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Research Article

The Novel Microwave Stop-Band Filter

R. E. Chernobrovkin, I. V. Ivanchenko, A. M. Korolev, N. A. Popenko, and K. Yu. Sirenko

Institute of Radiophysics and Electronics, National Academy of Sciences of Ukraine, 12 Proskury Street, 61085 Kharkov, Ukraine

Correspondence should be addressed to N. A. Popenko, buran@ire.kharkov.ua

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The stop-band filter with the new band-rejection element is proposed. The element is a coaxial waveguide with the slot in the centre conductor. In the frame of this research, the numerical and experimental investigations of the amplitude-frequency characteristics of the filter are carried out. It is noted that according to the slot parameters the two typical resonances (half-wave and quarter-wave) can be excited. The rejection band of the single element is defined by the width, depth, and dielectric filling of the slot. Fifth-order Chebyshev filter utilizing the aforementioned element is also synthesized, manufactured, and tested. The measured and simulated results are in good agreement. The experimental filter prototype exhibits the rejection band 0.86 GHz at the level −40 dB.

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1. INTRODUCTION

Review of the microwave filters technology, applications perspective, as well as filter designs is described in [1]. The narrow-band tunable filters are usually realized by using the rectangular waveguide with the dielectric resonator [2] or microstrip resonators [3]. In order to provide the wideband filter, the resonators with low Q-factor such as the ring resonator with direct-connected orthogonal feed lines [4] or coplanar stripline resonators [5] are applied.

The slot resonator as a basic element of the microwave filter has been proposed earlier in the paper [6]. The main advantages of this resonator are the small sizes, the simplicity of manufacturing, as well as a possibility of its natural integration into the coaxial line. In this paper, the slot resonators on the TEM waves are used in designing the stop-X-band filter.

The paper is organized as follows. In Section 2, the different designs of the band-rejection element as well as the EM field distributions in the slot are considered. Furthermore, the behavior of the resonance frequency and the loaded Q-factor is studied depending on the slot dimensions. The results of experimental investigations of the rejection filter with a single slot are discussed in Section 3 and point to the capability of developing the more complicated filter designs. Section 4 is devoted to the synthesis and experimental investigations of the Chebyshev rejection filter prototype.

2. BAND-REJECTION ELEMENT

Schematic view of the novel band-rejection element is presented in Figure 1. The band-rejection element is the axial-symmetrical structure which consists of the coaxial waveguide with the centre conductor radius a, and outer conductor b, respectively. The coaxial waveguide is filled by the dielectric with permittivity ε_1. The slot in the centre conductor has the width w and the depth d (Figure 1) and it is filled by the dielectric with permittivity ε_2. Two different filter designs can be realized by means of both the complete slot $d = a$ (Figure 1(1)) and the partial slot $d < a$ (Figure 1(2)).

In order to excite the resonance with the component $H_\rho = 0$ in this structure, the condition $w \ll d$ has to be realized [6]. In this case, the magnetic field distribution is the axial-symmetrical one. It should be noted that the two types of resonance can be excited in this structure depending on the relation between the slot depth d and the centre conductor radius a (Figure 1). The maximal magnitude is located in the slot centre for $d = a$ (Figure 2(a));

TABLE 1: Geometrical and physical parameters of the band-rejection element.

	$w = 0.5\,\text{mm}$ $d = 6.0\,\text{mm}$ $\varepsilon_2 = 1$	$w = 0.5\,\text{mm}$ $d = 5.0\,\text{mm}$ $\varepsilon_2 = 1$	$w = 1.5\,\text{mm}$ $d = 5.0\,\text{mm}$ $\varepsilon_2 = 1$	$w = 0.5\,\text{mm}$ $d = 9.0\,\text{mm}$ $\varepsilon_2 = 3.78$	$w = 1.5\,\text{mm}$ $d = 9.0\,\text{mm}$ $\varepsilon_2 = 3.78$
f_0 GHz	9	11	10.7	10.3	10.27
Q-factor	17	17	5	91	37
	Quarter-wave resonance			Half-wave resonance	

