Proceedings Paper:

Joseph, S.D. and Ball, E.A. orcid.org/0000-0002-6283-5949 (2025) Multiple bondwires for E band MMIC to antenna array interconnections for beamforming. In: 2025 19th European Conference on Antennas and Propagation (EuCAP). 2025 19th European Conference on Antennas and Propagation (EuCAP), 30 Mar - 04 Apr 2025, Stockholm, Sweden. Institute of Electrical and Electronics Engineers (IEEE) ISBN: 9798350366327 ISSN: 2164-3342 EISSN: 2164-3342

https://doi.org/10.23919/eucap63536.2025.11000045

Multiple Bondwires for E Band MMIC to Antenna Array Interconnections for Beamforming

Sumin David Joseph[1], Edward A Ball[2]
[1] The University of Sheffield: School of Electrical and Electronic Engineering, Sheffield, U.K, s.d.joseph@sheffield.ac.uk
[2] The University of Sheffield: School of Electrical and Electronic Engineering, Sheffield, U.K, e.a.ball@sheffield.ac.uk

***Abstract*—This paper presents an analysis of the effect of bondwire for low-cost E band interconnections from phase shifter MMIC to an off-chip antenna array for beamforming applications. A microstrip patch antenna array at 72.5 GHz is initially designed and its performance is optimized. The performance changes are evaluated with a 25 µm bondwire connecting the array to the GaAs phase shifter MMIC, showing reduced antenna gain and impaired impedance matching. To address bondwire losses, multiple bondwires are fabricated, showing that triple bondwires reduce insertion losses and improve matching. As compensation circuits require more space and are difficult to design, matching networks are challenging to incorporate. Multiple bondwires in the same pad area significantly reduce insertion losses and improve matching, providing an effective solution for maintaining performance without the need for additional compensation circuits.**

***Index Terms*—antenna array, bondwires, measurements, millimeter wave devices, packaging.**

I. Introduction

In today's advanced wireless communication systems, particularly those operating at millimeter-wave frequencies, the need for efficient, reliable, and cost-effective interconnections between various components is more critical than ever. As technology continues to evolve toward higher frequency bands, such as the E-band (60-90 GHz), applications like 5G, automotive radar, and satellite communications rely heavily on the seamless integration of active and passive components [1],[2]. A key aspect of these systems is the connection between monolithic microwave integrated circuits (MMICs), which perform signal processing functions, and off-chip components like antenna arrays, which transmit and receive signals for tasks such as beamforming.

At these high frequencies, traditional interconnection methods for die to PCB, such as bondwires, are widely used due to their simplicity and low cost. However, while bondwires are economical, they introduce several performance challenges that are amplified in millimeter-wave systems. Specifically, bondwires can cause increased insertion losses, phase distortions, and impedance mismatches, all of which can degrade the overall system performance and reduce the effectiveness of beamforming[3],[4]. Maintaining optimal performance requires careful consideration of these interconnections, particularly when dealing with high-frequency signal transitions between MMICs and antennas.

There are limited models in the literature that characterize bond wires. One approach, described in [3], uses a behavioral model to derive input impedance from network analyzer measurements. Similarly, Xue et al. [4] developed a method using lumped element models for bond wires of arbitrary shapes. Other techniques, such as those in [5]–[7], rely on direct calculations of S- and Y-parameters through causal equations or the finite-difference time-domain (FDTD) method, accounting for generalized cases, including irregularly shaped wires. Several techniques were introduced to reduce the adverse effects of bondwire interconnects and to improve impedance matching [8]-[12].

In the context of E-band applications, where precision and performance are paramount, mitigating the adverse effects caused by bondwires is essential for achieving the desired system efficiency. This introduces the challenge of optimizing bondwire configurations while balancing the need for cost-effectiveness, manufacturability, and high-frequency performance. In this work, E-band series fed patch antenna arrays are integrating with the MMIC chips using bondwire interconnect as shown in Fig. 1. This paper is organized as follows: Section II investigate the problems associated with bond wires while interconnecting antenna array and MMIC chips. Section III presents the measured results and analysis of fabricated single and multiple bondwires. Sections IV discusses the performance of triple bondwire for interconnection with circuits and off chip antenna arrays. Finally, Section V presents the conclusions.

