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MICROSTRIP-TO-PARALLEL STRIP TRANSITION BALUN INTEGRATED WITH STUBS AND DGS FOR 3-D HARMONIC SUPPRESSED DIPOLE ANTENNA

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ABSTRACT
This paper presents a tapered baluns of microstrip-to-parallel strip transition using triangular structure with linear transition that suitable for a 3-dimensional (3-D) harmonic suppressed dipole antenna (3D-HSDA). The original balun consists of linear profile with the size of a quarter-wavelength for both the height and width with broadband characteristic (from 0 to 7 GHz). However, for some application such as narrowband HSA design, the suppression of the high operating band is needed. By using three open circuit stubs and three rectangular element of defected ground structure (DGS), two tapered baluns have been produced having the stop band feature from 2.1 GHz to 7 GHz of frequencies. They are named as balun-stubs and balun-DGS, respectively, that operate from 0 to 2 GHz. Simulated and measured results based on the return loss and insertion loss for these baluns were found to be better than -10 dB and -3 dB, respectively, from 0 to 2 GHz. The employment of the stubs and the DGS made these baluns the capability to reject the unwanted high frequency band. At last, these balun are integrated with dipole antenna for validation purpose. The results shows the antenna with balun-stubs and antenna with balun-DGS operates at 900 MHz and removed undesired higher order modes at 2.75 GHz, 4.47 GHz and 6.2 GHz without affecting the operating frequency.

Key words: Tapered balun・Tapered balun-stubs・Tapered balun-DGS・Broadband・Stopband・Dipole

INTRODUCTION
Integration of the tapered balun with stubs and tapered balun with defected ground structure (DGS) produced a new characteristic of operation band of the tapered balun. They are one of the best candidates of the feeding circuit for the latest development balanced antenna design such as harmonic suppressed antenna (HSA) and it's practical for the plane and three dimensional (3-D) shape, respectively. The original tapered balun uses a microstrip-to-parallel strip transition having broadband feature and low insertion loss. This conversion is very suitable in RF circuit such as filter, power divider, duplexer, phase shifter and coupler (Q Xue, 2008) with a few methods such as bent tapered balun and linear tapered. Figure 1 shows *i*-number of stacked impedance transformer from Z_1 to Z_i of this transition.

The original tapered balun which consists of simple geometry may operate at large bandwidth and can be easily developed. However, at certain application such as harmonic suppressed dipole antenna (HSDA), the feature of the balun need to be altered by suppressing higher frequency band so that it can work at narrowband. The conventional method employs outside filter circuit which inherently increases the size of the antenna particularly the RF-front-end circuit. This effect is obvious at UHF band.

Harmonic Suppressed Antenna (HSA) is an antenna that is impedance matched at the desired operating frequency while producing maximum reflections at harmonics frequencies. This antenna is usefull in rectifying antenna (rectenna), an active integrated microwave antenna and antenna array. Employing HSA can simplify frequency agile RF front-ends unit and reduce an electromagnetic interference (EMI). Some cases have demonstrated the ability of the antenna can effectively suppress the harmonic frequency. The antennas used either an open circuit stubs, electromagnetic band gap (EBG) structure, combines an EBG structure and a tuning stub, DGS circuit, Low pass filter (LPF) integrated with antenna, a photonic band gap (PBG) structure, combine a PBG and DGS, a slotted antenna, combined a slotted and tuning stub and external transistor to eliminate the harmonics frequencies in a printed dipole antenna, rentangular patch antenna or circular patch. Meanwhile, a 50 Ω matching circuit such as microstrip line and a tapered balun, CPW feed, transmission line feed, a proximity couple feed or a coaxial feed are used. In this article, two methods are basically proposed: (1) stubs circuit and (2) DGS circuit is integrated with balun to suppress high frequency band from 2 GHz to 7 GHz. The circuit performance for balun-stub and balun-DGS are similar and able to suppress higher frequency mode in the dipole antenna. Tapered balun with linear profile published in (S. A. Hamzah et al., 2012) can produce balance mode while in (M. Kamper et al., 2014), (G. Wenjum et al., 1999), (S.A.P. Rizvi and R. A. A. Khan, 2012), and (M. Vahdani, 2008) reported other type of structures that were used widely with wideband feature and simple to be designed such exponential, Tchebyscheff, Klopfenstein and elliptical.

