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Novel Low THz Frequency Extenders for Vector Network Analyzers

D R Vizard¹, E G Hoare², M Gashinova² and M Cherniakov²

¹ VivaTech SARL, Nice, France

² EECE, University of Birmingham, Birmingham, UK

Email: drv@vivatech.biz

Abstract. The Low THz spectrum has potential for high resolution imaging applications such as automotive radars and high data rate communications. Propagation studies and test platforms require compact portable equipment which may be achieved by extending the frequency range of commercial battery powered vector network analyzers (VNA). The development of both desktop and portable 110 – 670 GHz VNA based extenders is described along with some recent experimental test data using these instruments.

1. Introduction

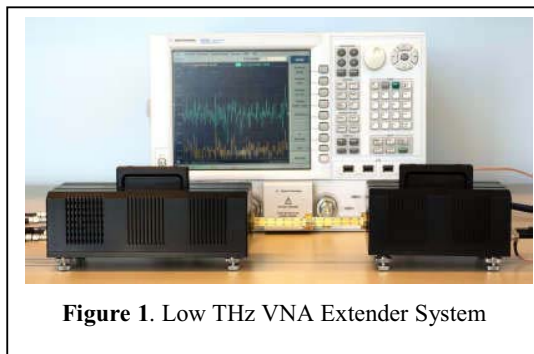
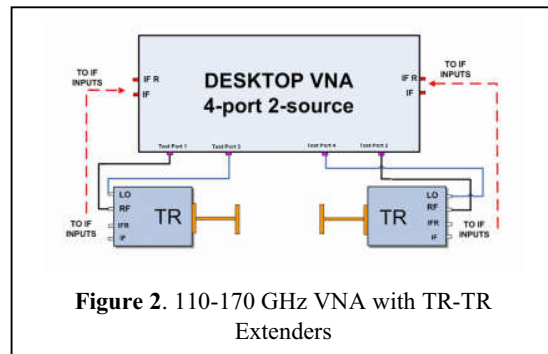
Autonomous navigation and ‘hands-off’ driving are widely anticipated features of future vehicles and mobile robots, where smart sensors must establish vehicle “cognition” under all weather conditions. The TeraHertz (THz) portion of the electromagnetic spectrum may be exploited to enable the high definition imaging radar systems required. Further, the needs of high data rate communications require the development of THz transmitter and receiver systems. Current solid state semiconductor THz technologies allow the implementation of VNA (Vector Network Analyzer) extenders and test instruments essential to the development of components and systems. Compact and battery portable equipment ideal for field testing can also be based on low cost commercial VNA’s by adding appropriate THz extenders. This paper is an extended version of a presentation at the IEEE 2018 Radio Days, Mauritius, Oct. 2018. [4]

2. Desktop VNA Extenders

Laboratory VNA’s are in extensive use but are in general limited to < 40 GHz coverage. Beyond this frequency ‘add-on’ extenders can be used to reach up to 1.1 THz, depending on the instrument in question. They are, however, bulky and best suited to laboratory environments. Such extenders rely upon the access to the internal oscillators and IF chain of the instrument. A common approach is to generate the higher frequencies by multiplication of the VNA internal microwave oscillators and use a harmonic mixer down-conversion process in the receiver. By using internal high-directivity couplers the full range of S-parameters can be extracted by comparisons of the transmitted and received power levels. An example of a 110 – 170 GHz VNA desktop extender is shown in figure 1. The conventional interface to a standard microwave VNA is described in figure 2.

The device under test (DUT) is placed between the waveguide ports of the two TR (transceiver) extender units. In this way, the S-parameters can be determined by exciting the DUT in transmission or reflection from either direction.

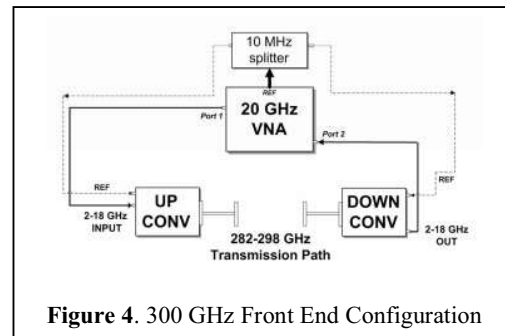


**Figure 1.** Low THz VNA Extender System**Figure 2.** 110-170 GHz VNA with TR-TR Extenders

3. Portable VNA Extenders

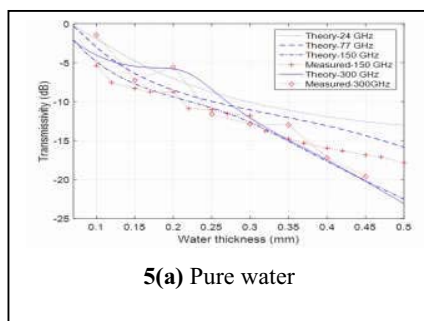
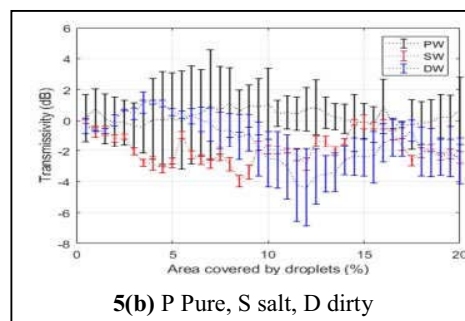
Recent developments in compact portable battery powered VNA instruments allow their use in field applications such as tower testing in communications, spectrum monitoring and others. Such instruments are available up to 50 GHz and may be readily adapted to THz applications such as field trials of automotive radars and others.