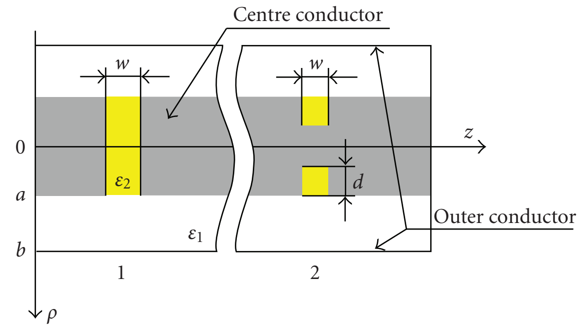


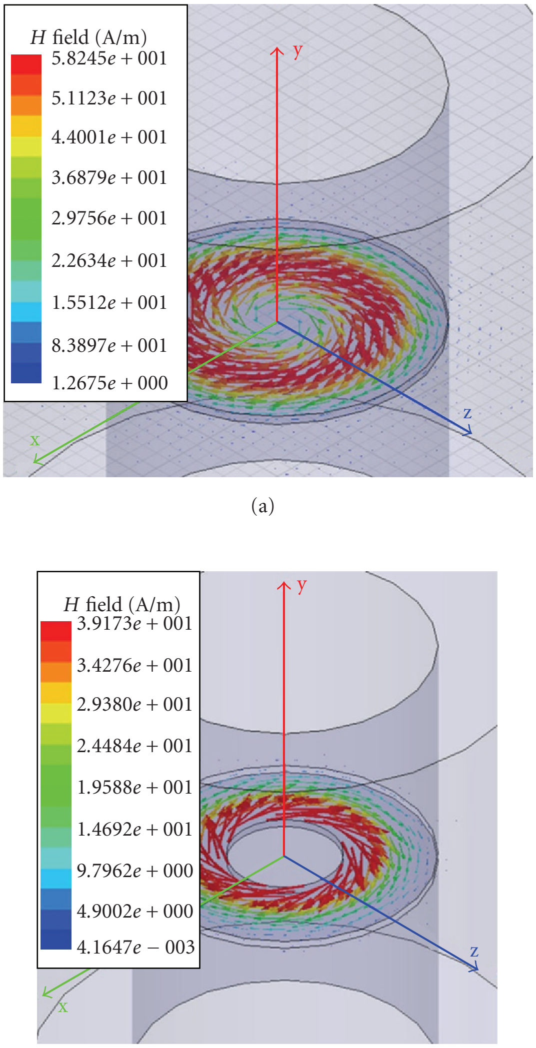
FIGURE 1: The problem geometry: (1) $a = d$; (2) $a > d$.

whereas for $d < a$, the maximal magnitude is located on the centre conductor surface (Figure 2(b)). Based on the amplitude distributions of the magnetic field noted above, the authors of [6] called "half-wave resonance" when $d = a$ (Figure 2(a)) and "quarter-wave resonance" when $d < a$ (Figure 2(b)).

From the beginning, let us analyze the influence of the depth (d), width (w), and permittivity (ε_2) on the single-slot performance. For the quarter-wave resonance ($d < a$), the slot-depth increase leads to moving the resonance frequency from $f_0 = 9\,\text{GHz}$ to $f_0 = 11\,\text{GHz}$ (Figures 3(a) and 3(b), Table 1). In this case, the slot-width variation from 0.5 mm to 1.5 mm results in the Q-factor changing about 72% whereas the resonant frequency is slightly changed (Figures 3(b) and 3(c), Table 1).

We note that for the half-wave resonance ($a = d$), the slot width variation points to the similar results (Figures 4(a) and 4(b)). It is quite clear that the dielectric filling of the slot leads to changing the resonant frequency of the single element. So, the dielectric filling of the slot allows reducing the radius of the centre conductor of the given coaxial waveguide. In this case, there is a possibility to provide the efficient rejection-band control of the aforementioned filter.

