Interview

Exploring the Terahertz Band, a Frontier between Radio and Light

Beyond 5G - and further

Terahertz Technology Research Center

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After completing a doctoral program, Iwao HOSAKO worked for NKK Ltd. (currently JFE). In 1996, he joined the Communications Research Laboratory, Ministry of Posts and Telecommunications (currently NICT). He has been engaged in research and development of terahertz semiconductor devices and various application systems. Ph. D. (Science).

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After achieving a master's degree, Hiroyo OGAWA started working for Nippon Telegraph and Telephone Corporation (currently NTT). In 1998, he joined the Communications Research Laboratory, Ministry of Posts and Telecommunications (currently NICT). He has been engaged in research, development and standardization of millimeter-wave and terahertz systems. IEEE Fellow, Ph. D. (Engineering).

Ever since Guglielmo Marconi invented radio telegraphy, technologies that use radio waves have drastically altered our everyday lives, as well as society as a whole. One only needs to look at the smartphones people carry with them to see how this technology has benefitted us. Speaking of smartphones, 5G (fifth-generation mobile communication systems) service starts in Japan this year, and research institutes are already formulating development plans for Beyond 5G — and even more advanced systems.

The terahertz band, an almost unexplored frequency band, is now the focus of significant attention. With a frequency from 100 GHz to 10 THz — 3 mm to 30 µm, converted to wavelengths — one might ask: why do we need such high frequencies? Furthermore, how is this band being researched and standardized for use? For the answers to these questions and more, we sat down with HOSAKO Iwao, Director General of the Terahertz Technology Research Center, and OGAWA Hiroyo, who worked in standardization at the same Center.

Why the terahertz band

——Tell us about the current state of terahertz band development.

HOSAKO The terahertz band is a band of waves with an extremely high frequency. The band of several hundred GHz on the lower end of that spectrum appears to be very useful in future radio communications, so we've been engaged in research and development of the band for some time now.

NICT was originally a laboratory for researching radio waves, so we already have a lot of valuable data in terms of wireless research and development. Looking at radio use and research thus far, there is a trend toward using higher and higher frequencies, and we are just breaking into the terahertz band now. It's a frequency band that is about to become mainstream, so you could say that it's the frontier of radio research.

——Why is the terahertz band necessary?

HOSAKO Simply, to create faster, higher-bandwidth communication systems. 5G service starts here in Japan this year, and provides transmission speeds of more than 10 Gbps. That's more than ten times what 4G offers. There are always people who say we don't need any more speed, but surely the drive to reach ever faster speeds and greater bandwidths is part of our programming as humans.

Higher frequencies become necessary as you push toward higher speeds, and the 3.6 GHz band is the highest frequency band being used with the current 4G technology. 5G uses the 28 GHz band as well, which means that the frequency for 5G is ten times higher that used for the current 4G. At this rate, we'll probably be seeing frequencies around 300 GHz ten years from now, in the year 2030. Of course, that means we'll be using the terahertz band.

In that sense, you could say that the terahertz band frequencies being successfully identified at the WRC-19 in November of last year was very good timing.

Finalizing frequency identification

——Dr. Ogawa, you were instrumental in identifying the terahertz band frequencies, correct?

OGAWA The International Telecommunication Union (ITU), which is a United Nations (U.N.) specialized agency, publishes some-

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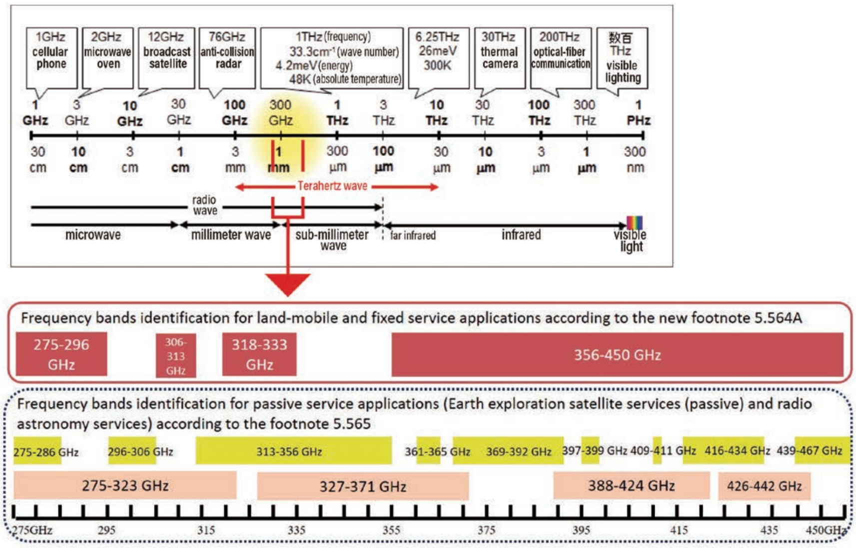

