THz end-to-end wireless systems
supporting ultra-high data Rate applications

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ThoR project newsletter #2

June 2019

Welcome to the second ThoR project newsletter!

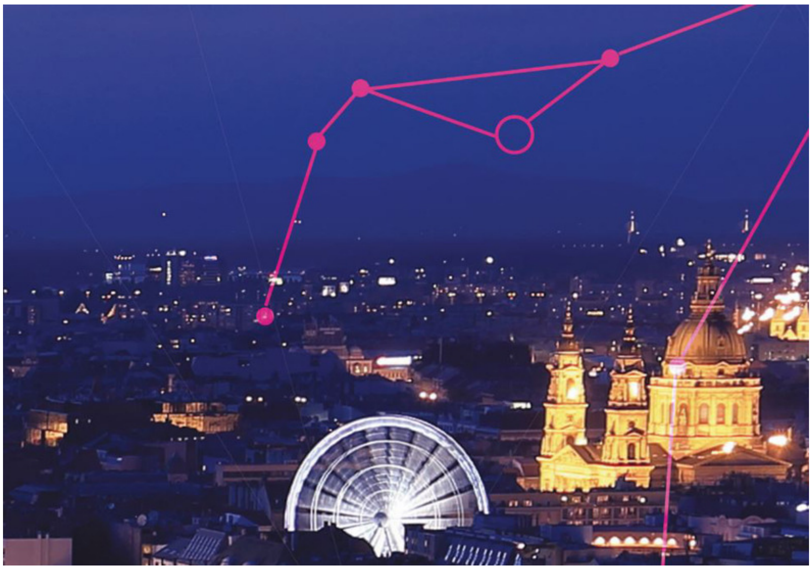


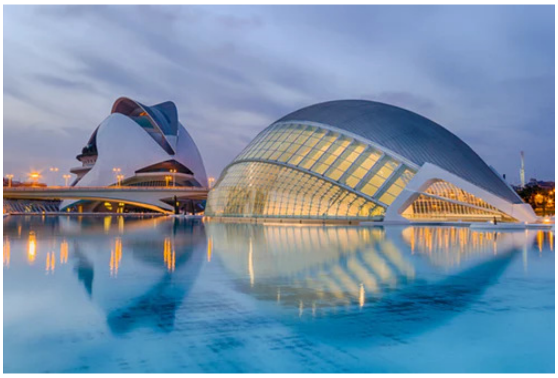
Image courtesy of Deutsche Telekom.

The project has had a very successful initial phase, with promising early results and a number of highlights. This newsletter includes:

- Near-field measurements and antenna characterisation at 300 GHz by Gifu University
- 300 GHz front end development by Fraunhofer IAF and Univ. Stuttgart
- ThoR DEMO-1 and circuit design by the project team
- Development of a high power TWTA at 300 GHz band by NEC

More information is available on the project website www.thorproject.eu

ThoR at EUCNC 2019!



ThoR will participate in the H2020 Beyond 5G Cluster booth (#60) at EUCNC 2019 (18-21 Jun-2019; Valencia, Spain). There will also be a ThoR-related presentation from Prof. Thomas Kuerner (TU Braunschweig) on "Regulatory Aspects of THz Communications and Activities towards WRC 2019" at Special Session 2 Advanced THz technologies towards terabit/s wireless communications.

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Near-field measurements and antenna characterization at 300 GHz

GIFU UNIVERSITY

The antenna is one of the key components in any wireless communication system. Far-field characterisation is commonly conducted in the lower frequency region. Antenna gain, beam width, side-lobe levels *etc.* can be characterised by far-field measurements. In addition, near-field measurements can reveal further information, *e.g.* the amplitude and phase uniformity of phased array antennas.

Gifu University (GU) has been developing a terahertz near-field measurement system based on a self-heterodyne method and a non-polarimetric electro-optic (EO) sensing technique; both have been proposed and demonstrated by GU. It has also been developing a fibre-mounted EO sensor which is based on an organic EO crystal.

