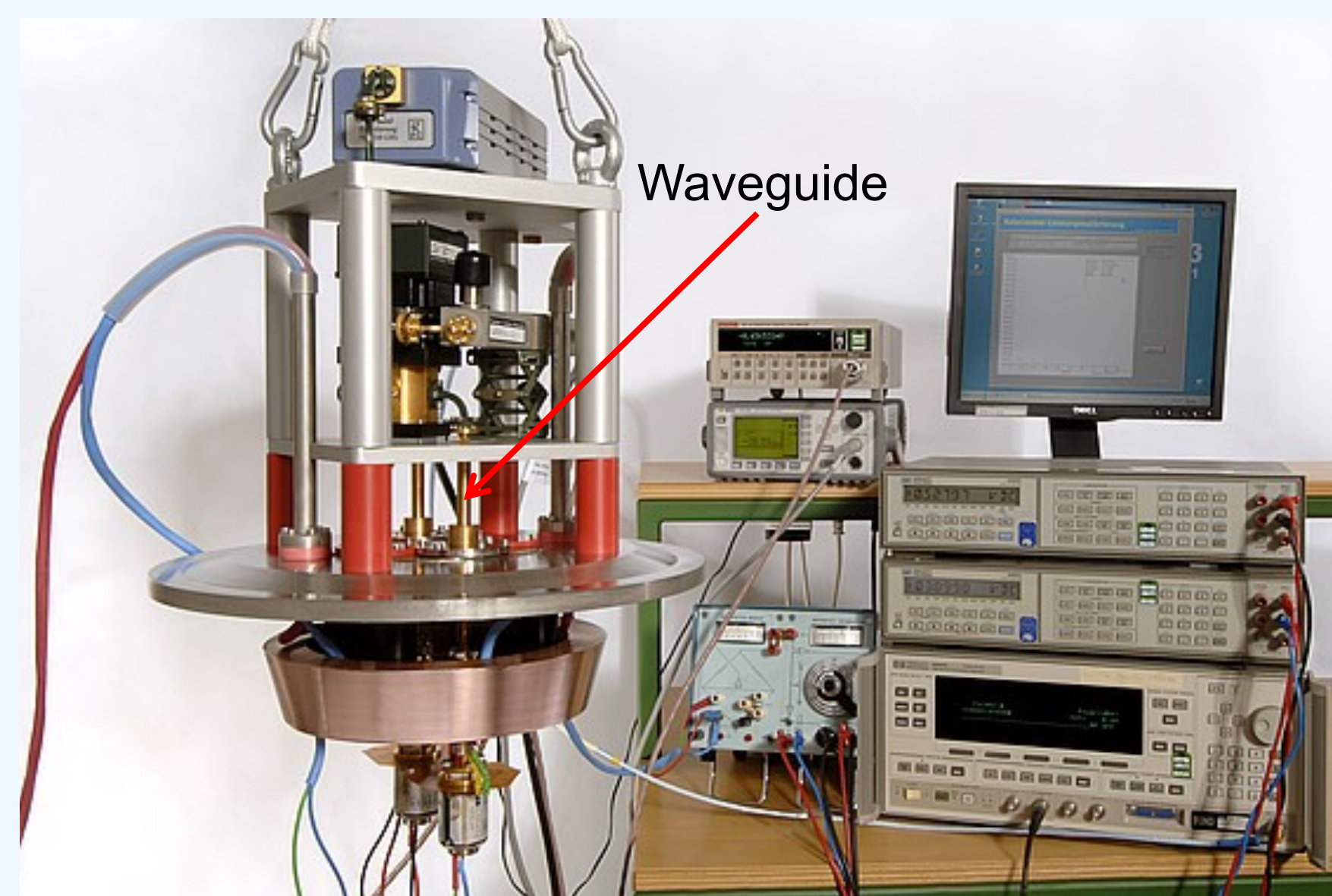