Figure: WRC-19 frequency identification results

thing called the Radio Regulations (RR), and frequencies are allocated here in Japan according to the Radio Regulations. This is revised basically every four years at the World Radiocommunication Conference (WRC). The WRC reviews frequency allocations in light of technological progress, societal needs, and so on.

In this case, the frequency identification was done at the World Radiocommunication Conference 2019 (WRC-19). Until then, frequencies higher than 275 GHz had not been allocated for radiocommunication services. The only frequencies identified were basically for radio astronomy and Earth exploration satellites services, which are passive services (receive-only services).

At this WRC, we added a new footnote identifying new frequency bands that can be used in radiocommunication active services to the Radio Regulations.

——And that was needed in order to start using the terahertz band?

OGAWA That's right. There is increased demand for both passive and active services. You could call it demand for short-range, high capacity radiocommunication systems.

We spent four years in discussions with the main authorities from each country through the ITU-R and were ultimately able to identify four bands and list them in the Radio Regulations. The four bands are 275 to 296 GHz, 306 to 313 GHz, 318 to 333 GHz, and 356 to 450 GHz, for a total bandwidth of 137 GHz (see figure).

This is a broad range of frequencies, the likes of which have never been provided for mobile communications. Having the frequencies identified means that they can now be used by wireless businesses. I admit that I'm rather proud of this major achievement by the Terahertz Technology Research Center.

HOSAKO The results of WRC-19 come from international agreements, and because each country uses radio differently, we needed to coordinate with various countries around the world. In this case, we organize the Asian region first, and submit a proposal representing Asia to the WRC. Representatives from all of the countries then gather for the main WRC conference, discuss the proposals, and make a decision. This time, the agenda was set in February of 2015, and those bands were identified in November of 2019, so it took more than four years. And of course, we did studies within Japan before the Asian conference, including consultations with groups using passive services, such as the National Astronomical Observatory of Japan and JAXA (the Japan Aerospace Exploration Agency).

——What changes once the frequencies have been identified?

OGAWA Deciding how the new bands will be used is the next step, but they will most likely be applied mainly in mobile radiocommunication systems, fixed radiocommunication systems, and so on.

HOSAKO That's exactly right. With the bands now being identified, they can be used in radiocommunication, which also makes it easier for companies to invest with an eye to new business ventures.

Cooperation with other groups

OGAWA The Terahertz Systems Consortium, of which I am the Deputy Chairman, played a major role in the frequency identification. The Consortium has some manufacturers as members as well, which made it possible for us to submit technical and operational characteristics, including antenna and propagation characteristics when working in the terahertz band, to the ITU-R.

—Have you collaborated with any universities or academic societies?

HOSAKO The Institute of Electronics, Information, and Communication Engineers has a Technical Group on Terahertz Application Systems. NICT is also sending out researchers to engage in research. The Japan Society of Applied Physics has a Terahertz Electromagnetic Wave Research Group, with which we have partnered as well. We are also actively collaborating with a technical exchange organization called the Terahertz Technology Forum.

For example, having a radio wave propagation model — called "channel modeling" — is an essential part of radiocommunication. As I mentioned earlier, NICT was formerly a radio wave research laboratory, and is thus very strong in this area. NICT has channel models for everything up to millimeter waves.

Terahertz waves have extremely short wavelengths. The propagation state changes subtly depending on objects, human movement, and more, which means the waves travel over an extremely high number of paths. This makes channel modeling quite complicated, and it won't be possible to apply terahertz waves in actual operations until we gather a lot of data.

Support for Beyond 5G

——Using terahertz will become a reality with Beyond 5G, the next-generation communication standard, correct?

