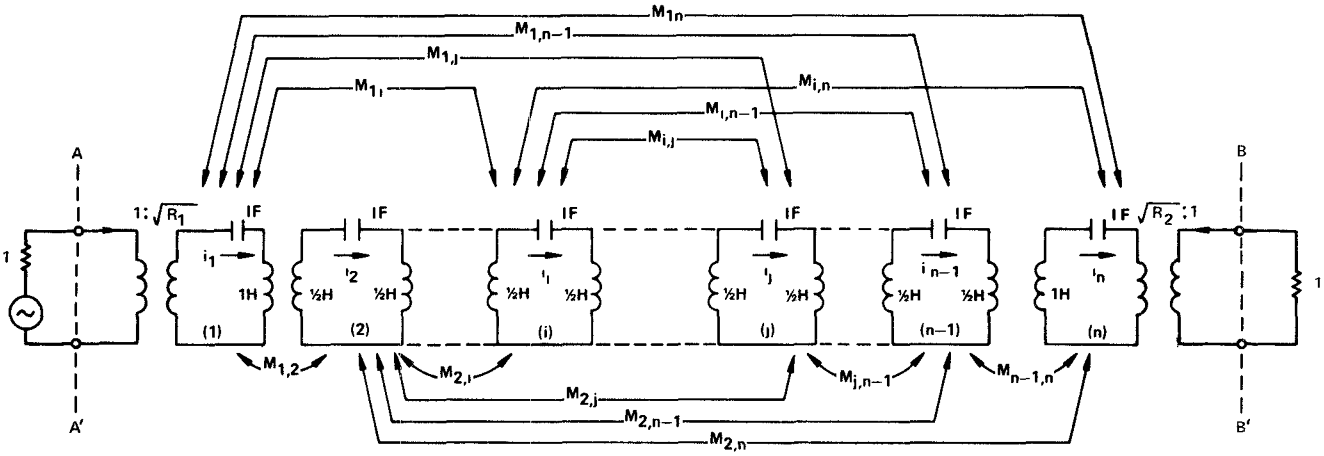

Fig. 1. Lumped circuit representation for an N-pole synchronously tuned cavity filter.

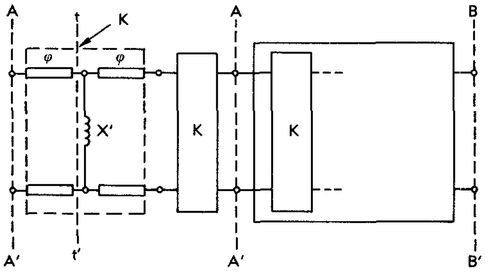

Fig. 2. Modified representation with proper reference plane for the network in Fig. 1.

AA'. Thus this short-circuited filter may be used to set the tuning and coupling screws one by one as the cavity resonance is progressively changed from a detuned to a tuned condition. However, the reference plane for a waveguide filter in the tuning setup is usually coincident with the input slot, which is unfortunately not on plane AA' in the network model of Fig. 1. Therefore, it would be necessary to modify the network model to have a reference plane at the location of the input slot.

As is well known, the first or last section of a waveguide filter is usually an impedance inverter with the parameter determined by the input or output impedance of the filter. The network in Fig. 1 may be reconstructed as shown in Fig. 2, where two impedance inverters have been added in cascade at the input port. Adding two impedance inverters as shown in Fig. 2 does not change the impedance characteristics for the filter, but provides access to the inside of an impedance inverter without disturbing the network representation from AA' and BB'. The shunt inductance X' is the normalized inductance for the input slot, and [5]

$$\phi = -\tfrac{1}{2}\tan^{-1} 2X' \tag{4}$$

$$K = \tan|\phi|. \tag{5}$$

As shown in Fig. 2, a network with an input port at tt' may be realized by adding an impedance inverter, K; a section of 1-Ω transmission line with a phase shift of ϕ; and a shunt inductance X' in front of the input port of the original network. The shunt inductance X' represents the input slot, which is located on the tt' plane in a practical waveguide filter. Since this network has access to the inductance that