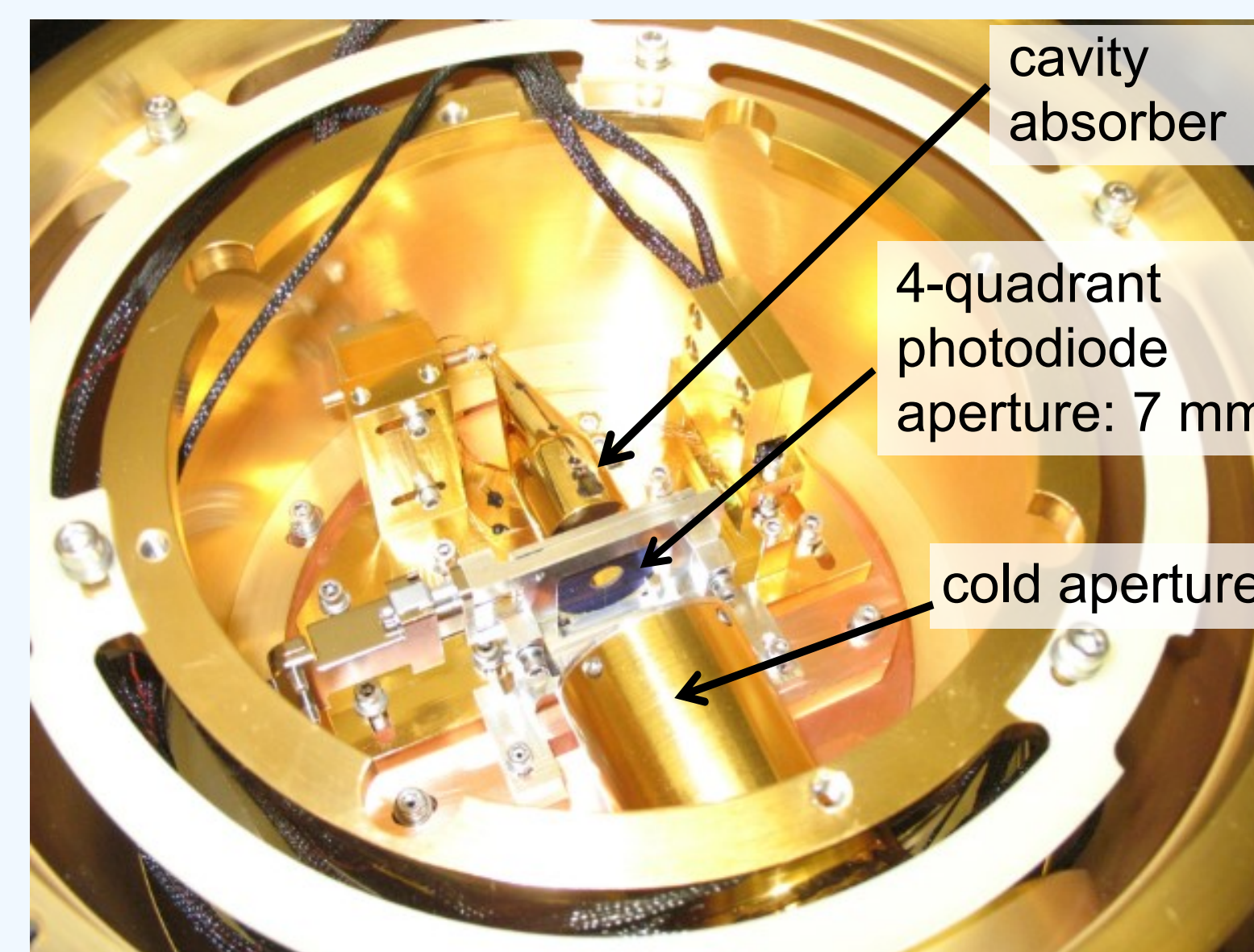


