Photonic Transmitters with Rectangular Waveguide Output for E-Band Radio-over-Fibre Communication Systems

Ivan Flammia, Matthias Steeg, Andrzej Jankowski, Sebastian Babić, Vitaly Rymanov, Andreas Stöhr
Affiliation
University of Duisburg-Essen
Centre for Semiconductor Technology and Optoelectronics
Lotharstr. 55
47057 Duisburg, Germany

Email: ivan.flammia@uni-due.de
Introduction

The local minimum in the atmospheric attenuation that extends through most of the E-Band (60-90 GHz) and the increased antenna gain (for a given physical size) when compared to lower frequencies make this region of the spectrum particularly attractive for high-speed point-to-point wireless communication.

In this scenario, Radio-over-Fibre (RoF) allows the achievement of fibre-like wireless connectivity for the expansion of the existing optical networks [1].

In this work we present the development of novel photodiode (PD) modules for RoF applications, based on high-frequency laminates and optimized for operation in the 71-76 GHz band.
Radio-over-Fibre (RoF)

- Potentially able to provide multi-gigabit data rates, allowing *fiber-like* wireless connectivity.
- Expansion of existing optical networks: last mile coverage, redundant connection, broadband wireless access, disaster recovery.

E-Band (60-90 GHz)

- **Local minimum** in the atmospheric attenuation (f > 70 GHz).
- **71-76 GHz** and **81-86 GHz** bands allocated worldwide for wireless communication applications (10 GHz of unlicensed spectrum bandwidth).

Fig. 1. Typical Radio-over-Fibre link: the *photonic transmitter (PT)* operates the optical-to-electrical conversion by means of a high-frequency photodiode and transmits the RF signal via an opportune antenna.
E-Band Photonic Transmitter (PT)

Concept

- **Use of RF laminates** as integration platform for RoF applications [2].
- Photodiode (PD) connected by means of short **wire bonds** to grounded coplanar waveguide (GCPW).
- **Rectangular waveguide (RW) output:**
  - Low loss, high power handling.
  - Used for filters, resonators, amplifiers and as antenna feed.
- **GCPW-to-RW transition:**
  - **WR12** (dimensions: 3.1 mm x 1.6 mm).

Fig. 2. Photonic transmitter concept.

Fig. 3. Interface between high-frequency photodiode and RF laminate.
GCPW-to-RW Transition

- **Double-slot coupling** through GND plane [3].
- Matching structures on the top metal layer.
- Optimized for the 71-76 GHz band.

Fig. 4 Exploded view of the transition.

Fig. 5. Simulated scattering parameters.

Fig. 6. Propagation of the electric field (73 GHz) in the transition.

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S_{22} = \text{- return loss (RW)} \\
S_{11} = \text{- return loss (GCPW)}
\]
E-Band Photonic Transmitter

- Use of commercial photodiode with on-chip bias tee [4].
- Maximum output power delivered by the PT: -12 dBm [5].
- Demonstrated error-free (BER<10^{-9}) guided transmission without RF amplification [6].

Fig. 7. Top view of the photonic transmitter.

Fig. 8. Experimental RoF system setup for the guided transmission of a 1.025 Gb/s NRZ-OOK signal.

Fig. 9. BER characteristics for 1 Gb/s guided transmission.
E-Band Photonic Transmitter

- Maximum output power delivered by the PT: -12 dBm.
- **Higher output power** needed to achieve wireless transmission!
- Use of **external amplification** [7]:
  - Demonstrated 2.5 m error-free (BER<10^{-9}) wireless transmission!

Fig. 10. Experimental RoF system setup for the wireless transmission of a 1.025 Gb/s NRZ-OOK signal.

Fig. 7. Top view of the photonic transmitter.

Fig. 11. BER characteristics for 1 Gb/s wireless transmission.
GCPW-to-RW Transition with Integrated Planar Bias Tee

- Inclusion of **RF-choke** and **DC-block** to allow the biasing of the PD [8].
- Simplified circuitry on the PD chip (less chip area)!

Fig. 14. Current density distribution (73.5 GHz) in the transition with integrated bias tee.

Fig. 13. Simulated scattering parameters.

Fig. 12. Transition with integrated bias tee.
Photonic Transmitter with Integrated Planar Bias Tee

- **Submount** used to host the transition on the RW boss.
- PT prototype: **successful biasing** of PD and **generation of RF signal** (73 GHz)!
- High-loss from PD to RW (~9 dB) due to long wire bonds (confirmed by simulations) and non-ideal transition and setup.

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**Fig. 15.** Integration platform: RW and brass submount (left) and platform with GCPW-to-RW transition (right).

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**Fig. 16.** PT prototype (left), integrated PD with long wire bonds (center) and HFSS model (right). The PD bias voltage is -8 V (with an operating photocurrent of 0.3 mA).

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**Fig. 17.** Simulated scattering parameters of the PT with the PD configuration depicted in Fig. 16.
Photonic Transmitter with Integrated Amplification

- Use of PDs with low output power:
  - **Higher output power** needed to achieve wireless transmission!

1. Use of external amplification (demonstrated).

2. Hybrid integration of amplifiers:
   - GaAs HEMT **LNA**: 71 - 86 GHz → 13 dB gain; thickness of the chip = 100 µm.
   - GaAs HEMT **MPA**: 71 - 76 GHz → 24 dB gain; thickness of the chip = 50 µm.

Fig. 18. Schematics for amplifiers’ integration [9, 10].
Photonic Transmitter with Integrated Amplification

- RF laminate used as substrate for integration.
- Wire and ribbon bonds used for DC and RF connections.

Fig. 19. Integration approach for MMIC amplifiers: the laminate houses the amplifiers’ chip and the SMD components of its bias network.
Photonic Transmitter with Integrated MPA

- Expected gain ~ 24-25 dB [10].
- Measured gain ≤ 17 dB (including losses of probes and transition) due to damaged final amplification stage.

Fig. 20. Module with integrated MPA. Wire bonds only have been used for the integration.

Fig. 21. Measured gain of the integrated MPA: input power applied by means of G-S-G probe and output power detected by mixer with RW input connected to a spectrum analyser.
Photonic Transmitter with Integrated LNA

- Expected gain ~ 12-13 dB [9].
- Measured gain ≤ 13 dB (including losses of probes and transition).

Fig. 22. Module with integrated LNA. Wire bonds only have been used for the integration.

Fig. 23. Measured gain of the integrated LNA: input power applied by means of G-S-G probe and output power detected by mixer with RW input connected to a spectrum analyser.
Photonic Transmitter with Integrated LNA and MPA

- Further improvement: achievable total gain ~ 36-38 dB.
- Two approaches to minimize the effects of the wire bonds:

Fig. 24. Integration of amplifiers with cavity.

Fig. 25. Integration of amplifiers without cavity.
Conclusions

• **Photonic transmitter** for E-Band RoF applications featuring a RW output (*ad hoc* GCPW-to-RW transition):
  – Demonstrated error-free 1 Gb/s guided transmission.
  – Demonstrated 1 Gb/s wireless transmission (external RF amplifier).
• Improved GCPW-to-RW transition featuring a **fully planar bias tee**:
  – **New photonic transmitter** with PDs without integrated planar bias network!
  – Demonstrated generation of signals in the E-band (73 GHZ)!
• Hybrid **integration of MMIC amplifiers**:
  – Demonstrated integration of LNA and MPA.
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References


References