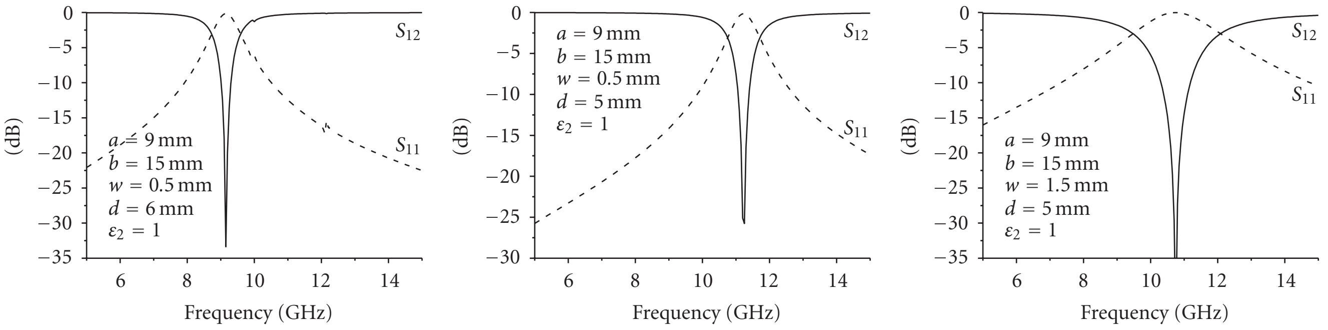
With these remarks in mind, one may summarize that the resonance frequency is defined by the slot depth and the dielectric permittivity ε_2. At the same time, the Q-factor depends on the slot width and dissipations in the dielectric and the metal. For the illustration of these statements, the dependences of numbered above parameters on the slot dimensions are shown for both the half-wave ($d = a$) and quarter-wave ($d < a$) (Figures 5 and 6) resonances. In both cases, the radius of centre and outer conductors are constant. We have chosen the permittivity $\varepsilon_2 = 1$ for the slot when $d < a$ and $\varepsilon_2 = 3.78$, $\tan\delta = 0.0001$ for the slot when $d = a$. The choice of such values of dielectric permittivity ε_2 allows us to remain in the same frequency band. For both slots, the resonance frequency has the linear dependence on the slot depth (Figure 5). Q-factor reduction is explained by increasing the radiation losses with the slot-width increase (Figure 6). The highest value of Q-factor can be achieved by using the slot-width parameter $d = a$.



(a)

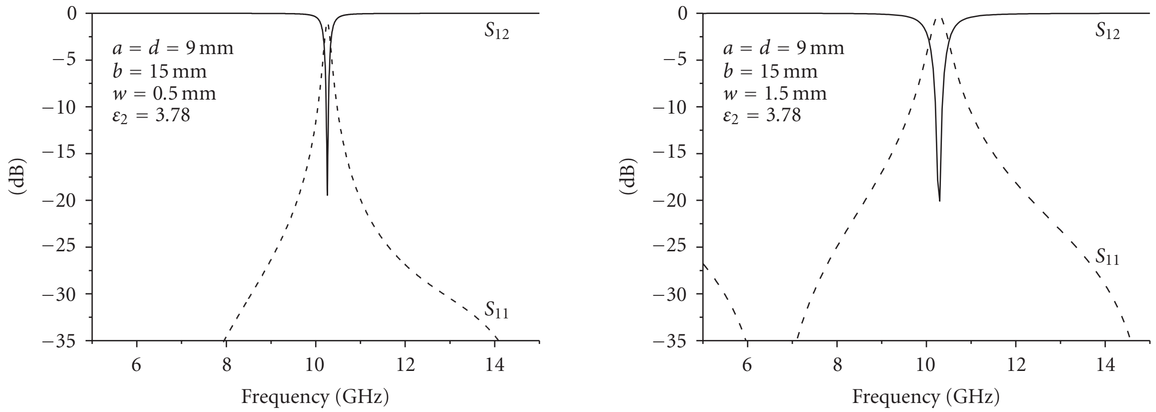
(b)

FIGURE 2: The magnetic field distribution in the slot: (a) $d = a$; (b) $d < a$.



