BANDPASS FILTER WITH STEPPED IMPEDANCE SUB-HARMONIC STUBS.

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ABSTRACT: *Structures with shunt stubs in a sub-harmonic ratio that realize bandpass performance have limited application due to the inherent problem of fixed transmission zero positions in the stopband. By application of the principle of splitting the sub-harmonic stubs into cascades of transmission line sections, structures can be realized that have transmission zeros at arbitrary positions. A bandpass filter employing stepped impedance stubs is developed, and it is shown that moderate bandwidth can be achieved.*

Key words: *Pseudo-elliptic function filter, bandpass filter, sub-harmonic stubs.*

1. Introduction

Bandstop filters with sub-harmonic resonant stubs have been shown to exhibit sharp cutoff properties and are readily realizable for wide bandwidths [1] – [3]. However, only one bandpass filter employing sub-harmonic stubs has been described to date [4]; the latter made use of overlay lines in a 1-2-4 stub length ratio ($\ell = \{\ell_0, 2\ell_0, 4\ell_0\}$, $\ell_0 = \lambda_0/4$). The positions of the transmission zeros realized by these stubs are fixed by their lengths, and consequently the range of realizable filters is severely restricted.

The open circuit shunt stubs contribute transmission zeros at their resonant frequencies. In [3] it was shown that by halving the lengths of the $2\ell_0$ and $4\ell_0$ open circuited shunt stubs, shunt Foster sections are formed, which enables the transmission zeros created by the stubs to be shifted.

In this paper, the properties of suitable stepped harmonic and sub-harmonic shunt stubs will be developed, with a view of application to bandpass filters.

2. Stepped Stub Properties

Figure 1 shows a simple structure, with stub lengths $\ell = \{\ell_{0\ \mathrm{SHORT}}, 2\ell_{0\ \mathrm{OPEN}}, 3\ell_{0\ \mathrm{SHORT}}\}$, $\ell_0 = \lambda_0/4$); SHORT and OPEN refer to the termination of the stubs.

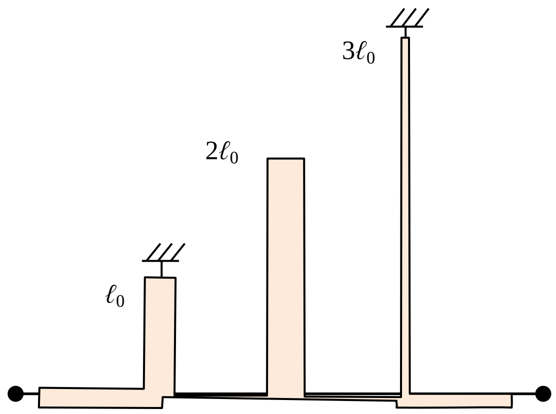

Figure 1 Simple 1-2-3 stub ratio bandpass filter.

Spaced by appropriate quarterwave sections (unit elements, UE), the three stubs will contribute to the response of the filter by creating transmission zeros at the frequencies shown in Table 1.

TABLE 1 Position of stub zeros

Stub length	Position of zeros			
ℓ_0 SHORT	0			$2f_0$
$2\ell_0$ OPEN	$0.5f_0$		$1.5f_0$	
$3\ell_0$ SHORT	0	$0.667f_0$	$1.333f_0$	$2f_0$

Depending on the impedances chosen, the responses of the individual stubs are shown in Figure 2, together with a typical transmission response.

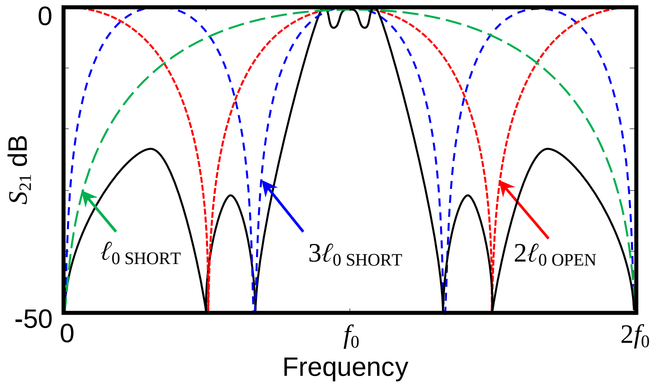

Figure 2 Individual transmission responses of ℓ_0 SHORT, $2\ell_0$ OPEN, and $3\ell_0$ SHORT stubs connected to a through line.

Due to the positions of the transmission zeros being fixed, the realizable response is extremely limited, as the only variables are the impedance levels of the stubs and UE's. The positions of the real frequency zeros mean that the outermost lobe in the stopband is large, and due to the fixed inner zeros, the passband bandwidth is limited. The reason for the choice of an OPEN circuit stub of $2\ell_0$ is apparent: a short circuited stub, while contributing zeros at $(0, 2f_0)$, would also create a zero at f_0.