HOSAKO Beyond 5G is expected to start in 2030, and a lot of ideas are being proposed around the world at this moment. Next year is the final year of NICT's 4th Medium- to Long-Term Plan, so we are in the process of considering how to approach Beyond 5G with an eye to our 5th Medium- to Long-Term Plan.

One of the characteristics of Beyond 5G garnering attention is this image of an efficient, low-power, "cool" network, which not only expands on higher bandwidths, lower latencies, and greater numbers of connections, but also does things like apply AI to network slicing (dividing a network virtually for more efficient operations). We will also likely see three-dimensional networks with drones, high-altitude platform stations (HAPS), Global Navigation Satellite Systems (GNSS), connected cars, IoT devices, and more. We think these areas offer opportunities to apply terahertz waves, and NICT will likely be pouring tremendous energy into collaborations focused on Beyond 5G terahertz technologies. I hope we can make good use of the cutting-edge techniques that only NICT can offer. One example is building compact atomic clocks into terminals. NICT is currently engaged in research for implementing atomic clocks in chip form, and is also researching micro-fabricated ion traps, which have an even higher level of accuracy than atomic clocks. Such technology enables device times to be synchronized with atomic clock-level accuracy, eliminating the process of synchronization when establishing communication and increasing speeds by that amount.

Additionally, quantum cryptography offers the ultimate in security. While photons are typically used, we are also researching physical-layer cryptography which dispenses with photons. We are considering how to create terrestrial, satellite, inter-satellite, aircraft, and other such networks using this physical-layer cryptography.

Although these technologies are still a ways off, they might be ready in time for whatever next-next-generation communication standards will start around 2040.

Image sensing using the terahertz band

HOSAKO Beyond communications, the terahertz band is proving useful in sensing applications such as passenger scanners in airports. This is an area garnering great interest as a counterterrorism measure.

We've started exploring whether this can be implemented in the W band (75 to 110 GHz), which includes part of the terahertz band. The technique uses a slightly lower frequency band than the terahertz band. This is because if the frequency is too high, the waves can't properly penetrate clothing, while a high spatial resolution brings up issues of privacy. Our solution is to use the W band to avoid such privacy issues while utilizing AI to increase the identification accuracy.

Future prospects

OGAWA By identifying the terahertz band frequencies, we've been able to secure a large band, around eight times the total bandwidth of 17.25 GHz identified for 5G at the World Radiocommunication Conference 2019. So I think this spectrum resource will be sufficient for another 20 years. But then in another 20 years, people might be saying that 137 GHz is not enough.

HOSAKO I think that would actually be more interesting. Japan has been somewhat behind the curve when it comes to 5G, so I'd like to focus all our energy on Beyond 5G. NICT has a large amount of basic research, applied research, and data in a broad range of related fields, so I want us to push forward as the driving force behind next-gen and next-next-gen communication technologies in Japan.

We received assistance from a lot of people during the standardization process. Within NICT itself, we had help from the Innovation Promotion Department's Standardization Promotion Office, and received support from the Terahertz Systems Consortium and relevant departments at the Ministry of Internal Affairs and Communications. It's our hope to use that accumulated knowledge and support as the seeds for even stronger research and development in the future.

ITU: International Telecommunication Union
ITR: International Telecommunication Regulations
WRC: World Radiocommunication Conference
ITU-R: ITU Radiocommunication Sector

Helping identify a total frequency bandwidth of 137 GHz at WRC-19

Based on the results of research and development in terahertz radiocommunication fundamental technologies using frequencies over 275 GHz, the Terahertz Technology Research Center proposed and contributed to the establishment of WRC-19 agenda item 1.15 at WRC-15 in 2015, which identifies frequency bands for mobile and fixed service applications in the frequency range 275-450 GHz.

Subsequently, in the relevant Working Parties held from 2016 to 2019, the technical operational characteristics of terahertz radio systems and the results on sharing and compatibility studies with passive services were reflected in the work of WRC-19 agenda item 1.15, in cooperation with the Terahertz Systems Consortium's member companies. These results were provided as input at WRC-19, held from October 28 to November 22, 2019, and contributed to the revision of the Table of Frequency Allocations in the frequency range 275-450 GHz in the Radio Regulations, carried out during the conference. (See Figure.)