MICROSTRIP TWO-SECTION DUAL-BAND IMPEDANCE TRANSFORMER DESIGN WITH SPURIOUS MATCHING SUPPRESSION

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ABSTRACT

In this paper, a novel two-section dual-band impedance transformer with embedded spurline sections is proposed. With this new structure, the intrinsic spurious matchings at the 3rd and 5th harmonic frequency bands can be significantly suppressed, whilst the matching at the two designed operating frequencies can be maintained. In order to demonstrate the proposed transformer performance, a GSM dual-band (900 MHz and 1.8 GHz) impedance transformer was designed and implemented. From the simulation and experimental results, the proposed transformer maintains the good matching of 35 dB at the dual GSM frequency bands and suppresses all unwanted matching upto its 5th harmonic band.

KEYWORDS — **Dual-band, impedance transformer, transmission zero placement, spurline, spurious matching.**

I. INTRODUCTION

The latest multi-standard communication system developments usually need dual-band or triple-band RF/MW components to implement the required signal processing, like in the case of the common dual-band mobile communication system. Here, the design of new components like the dual-band coupler, the dual-band bandpass filter, the dual-band impedance transformer and others, has recently been addressed due to its industrial importance.

Conventionally, the λ/4 impedance transformer is used for matching a specific load at a single frequency; but may not be useful in a dual-band system. Recently, a simple two-section dual-band impedance transformer with total λ/3 length, shown in Fig. 1, was introduced for matching at the frequency f_1 and its first harmonic $2f_1$, with the numerical solution and analytical formulation provided in [1] and [2], respectively. Besides the above harmonic matching, this two-section dual-band impedance transformer was extended for the operation at two arbitrary frequencies f_1 and f_2. On the other hand, in [3, 4], a set of analytical design equations is given to characterize the two-section dual-band impedance transformer; where it is also demonstrated that the length of each section will be quarter-wavelength at the center frequency f_o for the two designed frequencies (f_1 and f_2). However, the transformer intrinsically suffers spurious matchings for all odd harmonic frequency bands, and so has additional matching frequency bands at $nf_o+(f_2-f_1)/2$ and $nf_o+(f_2-f_1)/2$, for n = 3, 5, 7, 9, … etc. Since the suppression of this intrinsic spurious-matching has not yet been reported its detailed analysis can be considered of paramount importance for future multi-standard communications.

In order to retain the compactness and geometry simplicity of the above two-section impedance transformer here it will be considered the possibility of embedding the spurline into the transformer, where the manipulation of its length will control the corresponding zero characteristic [5, 6]. And, the introduction of such an element could lead also to the elimination of unwanted matching whilst the fundamental matching is kept unchanged.

Based on the above this paper proposes a novel dual-band impedance transformer approach based on embedded spurlines for spurious matching band suppression. Also, the extension of the spurline analysis, in terms of its geometrical orientation and location will be included. The design of the proposed structure can be derived from the conventional two-section impedance transformer basic equations. Additional formulas and guidelines for spurline physical parameters design will also be presented. For verification, both simulated and measured results of a microstrip two-section dual-band impedance transformer for GSM will be introduced and compared with the behavior of a conventional structure.

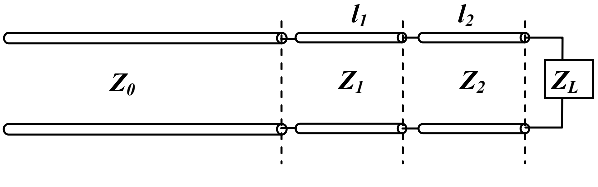

Fig. 1. Two-section dual-band impedance transformer.