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Then, these baluns are integrated with dipole antenna in 3-D structure.

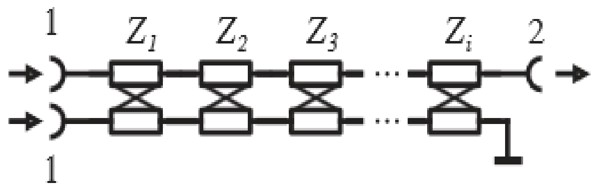

Figure 1: Tapered balun as a gradually changing impedance transformer (M Kamper and press, 2014)

Section II presents the design and fabricated prototype. Simulation and experimental results are presented and discussed in Section III. The last section concludes the paper.

PROPOSED DESIGN

Balun-stubs and balun-DGS design

The proposed geometries of the transition are designed using FR-4 board with 4.6 dieletric constant, thickness of 1.6 mm and thin triangle shape. Figure 2 (a)-(c) present the photograph of the proposed balun by means of back-to-back configuration layout. The original balun is designed at 900 MHz operating frequency with 128 mm long. Taper's section (bottom layer) has half-wavelength of height and width of 64 mm. Meanwhile, the line (top layer) has 3.0 mm of width. The second balun geometry is integrated with three open circuit stubs while the third balun geometry is integrated with three rectangular DGS, respectively. The length of the stub as well as DGS is λ/4 of the regarded frequency (i.e. 2.7 GHz, 4.5 GHz and 6.3 GHz). The width is fixed at 3 mm. The stub sizes are 26 mm x 3 mm, 20 mm x 3 mm and 15 mm x 3 mm. In addition, the DGS size elements are same with the stubs. Balun-stubs are optimized with 138 mm long while the balun-DGS remained the same as the original dimension. The optimized position of the stubs and the DGS are obtained by using parametric study using CST simulation tool. In this work, both baluns are used impedance matching between 50 Ω microstrip line to 70 Ω parallel strip characteristic impedance with the 3 mm of microstrip line width (top layer). Hence, the balun only has 2-number of stacked impedance transformer of Z_1=50 Ω and Zi = 70 Ω in this transition. The proposed balun is named as balun-stubs and balun-DGS, respectively. The complete optimized layouts of the balun are depicted in the figure.

Dipole antenna integrated balun

The configuration of the proposed design is illustrated in Figures 3, 4 and 5. The microwave board used is a low cost substrate, FR-4 board as mentioned before. The radiating element is 1.5 mm thick, 132 mm x 20 mm of height and length. Baluns in Figure 2 were used as matching circuitry that produced a 3-D antenna as shown in Figures 3 to 4. They are named as original dipole, dipole with integrated stubs and dipole with integrated DGS, respectively.