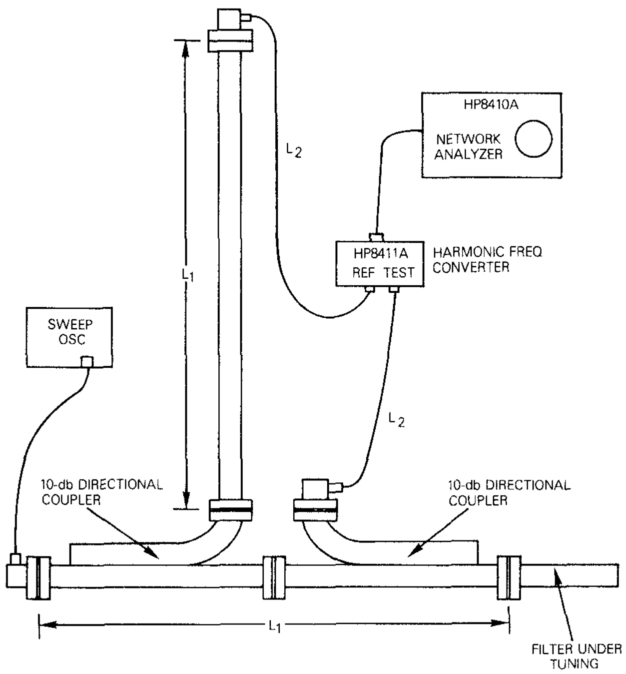

Fig. 3. Experimental setup for short-circuit filter tuning.

represents the input slot, the frequency dispersion of the input slot may also be added conveniently. However, if the frequency dispersion of the input slot is not a concern for some filters with very narrow bandwidths, this network is equivalent to that realized by adding a 1-Ω transmission line with $-\phi$ phase shift to the AA'–BB' network.

Tuning Procedure

The short-circuit filter tuning is based upon the network model as described in the previous section; the tuning or coupling screws are set one by one according to the match of the input impedances. A good experimental setup is an essential requirement in this tuning practice since any residual error in the setup could lead to error in the tuning or coupling screw position. Moreover, the error is accumulative; tuning error in the first tuning screw would lead to error in the second tuning screw, etc. As shown in Fig. 3, it has been found that a setup for measuring the reflected signal is

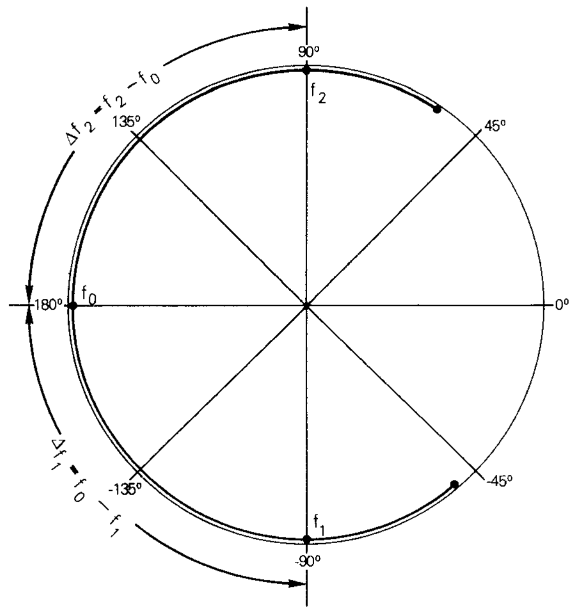

Fig. 4. Computed input impedance characteristics of a short-circuited filter with the first cavity tuned and the other cavities detuned.

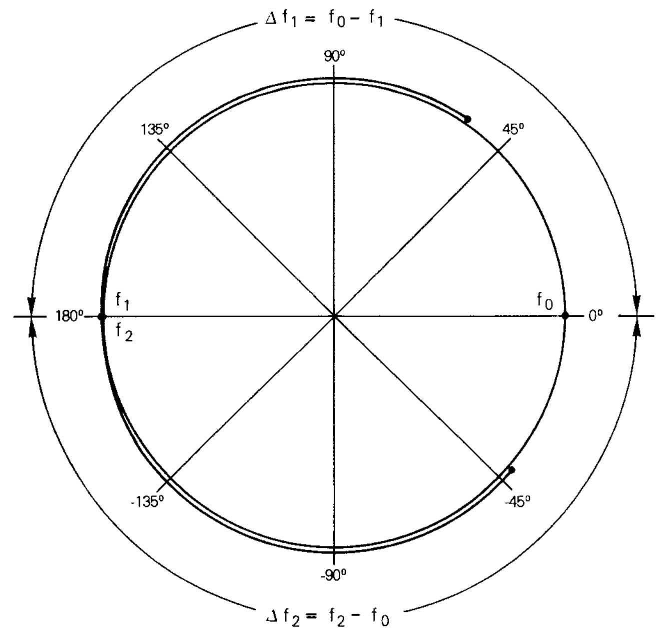

Fig. 5. Computed input impedance characteristics of a short-circuited filter with the first and second cavities tuned and the other cavities detuned.

suitable for tuning a multiple cavity filter with waveguide input. This setup eliminates the waveguide to coax adapter which would be needed if a reflection and transmission box were used.