Introduction

- The rapid growth of millimeter wave and terahertz (THz) technologies including applications in security imaging, medical diagnostics, and communication necessitate precise and traceable electromagnetic power measurements.
- The power of electromagnetic waves is determined through different methods:
Within a waveguide (millimeter wave) at room temperature, In free-space (THz) at liquid helium temperature.



Microcalorimeter: 75 GHz - 110 GHz.

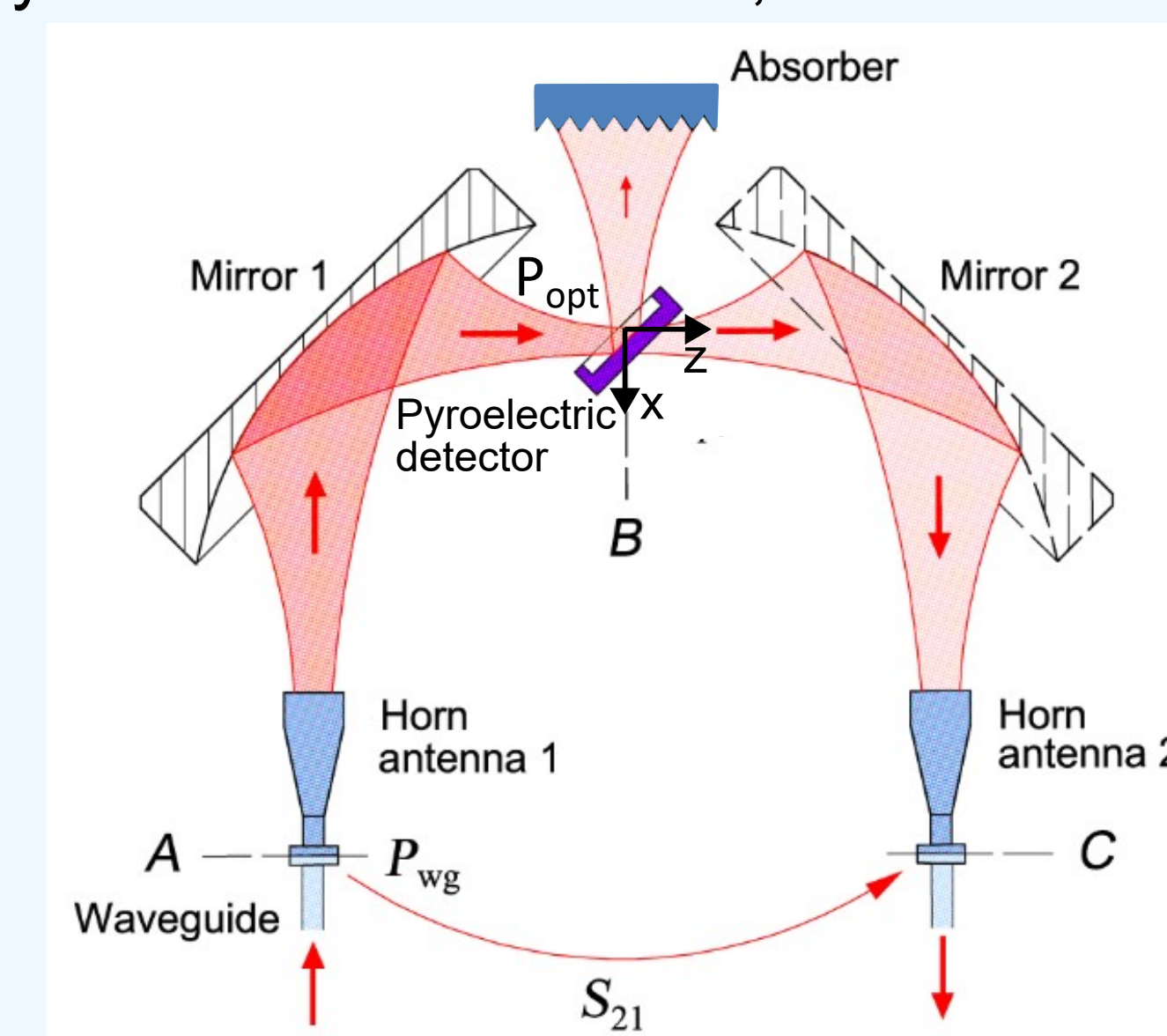


Cryogenic radiometer: ultraviolet (UV) - infrared (IR).