(a) (b) (c)

FIGURE 3: Amplitude-frequency characteristics of the band-rejection element in the case of the quarter-wave resonance.



(a) (b)

FIGURE 4: Amplitude-frequency characteristics of the band-rejection element in the case of the half-wave resonance.

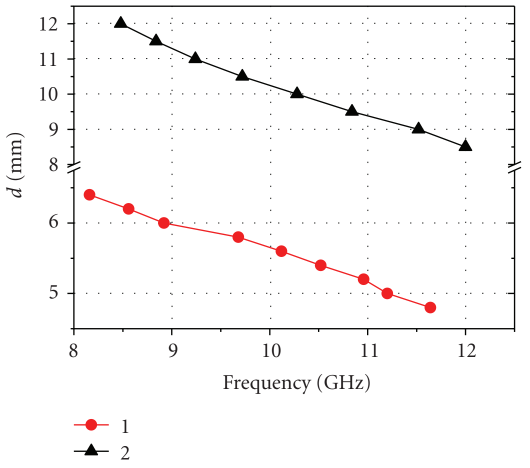


FIGURE 5: The dependence of the resonance frequency on the slot depth: (1) $a = 9$ mm, $b = 15$ mm, $w = 0.5$ mm, $\varepsilon_1 = \varepsilon_2 = 1$; (2) $a = d$, $b = 15$ mm, $w = 0.5$ mm, $\varepsilon_1 = 1$, $\varepsilon_2 = 3.78$.

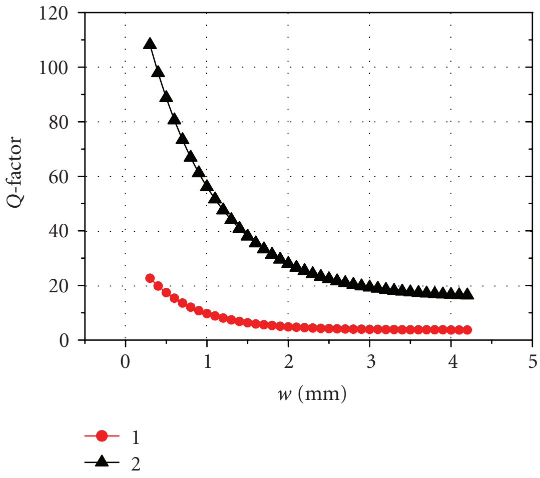


FIGURE 6: The dependence of the loaded Q-factor on the slot width: (1) $a = 9$ mm, $b = 15$ mm, $d = 5.5$ mm, $\varepsilon_1 = \varepsilon_2 = 1$; (2) $a = d = 9$ mm, $b = 15$ mm, $\varepsilon_1 = 1$, $\varepsilon_2 = 3.78$.

3. EXPERIMENTAL VERIFICATION

Experimental investigations of characteristics of the single-slot filter prototypes were carried out on the Agilent network analyzer PNA-L N5230A in the frequency band 8–14 GHz. The manufactured filter prototype is shown in Figure 7. The filter parameters are as follows: $d = a = 9$ mm, $b = 15$ mm, $\varepsilon_1 = 1$, and $\varepsilon_2 = 3.78$. A fair agreement

Table 2: The parameters of the Chebyshev filter.

