Compact Photonic Package for High-Power E-Band (60-90 GHz)
Photoreceiver Modules

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Abstract
In this work, we present a novel photonic package for high-power photoreceiver modules operating within the E-band (60-90 GHz). The developed Kovar package features a compact size of only 6x3.5x2 cm\textsuperscript{3} and comprises an optical single-mode fiber (SMF) input, DC bias supply connections and a WR-12 output for coupling out of the radio frequency (RF) signal. As integration platform, a RF laminate submount with implemented planar bias-T based upon grounded coplanar waveguide (GCPW) transmission line circuitry is used for efficient mmW propagation, concluding in a GCPW-to-WR-12-transition. Finite element method (FEM) simulations have been carried out to analyze the frequency range of interest. Besides applied adhesive and wire bonding approaches for assembly inside the package, the RF submount exhibits sections for hybrid integration of single components, e.g. of a high-frequency waveguide photodiode. Optionally, up to two high-electron-mobility-transistor (HEMT) power amplifiers can be integrated within the GCPW circuitry. In addition, the RF laminate is mounted on a brass platform. For uniform thermal expansion within the module, a Peltier element is integrated. Concerning the saturation output power of given HEMT amplifiers, e.g. in the order of +17.5 dBm, corresponding power levels are achievable for packaged devices. For instance, an output RF power of only -19.5 dBm within the 71-76 GHz band is required from the photodiode in conjunction with two cascaded HEMT amplifiers, which results in a total gain of ~37 dB. A small series of the introduced device has been already fabricated. First experimental achievements with in-house fabricated modules will be presented.

Key words
Compact photonic packages, E-band (60-90 GHz) communications, high-electron-mobility-transistor power amplifiers, high-power photoreceiver modules, high-speed waveguide photodiodes, hybrid integration, radio-over-fiber applications

I. Introduction
Photonic millimeter wave (mmW) generation is essential for many emerging markets. Especially within the emerging market of E-band (60-90 GHz) radio-over-fiber (RoF) communications, the recently regulated bandwidths within the 71-76 GHz and 81-86 GHz bands are of particular interest. Designed to coexist, these allocations allow up to 10 GHz bandwidth; enough for transmission of multi-gigabit capacities [1].

However, appropriate photoreceiver modules used in wireless communication systems comprise several mmW components such as costly coaxial cables or rectangular waveguide connectors to connect the photodiode with the amplifier and further with the output transition, which results in power losses and bulky module size [2]. Thus, it would be beneficial to integrate such a photoreceiver module within a single device, approaching high-power operation [3], [4]. For this purpose, low-cost, compact and integrated solutions are required.

Here, we present a novel photonic package as a compact solution for integration of high-power photoreceiver modules, which are applicable in E-band RoF communication links. First experimental results demonstrating high-power operation will be presented using in-house fabricated modules.
II. Materials, Design and Packaging
Since the integration platform within the photonic package aims at comprising an implemented bias-T circuitry (for the photodiode [5]) based upon GCPW transmission line circuits and a GCPW-to-WR-12-transition, several approaches have been discussed for efficient mmW propagation [6]. Because of suitability and processing properties required for the RF submount, the decision was made to use low-loss RF laminates [4]. In Fig. 1, the top view of the developed package is presented, giving an overview of integrated components.

![Fig. 1: Top view of the photonic E-band photoreceiver package and overview of integrated components](image)

The raw housing is made of Kovar due to the appropriate thermal expansion coefficient for the interaction with the inlayed brass platform, which is used as an interlayer between the integrated RF laminate and an additional Peltier element for uniform thermal expansion within the module. Furthermore, the package comprises an optical SMF input, DC bias supply connections and a WR-12 waveguide output for coupling out of the RF signal. A closer view on the front and back sides of the package can be found in Fig. 2.

![Fig. 2: Back side (with WR-12 output) (a) and front side (with optical fiber input) (b) of the photonic E-band photoreceiver package](image)

Besides adhesive and wire bonding approaches to assemble applied components inside the package, supporting sections for hybrid integration of single components, e.g. of a high-frequency waveguide photodiode and up to two HEMT power amplifiers, are considered in the design of the GCPW circuitry [4], [5].

The packaging process is finalized by closing the housing with a cover plate. A limited series of the introduced device has been already fabricated and is presented in Fig. 3. The package exhibits a compact size of only 6x3.5x2 cm³.