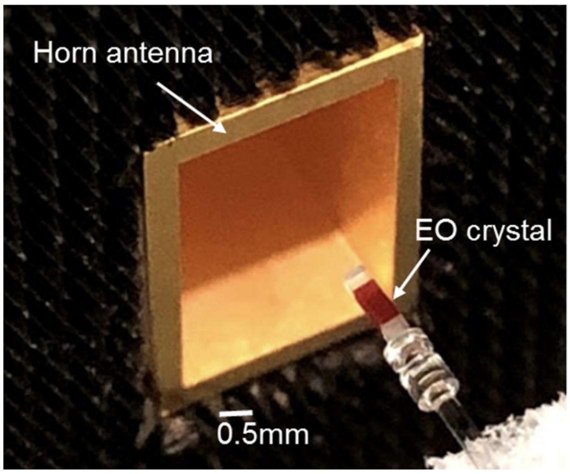

Fig. 1: WR3 horn antenna and EO probe

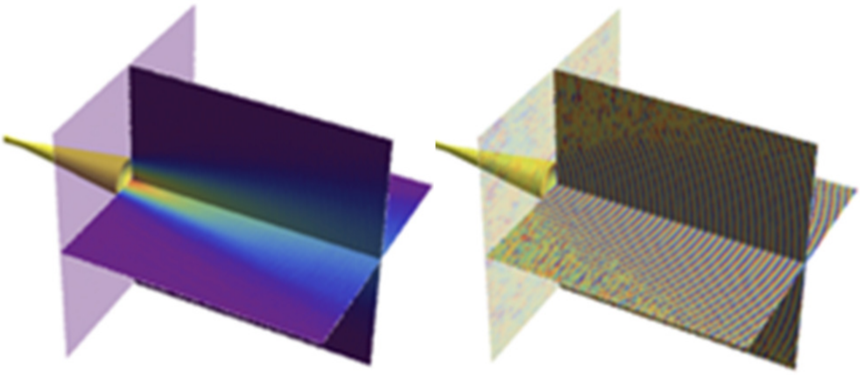

Fig. 2: Experimentally visualised near field amplitude (left) and phase (right) at 310 GHz.

Fig. 1 shows a WR3 horn antenna and the EO probe. The EO sensor is scanned across the antenna surface to visualise the amplitude and phase distribution. Fig. 2 shows typical images of experimentally visualised near-field distributions for such an antenna.

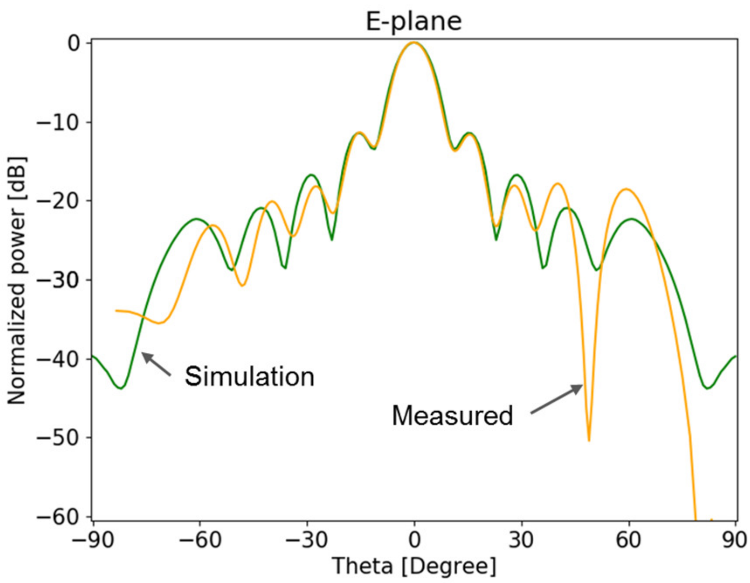

Fig. 3: Far-field pattern (E-plane) calculated from measured near-field distribution.

Fig. 3 shows the far-field pattern (E-plane) calculated from the measured near-field distribution. The measured far-field pattern agrees extremely well with the simulated result. GU is now developing the probe compensation technique to characterise the antennas more accurately.