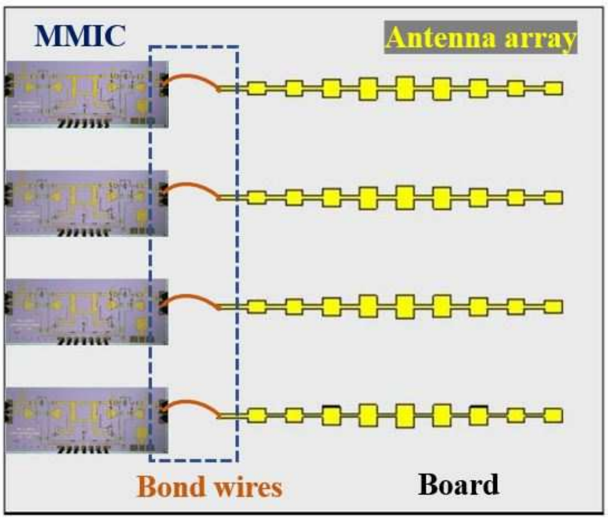


Fig. 1. Patch antenna array and GaAs MMIC phase shifter integration by bondwire interconnects for beamforming.

II. ANTENNA ARRAY AND BONDWIRE INTERCONNECT

To analyze the antenna array and bondwire interconnect, a microstrip patch antenna array is initially designed at 72.5 GHz with 9 elements. The proposed antenna array is designed on a low loss Rogers substrate RO4003C with 0.203 mm thickness with a relative dielectric constant 3.55, and tangential loss of 0.0027 for high performance. The designed antenna array has a directivity of 12 dBi and realized gain of 10 dBi.

To integrate the PCB antenna array with the MMIC phase shifter or other chips, a bondwire is necessary to employ as a low cost interconnect. Therefore, a bondwire with a length of 850um and a standard diameter of 25 µm is employed in this work as an interconnect. Fig. 2 shows the reflection coefficient curves of the antenna array and the bondwire – array integration. It can be observed that the impedance matching at 72.5 GHz in the patch antenna array is shifted to 72 GHz with a reduced S11 level of -6 dB from the initial -28 dB. Therefore, the realized gain of the array and bondwire interconnection reduced to 6.47 dBi compared to direct connection as shown in Fig. 3.

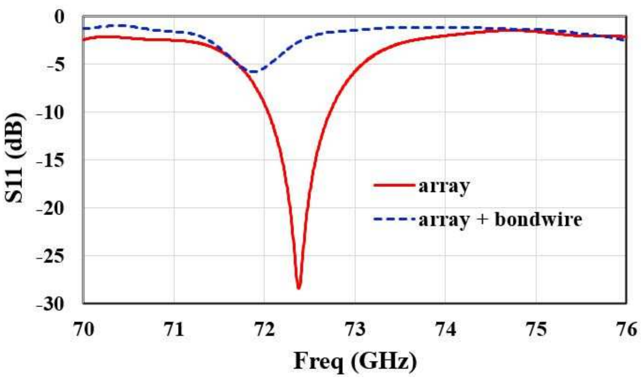


Fig. 2. Reflection coefficient of the patch antenna array and array with bondwire interconnect of length 850um.

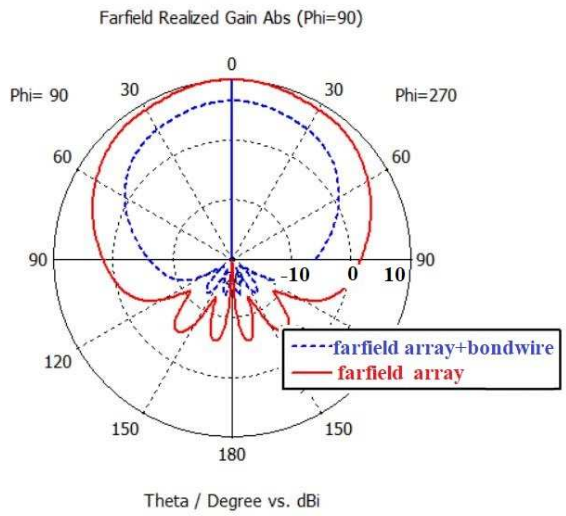


Fig. 3. Realized gain of the patch antenna array and array with bondwire interconnect