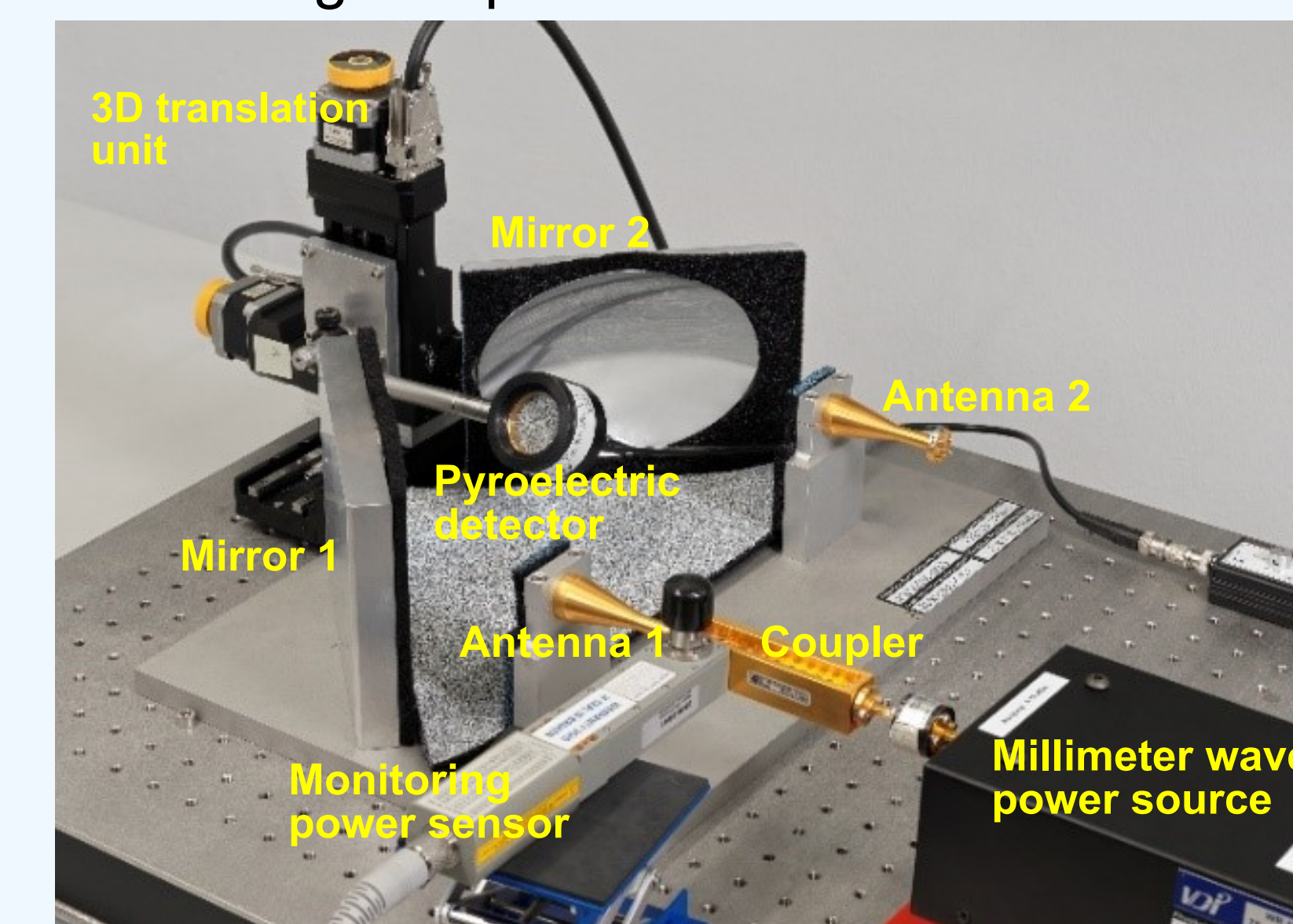
- Waveguide-based power faces challenges in extending traceability to higher frequencies due to the difficulty in developing corresponding microcalorimeters and waveguide based power sensors.
- Free-space power measurements employ thermal detectors, such as pyroelectric thin film detectors (PTFDs), which offer broadband response and are calibrated against optical standards.
- As traceable guided-wave power measurements extend to higher frequencies, an overlap exists between both ranges in the millimeter wave frequency range, allowing for a direct comparison of their power scales.

Measurement Setup

- Measurements in the WR 10 frequency band were conducted in two spatially distinct planes of a quasi-optical / waveguide measurement setup.
- Setup operates in two different modes: electrically chopped mode at a frequency of 72 Hz for the pyroelectric THz detector, and continuous-wave mode for the waveguide power measurement.



