

# A Modified Low Loss and Compact Bias Tee with Improved Isolation and Reduced Loading Effect

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**Abstract**— This paper introduces a low-loss, compact bias tee circuit based on microstrip line technology. The design uses an appropriate combination of radial stubs and a meandered line in the DC bias path to achieve improved RF isolation. The design does not involve any inductor. A prototype is fabricated. The circuit shows measured isolation of over 34 dB across the entire X and Ku bands. The measured IL is less than 1 dB within the frequency range of 5.75–13.25 GHz, less than 2 dB within 5–14 GHz, and less than 3 dB up to 16.5 GHz, along with a VSWR < 2 over 6–16.5 GHz. The complete bias tee has an overall size of  $0.6\lambda_g \times 1.25\lambda_g$ , where  $\lambda_g$  is the guided wavelength at 10 GHz.

**Index Term** —bias tee, butterfly radial stub, microstrip line, PCB.

## I. INTRODUCTION

A bias tee is a key circuit component commonly used to bias active devices in RF circuits such as amplifiers, phase shifters, and switches [1]–[3]. As shown in Fig. 1(a), a traditional bias tee comprises of an inductor and a capacitor for isolation between the RF and DC sources. At higher GHz frequencies, inductors are typically avoided due to their low quality factor and self-resonant frequency. Instead, a bandstop filter (BSF) is used in the DC path to block RF signals. An example is shown in Fig. 1(b), where a radial stub acts as a BSF. Key performance parameters of a bias tee include isolation between RF and DC ports, elimination of loading effects on the active device due to the DC arm, bandwidth, and physical size of the tee.

Few attempts are made to reduce the loading effect and improve RF-DC isolation in bias tees. In [4], low insertion loss (IL) and high isolation are achieved using various meander line geometries. Modified radial stubs in [5] provide improved isolation by at least 7.5 dB and 13 dB using single and double BSF, respectively, in the X-band. Double mirror stubs are employed in [6]. A low IL and an isolation of at least 30 dB are achieved using grounded-CPW in [7]. A wideband substrate-integrated coaxial line-based bias tee is designed for mm Wave in [8]. However, the IL in the RF path is significantly high for [4]–[6], and the circuit size in [7] and [8] is excessively large.

This paper presents a modified bias tee for the X-band applications, which can also operate in the Ku-band with slightly increased IL. It offers good isolation in both X- and Ku-bands while significantly reducing the loading effect on the RF active device. These improvements are achieved through the careful design of radial stubs and a gradually varying meandered line. The technique also can be used at other microwave and lower millimeter wave bands.

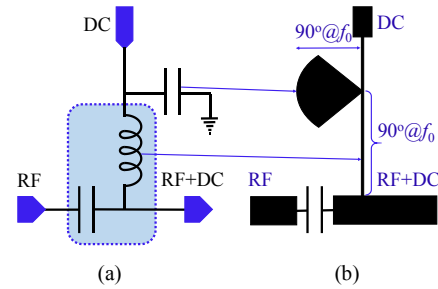


Figure 1. Standard (a) lumped component, and (b) microstrip line based bias tees.

## II. MODIFIED BIAS TEE DESIGN AND RESULTS

A conventional bias tee with a pair of radial stubs offers isolation of 20 dB and 30 dB within 6–14 GHz and 6.5–10 GHz, respectively, on a 20-mil thick RO4003C substrate with  $\epsilon_r = 3.55$  and  $\tan\delta = 0.0027$  [5]. To improve the isolation performance further on the same substrate, the number of butterfly stubs is increased to three, with spacing set as multiples of  $\lambda_g/4$  at the design frequency. A simulation study using Ansys HFSS shows that the minimum input impedance of the DC bias arm, as seen from the device across the entire X-band, improves from 240  $\Omega$  to 250  $\Omega$  and 265  $\Omega$ , while isolation improves from 17 dB to 25 dB and 40 dB, when the number of butterfly stubs is increased from 1 to 2 and 3, respectively. Various configurations are explored to reduce the loading effect further without compromising IL. It is observed that introducing a meandered microstrip line section of length  $21*\lambda_g/4$  between two extreme butterfly stubs significantly improves the loading effects. Gradient meandering is employed to accommodate a longer line within a small area, achieving higher input impedance as seen from the active device toward the DC source. Consequently, the minimum input impedance of the DC path improves by at least 60%, from 265  $\Omega$  to 425  $\Omega$  across the X-band, and by 300%, from 50  $\Omega$  to 240  $\Omega$  across the entire X- and Ku-bands, as shown in Fig. 2. The placement of the meander line geometry plays a crucial role in reducing the loading effect. In the present structure, if the meandered line is connected before the first, second, and third butterfly stubs from the active device, the minimum input impedances are 25  $\Omega$ , 228  $\Omega$ , and 425  $\Omega$ , respectively, over the X-band.