In the ThoR project, measurements have been performed at University of Lille and NICT, in collaborative EU-Japanese work, which includes comparison of the measurements. These measured far-field patterns have already been used in sharing investigations to ensure compatibility with passive services and in the software simulation which will be shown in DEMO-4 near the project end.

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300 GHz front end development

A key enabling technology for the implementation of the 300 GHz front end is Fraunhofer IAF's InGaAs metamorphic high electron mobility transistor (mHEMT) technology, which is used for the implementation of the solid-state receiver and transmitter MMICs, including a 300 GHz solid-state power amplifier (SSPA). The processing and characterisation of the first frequency multiplier, mixing and amplifier circuits for the super-heterodyne ThoR approach have been completed. Based on these results, a first version of the 300 GHz single-chip transmitter and receiver MMICs were designed by the University of Stuttgart and are currently being fabricated at Fraunhofer IAF. The MMICs will be available for measurement in a couple of months and the waveguide modules for packaging are at the planning stage.

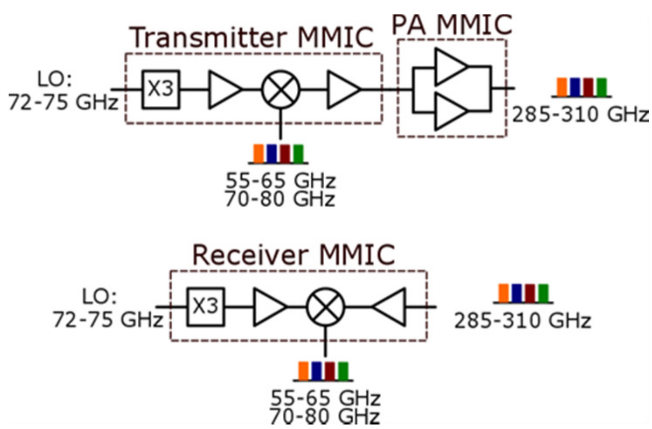

Fig. 4: Simplified block diagram of the 300 GHz front ends

In order to use high-order modulation formats (*e.g.* 128-QAM) and achieve a transparent up and down conversion, linear amplification will be required. This puts high demands on the front-end MMICs and especially the SSPA. The 300 GHz power amplifier cells, which were developed in the first months of ThoR, achieve high output power levels (>10 mW) over a wide bandwidth. Based on these circuits, amplifier MMICs with linear output power >10 mW are being developed. In order to increase the output power, several MMICs will be combined at waveguide level. *[These results have been submitted for publication and will be reported publicly in due course.]*

