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An Investigation of Second-Harmonic Shifting Characteristic of Stepped-Impedance Resonators

Proceedings

September 12–16, 2011
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An Investigation of Second-Harmonic Shifting Characteristic of Stepped-Impedance Resonators

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Abstract— This paper reports an investigation of second-harmonic shifting characteristic of SIR technology. In our study, two features of SIR technology including shortened length and second-harmonic shifting characteristic have been investigated with respect to electric current density and equivalent model. It is found that those features are obtained by the effect of equivalent L-C lumped circuits at steps which are confirmed in our study. In addition, proper SIR dimensions enabling second-harmonic frequency at greater than two times of a fundamental frequency ($> 2f_0$) have also been recommended in this paper.

1. INTRODUCTION

The microstrip stepped-impedance line was early proposed by Riblet since 1960 [1], and further studied in later years by well-known pioneers such as Yong, Matthaei, Chang, Horton, Rhodes, and Makimoto [2–7]. Recently, SIR technology is still attracting attention, and is widely applied in various works. Because of two advantages of this technology consisting of shortened length and second-harmonic shifting characteristic, it has therefore been applied for miniaturized filters design having second-harmonic suppression [8–15]. Applying this technology, the length of resonator can be decreased by two times of conventional uniform impedance resonator (UIR) and second-harmonic frequency can also be shifted at more than two times of fundamental frequency ($> 2f_0$). Although these advantages are well recognized, the circumstance of shortened length and second-harmonic shifting characteristic is not clarified yet in any reports.

In our study, SIR technology has been investigated with respect to electric current density and equivalent model, which are also compared with that of UIR. In particular, an investigation of second-harmonic shifting characteristic of SIR has been demonstrated in this paper with ease of understanding in why the length of SIR shorter than the length of UIR and how second-harmonic frequency shifted. Furthermore, we also recommend the proper dimensions of SIR technology.

2. SCHEMATICS OF UIR AND SIR

In our study, SIR technology has been investigated and compared with UIR technology. Their schematics are shown in Figure 1. In this figure, the total length of UIR is defined by L and strip-width W is corresponding to impedance Z_0. On the other hand, the schematic of SIR consists of two low-impedance and a high-impedance parts. The low-impedance parts are defined on the length L_1 and width W_1 is corresponding to impedance Z_1. The high-impedance part is defined on the length L_2 and width W_2 is corresponding to impedance Z_2. Thus, the total length of SIR is $2L_1 + L_2$. It is noted that UIR has only a 50-Ω impedance (Z_0) while SIR has two low-impedance ($Z_1 < Z_0$) parts and a high-impedance ($Z_2 > Z_0$) part.

These resonators are designed and fabricated on a NPC-F260A laminate having substrate thickness (h) = 1.2 mm, dielectric constant (ε_r) = 2.6, tangential loss factor ($\tan\delta$) = 0.0015, and copper-strip thickness (t) = 9 µm. Hence, the total length of UIR (L) corresponding to a fundamental frequency of 2 GHz and strip-width of a 50-Ω impedance (Z_0) can be calculated at 51.197 mm, and 3.32 mm, respectively [16]. Meanwhile, the dimensions of SIR are designed at $W_1 = 6.78$ mm ($Z_1 = 30\,\Omega$), $W_2 = 0.92$ mm ($Z_2 = 100\,\Omega$), $L_1 = 7.32$ mm, and $L_2 = 2L_1 = 14.64$ mm [17], where the total length of SIR is corresponding to a fundamental frequency of 2 GHz same as that of UIR. The frequency response of these resonators is shown in Figure 2.

Figure 2 shows frequency response of UIR and SIR having the same fundamental frequency f_0 at 2 GHz but second-harmonic frequency of SIR ($f_{s,SIR}$) is greater than that of UIR ($f_{s,UIR}$). The second-harmonic frequency of UIR is at $2f_0$ but second-harmonic frequency of SIR is at $3.2f_0$. Typically, the location of second-harmonic should be better than $2f_0$ because it may harmful

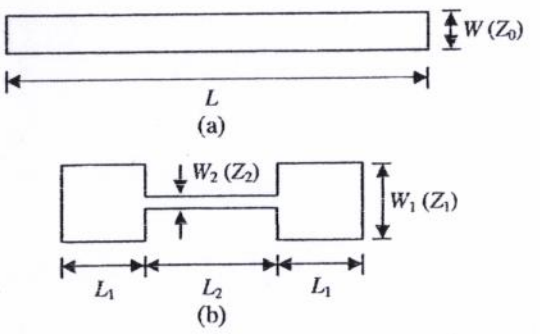

Figure 1: Schematics of (a) UIR having the length L and width W is corresponding to impedance Z_0, and (b) SIR having two low-impedance parts defined by length L_1 and width W_1, and a high-impedance part defined by length L_2 and width W_2.

