Proceedings Paper:

Ali, M., Ball, E. orcid.org/0000-0002-6283-5949, Joseph, S.D. et al. (2 more authors) (2025) Bridging 5G and 6G: a low-complexity dual-band mmWave down-converter mixer (28/73 GHz) for 6G. In: 2025 IEEE International Mediterranean Conference on Communications and Networking (MeditCom). 2025 IEEE International Mediterranean Conference on Communications and Networking (MeditCom), 07-10 Jul 2025, Nice, France. Institute of Electrical and Electronics Engineers (IEEE), pp. 1-4. ISBN: 9798331529666.

https://doi.org/10.1109/MeditCom64437.2025.11104417

Bridging 5G and 6G: A Low-Complexity Dual-Band mmWave Down-Converter Mixer (28/73 GHz) for 6G

Mubasher Ali
Electrical and Electronic Engr. Dept.
University of Sheffield
Sheffield, United Kingdom
mubasher.ali@sheffield.ac.uk

Edward A Ball
Electrical and Electronic Engr. Dept.
University of Sheffield
Sheffield, United Kingdom
e.a.ball@sheffield.ac.uk

Sumin David Joseph
Electrical and Electronic Engr. Dept.
University of Sheffield
Sheffield, United Kingdom
s.d.joseph@sheffield.ac.uk

Timothy O'Farrell
Electrical and Electronic Engr. Dept.
University of Sheffield
Sheffield, United Kingdom
t.ofarrell@sheffield.ac.uk

Mohammad Reza Anbiyaei
Electrical and Electronic Engr. Dept.
University of Sheffield
Sheffield, United Kingdom
m.anbiyaei@sheffield.ac.uk

***Abstract*—A dual-band mixer capable of receiving signals in both the 5G band (n257) and a candidate 6G band (E-band) is designed and simulated using a 0.1 μm GaAs pHEMT from the UMS PH10 PDK. The device incorporates a dual-band rat-race coupler and an active FET mixer. The dual-band rat-race coupler is specifically designed to operate at 28 GHz and 73 GHz, enabling the mixer to function across both bands. The mixer achieves a conversion gain of 2.6 dB at 28 GHz and 1.1 dB at 73 GHz. The LO leakage to the IF port is measured at less than -32 dB at 28 GHz and -38 dB at 73 GHz. Additionally, the mixer demonstrates a IP_{1dB} of -8 dBm and an IIP3 of 1.2 dBm at 28 GHz with power consumption of 6.9 mW while at 73 GHz, it achieves a IP_{1dB} of -3 dBm and an IIP3 of 5.4 dBm with power consumption of 12.6 mW. The performance of the mixer shows promising results in both mmWave frequency bands, making it a suitable candidate for future 6G radio architectures.**

***Index Terms*—5G, GaAs pHEMT, dual-band, mm-wave integrated circuits, mixer, down-conversion**

I. Introduction

Driven by the growing need for ultra-reliable, low-latency, and massive connectivity, the evolution from 5G to 6G is gaining momentum as a significant step in next-generation wireless communication. As the transition from 5G to 6G accelerates, the E-band frequencies (60-90 GHz) emerge as a vital enabler for ultrahigh-capacity wireless links. These frequencies, combined with advanced RF front-end components, are expected to support the demanding requirements of 6G. Global standardization bodies, including the ITU,3GPP, and ETSI, have identified the E-band and above as a promising spectrum for future 6G communication [1]. From a development and hardware cost perspective, it is advantageous for 6G frontends and their sub-blocks to support multiband operation, ensuring compatibility with 5G. Fig. 1 illustrates a potential wireless network architecture aligned with O-RAN principles, where the proposed dual-band (28/73 GHz) mixer can be integrated into the overall transceiver system [2]. This configuration facilitates flexible and scalable deployment across disaggregated RAN components, enabling efficient dual-band operation and enhanced spectral utilisation in next-generation mmWave communication systems. Recently, several dual-band and broadband mixers operating exclusively in 5G mmWave bands have been reported [3]– [4].