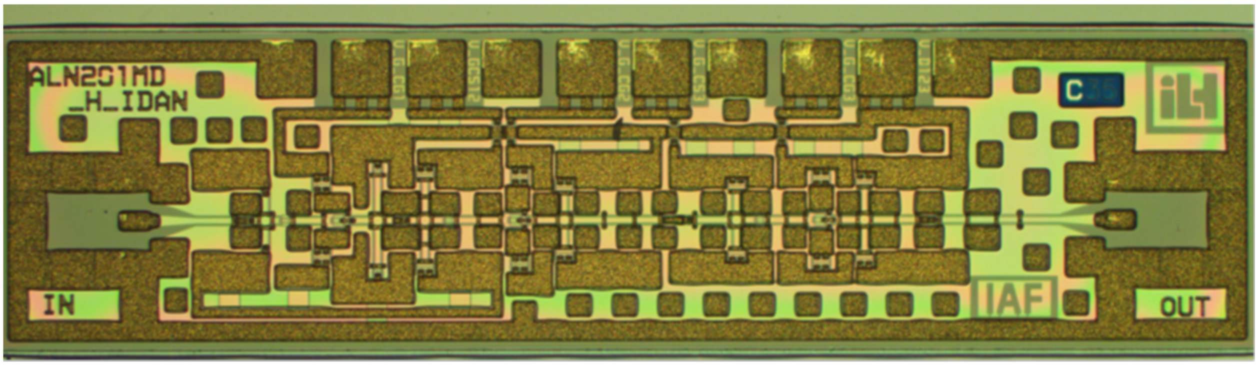

Fig. 5: Low-noise amplifier MMIC

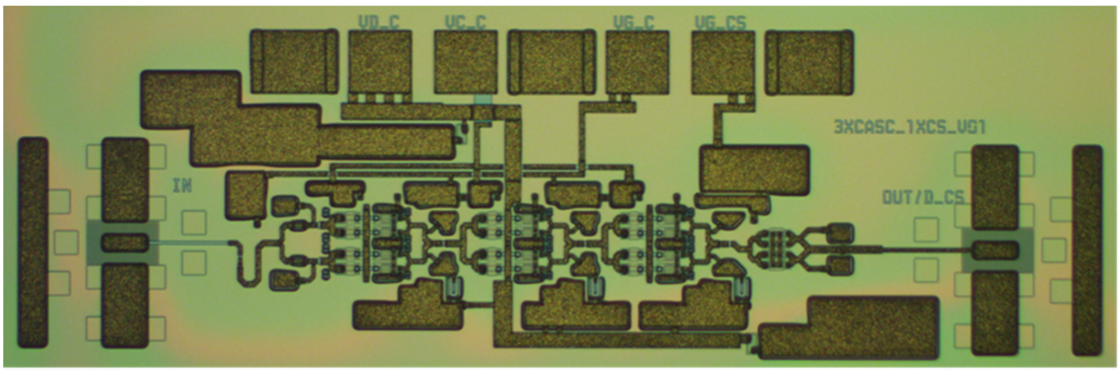

Fig. 6: Compact power amplifier MMIC

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ThoR DEMO-1 and circuit design

Wireless communication is one of the fastest growing industries, influencing our daily lives. It is obvious that today's technologies will not be able to keep up with this exponential growth in the demand for high data rates. This is why scientific and industrial communities are both looking seriously into the spectrum above 200 GHz. In the last decade many activities in this area have been reported. Very high data rates, above 100 Gbps (equivalent to transmitting the content of a blue-ray disc in a quarter of a second) have been achieved by various groups using different technologies. All these extremely fast wireless experiments have been conducted using pseudo random bits and expensive digital to analogue and analogue to digital converters.

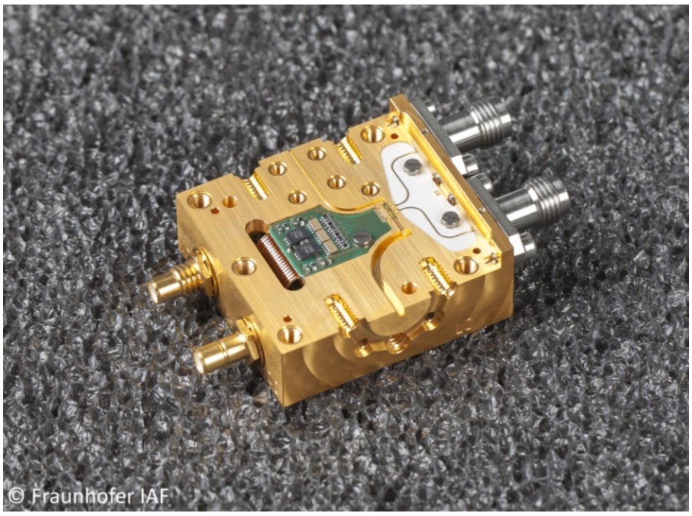

Fig. 7: 300 GHz transmitter module developed in the TERAPAN project

The scope of ThoR is to bring terahertz wireless communication a step closer to real life applications by combining state-of-the-art modems in E and V band (70/80 GHz and 60 GHz) with 300 GHz electronic up and down converters. This involves the use of a superheterodyne architecture, which has never been realized before at such high frequencies. At the beginning of the project, a demonstration of the concept was carried out using existing hardware available in the ThoR consortium. The transmission experiment was realised in a laboratory environment using 300 GHz transmit and receive modules (shown in Fig. 7) which were developed in a previous project, TERAPAN (www.terapan.de). This previous project was designed for another architecture, with no intermediate frequency, therefore the goal was not to achieve extremely high data rates, but to show the feasibility of the concept and of the superheterodyne architecture (Fig. 8).