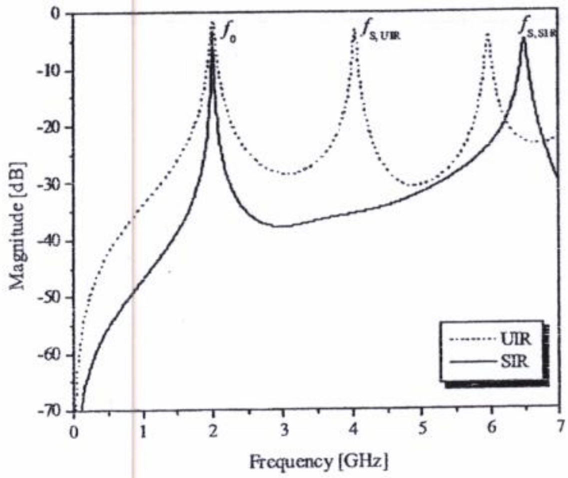

Figure 2: Frequency response of UIR and SIR with the same fundamental frequency at 2 GHz where second-harmonic frequency of UIR is at $2f_0$ and second-harmonic frequency of SIR is at $3.2f_0$.

to fundamental frequency which is an information signal of wireless communication systems. In addition, the length of SIR is also shorter than that of UIR. The shortened length and second-harmonic shifting characteristic mentioned above are two features of SIR technology which have been investigated and demonstrated as detailed in Section 3.

3. INVESTIGATION OF SIR TECHNOLOGY

In this study, the total length of UIR and SIR is designed at the same length and both resonators are analyzed together with respect to electric current density (J) and equivalent model. The electric current density flowed along the resonator length and equivalent model of those resonators are shown in Figure 3.

Figure 3 shows electric current density (J) flowed along the length of UIR and SIR in fundamental and second-resonant modes, which is calculated by IE3D software, and their equivalent models. The total length of UIR and SIR for this case is designed at the same length ($L_{T,UIR} = L_{T,SIR}$). In fundamental mode, maximum electric current density of those resonators is at the center which is a short-circuit position, and minimum electric current density is at the ends which are the open-circuit positions. In second-resonant mode, minimum electric current density is at the open-circuit positions. The maximum electric current density of UIR is at the short-circuit positions while maximum electric current density of SIR is near the short-circuit positions where are on the narrow strip of a high-impedance part, due to current concentration on the narrow-width strip. The equivalent model of UIR consists of a transmission line having an impedance Z_0 and total length $l = \lambda_g/2$ while the equivalent model of SIR consists of two low-impedance transmission lines ($Z_1 < Z_0$) having the length l_1 and a high-impedance transmission line ($Z_2 > Z_0$) having the length $l_2 = 2l_1$. Furthermore, equivalent L-C lumped circuits are also modeled at steps of SIR where L_1 is larger than L_2. These circuits do not effect to second-resonant mode because they are at the short-circuit positions in second-resonant mode but they only affect fundamental mode. The electrical length of SIR in fundamental mode is accordingly lengthened. Consequently, fundamental frequency of SIR is shifted down but second-resonant frequency is not change which is same as that of UIR, as shown in Figure 4.

Figure 4 shows the frequency response of UIR and SIR where the total length of these resonators is same. The L-C lumped circuit occurred at steps of SIR effects to fundamental mode and this frequency is therefore shifted down because electrical length of SIR is lengthened, as mentioned above, while second-resonant frequency is not change which is same as that of UIR at approximately 4 GHz. In order to adjust fundamental frequency of SIR same as that of UIR at 2 GHz, the total length of SIR must be shortened. Thus, fundamental and second-resonant frequencies of SIR are shifted up together. The results of UIR and shortened SIR can see in Figures 1 and 2. In those