Funded by the UK Government DSIT through YO-RAN project

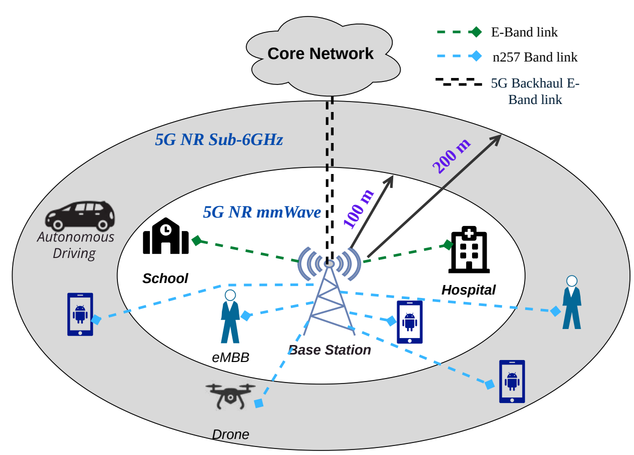


Fig. 1. Potential wireless network with dual band / multiband transceiver architecture

This paper presents a dual-band mixer operating at 28 GHz (n257) and 73 GHz (E-Band), covering both 5G and 6G mmWave bands relevant to the 3GPP standard. The proposed mixer is designed to meet the requirements of the Yorkshire

Open Radio Access Networks (YORAN) initiative, which aims to enhance interoperability and streamline different infrastructure elements within mobile communication networks, making it suitable for potential 6G architectures [4]. The mixer core is designed with a single-ended FET pumped transconductance configuration to minimize circuit complexity. It utilizes a dual-band rat-race coupler to combine the RF and LO signals for both the n257 and E-band frequency ranges. The paper is structured as follows: Section II details the circuit design, Section III presents the results, and Section IV provides the conclusion.

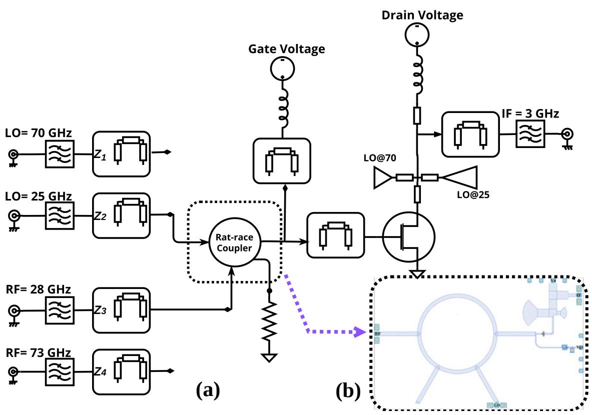


Fig. 2. The structure of the proposed down-conversion mixer

II. Circuit Design

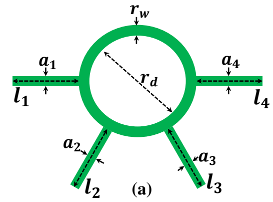
The schematic of the proposed downconverter mixer is shown in Fig. 2 The mixer consists of a single FET transconductance stage, a dual-band rat-race coupler at both the LO and RF ports, and a matching and LO suppression network at the drain. The mixer converts RF signals at 28 GHz and 73 GHz to a common IF of 3 GHz. The dual-band coupler efficiently combines the RF and LO signals at both frequency bands, while the transistor facilitates the mixing process. Careful design of matching networks and layout optimization ensures efficient mixing. The mixing FET has a gate width of 20 μm with 2 fingers and is biased in the saturation region to modulate the transconductance (gm) by the LO. The gate biasing voltage and LO power are independently selected for each band to achieve optimal performance.

A. Dual Band Rat-Race Coupler

To achieve dual-band operation at frequencies f and $3f$, we utilize the periodic nature of phase shifts in the transmission lines of a rat-race coupler. A conventional rat-race coupler consists of 90° (λ/4) sections and one 270° (3λ/4) with a total circumference of 1.5λ at the design frequency f. The phase shift along one section is:

$$\text{at } f \qquad \theta = \frac{2\pi}{4} = \frac{\pi}{2} \tag{1}$$

$$\text{at } 3f \quad \theta_{3F} = 3 \times \frac{\pi}{2} = \frac{3\pi}{2} = \frac{\pi}{2} + 2\pi m \quad m \in \mathbb{Z} \tag{2}$$



Parameter	Size(mm)	Parameter	Size(mm)
a_1	0.103	l_1	1.02
a_2	0.099	l_2	1.04
a_3	0.152	l_3	1.03
a_4	0.106	l_4	1.01
r_w	0.095	r_d	0.97

(b)

Fig. 3. Dimensions of the dual-band rat-race coupler

At f, sections are 90° and 270°; at $3f$, these become 270° and 810°(i.e 90°), respectively. This preserves the necessary 180° phase differences for coupling/isolation at both frequencies, enabling dual-band operation without structural changes. Fig. 3 provides the dimension of the optimised rat-race coupler. Fig. 4(a) illustrates the dual-band frequencies of 24.4 GHz and 73 GHz using a conventional rat race coupler (f and 3f). The characteristic impedances of the transmission line sections were carefully tuned to ensure operation within the required 28 GHz (n257) and 73 GHz bands, and the results are presented in Fig. 4(b).