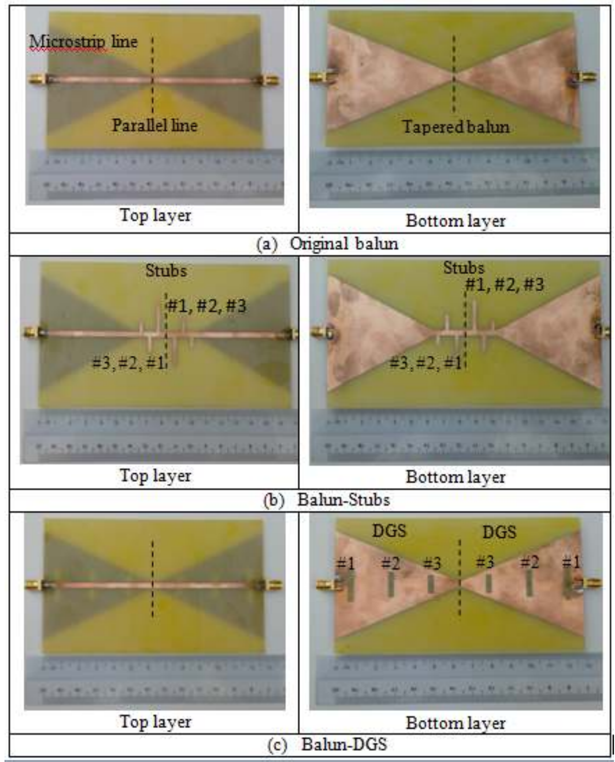

Figure 2: Picture of the fabricated back-to-back configuration of the proposed tapered balun from 0 to 7 GHz