The number of resonators	Ripple [dB]	f_1 [GHz]	f_2 [GHz]	f_0 [GHz]	$f_2 - f_1$ [GHz]	Source and load [OH]
5	0.1	9.5	10.5	10	1	50

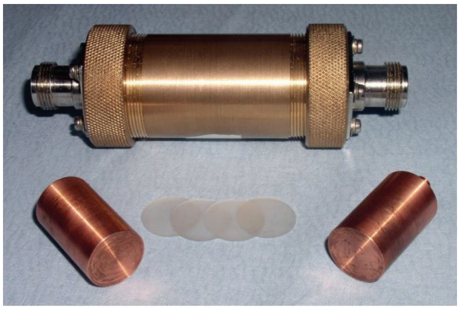


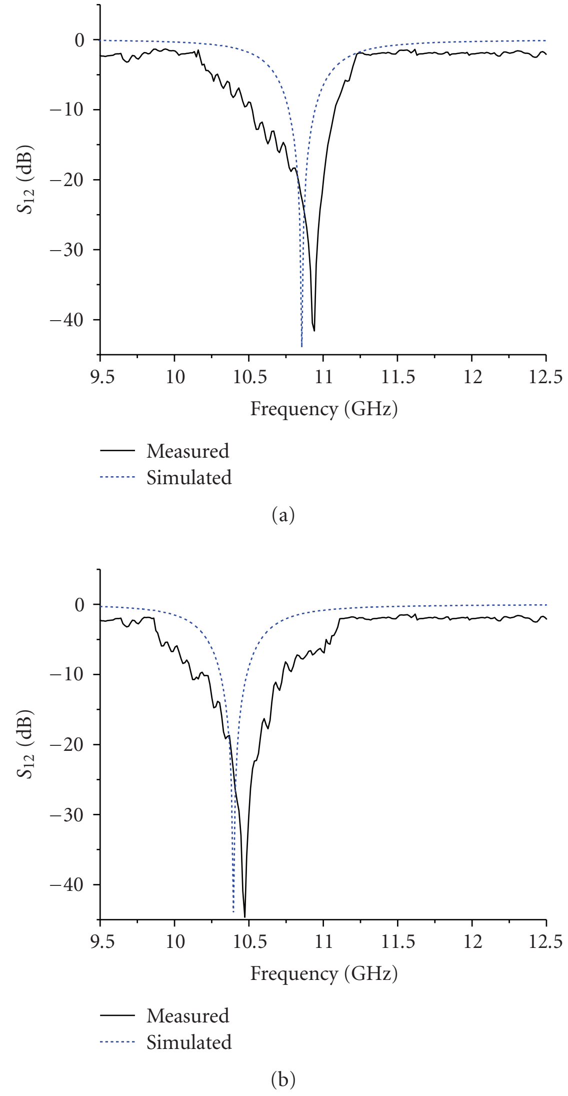
Figure 7: General view of the filter prototype with the single slot.

between the measured and simulated S_{12}-parameters for the single slot with different widths ($w = 1$ mm and $w = 2$ mm) is observed (Figure 8). The dissimilarity at the resonance frequency is less than 0.05 GHz and can be explained by the manufacturing inaccuracy of the filter as well as by the difference between the real dielectric permittivity in the experiment and that used in the simulations.

4. SYNTHESIS OF THE CHEBYSHEV FILTER

The stop-band filter with initial parameters mentioned in Table 2 will be synthesized below. The slots filled with the air ($\varepsilon_2 = 1$) in the case of quarter-wave resonance were chosen as a basic element of this filter. Equivalent circuit of the filter is shown in Figure 9 (top). Based on the simulated results, the values of all elements of the equivalent circuit as well as the resonant frequency and Q-factor of each resonator were determined. The initial values of the geometric parameters of slots (w and d) were chosen from Figures 5 and 6. The desirable impedances were provided by the changing of centre conductor radius a. Further filter optimization was carried out by means of the full wave simulator developed by us earlier [6]. In this case, the resonators are located at the distance $3\lambda/4$ ($\lambda = 30$ mm) from each other to provide the minimal coupling between resonators (Figure 9, bottom). As the goal function, the S-parameters were chosen, and the slot width w and the slot depth d were varied within the limits ±5%.

The optimized filter with parameters highlighted in Table 3 was designed, manufactured, and investigated. The S-parameters of the filter prototype noted above are shown in Figure 10. Based on the analysis of these data, we can formulate some conclusions, namely, (i) the measured S-parameters are in good agreement with the simulated ones at the most frequency points over the entire pass-band and stop-band; (ii) the rejection band is 0.86 GHz at the leve −40 dB.