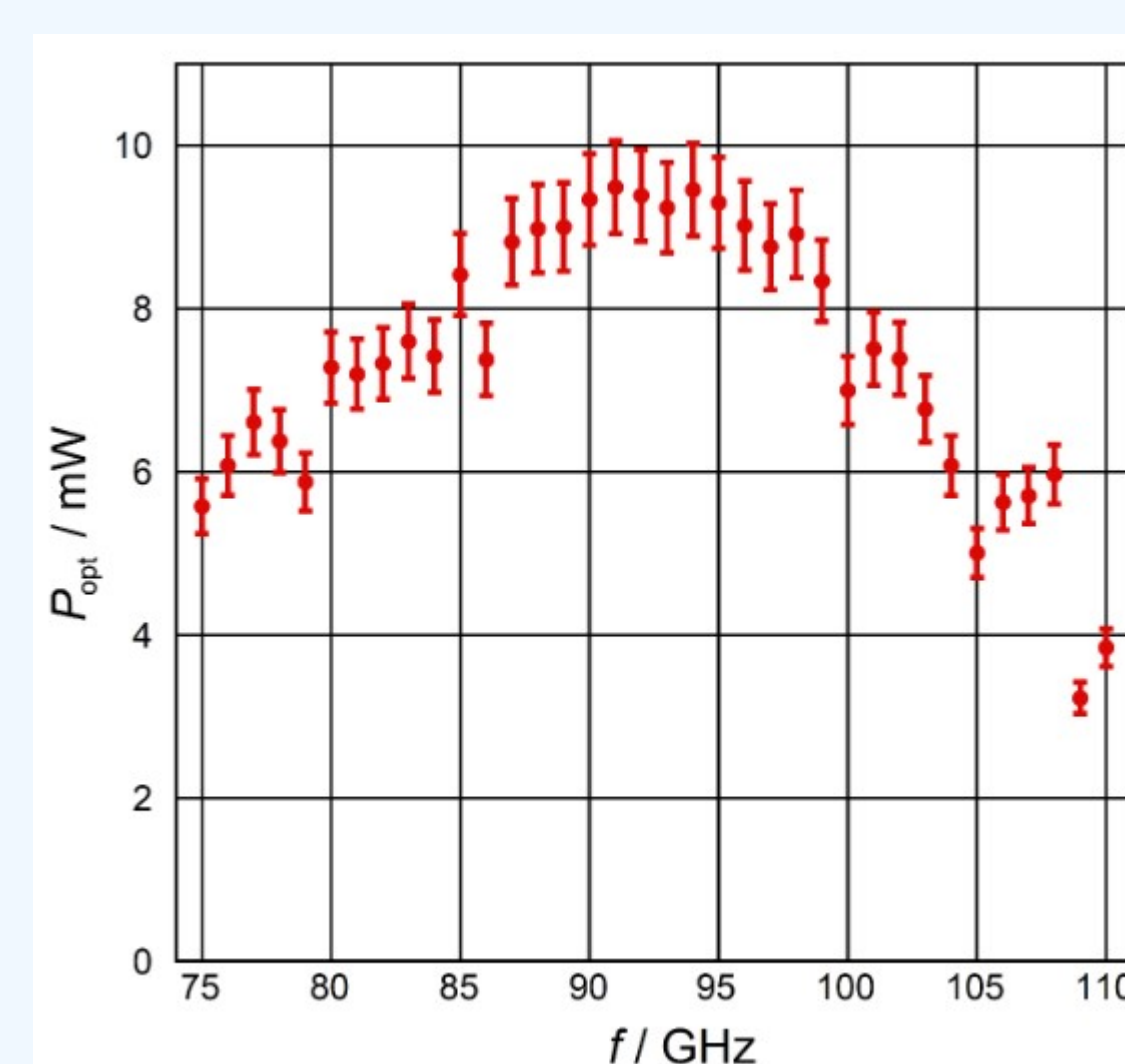
Sketch of quasi-optical setup.