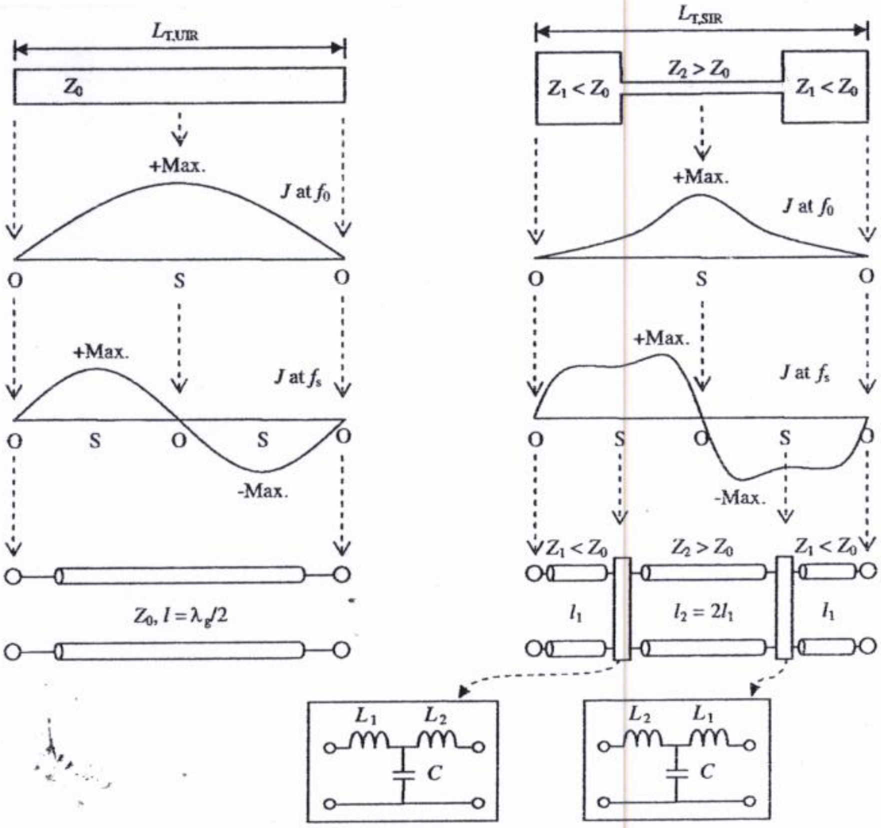

Figure 3: Electric current density (J) flowed along the length of UIR and SIR in fundamental (f_0) and second-resonant (f_s) modes, and their equivalent models, where the total length of these resonators is designed at the same length ($L_{T,UIR} = L_{T,SIR}$). Symbols O and S denote open- and short-circuit positions.

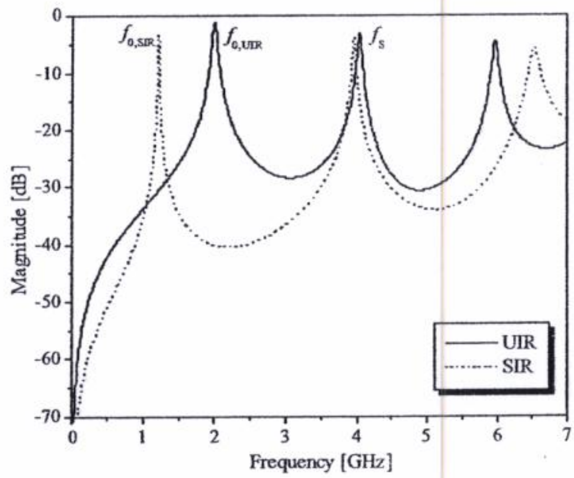

Figure 4: Calculated result of frequency response of UIR and SIR where the total length of these resonators is same. The fundamental frequency of SIR is shifted down while second-resonant frequency of SIR is not change which is same as that of UIR (at approximately 4 GHz).

figures, the fundamental frequency of UIR and SIR is same at 2 GHz but second-resonant frequency of UIR is at $2f_0$ while second-resonant frequency of SIR is at $3.2f_0$, and the total length of SIR is shorter than that of UIR.

4. DIMENSIONS OF SIR

The recommended dimensions of SIR technology are given in [17], where the length ratio $N = L_2/L_1$ is recommended in a range of 1.5 to 2.0 and impedance ratio $R = Z_1/Z_2$ is recommended in a range of 0.2 to 0.3. At those ratios, second-harmonic frequency can be improved at greater than $3f_0$ which is required for high-performance bandpass filters employed in commercial wireless systems. Thus, the proper dimensions of SIR for a NPC-F260A laminate are as follows: $W_1 = 6.78\,\text{mm}$ ($Z_1 = 30\,\Omega$), $W_2 = 0.92\,\text{mm}$ ($Z_2 = 100\,\Omega$), $L_1 = 7.32\,\text{mm}$, and $L_2 = 2L_1 = 14.64\,\text{mm}$, where ratios N and R are respectively 2.0 and 0.3. Second-harmonic frequency can be shifted up to $3.2f_0$ which is satisfactory for further application [17].