II. DUAL-BAND SPURLINE IMPEDANCE TRANSFORMER – ANALYSIS AND DESIGN

A. Two-Section Dual-Band Impedance Transformer [4]

For the microstrip two-section dual-band impedance transformer, as shown in Fig. 1, operated at the two designed frequencies f_1 and f_2, its parameters can be determined as follows:

$$l_1 = l_2 = \frac{\lambda_0}{4} = \frac{\lambda_1}{2(r+1)} \qquad (1)$$

$$Z_1 = \sqrt{\frac{Z_o}{2t_1^2}\left[Z_L - Z_0 + \sqrt{(Z_L - Z_0)^2 + 4t_1^4 Z_L Z_0}\right]} \qquad (2)$$

$$Z_2 = Z_L Z_0 / Z_1 \qquad (3)$$

where $r = f_2/f_1$ is the ratio of the two designed frequencies; λ_0 is the wavelength at the center frequency $f_o = (f_1+f_2)/2$; and the variable t_1 is defined as $t_1 = tan(\frac{\pi}{2}\frac{f_1}{f_0})$.

B. Spurline Section Design for Transmission Zero Placement

Fig. 2(a) shows a microstrip symmetrical spurline section and its equivalent circuit [6]. The spurline section is equivalent to a transmission line with characteristic impedance $Z_{oe}/2$ and electrical length $\theta_e = (2\pi f/v_{pe})l$ in series with a short-circuited stub with characteristic impedance $Z_{oo}/2$ and electrical length $\theta_o = (2\pi f/v_{po})l$; where l is the physical length of the spurline, f is the frequency of interest, and v_{po} and v_{pe} are the phase velocities for odd- and even- modes respectively. Since the impedance of the short-circuited series stub will become infinity when $\theta_o = \pi/2$, that is when the length of spurline is

$$l = v_{po}/4f \qquad (4)$$

From (4), it is shown that a transmission zero can be created and the reflection will be maximized at some frequency f by controlling the spurline length. As such, embedding this spurline section into the microstrip two-section impedance transformer can achieve the spurious matching frequency band suppression.

By using $v_p = \lambda f$ and $\lambda = c/\left(f\sqrt{\varepsilon_{re}}\right)$, the spurline physical length can be further re-expressed as a fraction of the impedance transformer sectional length l_i:

$$l = li\frac{f_0}{f}\sqrt{\frac{\varepsilon_{re}}{\varepsilon_{re}^o}} \qquad (i = 1, 2) \qquad (5)$$

where c is the velocity of light, ε_{re} and ε_{re}^o are the effective dielectric constant and its odd-mode value.

C. Spurline Geometrical Orientation and Location

According to the equivalent circuit of the microstrip spurline section embedded in a transmission line, as shown in Fig. 2(b) and (c), it is found that there is no transfer characteristics difference due to the orientation of spurline (left-hand side or right-hand side configuration) as long as the slot opened on the strip edge is small enough ($g << l$), and its position and length are unchanged.

In the above section, it has been shown that the transmission zero placements can be simply controlled by adjusting the length of spurline. However, the physical location of the embedded spurline in an impedance transformer section does affect the reflection at neighboring frequencies. To illustrate the spurline location effect on the transformer matching characteristics, a conventional quarter-wavelength transformer embedded with a spurline section at different position is studied. This quarter-wavelength transformer is designed to operate at 1 GHz and matches well with a 180 Ω resistive load and a 50 Ω source. The embedded spurline is of *1/5* total strip length so that the 5th harmonics (i.e. 5 GHz) is suppressed. The simulation results of the spurline location-effect are shown in Fig. 3.