At the beginning of filter tuning, all the cavities should be set in the detuned condition. Cavities 1, 2, 3, $\cdots$, may be changed from a detuned to a tuned condition one by one according to the match of the measured input impedance and the impedance computed through (1) with the resonance conditions for Z_{11}, Z_{22}, $\cdots$, changed accordingly. Since the input impedances to be compared are for the short-circuited filters, the reflection amplitude is near unity and insensitive to frequency; therefore, the main task during the filter tuning is matching of the reflection phase. Although the computed and measured reflection phase should be matched over a wide frequency range for every frequency, it has been found that matching them at the frequency interval which corresponds to a 90° phase change is sufficient during practical tuning.

To tune the first cavity, the input impedance is computed based upon the equivalent network in Fig. 2 with cavity 1 tuned and the other cavities detuned. As shown in Fig. 4, over a given frequency interval this computed impedance forms a half circle on a Smith chart, with frequency f_0 at 180° and the short-circuit reference at 0°. Frequency f_0 is not exactly the center frequency of the filter, which includes the modification contributed by the phase center shift, ϕ, as indicated in Fig. 2. Changing the tuning screw for the first cavity from the detuned condition to the tuned condition should move the f_0 point from near the 0° position to the 180° position on the polar display. If the input slot dimension, the equivalent input inductance (inductance X' in Fig. 2), and the detuned frequency are correct, the impedance characteristics for other frequencies should also match the computed impedance characteristics, as shown in Fig. 4. However, to obtain the correct input slot and the correct

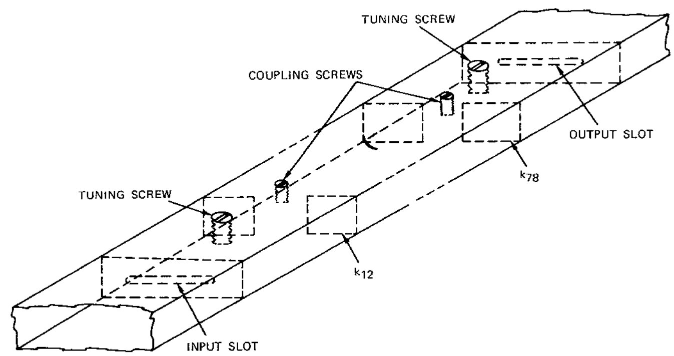

Fig. 6. 8-pole Chebyshev filter configuration for experimental model.

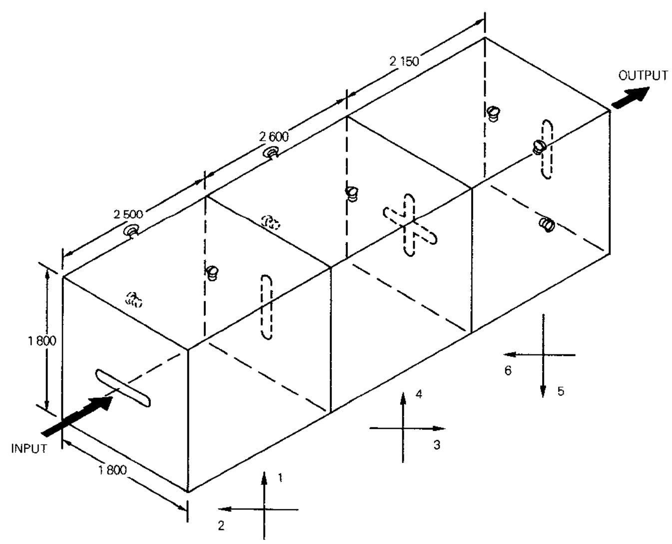

Fig. 7. 6-pole pseudoelliptic function filter configuration for experimental model.