III. Simulation Results

The proposed dual-band down-conversion mixer layout is simulated in the Keysight Advanced Design System (ADS) using a 0.1 μm GaAs pHEMT from the UMS PH10 PDKs. The mixer operates efficiently across both the 28 GHz and 73 GHz bands. When operating at the 28 GHz band, the mixer consumes 6.9 mW from a 2V supply with an LO input power of 4 dBm and -0.25V of V_{gs}. For the 73 GHz band, the total power consumption increases to 12.6 mW under the same supply voltage of 2V but with a LO input power of 5 dBm and -0.36v of V_{gs}. The conversion gain versus RF input power and LO power for both the 28 GHz and 73 GHz bands are illustrated in Fig. 5(a) and (b), with the IF fixed at 3 GHz. The mixer achieves a maximum conversion

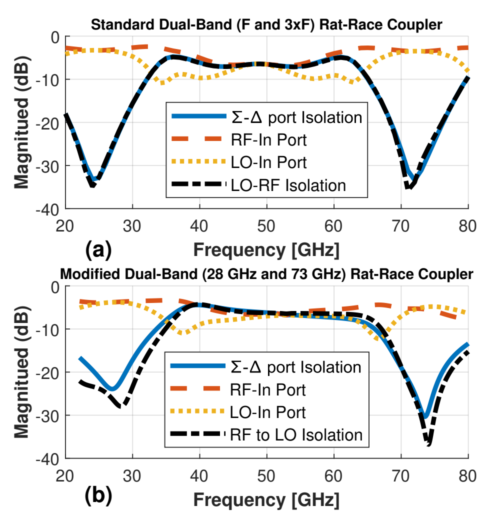


Fig. 4. S-Parameters plots of (a) standard and (b) modified dual-band rat-race coupler

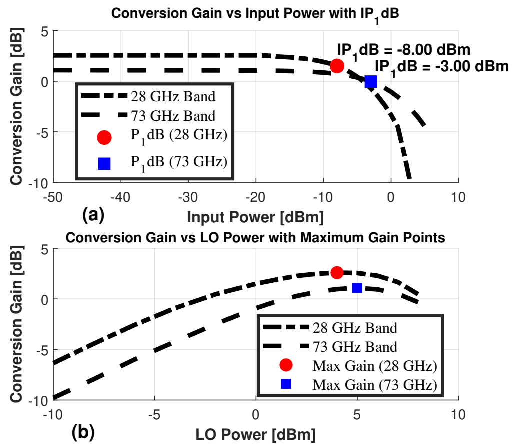


Fig. 5. Plots of conversion gain against (a) RF and (b) LO power at both bands

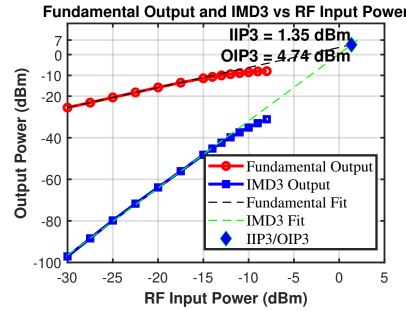


Fig. 7. Third-Order Input Intercept Point (IIP3) at 28 GHz

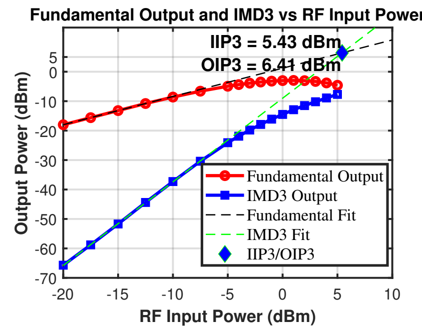


Fig. 8. Third-Order Input Intercept Point (IIP3) at 73 GHz

gain of 2.6 dB at 28 GHz, with a IP_{1dB} of -8 dBm. At 73 GHz, the conversion gain is 1.1 dB with a IP_{1dB} of -3 dBm, demonstrating good performance across both frequency bands. Isolation performance is shown in Fig. 6(a) and (b), where RF-to-IF and LO-to-IF isolations exceed 30 dB, and LO-to-RF isolation is greater than 15 dB for both the 28 GHz and 73 GHz bands. This highlights the mixer's good port-to-port isolation characteristics.

