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MICROSTRIP NONUNIFORM IMPEDANCE RESONATORS

M. Khalaj-Amirhosseini

College of Electrical Engineering
Iran University of Science and Technology
Narmak, Tehran, Iran

Abstract—In this paper, a new structure is introduced to design resonators with very short length and without any discontinuity. The introduced structure, called Nonuniform Impedance Resonator (NIR), is an open- or short-circuited Nonuniform Transmission Line (NTL). To synthesize NIRs, strip width or the characteristic impedance function of the microstrip NIRs is expanded in a truncated Fourier series, first. Then, the optimum values of the coefficients of the series are obtained through an optimization approach. The usefulness of the proposed method is verified using some examples.

1. INTRODUCTION

Resonators are important elements for filters, oscillators and mixers [1, 2]. Microstrip resonators are usually used in RF and Microwave circuits. The length of conventional resonators is a half of the wavelength (open-circuited resonators) or a quarter of the wavelength (short-circuited resonators) [1, 2]. However, there is a significant interest to design resonators with smaller (or larger) length than of the conventional resonators. The Stepped Impedance Resonators (SIRs) have been proposed [3–5] for this purpose, by now. SIRs are formed by connecting together two or three transmission lines with different characteristic impedance. Microstrip SIRs have discontinuities at the connecting points between two transmission lines.

In this paper, we introduce a new microstrip structure to design resonators with very short length, which have not any discontinuity. The introduced structure, called microstrip Nonuniform Impedance Resonator (NIR), is an open- or short-circuited Nonuniform Transmission Line (NTL). In fact, NIRs can be considered as a general case of SIRs. To synthesize NIRs we introduce a novel method, also.

First, strip width or the characteristic impedance function of the microstrip NIRs is expanded in a truncated Fourier series. Then, the optimum values of the coefficients of the series are obtained through an optimization approach. The usefulness of the proposed structures as resonators is verified using some examples.

2. ANALYSIS OF MICROSTRIP NIRS

In this section the analysis of microstrip NIRs is reviewed. Figure 1 depicts the longitudinal view and the cross section of a microstrip NIR, as an open-circuited or short-circuited resonator, depending to if the Z_L is being infinite or zero, respectively. The width of strip is $w(z)$ and also the relative electric permittivity and the thickness of the substrate are ε_r and h, respectively. The characteristic impedance of the NIR will be a nonuniform function $Z_c(z)$.

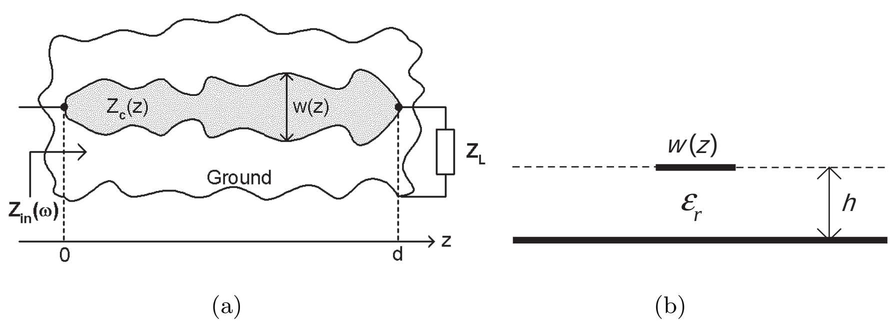

Figure 1. (a) The longitudinal view of a microstrip NIR (b) The cross section of the resonator at point z.

Analysis of NIRs is similar to analysis of NTLs. Also, there are some methods to analyze the NTLs such as finite difference [6], Taylor's series expansion [7] and Fourier series expansion [8]. Of course, the most straightforward method is subdividing NTLs into K uniform electrically short segments [9] with length of

$$\Delta z = d/K \ll \lambda_{\min} = \frac{c}{f_{\max}\sqrt{\varepsilon_r}} \tag{1}$$

in which c is the velocity of the light and $f_{\max}$ is the maximum frequency of the analysis. If the margin capacitance or inductance of open- or short-circuited port is omitted, the $ABCD$ parameters of the whole of NTL is obtained from those of the segments as follows