The final layout of the bias tee is shown in Fig. 3(a), with the dimensions detailed in the figure caption. Electric field distribution on bias tee, when RF is applied at port 1, is shown in Fig. 3(b). Electric field strength is decreased by at least 18000 at DC port, which ensures the effective isolation performance of the present bias tee.

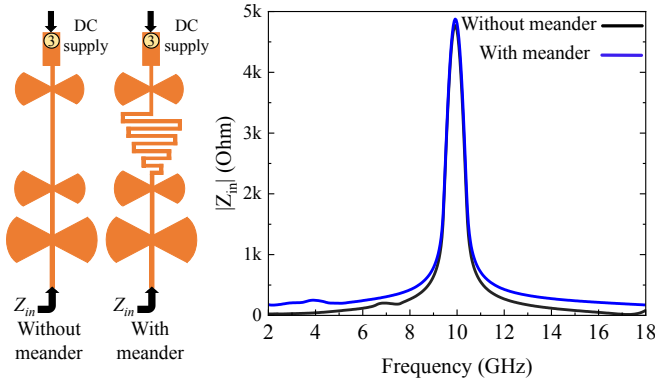


Figure 2. Effect of meandered microstrip line on the input impedance of DC path.

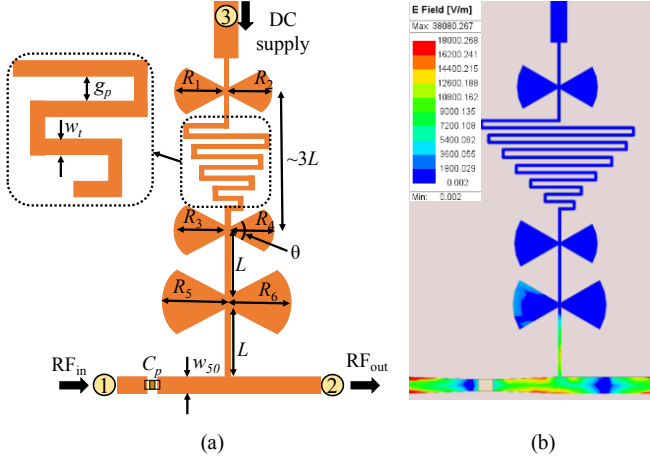


Figure 3. (a) Schematic of present bias tee, and (b) Field distribution at 10 GHz ( $g_p = 0.3$  mm, and  $C_p = 1.5$  pF,  $\theta = 60^\circ$ ,  $w_{50} = 1.14$ ,  $L = 4$ ,  $R_1 = 2.9$ ,  $R_2 = 2.7$ ,  $R_3 = 3.1$ ,  $R_4 = 2.7$ ,  $R_5 = 3.3$ ,  $R_6 = 3.3$ ,  $w_t = 0.2$ , units:mm).

A photograph of the fabricated bias tee on a 20-mil thick RO4003C is shown in Fig. 4(a). The overall size of the circuit is  $10 \times 20$  mm<sup>2</sup>. Coupling capacitor used in RF path is low cost 1.5 pF from Vishay. Simulated and measured results are shown in Fig. 4(b). Measured results show isolation of  $>34$  dB from 7.5 to 18 GHz and a minimum return loss of 10 dB from 6 to 16.5 GHz. Measured IL of  $<1$  dB and  $<2$  dB is achieved within 5.75–13.25 GHz and 5.3–14 GHz, respectively. The main source of IL is the low cost series capacitance used for DC blocking. An effective bandwidth of 78% is achieved with 34 dB isolation, 10 dB return loss, and 1 dB IL, covering the entire X band, which can be extended to 100% considering 3 dB IL, covering the Ku band as well. A comparison of the present design with recent works is provided in Table I. This design employs simple microstrip line technology to implement multiple butterfly stubs and gradient meander lines, achieving highest isolation among all. When compared for a single band, such as the X-band for the prototype, the key achievement is improved isolation and minimized loading effect without compromising with overall size, insertion loss, or effective bandwidth.