In order to be able to position the transmission zeros of a prototype filter, stubs with stepped impedances are employed.

2.1 Stepped $2\ell_0$ OPEN stub.

The stepped $2\ell_0$ OPEN stub shown in Figure 3 is described in [3] and forms a shunt Foster section that resonates at

$$f_{00} = f_0 \frac{2}{\pi} \tan^{-1} \frac{1}{\left\{ \pm \sqrt{\frac{Z_1}{Z_2}} \right\}}$$

$$= 0.5 f_0 \pm \Delta f \quad \text{and} \quad 1.5 f_0 \mp \Delta f \, . \tag{1}$$

By correct choice of the ratio of the impedances Z_1 and Z_2, the positions of the two outermost transmission zeros can be shifted, while the desired rate of cutoff can be achieved by choice of their absolute values.

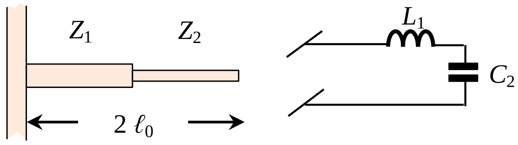

Figure 3 Stepped two-section stub forming a Foster section

2.2 Stepped $3\ell_0$ SHORT *stub.*

Figure 4(a) shows a stepped $3\ell_0$ SHORT stub schematically. In Figures 4(b) through 4(h), Kuroda's transforms are repeatedly performed on the shunt open circuited stubs and series shorted stubs that form capacitors and inductors under Richards' transform [5].

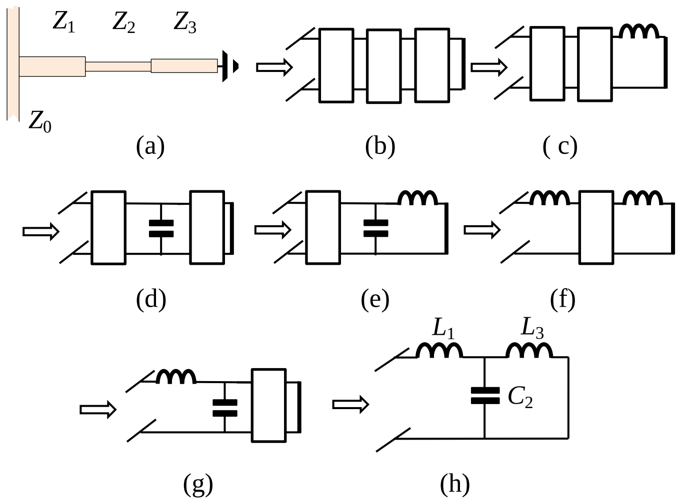

Figure 4 Equivalent circuit of three-section stepped impedance sub-harmonic stub. Physical structure; (b) to (g) development of equivalent circuit by repeated application of Kuroda's transform; (h) final equivalent circuit under Richards' transform

From the impedance representation of the stepped stub it can be seen that the circuit will create transmission zeros at 0, $2f_0$ and a pair of zeros,

$$S_{00} = j\Omega_{00}$$
$$\Omega_{00} = \pm\sqrt{\frac{L_1 + L_3}{L_1 C_2 L_3}}. \quad (2)$$

The relationship between Z_1, Z_2, Z_3 and L_1, C_2, L_3 is complex; the terminal impedance of the stub is readily found from the transmission line equations as

$$Z_{in1} = Z_1 \left\{ \frac{\left[Z_2 \left(\frac{Z_3 S + S Z_2}{Z_2 + S^2 Z_3} \right) \right] + S Z_1}{Z_1 + S\left[Z_2 \left(\frac{Z_3 S + S Z_2}{Z_2 + S^2 Z_3} \right) \right]} \right\}. \quad (3)$$

The positions of the real frequency zeros are found by setting the numerator of the terminal impedance to zero:

$$
\begin{aligned}
0 &= \left[Z_2 \left(\frac{Z_3 S_{00} + S_{00} Z_2}{Z_2 + S_{00}^2 Z_3} \right) \right] + S_{00} Z_1 \\
S_{00}^2 &= \frac{Z_2}{Z_1 Z_3} \left(Z_1 + Z_2 + Z_3 \right) \\
S_{00} &= j\Omega_{00} = \pm j \sqrt{\frac{Z_2}{Z_1 Z_3} \left(Z_1 + Z_2 + Z_3 \right)} \\
f_{00} &= \frac{2}{\pi} f_0 \tan^{-1}(\Omega_{00}) \\
&= f_0 \frac{2}{\pi} \tan^{-1} \left\{ \pm \sqrt{\frac{Z_2}{Z_1 Z_3} \left(Z_1 + Z_2 + Z_3 \right)} \right\} \\
&= 0.667 f_0 \pm \Delta f \quad \text{and} \quad 1.333 f_0 \mp \Delta f
\end{aligned} \tag{4}
$$

If $(Z_1 + Z_2 + Z_3) Z_2 / Z_1 / Z_3 > 3$, then $\Delta f > 0$; if $(Z_1 + Z_2 + Z_3) Z_2 / Z_1 / Z_3 < 3$, then $\Delta f < 0$.