![Fig. 3: Fabricated fiber-pigtailed photonic E-band photoreceiver package with a WR-12 waveguide output](image)

III. Numerical Results
As already introduced, the RF laminate submount offers an integrated bias-T based upon a GCPW transmission line circuitry. In contrast to the conventional approach employing $\lambda/4$ transmission lines presented in [6], a compact metamaterial-based bias-T circuit shown in Fig. 4 was developed, structuring electrically small resonators on the DC transmission line (e.g. line 3 in Fig. 4) with certain magnetic coupling distance in-between [7].

![Fig. 4: Simulated $S_{11}$, $S_{21}$ and $S_{31}$-parameters of the bias-T circuitry within 60-90 GHz (71-76 GHz band highlighted in red)](image)

To analyze the frequency range of interest (e.g. 71-76 GHz), FEM simulations have been carried out for the
developed circuitry. Simulated $S_{11}$, $S_{21}$ and $S_{31}$-parameters are given in Fig. 4 for the entire E-band. Highlighting the 71-76 GHz band, the input return loss (RL), the insertion loss (IL) and the RF isolation are found to be >23 dB, <0.24 dB and >29.5 dB, respectively.

To achieve wireless transmission by an external horn antenna, a coupling between the GCPW output circuitry and the WR-12 rectangular waveguide input is required, which can be accomplished by the designed GCPW-to-WR-12 transition with a circular short-circuited transmission line as a broadband load and an applied linearly tapered slot line as a slot antenna [8]. The concept of the designed GCPW-to-WR-12 transition approach is sketched in Fig. 5.

Investigations on required geometries of the GCPW circuitry have been performed applying further FEM analyses (see Fig.6).

In Fig. 7, simulated $S_{11}$- and $S_{21}$-parameters are presented covering a frequency range from 60-80 GHz. Within 71-76 GHz, the input RL of the GCPW-to-WR-12 transition is exceeding ~19 dB. A maximum RL of ~26 dB is found at a 71 GHz frequency. The IL is <0.16 dB. Also, a minimum IL of ~0.12 dB is determined at a frequency of 71 GHz. For enhanced signal transmission, both upper ground planes and the lower ground plane are periodically connected by metal vias to suppress the parallel plate and slot line modes.

**Fig. 5:** Designed GCPW-to-WR-12 transition with an applied slot antenna

**Fig. 6:** FEM analyses of the GCPW-to-WR-12 transition within 71-76 GHz

**Fig. 7:** Simulated $S_{11}$- and $S_{21}$-parameters of the GCPW-to-WR-12 transition within 60-80 GHz (71-76 GHz band highlighted in red)

**IV. Experimental Results**

For characterization, gain measurements have been performed within 71-76 GHz. For this purpose, a coplanar ground-signal-ground 50 Ω RF probe was used to apply RF power levels to the module by a RF signal generator. A drain bias voltage of 2 V was applied to the integrated HEMT power amplifier. The GCPW output circuitry was coupled to a WR-12 rectangular waveguide. A photograph of the measurement arrangement is presented in Fig. 8.

**Fig. 8:** Measurement arrangement for characterization of the photoreceiver module

For example, gain measurements at a frequency of 72 GHz are shown in Fig. 9. Here, a 24 dB gain due to one integrated GaAs HEMT power amplifier was measured at the output of the WR-12 waveguide, which confirms the specifications of the amplifier. Since the saturation output power of the given amplifier is around +17.5 dBm, comparable power levels are expected for completely packaged devices with a photodiode. In combination with a second cascaded low-noise amplifier, an applied RF power of only -19.5 dBm within the 71-76 GHz band would be necessary from the photodiode.
Fig. 9: Gain measurements with applied drain bias voltage of 2 V at a frequency of 72 GHz

V. Conclusion

In this paper, we presented a compact packaging solution for a novel photonic high-power E-band photoreceiver module approaching output RF power levels of approx. +17.5 dBm. Besides excellent numerical results for the integrated metamaterial-based bias-T circuitry (max. input RL of ~28 dB, min. IL of ~0.22 dB, max. RF isolation of ~34 dB) and the GCPW-to-WR12 transition (max. input RL of ~26 dB, min. IL of ~0.12 dB) within 71–76 GHz (e.g. 70 GHz band) using the FEM, a 24 dB gain thanks to an integrated GaAs HEMT power amplifier was experimentally demonstrated with in-house fabricated modules.

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References

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