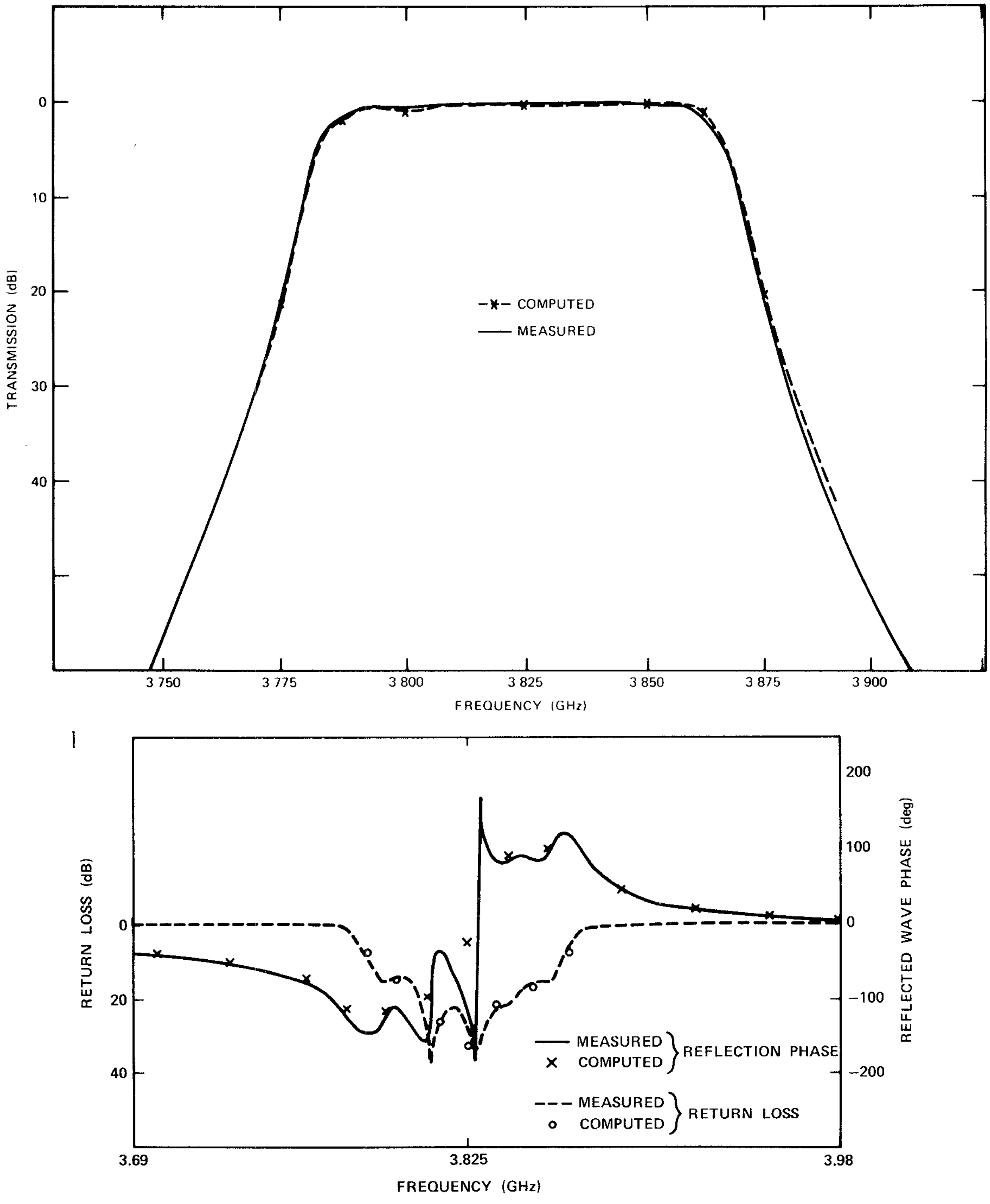

Fig. 8. Filter performances for an 8-pole Chebyshev filter.

equivalent inductance, several adjustments from the initial design might be required. The frequency span from $-90°$ to $+90°$, i.e., $\Delta f_1 + \Delta f_2$ in Fig. 4, is directly proportional to the input slot size. Thus the correct input slot dimension may be realized by this measurement. The imbalance of Δf_1 and Δf_2 may be overcome by adjusting the value of input inductance X' in Fig. 2.