5. CONCLUSIONS

An investigation of second-harmonic shifting characteristic of SIR has been demonstrated in this paper. In particular, two features of SIR technology including shortened length and second-harmonic frequency shifted has been investigated with respect to electric current density and equivalent model. Those features are obtained by the effect of equivalent L-C lumped model at steps which are confirmed by our study reported in this paper. This report is beneficial to make sure that why shortened length and how second-harmonic frequency shifted.

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บันทึกข้อความ

ส่วนราชการ กลุ่มงานวิชาการ สถาบันวิจัยและพัฒนา โทรศัพท์ ๐ ๒๕๔๙ ๔๖๘๒-๔ โทรสาร ๐ ๒๕๔๙ ๔๖๘๐

ที่ ศธ ๐๕๗๘.๑๗/ ๕๒๗ **วันที่** ๒๗ สิงหาคม ๒๕๕๔

เรื่อง การติดตามผลการดำเนินโครงการวิจัย ประจำปีงบประมาณ ๒๕๕๓ – ๒๕๕๔

เรียน หัวหน้าหน่วยงานภายใน

ตามระเบียบสถาบันเทคโนโลยีราชมงคล ว่าด้วยการใช้จ่ายเงินอุดหนุนการวิจัย พ.ศ. ๒๕๔๗ ได้มอบหมายให้สถาบันวิจัยและพัฒนา เป็นผู้ติดตามผลการดำเนินงานโครงการวิจัย ที่ได้รับงบประมาณให้ดำเนินโครงการวิจัย ความทราบแล้วนั้น

ในการนี้ สถาบันวิจัยและพัฒนา จึงใคร่ขอติดตามการดำเนินโครงการวิจัยที่ได้รับงบประมาณประจำปี ๒๕๕๓ – ๒๕๕๔ ดังนี้

กรณีที่ 1 หัวหน้าโครงการวิจัยที่ได้รับงบประมาณประจำปี ๒๕๕๔ ที่คาดว่างานวิจัยอาจไม่แล้วเสร็จตามระยะเวลาที่กำหนดไว้ในโครงการวิจัย ให้หัวหน้าโครงการวิจัยขอขยายระยะเวลาดำเนินการวิจัย โดยระบุวันที่คาดว่าจะดำเนินการแล้วเสร็จ ซึ่งต้องไม่เกินระยะเวลา ๑ ปีงบประมาณ เสนอต่อหัวหน้าหน่วยงานพิจารณาอนุมัติ ตามระเบียบสถาบันเทคโนโลยีราชมงคล ว่าด้วยการใช้จ่ายเงินอุดหนุนเพื่อการวิจัย พ.ศ. ๒๕๔๗ ข้อ ๑๔ และแจ้งมายัง สวพ. ภายในวันที่ ๓๐ กันยายน ๒๕๕๔

กรณีที่ 2 หัวหน้าโครงการวิจัยที่ได้รับงบประมาณประจำปี ๒๕๕๓ และยังมิได้ส่งเล่มรายงานฉบับสมบูรณ์ บัดนี้ใกล้ครบกำหนดการขยายระยะเวลาดำเนินโครงการวิจัยแล้ว คือ ภายในวันที่ ๓๐ กันยายน ๒๕๕๔ ดังนั้น สวพ. จึงใคร่ขอให้นักวิจัยส่งรายงานฉบับสมบูรณ์ จำนวน ๕ เล่ม พร้อมไฟล์ มายัง สถาบันวิจัยและพัฒนา ภายในวันที่ ๓๑ ตุลาคม ๒๕๕๔

จึงเรียนมาเพื่อโปรดทราบ และแจ้งหัวหน้าโครงการวิจัย ดำเนินการในส่วนที่เกี่ยวข้อง

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☑ เห็นควร...

(ผู้ช่วยศาสตราจารย์วาสนา เจริญวิเชียรฉาย)
รองผู้อำนวยการฝ่ายบริการและเผยแพร่ผลงานวิจัย
รักษาราชการแทน ผู้อำนวยการสถาบันวิจัยและพัฒนา