(a)

(b)

Figure 8: S_{12}-parameter of the filter prototype with the single slot: (a) $w = 1$ mm; (b) $w = 2$ mm.

Table 3: The geometrical parameters of the filter.

The number of resonators	1	2	3	4	5
w	0.29 mm	1.0 mm	1.25 mm	1.0 mm	0.29 mm
d	5.6 mm	5.6 mm	5.6 mm	5.6 mm	5.6 mm
a	9 mm	10.7 mm	11.72 mm	10.7 mm	9 mm

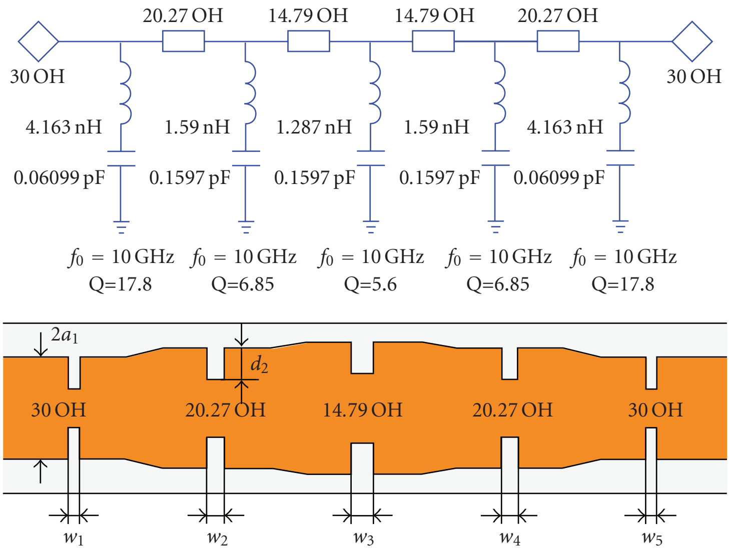


Figure 9: Low-pass block diagram and the general view of the Chebyshev filter prototype.

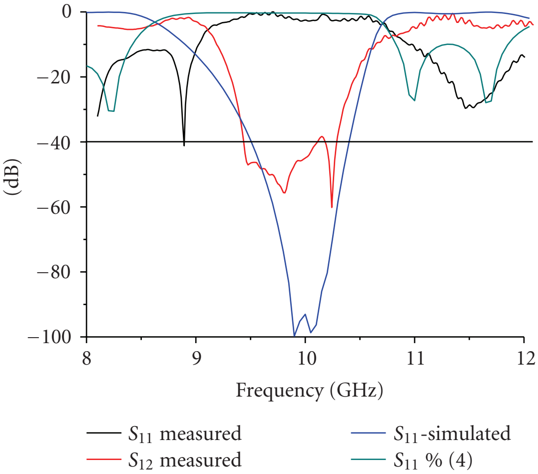


Figure 10: The measured and simulated S-parameters of the Chebyshev filter prototype.

5. CONCLUSIONS

The original band-rejection element as the slot in the centre conductor of the coaxial waveguide for designing the microwave stop-band filters is presented. The half-wave and quarter-wave resonances which are excited in this element have been studied and analyzed. The band-rejection element has been designed and manufactured. It has been found that for both cases the slot-width increase from $w/a = 0.056$ to $w/a = 0.23$ leads to decreasing the loaded Q-factor on 22%. The resonance frequency depends on the slot depth. The good coincidence of calculated and measured data is observed. Fifth-order Chebyshev filter with the given band-rejection element has been also synthesized, manufactured, and investigated. The measured S-parameters are in good agreement with the numerical ones at the most frequency points over the entire pass-band and stop-band. Notice that the filter characteristics are close to the simulated ones without any trimming elements. The rejection band is 0.86 GHz at the level −40 dB. The proposed stop-band filter can be naturally integrated into the coaxial waveguides and seems to be very attractive in different applications.