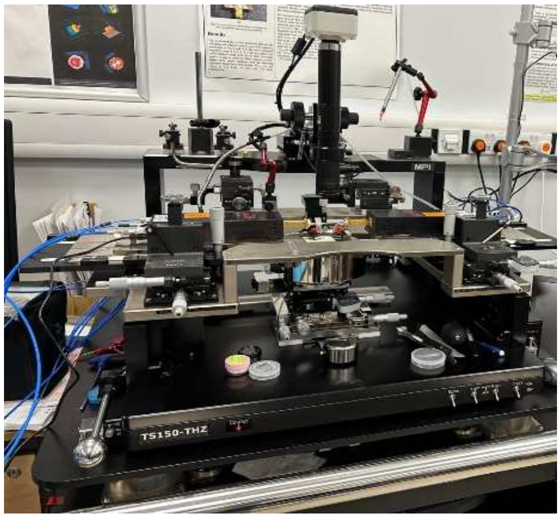


Fig. 4. Probe station for S parameter measurement.

III. MULTIPLE BONDWIRES ANALYSIS

To evaluate the performance of bond wires at millimeter-wave frequencies, a PCB was fabricated using Rogers RO4003C, low-loss substrate. The board has a thickness of 200 µm and includes pads designed for different bond wire lengths. In addition to the bond wire pads, the PCB incorporates Through, Reflect, Line (TRL) calibration standards, allowing for de-embedding of the Ground-Signal-Ground (GSG) probe transitions. A semi-automatic iBond5000 wedge wire bonder was utilized to create the bond wires.

Initially, a single 850 µm long gold bond wire was fabricated, as illustrated in the Fig. 5. The bond wire pads measure 100 µm in length and 450 µm in width, designed to have a characteristic impedance of 50 Ω to ensure impedance matching. On either side of the bond wire, a 1 mm microstrip line and a tapered line connect it to the GSG pads, which have a 150 µm pitch. The bond wire pads are spaced 520 µm apart, with a 40 µm offset between the bond wire ends and the edge of the pads. This configuration results in an overall bond wire length of 850 µm. Fig. 5 shows the fabricated single bond wire. Fabricated double and triple bond is shown in Fig. 6.

Analysis is initially carried out in the low frequency millimeter wave region performed at UKRI millimeter wave lab at TUoS [13]. A Keysight PNA N5245B and 150 µm pitch RF probes are used to measure the bond wire performance from 22 to 34 GHz.

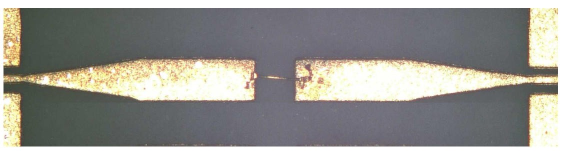


Fig. 5. Fabricated single bond wire with an overall length of 850um.