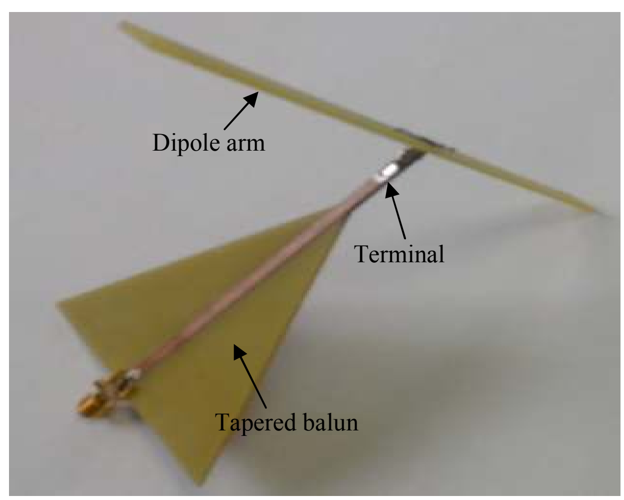

Figure 3: Original dipole

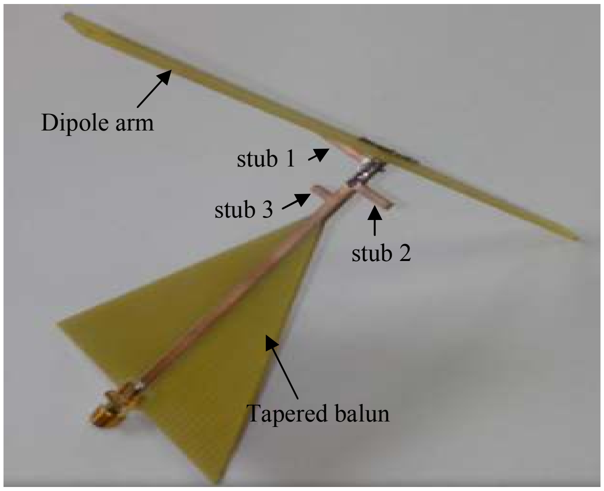

Figure 4: Dipole with integrated stubs

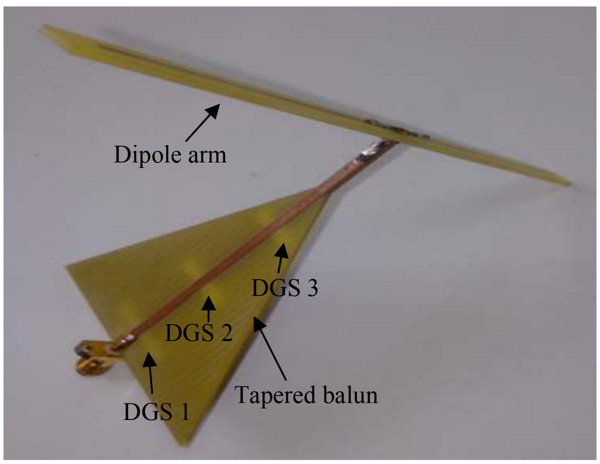

Figure 5: Dipole with integrated DGS

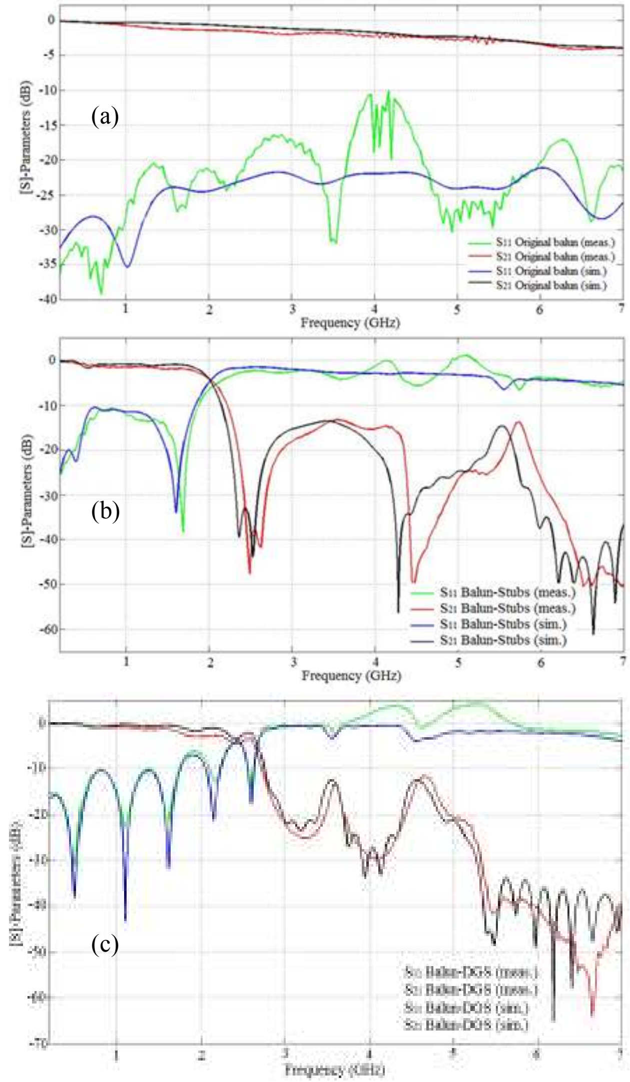

Figure 6: (a) Simulated and measured return loss, $|S_{11}|$ and insertion loss, $|S_{21}|$ of balun original, (b) Simulated and measured return loss, $|S_{11}|$ and insertion loss, $|S_{21}|$ of balun-stubs, and (c) Simulated and measured return loss, $|S_{11}|$ and insertion loss, $|S_{21}|$ of balun-DGS

RESULTS AND DISCUSSION

Balun-stubs and balun-DGS

Figure 3 presents the simulated and measured return loss and insertion loss of original tapered balun from 0 to 7 GHz frequency range. The observed measured return loss of $|S_{11}| < -10.5$ dB ($|S_{11}|$ minimum is close to -20.5 dB) from 0 to 2 GHz frequency range corresponds to the insertion loss, $|S_{21}|$ over these bands approaching -1.5 dB maximum. Moreover, the balun has approximately -1.5 dB minimum to -5.5 dB maximum of measured insertion loss for all entire bands. Good agreements are obtained for the simulation and measurement results.

Next, the simulated and measured return loss and insertion loss of balun-stubs from 0 to 7 GHz are presented in Figure 3(b). The balun has $|S_{11}|$ better than -10 dB (approximately from -10 dB minimum to -38.5 dB maximum) from 0 to 1.98 GHz. Its corresponding insertion loss over the band is approximately -3.5 dB maximum. The measured insertion loss changes from -5.0 dB to -40 dB from 1.99 GHz to 7 GHz showing that the balun is miss-matched, affected of the stubs. In conclusion, the integration of three stubs to the original balun does not degrade its performance at UHB band although can suppress the higher frequency band. Good aggreements are obtained for the simulation and measurement results

The simulated and measured return loss and insertion loss of balun-DGS from 0 to 7 GHz are presented in Figure 3(c). The measured return loss of the balun has $|S_{11}|$ better than -10 dB from 0 to 1.96 GHz. Its corresponding insertion loss, $|S_{21}|$ over these bands is good which is close to -3 dB maximum. As shown in the figure, the measured insertion loss varies from -4.5 dB minimum to -42 dB maximum indicating that the balun is well miss-matched. It can be inferred that the integration of the DGS with balun does not degrade its performance at UHF band although can suppress the higher frequency band. The complete measured results are tabulated in Table 2.