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \cdots \begin{bmatrix} A_k & B_k \\ C_k & D_k \end{bmatrix} \cdots \begin{bmatrix} A_K & B_K \\ C_K & D_K \end{bmatrix} \tag{2}$$

where the $ABCD$ parameters of the k-th segment are as follows

$$A_k = D_k = \cos(2\pi\Delta\theta) \tag{3}$$

$$B_k = Z_c^2((k-0.5)\Delta z)C_k = jZ_c((k-0.5)\Delta z)\sin(2\pi\Delta\theta) \tag{4}$$

where

$$\Delta\theta = 2\pi\frac{\Delta z}{\lambda} = \frac{2\pi}{c}\Delta z\sqrt{\varepsilon_{re}}f \tag{5}$$

is the electrical length of each segment. In (5), ε_{re} is the effective relative electric permittivity at the middle of the k-th segment. Finally, the input impedance of the NIR is determined as follows

$$Z_{in}(f) = jX_{in}(f) = \frac{AZ_L + B}{CZ_L + D} = \begin{cases} A/C; & Z_L = \infty \\ B/D; & Z_L = 0 \end{cases} \tag{6}$$

3. SYNTHESIS OF MICROSTRIP NIRS

In this section a general method is proposed to design optimally microstrip NIRs. Firstly, we consider one of the following truncated Fourier series expansion for the normalized characteristic impedance $\overline{Z}_c(z)$ or the normalized width $w(z)/h$.

$$\begin{aligned} \ln\left(\overline{Z}_c(z)\right) &= \ln(Z_c(z)/Z_0) \\ &= C_0 + \sum_{n=1}^{N}(C_n\cos(2\pi nz/d) + S_n\sin(2\pi nz/d)) \end{aligned} \tag{7}$$

$$\ln(w(z)/h) = C_0 + \sum_{n=1}^{N}(C_n\cos(2\pi nz/d) + S_n\sin(2\pi nz/d)) \tag{8}$$

where Z_0 is a reference impedance such as $50\,\Omega$. Of course, choosing each of the expansions in (7)–(8), the other function can be obtained from the known formulas related to the microstrip concept [10]. The truncated Fourier series expansion has been considered for $w(z)/h$ as in (7), in this paper. Utilizing truncated Fourier series expansion does not create any discontinuity in the analyzed NIR.

An optimum designed NIR has to have infinite impedance at the resonance frequency f_r. Therefore, the optimum values of the coefficients C_n and S_n in (7) or (8) can be obtained through minimizing the following error function.

$$\text{Error} = \frac{1}{|Z_{in}(f_r)|} \tag{9}$$

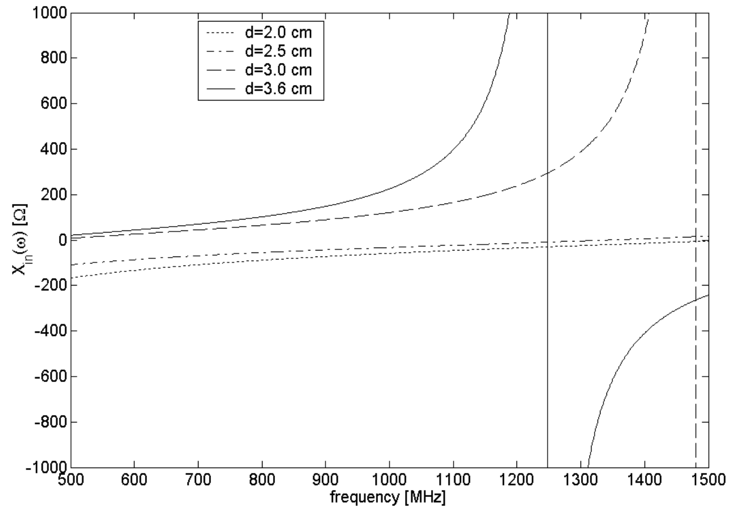

Figure 2. The input reactance of resonator with length $d \leq 3.6\,\text{cm}$.

Moreover, defined error function should be restricted by some constraints such as easy fabrication and small margin capacitance or inductance, like as the followings

$$(w/h)_{\min} \leq w(z)/h \leq (w/h)_{\max} \tag{10}$$

$$Z_c(0) = Z_c(d) \geq Z_0 \tag{11}$$

where $(w/h)_{\min}$ and $(w/h)_{\max}$ are the minimum and maximum values of $w(z)/h$, respectively, in the fabrication step.

It is worth to note that one can add some other terms such as "kz/d" to the expansions (7)–(8) to provide the possibility of having unequal values at $z = 0$ and $z = d$.