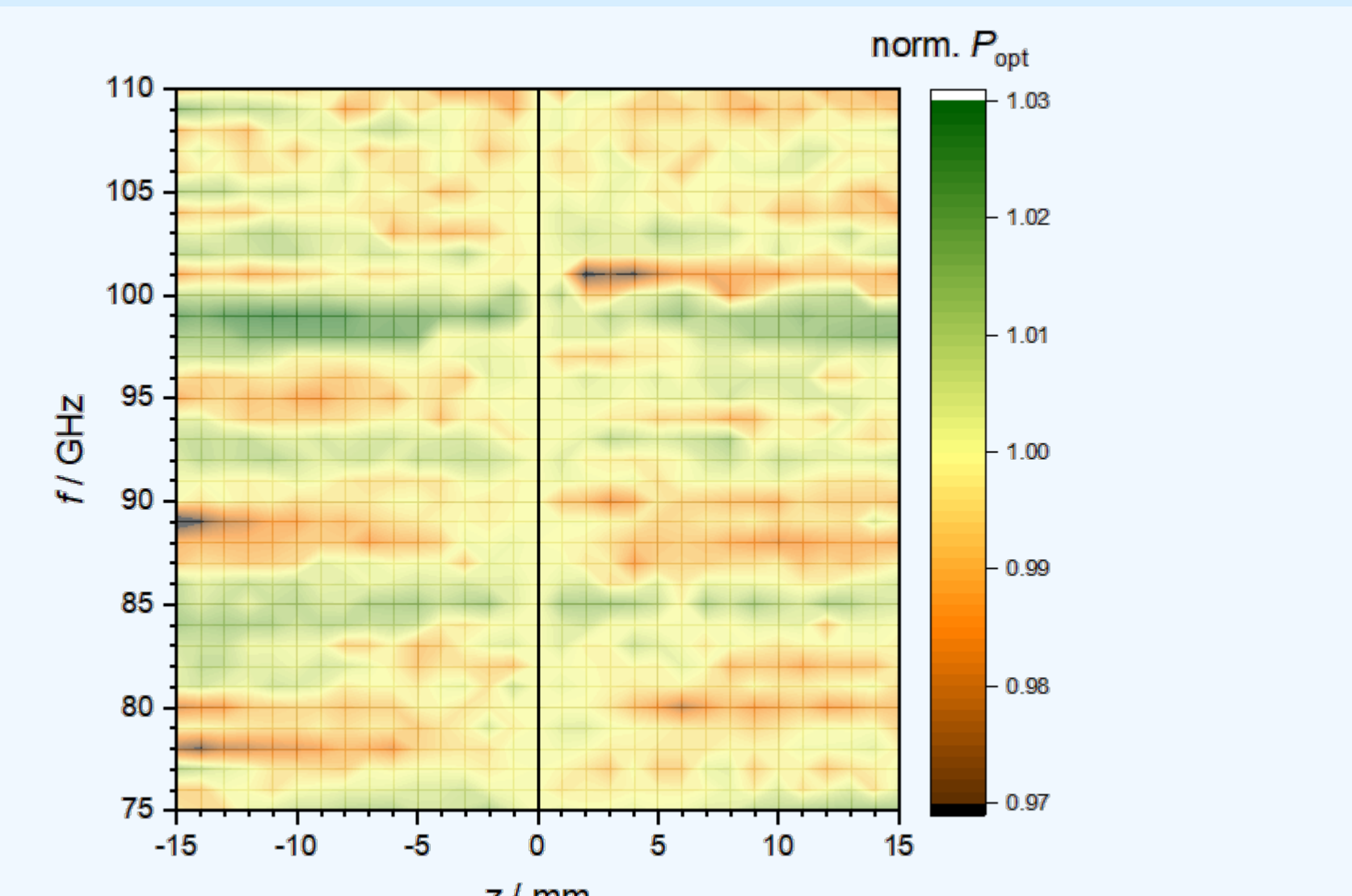
Photograph of the experimental setup.

- Corrugated horn antenna transforms the TE₁₀ waveguide mode into a Gaussian beam.
- Elliptical mirror collects and refocuses the beam without introducing diffraction.
- Pyroelectric THz detector positioned in plane B and rotated 45° to measure the free-space power (P_{opt}).
- Calibrated waveguide power sensor measures the waveguide-based power (P_{wg}) in plane A.
- Coupler compensates for any level variation in the millimeter wave power source.
- Components are symmetrically extended to a two-port setup between planes A and C for determining transmission loss.