Integration of the proposed baluns with dipole antenna

The measured results of the antenna are divided into three conditions: (1) original dipole, (2) Dipole with integrated stubs, and (3) Dipole with integrated DGS. Figure 7 shows the return loss of the original dipole at 0.9 GHz, and three higher frequency bands, 2.75 GHz, 4.4 GHz and 6.2 GHz, respectively. Referring to Figure 8, a dipole with integrated stubs operates at 0.9 GHz frequency and successfully eliminated the three harmonic frequencies as mentioned before. Stub 1 (length = 18 mm, width = 3mm), stub 2 (length = 13.5 mmhe frequency 2.79 , width 3 mm) and stub 3 (length = 10.5 mm, width = 3 mm) are used to suppress these unwanted higher frequencies. On top of that, a dipole with DGS operates at 0.9 GHz and successfully eliminated others three frequencies. The antenna employes DGS 1 (length = 20 mm, width = 3 mm), DGS 2 (length = 15 mm, width = 3 mm) and DGS 3 (lengh = 11 mm, width = 3 mm) to suppress these frequencies.

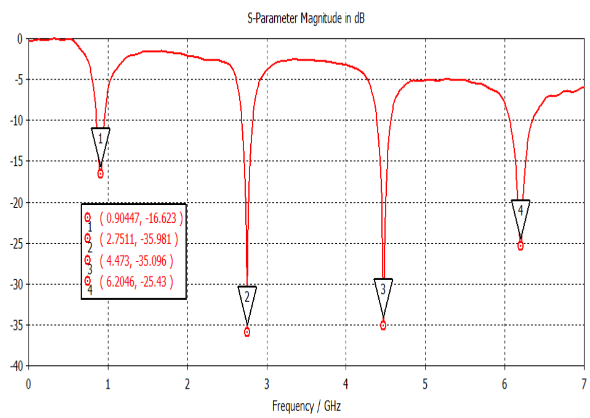

Figure 7: Original dipole: simulated return loss

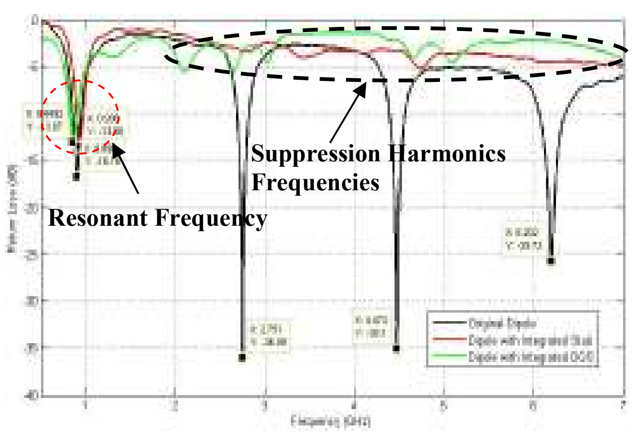

Figure 8: Measured return loss, $|S_{11}|$ of the original dipole, dipole with integrated stubs and dipole with integrated DGS

CONCLUSION

Two optimized baluns using microstrip-to-parallel strip conversion that integrated with stubs and DGS are proposed in this paper. The impedance between microstrip and parallel strip is matched easily by implementing the balun. The measurements based on the return loss and insertion loss parameters are found to be better than -10 dB and -3 dB, from 0 to 2 GHz of frequency. By employing these balun, dipole with integrated stubs and dipole with integrated DGS are proposed as harmonic suppressed 3D-dipole antenna. These antennas operate at 0.9 GHz and eliminate the frequency from 2 GHz to 7 GHz was designed, fabricated, and measured. The results show that the antenna has a capability to suppress the unwanted harmonic frequency ranges and does not degrade the operating frequency performance.

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