### III. CONCLUSION

This work presents a microstrip line-based bias tee with minimized loading effects, high isolation, and a compact size of  $0.75\lambda_g^2$ , covering the entire X and Ku bands. It incorporates

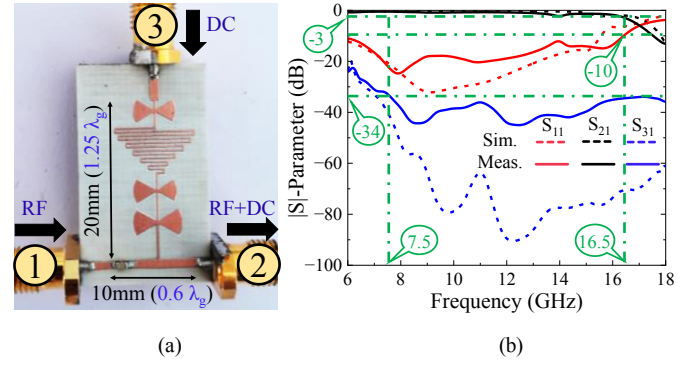


Figure 4. (a) Photograph, and (b) simulated and measured response of bias tee.

TABLE I. COMPARISON WITH PREVIOUS REPORTED BIAS TEE WORKS.

| Ref.      | Tech. used | I.L. (dB) | Iso. (dB) | Iso. B.W. (GHz)          | Size ( $\lambda_g^2$ ) | Fabrication Complexity |
|-----------|------------|-----------|-----------|--------------------------|------------------------|------------------------|
| [4]       | MSL        | 2.6       | 15        | 70 – 100                 | N. R.                  | Single layer           |
| [6]       | MSL        | 2         | 10        | 2.15 – 16.6              | 6.25                   | Single layer           |
| [7]       | GCPW       | 0.6       | 30        | 71 – 76                  | N. R.                  | Multi-layer            |
| [8]       | SICL       | 2         | 23        | 20 – 29                  | 6.44                   | Multi-layer            |
| This work | MSL        | 1<br>3    | 34        | 7.5 – 12.8<br>7.5 – 16.5 | 0.75                   | Single layer           |

multiple butterfly stubs and gradient meander lines, achieving 34 dB isolation within 7.5–18 GHz and a maximum IL of 3 dB within 5–16.5 GHz. Measured results closely match simulations. The IL can be further reduced using high-frequency capacitors from ATC.

### ACKNOWLEDGMENT

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### REFERENCES

- [1] E. A. H-Domínguez, et al., "Bias tee design for RF power amplifiers and GaN FETs characterization," in *Proc. IEEE MTT-S Latin America Microw. Conf. (LAMC)*, San José, Costa Rica, 2023, pp. 7-10.
- [2] L. Cai and D. Chu, "Compact liquid crystal based phase shifter with integrated bias tees," in *Proc. IEEE MTT-S Int. Wireless Symp. (IWS)*, Chengdu, China, May 2018, pp. 1-4.
- [3] A. Singh and M. K. Mandal, "Parasitic compensation and hence isolation improvement of PIN diode-based switches," *IEEE Trans. Circuits Syst. II, Exp. Briefs*, vol. 68, no. 1, pp. 97-101, Jan. 2021.
- [4] Z. -M. Li, et al., "Planar bias-tee circuit using gradient-meander line for broadband application," in *Proc. IEEE MTT-S Int. Wireless Symp. (IWS)*, Shanghai, China, 2020, pp. 1-3.
- [5] N. Jana, M. K. Mandal, and R. Shaw, "An improved design of a bias tee using a modified radial stub," in *Proc. IEEE MTT-S Int. Microw. RF Conf. (IMaRC)*, Mumbai, India, 2019, pp. 1-4.
- [6] R. Yadav, et al., "A double mirror stub design of broadband planar bias tee for system on chip integration," in *Proc. Microw. Mediterranean Symp. (MMS)*, Pizzo Calabro, Italy, 2022, pp. 1-4.
- [7] B. Khani, et al., "Planar bias-tee circuit using single coupled-line approach for 71–76 GHz photonic transmitters," in *Proc. German Microw. Conf. (GeMiC)* Nuremberg, Germany, 2015, pp. 276-279.
- [8] S. Shukla and S. Mukherjee, "A low-cost broadband millimeter-wave bias tee network using SICL technology," *Microw. Opt. Tech. Lett.*, vol. 65, no. 12, pp. 3171-3179, Aug. 2023.