Once again, the choice of the impedances of the stepped stub makes it possible to determine the position of the inner transmission zeros, as well as the effective impedance of the stub.

3. Bandpass Filter with stepped stubs

Figure 5(a) shows a bandpass structure employing the stepped stubs described above.

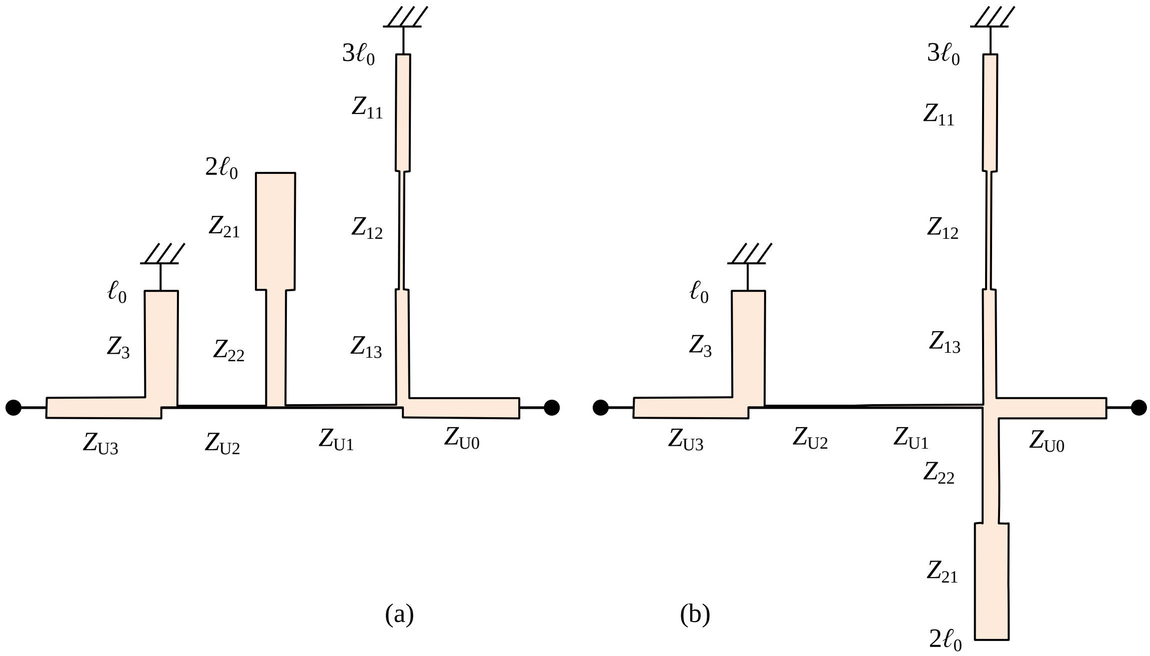

Figure 5 (a) Filter with central Foster section, and (b), Foster section moved to position parallel to $3\ell_0$ stub.

At very low frequencies, the susceptance of the single length stub is large, and dominates the response. As the resonant frequency of the $2\ell_0$ stub is approached, its susceptance begins to dominate. However, it is now shifted in phase through the first UE, and tends to cancel the contribution of the single stub, resulting in an elevated peak to the first stopband lobe. In order to correct this, the $2\ell_0$ stub is repositioned to be directly in parallel to the $3\ell_0$ stub, as shown in Figure 5(b) . Due to the position of the resonance frequency of the $3\ell_0$ stub closer to the passband, the undesired interference does not arise.

Presently, no means of obtaining a prototype is available. Values for a filter were found through optimization, with typical starting values for the inner UE's of 150Ω, and 50Ω for the outer UE's. The ℓ_0 SHORT stub will be very low impedance, 10 - 15Ω, with starting impedances of 50Ω for the other stubs elements. The resonant frequency of $2\ell_0$ OPEN is shifted to improve the shape of the stopband lobes, and will normally result in a high impedance for Z_{22}, in order to move the zero far enough. Table 2 gives the element values of a filter with -20 dB stopband level and return loss of 17 dB.