4. EXAMPLES AND RESULTS

Consider a microstrip NIR with $\varepsilon_r = 10$ and with assumptions of $f_r = 1.0\,\text{GHz}$, $(w/h)_{\min} = 0.1$, $(w/h)_{\max} = 10$, $Z_0 = 50\,\Omega$ and $N = 5$. Two kinds of resonators have been optimally designed:

a) *Open-Circuited Resonator*: Figures 2–4 illustrate $Z_{in}(f)$ versus frequency for $d = 2$–$8.5\,\text{cm}$. It is observed that the resonance at $f_r = 1.0\,\text{GHz}$ occurs for $3.7 \leq d \leq 8.5\,\text{cm}$. Also, Figures 5–7 and Figures 8–10 illustrate $Z_c(z)$ and the top view of the resulted microstrip NIRs for $d = 2$–$8.5\,\text{cm}$. We see that it is possible to have nonuniform resonators with smaller or larger length than uniform resonator, whose length is 5.8 cm in here. Also, the characteristic impedance near the ends of open-circuited NIRs is less than that at the center of them, when their length is smaller than that of uniform resonators.

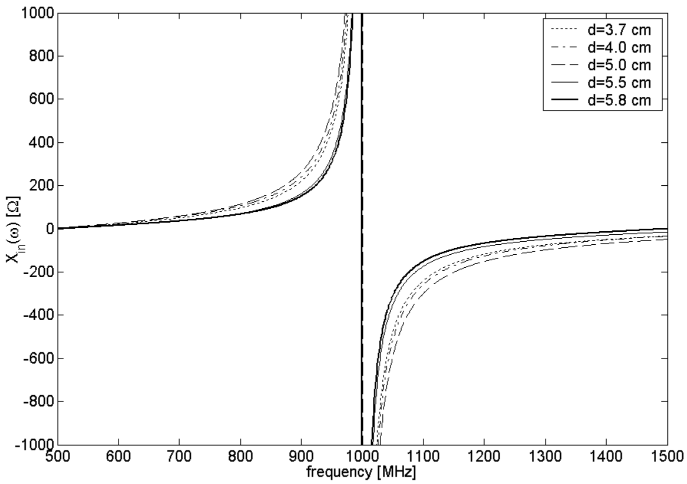

Figure 3. The input reactance of resonator with length $3.7 \leq d \leq 5.8$ cm.

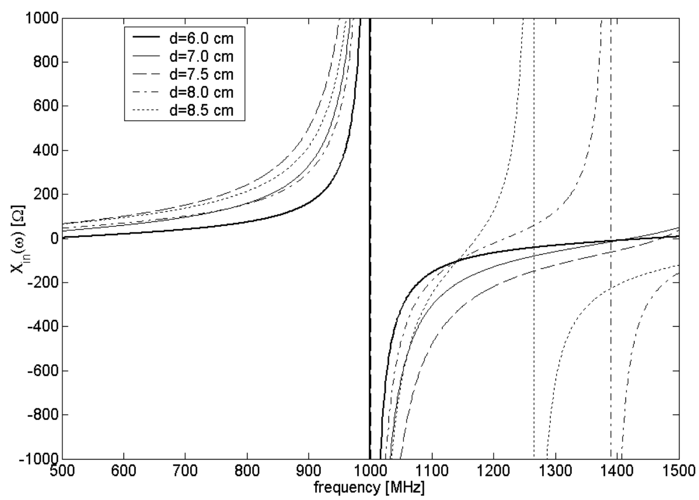

Figure 4. The input reactance of resonator with length $6.0 \leq d \leq 8.5$ cm.

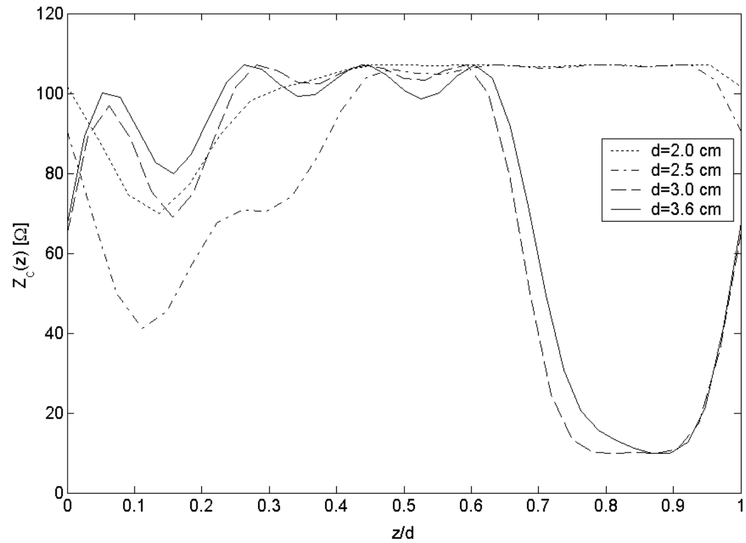

Figure 5. The characteristic impedance of resonator with length $d \leq 3.6\,\mathrm{cm}$.