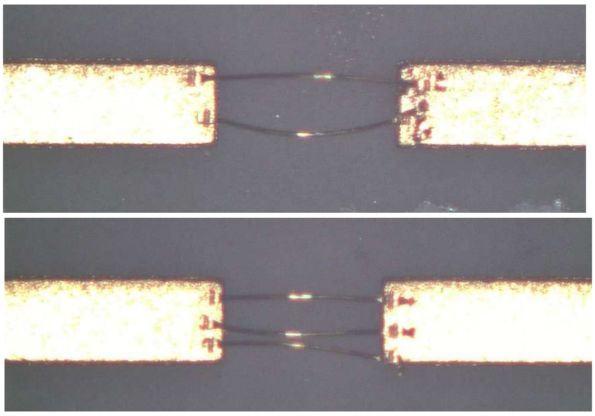
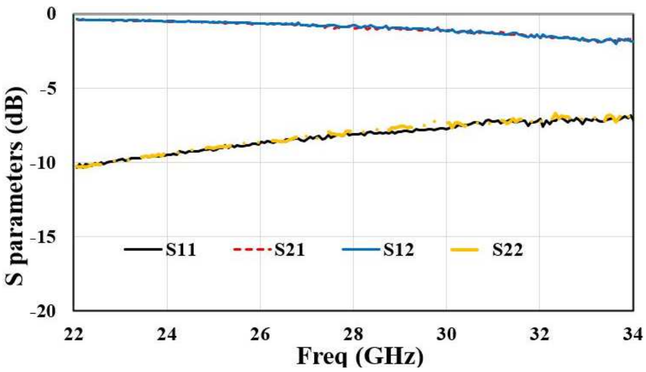
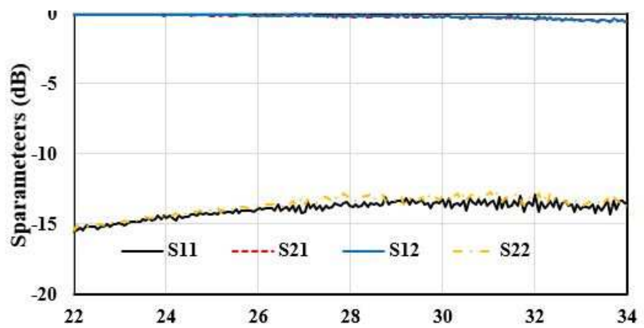


Fig. 6. Fabricated double and triple bond wire with an overall length of 850um.

Fig. 7(a) shows the measured S21 results vary from -0.4 to 2.1 dB and S11 varied from -10 to -7 dB in the frequency range. It can be observed that the transmission characteristics of the bond wire is degrading with frequency and thus the impedance matching. This is mainly due to the inductive effect of bond wire. Then, multiple bond wires performances are analyzed in the low millimeter wave frequency, by implementing double and triple wire bonds. Fig. 7(b) shows the measured S parameter results of triple bond wire. Insertion loss is readily reduced to 0.1 at 22 GHz to 0.6 dB at 35 GHz. Similarly the return loss curves are also improved and can achieve better impedance matching. Thus, in lower

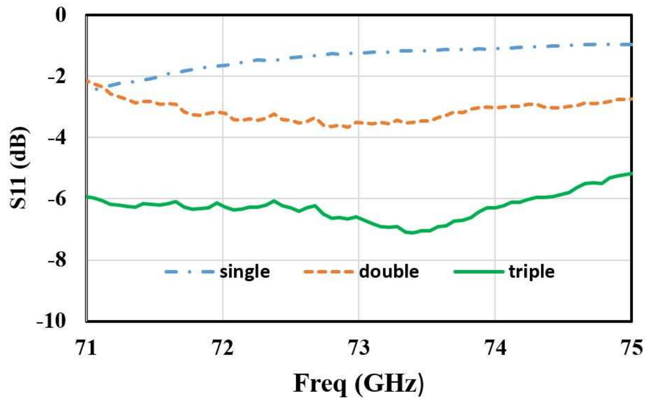


(a)

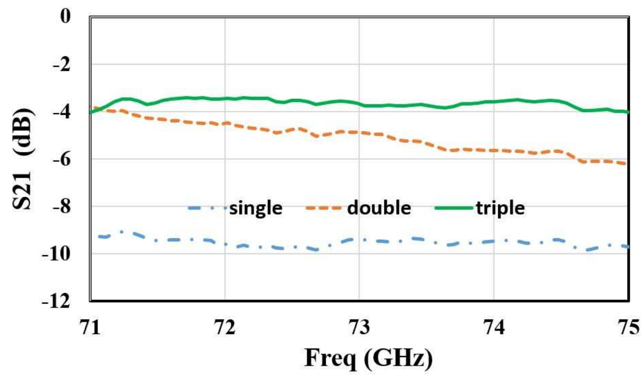


(b)

Fig. 7. Measured S parameter curves of (a) single bondwire (b) triple bond wire



(a)



(b)

Fig. 8. Mesaured S parameter curves of single, double and triple bondwire (a) S11 (b) S21.

frequencies by using multiple bond wires it is possible to reduce the losses associated with bondwire and improve matching.