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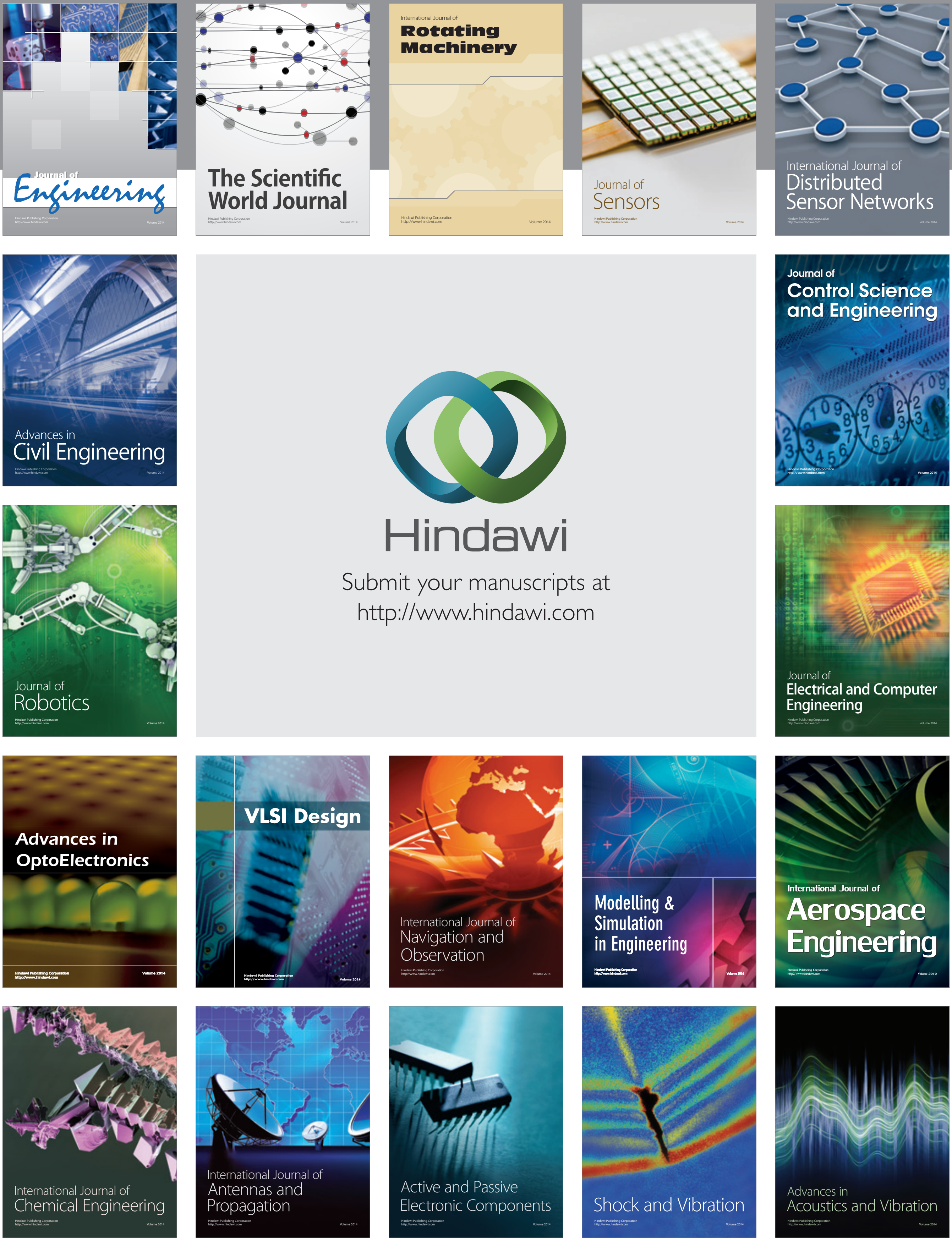
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