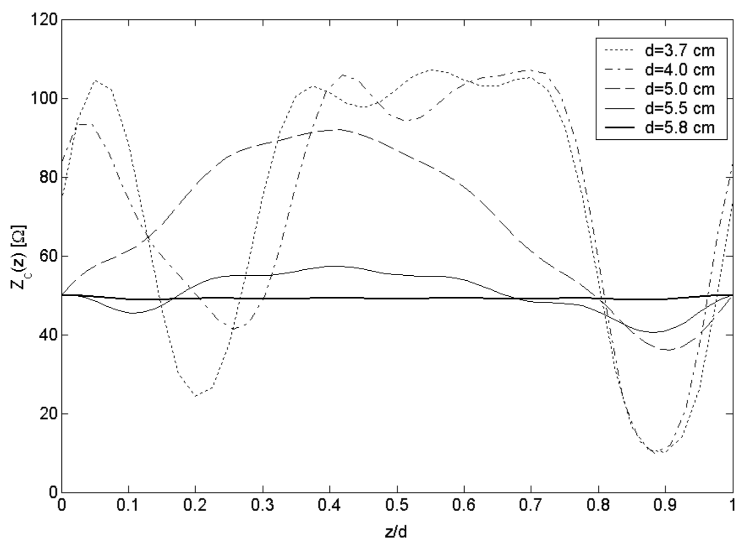

Figure 6. The characteristic impedance of resonator with length $3.7 \leq d \leq 5.8\,\mathrm{cm}$.

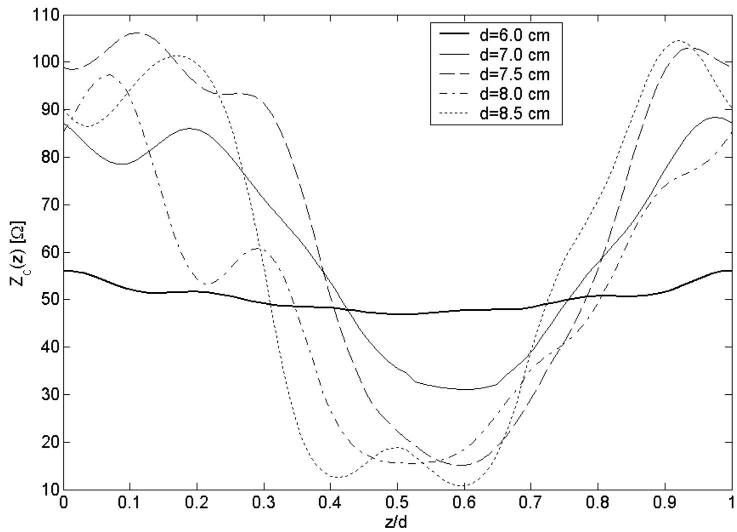

Figure 7. The characteristic impedance of resonator with length $6.0 \leq d \leq 8.5\,\text{cm}$.

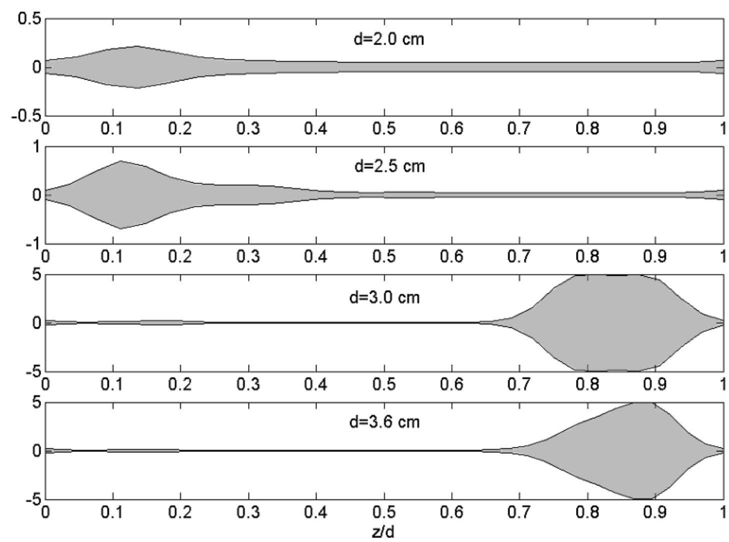

Figure 8. The top view of the resulted microstrip resonator with length $d \leq 3.6\,\text{cm}$.