For analysing the transmission performance in bondwires at high frequency millimeter wave bands, WR15+ VDI extenders are used along with PNA. Fig. 8 shows the measured S parameter results of the single and multiple bond wires. In the single bond wire, the transmission characteristics are degraded with frequency due to the inductive effect. At 72.5 GHz frequncy, it is possible to observe high insertion loss value of around 9 to 10 dB compared to less than 2 dB at 35 GHz. Similarly, the return loss curves are degraded to less than 2 dB range. Therefore, it is necessary to reduce the losses and to improve matching for high frequency circuits.

Double and triple wire bond performance at high millimeter wave frequencies are also shown in Fig. 8. Insertion loss values are improved to 4.75 and 3.5 dB respectively in double and triple bonds at 72.5 GHz. Return loss also improved to 3.4 in double bond and 6.4 dB in triple bond respectively. Therefore in high frequencies, the transmission performance and impedance matching can significantly improve by using triple bond wires instead of single bondwires.

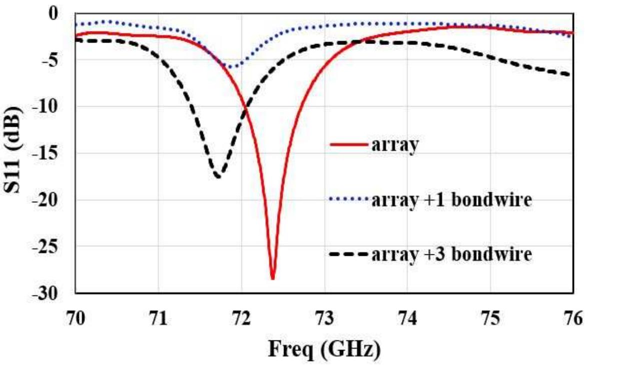


Fig. 9. Reflection coefficient of the patch antenna array and array with multiple bondwire interconnects.

IV. Multiple Bondwires for Array and MMIC Interconnect

Based on the analysis of the multiple bondwire, the low insertion loss and improved return loss can be utilized in the array and MMIC interconnect. Thus, triple bondwires are used instead of single bondwire. Fig. 9 shows the return loss curves of the single and multiple bondwires. It can be clearly observed that the triple bondwire has better return loss curve compared to single bondwire. Even though there is a mismatch in the resonant frequency, triple bondwires significantly improved the impedance matching without using any complex impedance matching or compensation circuits.

Realized gain of the array with triple bondwires is shown in Fig. 10. More than 3 dB increase is observed in triple bondwire compared to single bondwire. A peak realized gain of 9.9 dBi is achieved at 72.5 GHz with triple bondwire, which is quite similar to the array only realized gain of 10 dBi. This technique is easily adaptable for compact and low-cost integration and suitable for millimeter wave and sub terahertz applications.

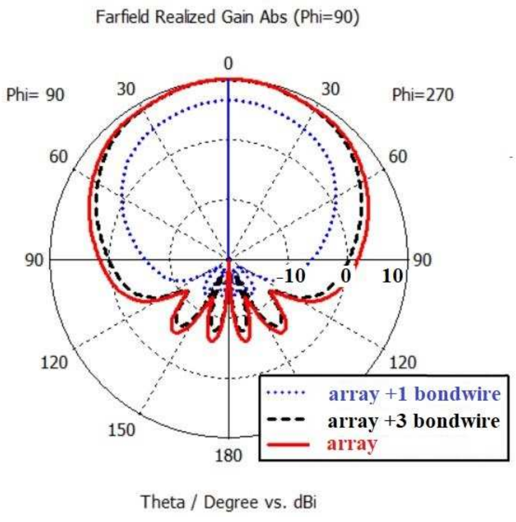


Fig. 10. Realized gain of the patch antenna array and array with multiple multiple bondwire interconnects.