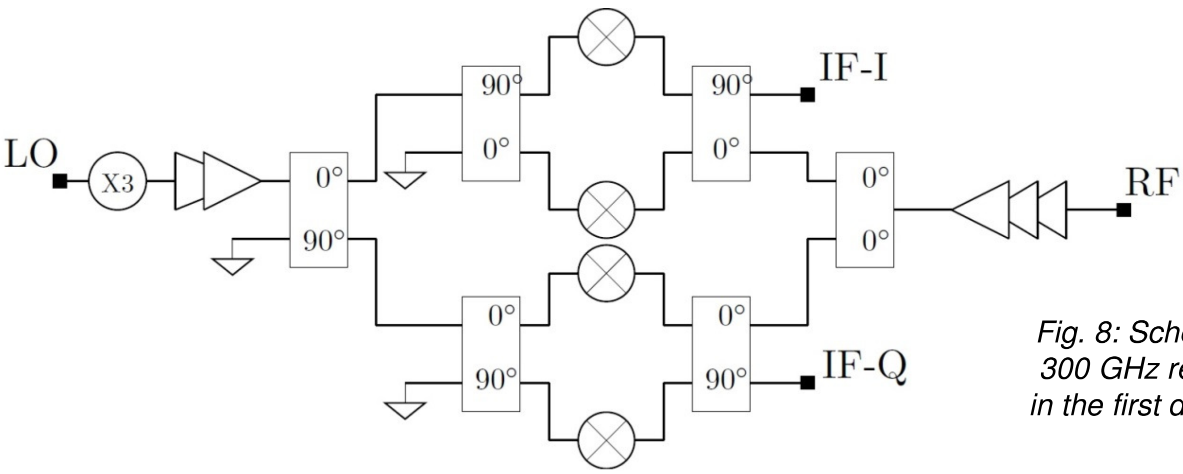

Fig. 8: Schematic of the 300 GHz receiver used in the first demonstration

Even with far from ideal conditions the demonstration was a success. Data rates of up to 60 Gbps and high modulation formats, up to 64-QAM, were achieved. As a comparison today's state-of-the-art indoor wireless connections have a maximum data rate of 2.4 Gbps.