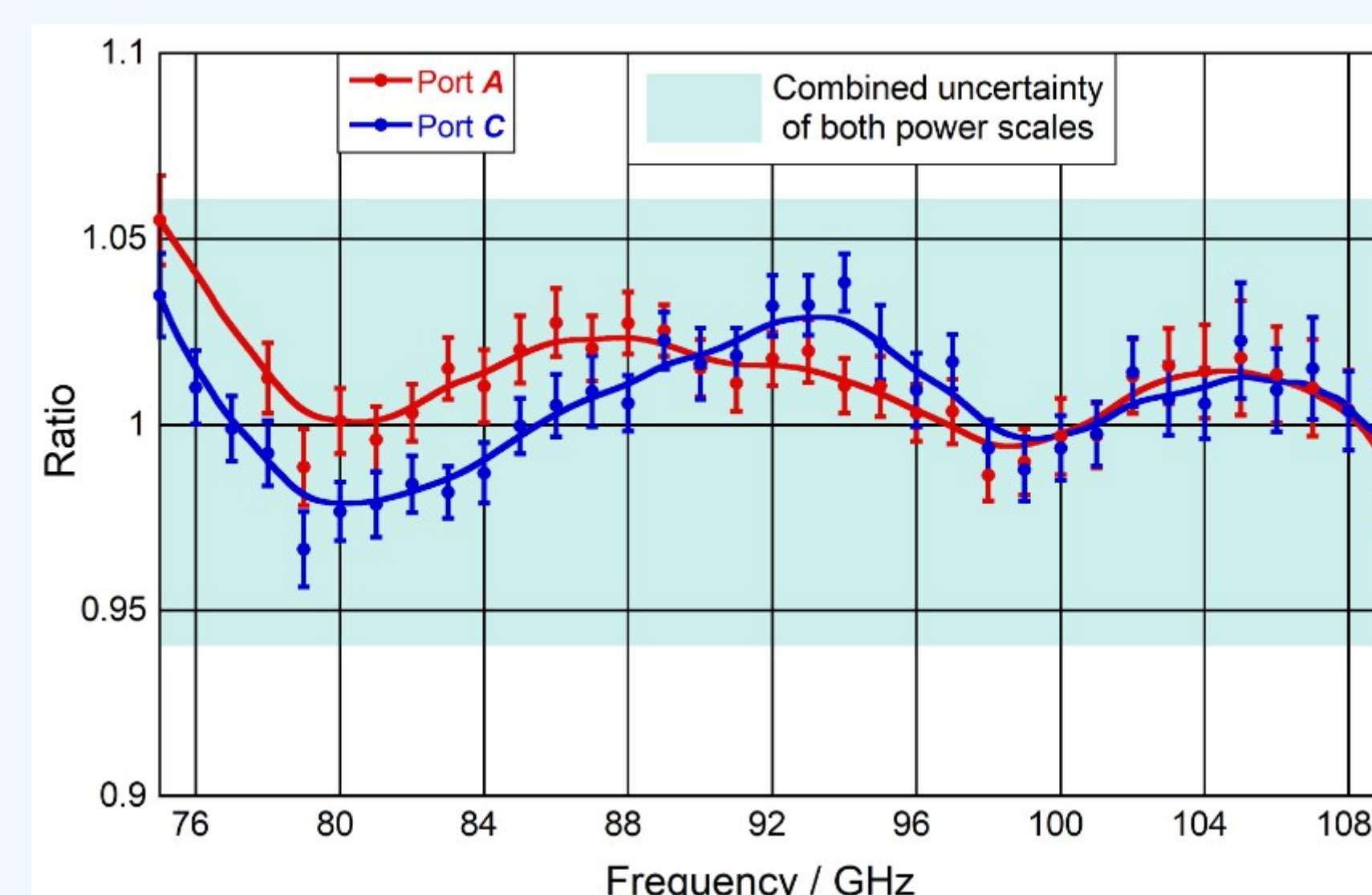
Results



Measured free-space power in plane B over the WR 10 frequency band.



Distribution of free-space power versus frequency along the optical axis (normalized to free-space power in plane B).