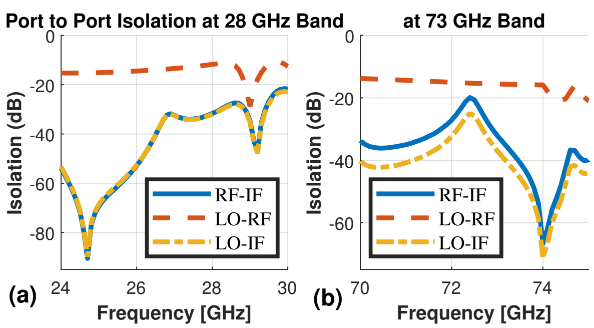


Fig. 6. Port to Port isolation results at (a) 28 GHz and (b) 73 GHz

Additionally, Fig. 7 and Fig. 8 present the third-order input intercept point (IIP3) values, which are 1.2 dBm at 28 GHz and 5.4 dBm at 73 GHz, respectively. These results demonstrate the mixer's good linearity performance across the two bands.

A performance comparison with previously published dual-band mm-Wave mixers, including those based on GaAs pHEMT technology, is presented in Table I. The proposed mixer demonstrates comparable conversion gain (CG) across both frequency bands, while consuming the lowest power (2.86 mW and 12.6 mW at 28 and 73 GHz). Additionally, it achieves better conversion gain than the mixers reported in [5] and [6],

TABLE I
COMPARISON OF RECENTLY REPORTED MMWAVE MIXERS

Ref.	Tech. Node	RF Freq. GHz	Conversion Gain(dB)	LO power (dBm)	DC power (mW)	dual-band	IIP_3 / IP_1dB (dBm)	Isolation (dB) LO-IF / LO-RF / RF-IF
[3]	90nm CMOS	24.2-29.5 37-40	4.2 0.8	10	50.9	yes	(N/A)/-0.2	N/A
[4]	90nm CMOS	26.7-28.9 37.2-39.5	-2.5 -1	-8 -4	38	yes	(N/A)/-2.5 (N/A)/-0.6	>40
[5]	0.15µm pHEMPT	75-120	<-17	7	24	No	N/A	29 / 40 / 41
[6]	0.1µm pHEMPT	206-232	<-13	7	28.8	No	(N/A)/0.5	5.2 / 20.4 / 23
This Work	0.1µm pHEMPT GaAs	27-30 71-74.5	2.6 1.1	4 5	6.9 12.6	yes	1.2/-8 5.4/-3	>30 / >16 / >32

while using the same GaAs pHEMT technology.

IV. Conclusion

This work presents a dual-band down-conversion mixer for 5G (28 GHz) and potential 6G (73 GHz) bands, simulated using a 100 nm GaAs pHEMT process. The dual-band rat-race coupler enables the mixer to operate across both frequency bands. The mixer achieves a conversion gain of 2.6 dB at 28 GHz and 1.1 dB at 73 GHz. Additionally, it demonstrates good linearity and low power consumption, with a 3 dB RF bandwidth of 27–30 GHz and 71–74.5 GHz, respectively. The ability to operate at both 28 GHz and 73 GHz bridges the gap between 5G and 6G technologies, making it a promising mixer candidate for future 6G front-end systems.

Acknowledgment

This work is supported by the Department of Science, Innovation and Technology (DSIT) UK through the Yorkshire Open Radio Access Networks (YO-RAN) project [7], as part of the Future Open Networks Research Challenge. This work was also supported in part by UKRI grant number MR/T043164/1.

References

[1] 3GPP TS 38.104 version 15.2.0 Release 15." [Online]. Available: http://www.3gpp.org/ftp/Specs/archive/38 series/38.104/38104-f20.zip.

[2] Edirisinghe, S., Galagedarage, O., Dias, I., Ranaweera, C. (2023). Recent development of emerging indoor wireless networks towards 6G. Network, 3(2), 269-297.

[3] B. Bae et al., "24–40 GHz Dual-Band Highly Linear CMOS UpConversion Mixer for mmWave 5G NR FR2 Cellular Applications,"IEEE Microwave and Wireless Components Letters, vol. 32, no. 8,pp. 999–1002, 2022.

[4] Xu, X., Wagner, J. and Ellinger, F., 2023, June. A 28 GHz and 38 GHz Dual-Band Up-Conversion Mixer for 5G Applications in 22 nm FD-SOI CMOS. In 2023 18th IEEE Conference on Ph. D Research in Microelectronics and Electronics (PRIME) (pp. 141-144).

[5] Kao, Jui-Chih, et al. "A W-band High LO-to-RF Isolation Triple Cascode Mixer With Wide IF Bandwidth." IEEE transactions on microwave theory and techniques 62.7 (2014): 1506-1514.

[6] Han, Xinli, et al. "A 220-GHz Active Down-Conversion Mixer Based on 0.1-μ m GaAs pHEMT Technology." IEEE Microwave and Wireless Technology Letters (2025).

[7] https://yo-ran.org/