V. Conclusions

This paper demonstrated the impact of bondwire interconnections on the performance of a low-cost E-band array system, specifically in beamforming applications connecting a phase shifter MMIC to an off-chip antenna array. The study reveals that bondwire interconnects, while cost-effective, introduce performance challenges such as increased insertion losses. To mitigate these issues, the use of multiple bondwires proves effective in minimizing losses and improving impedance matching, without the need for complex compensation circuits. The single bondwire reduced the realized antenna gain by 3.5 dB but using triple bondwires improved matching and recovered the gain to the original level. This approach offers a practical solution for maintaining performance in high-frequency applications like beamforming.

References

[1] Y. P. Zhang and D. Liu, "Antenna-on-chip and antenna-in-package solutions to highly integrated millimeter-wave devices for wireless communications," IEEE Trans. Antennas Propag., vol. 57, no. 10, pp. 2830–2841, Oct. 2009.

[2] T. Zwick, D. Liu, B. Gaucher, "Broadband planar superstrate antenna for integrated mmWave transceivers," IEEE Trans. Antennas Propag., vol. 54, no. 10, pp. 2790-2796, Oct. 2006.

[3] T.-P. Wang and Y.-F. Lu, "Fast and accurate frequency-dependent behavioral model of bonding wires," IEEE Trans. Ind. Inform., vol. 13, no. 5, pp. 2389–2396, Oct. 2017.

[4] H. Xue, C. R. Benedik, X. Zhang, S. Li, and S. Ren, "Numerical solution for accurate bondwire modeling," IEEE Trans. Semicond. Manuf., vol. 31, no. 2, pp. 258–265, May 2018.

[5] A. L. Nazarian, L. F. Tiemeijer, D. L. John, J. A. van Steenwijk, M. De Langen, and R. M. T. Pijper, "A physics-based causal bond-wire model for RF applications," IEEE Trans. Microw. Theory Techn., vol. 60, no. 12, pp. 3683–3692, Dec. 2012.

[6] W. Tian, H. Cui, and W. Yu, "Analysis and experimental test of electrical characteristics on bonding wire," Electronics, vol. 8, no. 3, 2019, Art. no. 365, doi: 10.3390/electronics8030365.

[7] F. Alimenti, P. Mezzanotte, L. Roselli, and R. Sorrentino, "Modeling and characterization of the bonding-wire interconnection," IEEE Trans. Microw. Theory Techn., vol. 49, no. 1, pp. 142–150, Jan. 2001.

[8] T. P. Budka, "Wide-bandwidth millimeter-wave bond-wire interconnects," IEEE Trans. Microw. Theory Techn., vol. 49, no. 4, pp. 715–718, Apr. 2001.

[9] J. Y. Chyan and J. A. Yeh, "Return loss reduction of molded bonding wires by Comb capacitors," IEEE Trans. Adv. Packag., vol. 29, no. 1, pp. 98–101, Feb. 2006.

[10] C. Karnfelt, P. Hallbjorner, H. Zirath, and A. Alping, "High gainactive microstrip antenna for 60-GHz WLAN/WPAN applications," IEEE Trans. Microw. Theory Techn., vol. 54, no. 6, pp. 2593–2603, Jun. 2006.

[11] H.-Y. Lee, "Wideband characterization of a typical bonding wire for microwave and millimeter-wave integrated circuits," IEEE Trans. Microw. Theory Techn., vol. 43, no. 1, pp. 63–68, Jan. 1995.

[12] H. R. Zhu, Y. F. Sun, and X. L. Wu, "Investigation of the capacitance compensation structure for wire-bonding interconnection in multichips module," in Proc. IEEE Elect. Design Adv. Packag. Syst. Symp., Dec. 2017, pp. 1–3.

[13] The National mmWave Measurement Laboratory. [Online]. Available: https://mmwave.group.shef.ac.uk.