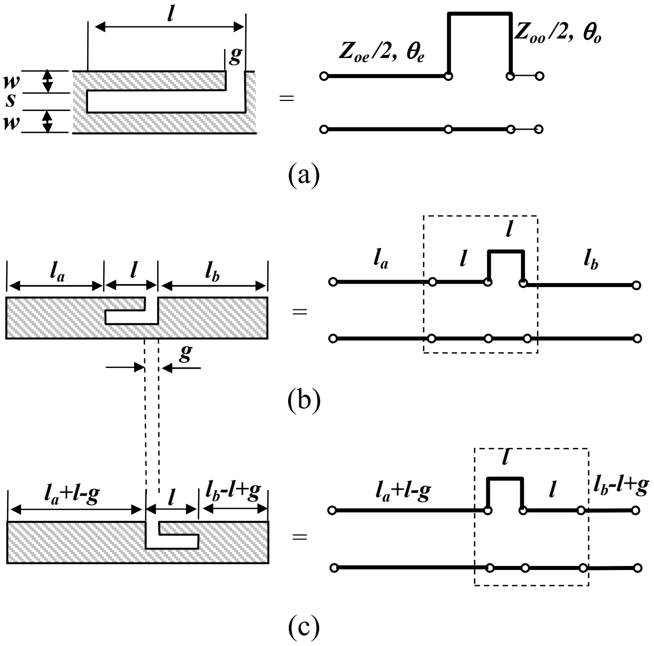

Fig. 2. (a) Spurline section and its equivalent circuit, (b) Spurline embedded (left-hand side configuration) transmission line and its equivalent circuit, (c) Spurline embedded (right-hand side configuration) transmission line and its equivalent circuit.

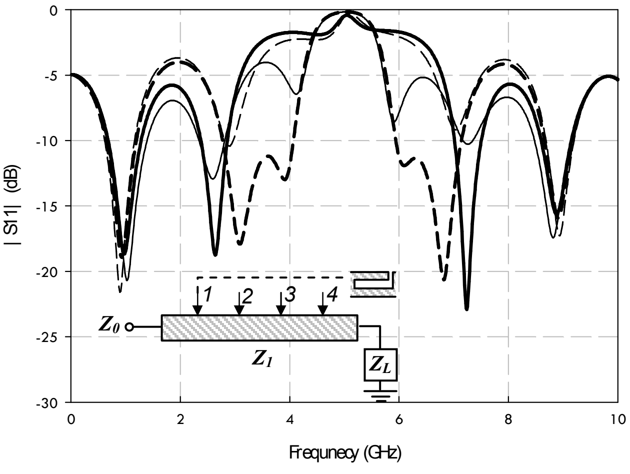

Fig. 3. Effect of Spurline location: Spurline located at position 1 (thin dash line), position 2 (thick dash line), position 3 (thick solid line) and position 4 (thin solid line).

From Fig. 3, the transformer shows different levels of spurious matching at the 5th harmonic proximity. And it is observed that placing the spurline at the position-3 (the slot is located at about 3/5 long of the strip length apart from the source) may cause minimum spurious matching on the neighboring frequency, whilst the matching at 5th harmonic frequency can be suppressed significantly.

To take full advantage of the above spurline effects, three spurline sections are embedded into the transformer to suppress the unwanted matching at $3f_o$ and $5f_o$. The final spurline is for matching level suppression between the two designed frequencies f_1 and f_2, so that the guard band between them is with good performance.

III. SIMULATED AND MEASURED RESULTS

To demonstrate the spurious matching suppression capability of the proposed impedance transformer, especially the lowest two harmonic frequency bands, the proposed and the conventional structure are designed for the dual GSM band frequencies (900 MHz and 1.8 GHz) with a 50 Ω source and a 180 Ω resistive load. In order to simplify the overall spurline design process, only the symmetrical spurline with equal strip width, coupling gap and the width of the slot opened on the strip-edge ($w = s = g$) will be considered.

These two microstrip impedance transformers are simulated with the MoM-based EM simulation package [7] and implemented on the Rogers RO4003 substrate with relative dielectric constant ε_r=3.38 and thickness h=1.524 mm. The layout parameters of the conventional two-section dual-band impedance transformer are firstly evaluated subject to the above specification and the design equations (1 - 3). Based on the analysis in section II, the proposed transformer, as shown in Fig. 4, is designed by choosing the lengths of the three spurline-sections as $l_{fo} \approx l_2$, $l_{3fo} = l_1/3$ and $l_{5fo} = l_1/5$ (for $l_1 = l_2$ = 34.92mm).