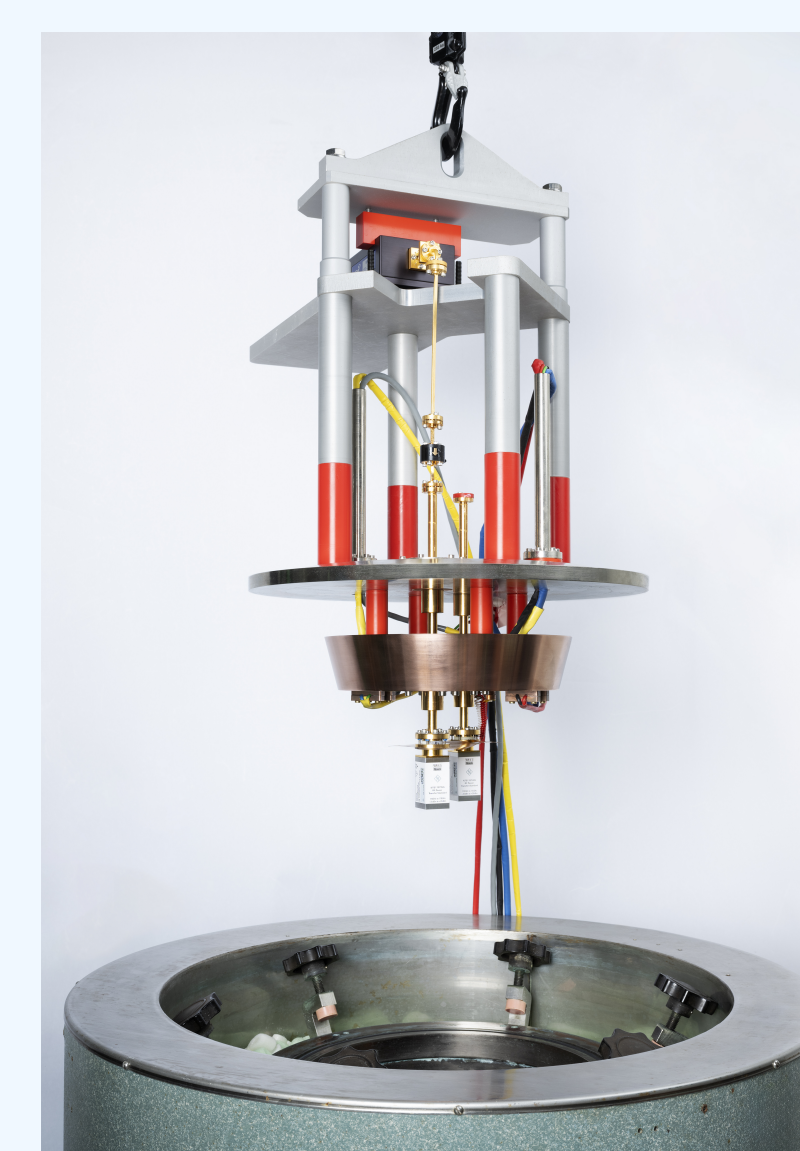


Ratio of free-space power and waveguide-based power.

- The relative change in free-space power due to axial detector position is smaller than the uncertainty of the power measurement.
- Comparison of waveguide-based and free-space power measurements shows good agreement, demonstrating the feasibility of using free space methods to bridge traceability gaps in high frequency applications.
- Ratio of the measured powers P_{opt} and P_{wg} corrected by the transmission loss S_{21} confirms the consistency of power scales.

Conclusion

- For the first time, two independent scales for absolute electromagnetic power have been successfully compared.
- The proof of equivalence enables the traceability of millimeter wave power in higher-frequency waveguide bands, extending into the THz range using free-space setups with THz detectors.
- This approach overcomes the challenge of manufacturing waveguide-based THz power sensors and developing the corresponding microcalorimeters.
- Further development in waveguide-based power measurement has continued in recent years for the 110–170 GHz frequency band, is currently being extended up to 220 GHz, and may even reach 330 GHz in the near future.



Waveguide microcalorimeter operating in the 110 GHz – 170 GHz range.



Transmission line of microcalorimeter using dielectric waveguide, including the transition section to WR 5 standardized devices (140 GHz – 220 GHz).

References

- [1] R. H. Judaschke, M. Kehrt, K. Kuhlmann and A. Steiger, "Linking the Power Scales of Free-Space and Waveguide-Based Electromagnetic Waves," in IEEE Transactions on Instrumentation and Measurement, vol. 69, no. 11, pp. 9056-9061, 2020.
- [2] W. K. Perangin-Angin, K. Kuhlmann and J. Rühak, "Dielectric Waveguide as Transmission Line for R 1.8k Microcalorimeter," 2024 Conference on Precision Electromagnetic Measurements (CPEM), Denver, CO, USA, 2024, pp. 1-2.

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