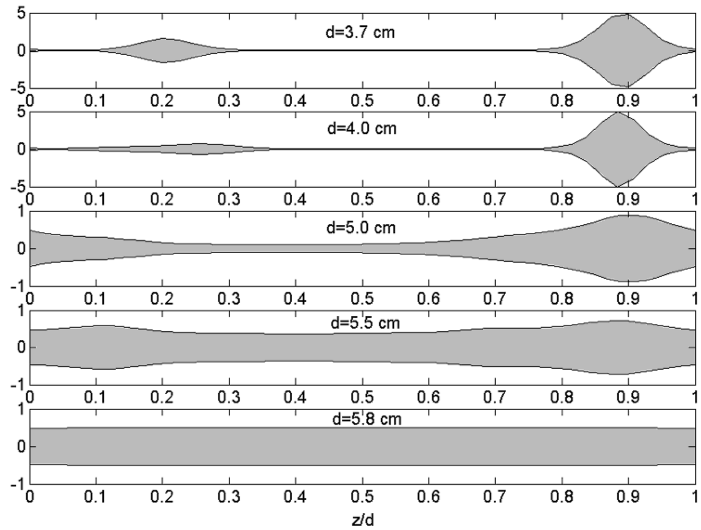

Figure 9. The top view of the resulted microstrip resonator with length $3.7 \leq d \leq 5.8\,\mathrm{cm}$.

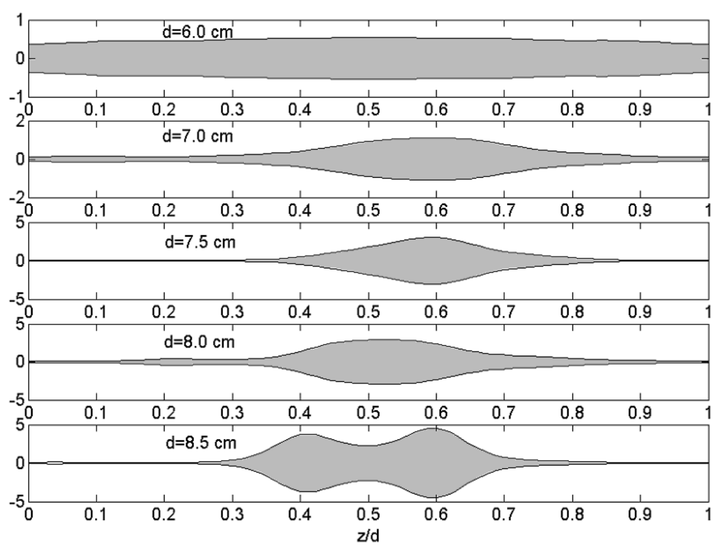

Figure 10. The top view of the resulted microstrip resonator with length $6.0 \leq d \leq 8.5\,\mathrm{cm}$.

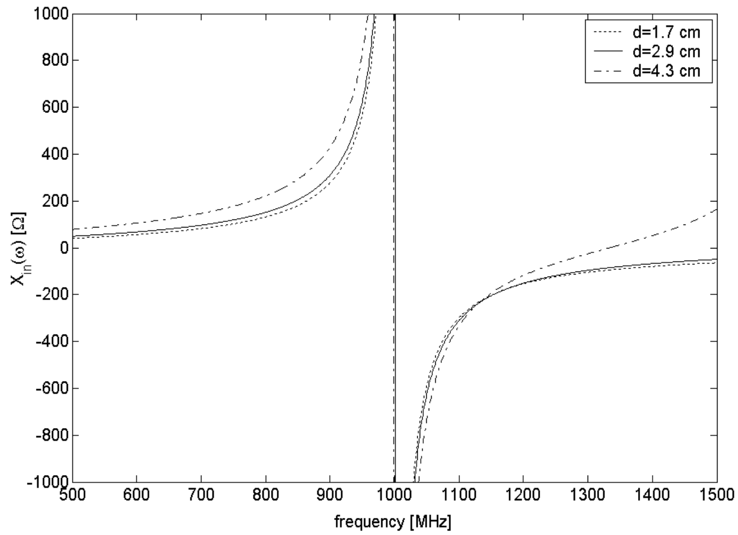

Figure 11. The input reactance of resonator with length $1.7 \leq d \leq 4.3\,\text{cm}$.

