Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Spectrum Horizons	)	ET Docket No. 18-21
	)	
James Edwin Whedbee Petition for Rulemaking to Allow Unlicensed Operation in the 95-1,000 GHz Band	)))	RM-11795

COMMENTS OF Keysight Technologies, Inc.

Test and Measurement Perspective and Thoughts

In paragraph 84 of the NPRM, the notice reads "We seek information on fundamental aspects of measurements of radiated and conducted emissions at these frequencies."

A banded measurement approach is preferred since the media of choice in the industry for measurements in these frequencies are with rectangular waveguides and would be aligned with the recently released IEEE 1785.1 waveguide designations for waveguide apertures. To cover the frequencies from 95 GHz to 275 GHz the band designations would be:

MIL-DTL-85/3C	IEEE Std 1785.1	Frequency
WR-08	WM-2032	90 GHz to 140 GHz
WR-06	WM-1651	110 GHz to 170 GHz
WR-05	WM-1295	140 GHz to 220 GHz

WR-04	WM-1092	170 GHz to 260 GHz
WR-03	WM-864	220 GHz to 330 GHz

Additionally, from a radiated perspective this would then drive the need for waveguide horn antennas and patch array antennas. Thus, antennas used in these measurements should be required to be standardized and highly characterized. Measurement receivers will also need to have a high dynamic range receiver using a Spectrum Analyzer with/without a frequency extender. One fundamental aspect in measuring at these frequencies is the lack of power measurement standards and calibrated power sensors above 110GHz. Potential candidates include calorimeters such as the Erickson PM5 (waveguide coupled). There is also an absolute power free space power meter from Terahertz (TK). There are power standards to 170 GHz at AIST in Japan. Both NIST and NIM (China) have standards in development to 170 GHz. PTB (Germany) are developing the capability as well. There are also pyroelectric free-space detectors from Gentec in Canada and Avantest, and there are guided-wave power sensors up to 220 GHz. Thermocouple technology could be adopted to higher frequencies as absolute power standards. In general, all metrology is based on impedance, power, noise and frequency. These are the fundamental aspects to the development of measurement techniques in the frequency ranges in question. There should be more focus on the development of power standards for guided wave and free space and the associated commercial instrumentation required to transfer the standards to engineering usage. In the area of receiver extenders, the extender

should allow for very good close-in phase noise performance using a high precision source to drive the measurement receivers. Also, for integrated devices this would require a probe antenna for the receiver sensor, not a waveguide. The probe antenna would also need to be standardized and characterized.

In paragraph 84 of the NPRM, the notice reads "What are ways to demonstrate compliance with procedures which are practical, repeatable, and do not have large margins of error."

The most appropriate way to address compliance is through a set of measurements of known signals across the bands. The repeatability for such conducted measurements would need to come from a waveguide alignment standard that is currently being worked on by IEEE. Additionally, having traceable power standards is a common practice for maintaining acceptable margins of error in measurements below 110GHz. For radiated measurements, the margins of error start to depend on the proximity of the sensor and the mm-wave energy coupling. Most importantly, sources of error must be well controlled for radiated measurements at millimeter-wave: these factors are path loss, pointing error (especially for narrow beams), signal level, and SNR in the measurement device.

In paragraph 84 of the NPRM, the notice reads "Specifically, Sections 15.255 and 15.257 of our rules apply to the use of an RF detector that has been specified to make millimeter-wave measurements. Is the use of an RF detector an appropriate method for measuring the frequencies above 95 GHz."

RF detectors with a waveguide horn and waveguide connectors are an appropriate method for measuring frequencies above 95 GHz. The nature of the detector will depend on the application. Power measurements may require diode, Schottky, EO, bolometer, or thermal detectors depending on the frequency and the power level. Detectors for frequency measurement typically require heterodyne techniques with harmonic detectors, and will require stable LO sources. NIST is currently working on a quantum field probe for these types of measurements (https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7256207).

In paragraph 84 of the NPRM, the notice reads "Are there industry measurement standards available for RF devices operating above 95 GHz."

The establishment of traceable methods of power measurement & waveform measurement prior to the definition of a compliance standard is essential. The industry is moving toward new standardized waveguides. There is currently no accepted power measurement industry standard for mm-wave power above 110 GHz. NIST and others (e.g. PTB, NPL) are working to establish traceable methods of power measurement & waveform measurement. The standard should also consider compliance performance close to the band edges to be different from mid band performance.

In paragraph 84 of the NPRM, the notice reads "We seek further comment on whether and how present procedures can be adapted or modified to appropriately address the specific technical challenges presented by millimeter wave devices."

The key technical challenges are that the measurement instruments must have highly sensitive receivers that will detect very low levels of power. Thus, a method

of detection may include a fundamental tool like a calorimeter as the front end to a measurement system like a spectrum or network analysis tool. Additionally, at these frequencies the coupling impedance will change with frequency, posing the need to define at what specific frequencies the measurements need to be done. Procedures and methods at higher frequencies will require equipment that becomes more specialized, where components are less widely available, and S/N ratios may be less. At these frequencies link budgets are in general, less generous and more care is required with connectors and waveguide connections and alignment accuracies will be more critical for radiated measurements. For signal power generation, semiconductor technology will be banded and desired power levels may depend on the application and frequency. In our view 140 GHz and 220 GHz are the best bands for long-range transmission.

In paragraph 85 of the NPRM, the notice reads "We seek comment on what other measurement procedures, such as those in ANSI C63.102013, may be used and whether we need to provide additional guidance (e.g., appropriate measurement bandwidth, cut-off frequency, etc.) to determine compliance with the out-of-band and spurious emission limits for millimeter-wave devices considering the technical challenges of such measurements."

Since the transmission is banded, a cut-off frequency is going to be essential. In addition, sensitivity will be dependent on the measurement bandwidth, this is certainly something that will be needed and the sensitivity and power in-band is going to be a key part of this. The conduct of out of band and spurious

measurements will require additional instruments especially if the spurious signals are at a higher frequency than the main transmission frequency.

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We appreciate the opportunity to comment on the FCC proposed rulemaking.

Yours sincerely,

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