To tune the second cavity, the computed input impedance based upon the network in Fig. 2, with cavities 1 and 2 tuned, forms one and one-half circles as shown in Fig. 5 with f_0 moved from 180° to 0°. The frequency span $\Delta f_1 + \Delta f_2$ is determined by the coupling value between cavities 1 and 2. Therefore, the coupling value can be adjusted if required. Tuning of the following cavities is mainly based upon shifting the f_0 position to the opposite side on the polar display. Since the tuning error is accumulative, the error on the polar display should be kept within $\pm 1°$ to ensure correct tuning.

Experimental Results

An 8-pole singly terminated Chebyshev filter (see Fig. 6) and a 6-pole singly terminated pseudoelliptic function filter

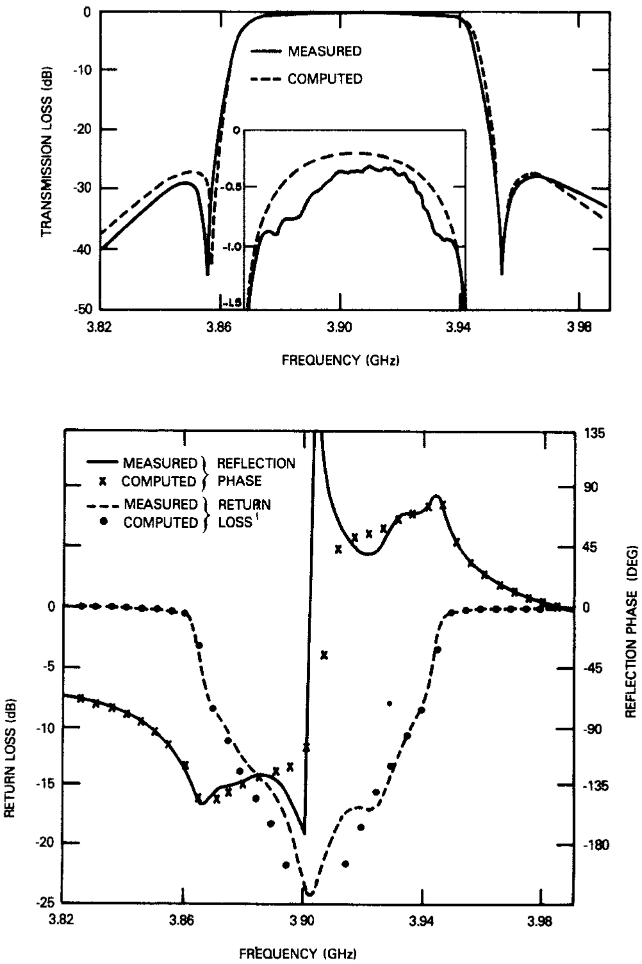

Fig. 9. Filter performances for a 6-pole pseudoelliptic filter.

(see Fig. 7) tuned by using this short-circuit tuning method have yielded satisfactory results. Since the filters have been constructed as cascading structures, each filter may be divided into two short-circuited pieces and tuning may proceed from both input and output ports.

In tuning the Chebyshev filter, tuning screws 1, 2, 3, and 4 and coupling screws (1,2), (2,3), (3,4), and (4,5) may be set by the input port tuning, and tuning screws 8, 7, 6, and 5 and coupling screws (7,8), (6,7), and (5,6) may be set by the output port tuning. After the tuning screws and coupling screws have been set, the filter may be reassembled and should have the correct responses without any adjustment. The transmission loss, return loss, and reflection phase performance are presented in Fig. 8.

In tuning the 6-pole pseudoelliptic filter, tuning screws 1–4 and coupling screws (1,2) and (3,4) may be set by the input port tuning, and tuning screws 6 and 5 and coupling screw (5,6) may be set by the output port tuning. The transmission loss, return loss, and reflection phase performance are presented in Fig. 9.

Conclusions

The short-circuit tuning method is a step-by-step tuning method which is both accurate and time saving. It is applicable to singly as well as doubly terminated filters.

Correct tuning for the singly terminated filter is a key to the success of a contiguous band multiplexer [1]. The out-of-band reactance, which has usually been disregarded in conventional tuning, plays an important role in a contiguous band multiplexer. With the short-circuit tuning method, the out-of-band reflection phase can be correctly tuned.

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