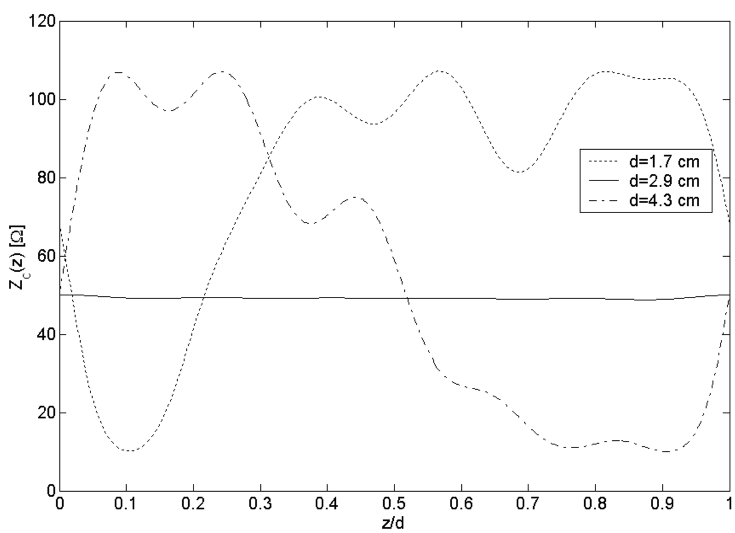

Figure 12. The characteristic impedance of resonator with length $1.7 \leq d \leq 4.3\,\text{cm}$.

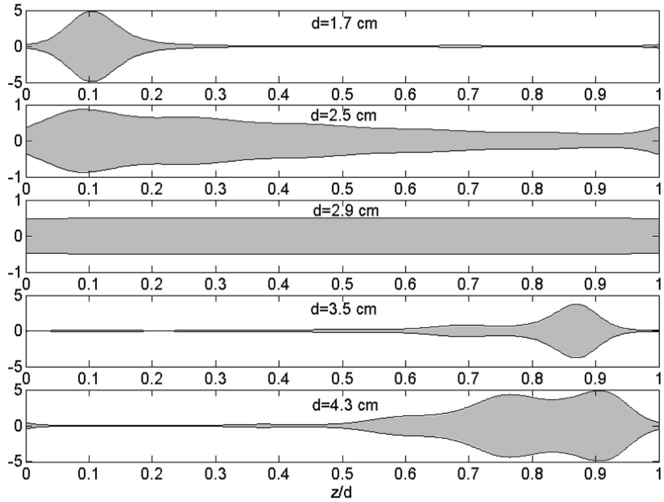

Figure 13. The top view of the resulted microstrip resonator with length $1.7 \leq d \leq 4.3\,\text{cm}$.

b) *Short-Circuited Resonator*: Figure 11 illustrates $Z_{in}(f)$ versus frequency for $d = 1.7 - 4.3\,\text{cm}$. The resonance at $f_r = 1.0\,\text{GHz}$ occurs for $1.7 \leq d \leq 4.3\,\text{cm}$. Also, Figures 12 and 13 illustrate $Z_c(z)$ and the top view of the resulted microstrip NIRs for $d = 1.7 - 4.0\,\text{cm}$. Again, we see that it is possible to have nonuniform resonators with smaller or larger length than uniform resonator, whose length is 2.9 cm in here. Also, the characteristic impedance near the input of short-circuited NIRs is less than that at the end of them, when their length is smaller than that of uniform resonators.

It is seen that both kinds of designed NIRs have no discontinuity, in contrary to the SIRs. Also, one can see that the spurious resonance frequencies of short-length NIRs are farther from the main resonance frequency than of the uniform resonators.

5. CONCLUSION

A new structure was introduced to design resonators with very short length and without any discontinuity. The introduced structure, called Nonuniform Impedance Resonator (NIR), is an open- or short-circuited Nonuniform Transmission Line (NTL). To synthesize NIRs, strip width or the characteristic impedance function of the microstrip NIRs is expanded in a truncated Fourier series, first. Then, the optimum values of the coefficients of the series are obtained through an optimization approach. Utilizing truncated Fourier series expansion does not create any discontinuity in the analyzed NTL. The usefulness of the proposed method was verified using some examples. We saw that it is possible to have nonuniform resonators with smaller or larger length than uniform resonator. Also, designed NIRs have no discontinuity, in spite of SIRs.

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