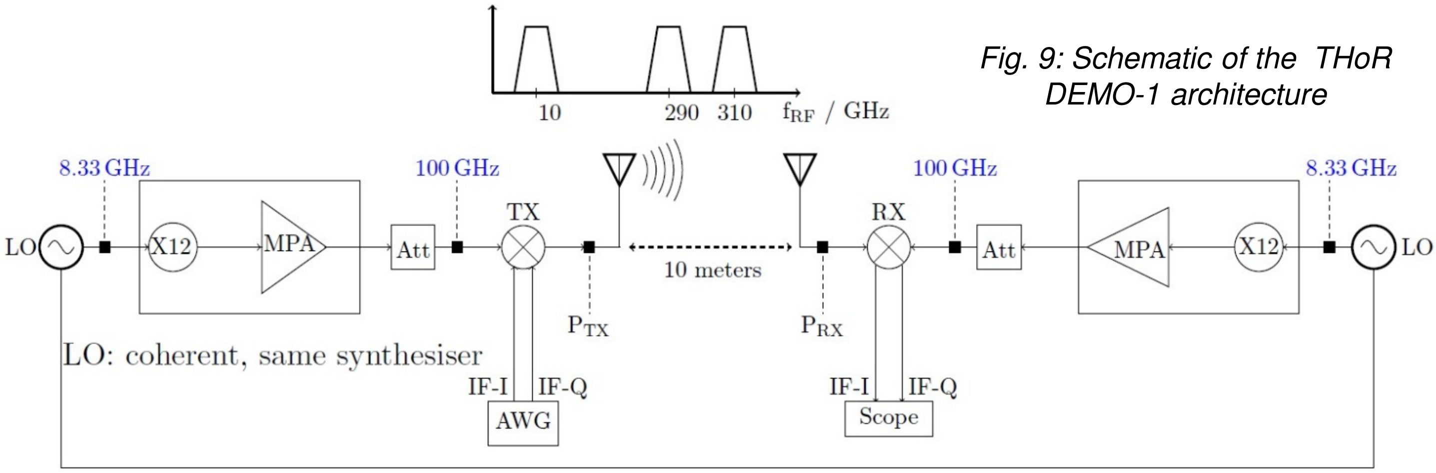

Fig. 9: Schematic of the THoR DEMO-1 architecture

Furthermore, the transmission distance of 10 m shows that the link is suitable for indoor applications *e.g.* smart offices and data centres. Another success was the ThoR concept of the transmission of a multi-carrier signal, where different channels in the lower frequency region of the E- and V-band are parallelised to achieve real time high data rates. [Detailed results will be presented at European Microwave Week in Paris in Oct-2019.]

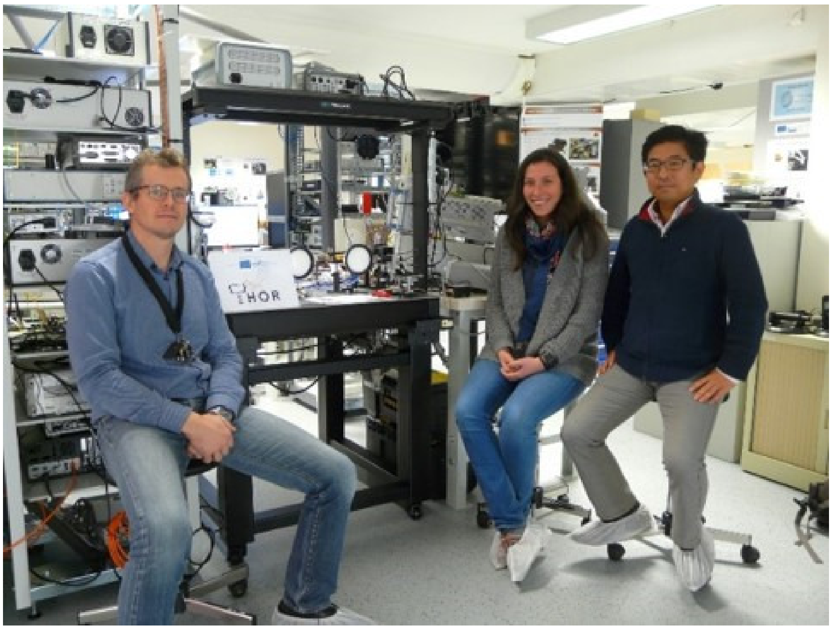

Fig. 10: Part of the THoR DEMO-1 team (Univ. Lille Nov-2018)

Although the concept of superheterodyne transmission is not new, 300 GHz up and down converters using intermediate frequencies above a couple of GHz have never been reported before. Very fast transistor technology developed by Fraunhofer IAF enables the realisation of circuits operating at such high frequencies. Since the intermediate frequency systems are complex, including different channels and frequencies, the requirements on the 300 GHz converter are very high, especially in terms of bandwidth, gain ripple, amplitude and phase imbalance.

Another key aspect in the design of the 300 GHz system is the use of a travelling wave tube amplifier (TWTA) as an output stage for the transmitter chain to enhance the transmitted output power and extend link distance. The 300 GHz transmitter needs to provide enough input power and linearity for the TWTA to assure that there is no contribution from the 300 GHz transmitter to the system linearity performance. Linearity is very important when transmitting complex modulation formats (*e.g.* 64-QAM). After an analysis of possible architectures the final 300 GHz up and down converter will include a ×3 multiplier (hence input frequencies lie at ~70 GHz), a buffer amplifier, fundamental mixers for up- and down-conversion and pre- and post-amplifier stages. The integrated chips will then be packaged in a compact waveguide module and will be used in two other demonstrations.

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Development of TWTA at 300 GHz band

For the wireless communication at 300 GHz band, a traveling wave tube amplifier (TWTA) is useful for link distance expansion. The latest prototype of TWT device developed by NEC is shown in Figure 11. Micromachining technology is introduced to manufacture an amplification element of the TWT device which requires extremely high accuracy. The amplification element has been improved to achieve more than 15 dB gain. At the time of writing, measurement of the gain is in progress.