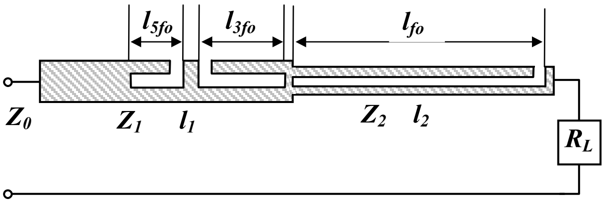

Fig. 4. Two-section dual-band impedance transformer with three-sections of embedded spurline.

Fig. 5 shows the reflection coefficient simulation of the above transformers. It is obvious that the proposed transformer has suppressed the spurious matching till its 5th harmonic band to a level of about 5 dB. The matching between 900 MHz and 1.8 GHz is also suppressed to 0 dB.

In addition, the above two transformers were implemented and measured. Their experimental reflection coefficients are recorded in Fig. 6; where it can be seen that the matching characteristics in the 3rd and 5th harmonic bands are suppressed to the level of 5 dB and 7 dB respectively, whilst the matching of the designed dual GSM frequencies is about 35 dB. As such, this confirms the proposed structure performance. Moreover, the matching at the guard band between the two operating frequencies is also suppressed to a level of 2 dB.

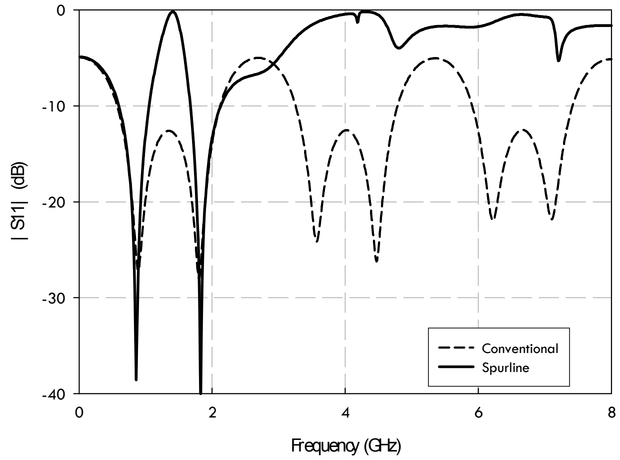

Fig. 5. Simulated reflection response for conventional two-section dual-band impedance transformer (thin dashed line), and for the proposed structure (thick solid line).

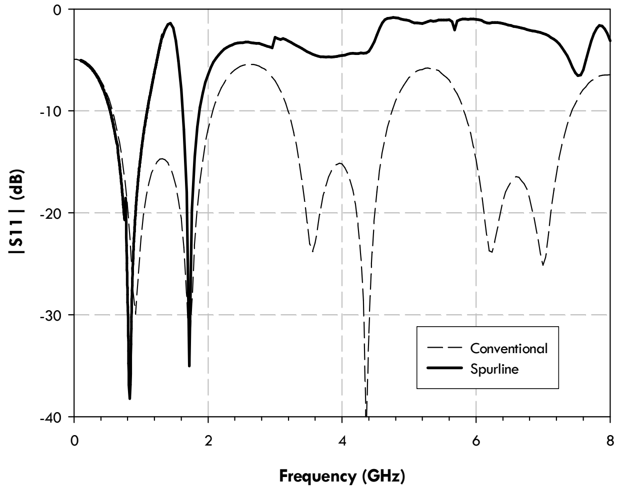

Fig. 6. Measured reflection response for conventional two-section dual-band impedance transformer (thin dashed line), and for the proposed structure (thick solid line).

IV. CONCLUSIONS

A novel two-section dual-band impedance transformer based on embedded spurline sections has been proposed to suppress the spurious matching frequency bands at the higher harmonic frequencies and the unwanted matching between the two operating bands. In order to validate this novel structure, two prototypes microstrip impedance transformers for dual GSM bands, using the proposed novel and the conventional two-section structures were designed and experimentally characterized. The new transformer offers a spurious matching elimination at the 3rd and 5th harmonic frequency bands; whilst the matching of the designed dual GSM bands are kept at a level close to 35 dB. This new method offers additional flexibility and improved performance in conventional two-section dual-band transformer design.

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