TABLE 2 Stub and Unit element Impedances, Ω

$3\ell_0$ SHORT			$2\ell_0$ OPEN		ℓ_0 SHORT	Unit Elements			
Z_{11}	Z_{12}	Z_{13}	Z_{21}	Z_{22}	Z_3	Z_{U0}	Z_{U2}	Z_{U2}	Z_{U3}
35.2	87.5	41.8	42.5	168	10.0	38.0	119	170	54.0

4. Filter construction and performance.

A filter was constructed on RT Duroid 5880 with dielectric constant ε_r = 2.2 and dielectric thickness 1.575 mm. The etch layout for the filter is shown in Figure 6.

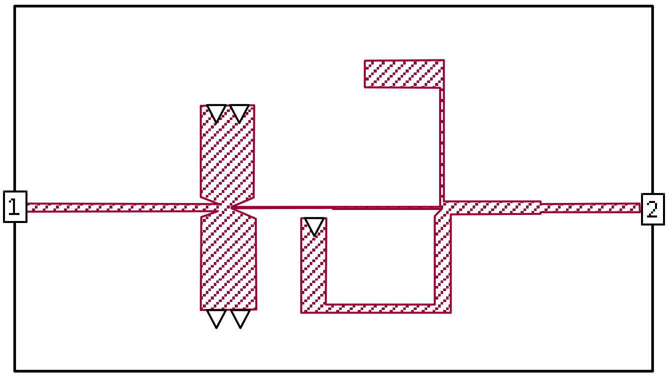

Figure 6 Etch layout for bandpass filter. ∇ denotes via earths.

Because of the low impedance of the ℓ_0 SHORT stub, it was realized as two 20Ω stubs in parallel, and to reduce the junction effect, the stubs were trimmed back at the join with the UE's. The $2\ell_0$ OPEN stub was folded once, and the $3\ell_0$ SHORT stub twice, to conserve space. The earths were formed by drilling a series of holes, with copper wire soldered to track and ground plane.

Figure 7 shows the theoretical response of the filter, and is compared to the response of a Cauer filter designated C 0325, Θ = 41° [6], which has a performance similar to the prototype filter. The cutoff rate of the prototype filter is similar to that of the Cauer Filter.

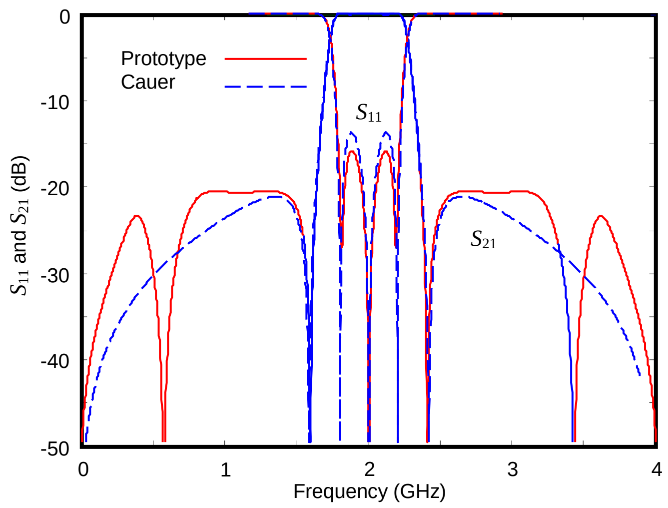

Figure 7 Frequency response of the prototype filter compared to a Cauer Filter.

In Figure 8 the measured transmission and reflection response of the prototype filter is compared to the design values.

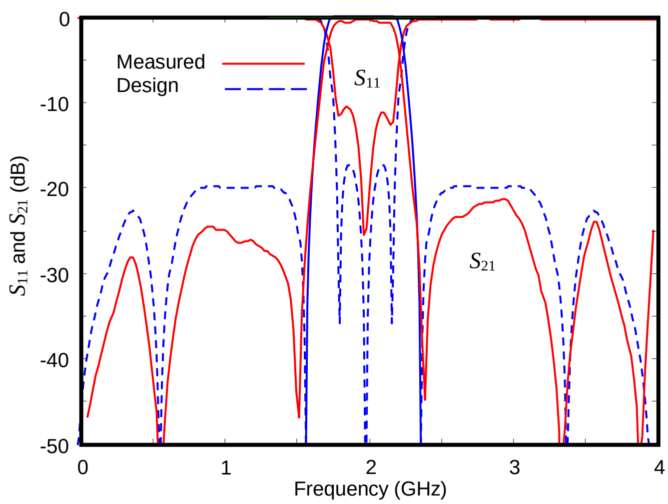

Figure 8 Measured frequency response of the prototype filter compared to the design response.

5. Conclusion

The application of a shorted three-element cascade shunt stub with different UE impedances, as well as the open two-element shunt stub, has enabled the positioning of the transmission zeros optimally. The resultant filter structure represents a substantial advance over previous bandpass filters that do not have movable transmission zeros.

A constructed prototype performed well compared to the theoretical response. Slight tuning of lengths and junction effects will improve the performance to a better agreement with the calculated values.

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