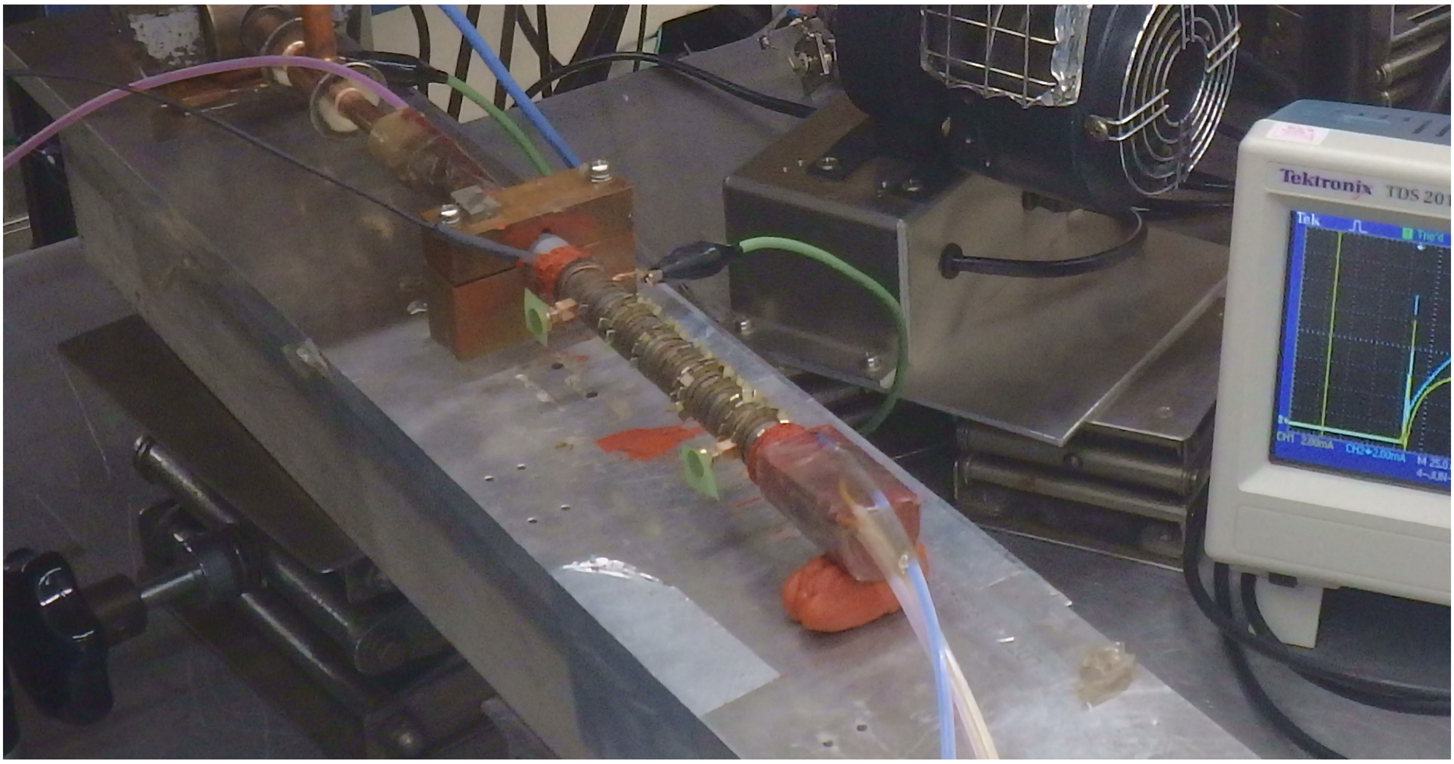

Fig. 11: ThoR prototype TWTA developed at NEC

Item	**Target / Spec**
Input Level	10 mW
Gain	20 dB (at 290 GHz)
Output Level（Saturation）	1 W
Effective Bandwidth	5 GHz
I/O Interface (Waveguide)	WR-3 (same as WR-3.4): 220 to 330 GHz Inside Dimension: 0.864 mm × 0.432 mm
Expected VSWR for I/O object	< 1.2

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