Novel architectures are required for such extenders, however, because these portable instruments have no access to their internal microwave local oscillators and receiver IF chains. A solution that we have implemented uses up and down converters phase locked to the instrument 10 MHz reference clock to generate the required THz transmission and receiver functions. The dynamic range equals or exceeds that of conventional desktop instruments and enables their use in field trials of communication systems or automotive research. Further, interfaces are considerably simplified. An example of an extender configuration operating at 300 GHz is described in figures 3 & 4. The system forms the front end for an experimental automotive radar. The transmit power was -10 dBm (100uW) and the receiver noise figure is 14 dB (DSB).

**Figure 3.** Portable 300 GHz VNA Radar Front**Figure 4.** 300 GHz Front End Configuration

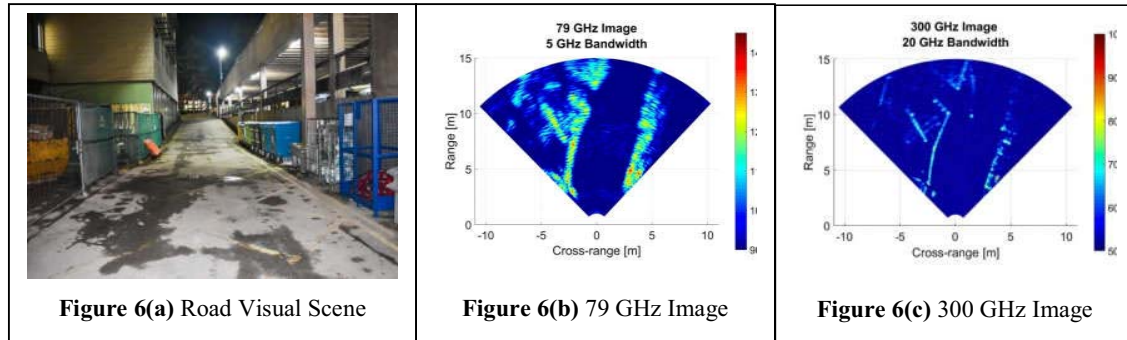
4. Radome Transmissivity Measurements

The 300 GHz VNA radar front end was used to measure the transmission properties of thin water films on radome material, and compare these with data and measurements at lower frequencies. Additionally, the effect of a range of contaminants found in typical automotive environments, such as salt, sand, diesel and gasoline fuel was measured. Compilations shown in figures 5 (a) and (b) demonstrates that there is no dramatic difference between the transmissivity of thin water films at common automotive frequencies (24 and 77 GHz) and at low THz frequencies (150 and 300 GHz). Full details of this work are available in Ref [3].

**5(a)** Pure water**5(b)** P Pure, S salt, D dirty**Figure 5.** Comparative Transmissivity of Water Films 24-300 GHz

5. Radar Resolution Comparison Measurements 77/300 GHz

In order to demonstrate the improved resolution that may be achieved with the 300 GHz radar, a comparison was made between the low THz mobile test platform and a 77 – 79 GHz radar of equivalent antenna beam pattern. The radars were mechanically scanned over the same azimuth plane, viewing a typical mixed road scene (figures 6a, 6b, 6c).



6. A 656-672 GHz Hybrid VNA Extender

In order to further improve resolution and explore the THz transmission properties of the atmosphere and materials under adverse conditions (snow, ice, fog, dirt and dust) a 670 GHz extender was developed. A radar using this extender will be used to evaluate the achievable range and resolution when operating in this frequency band. Given the shorter wavelength obtaining sufficient transmitter power for an effective radar is challenging. The use of a converter approach as deployed at 300 GHz would provide inadequate output power due to the limitations of mixer up-converters at 670 GHz. This is due to the reduced output power of a mixer based up-converter which is constrained by : (a) saturation of the mixer, (b) available local oscillator drive power and (c) mixer conversion loss.

A comparison of these parameters for 300 GHz and 670 GHz mixer up-converters predicted an expected output power reduction of 10 – 15 dB for the higher frequency, (see table 1).

Table 1. Comparison of Mixer Upconverter Output Power at 300 and 670 GHz

Frequency (GHz)	Measured Output Power (dBm)	Extrapolated Output Power (dBm)
300	-15	
670		-25 to -30

Considering the 670 GHz output power estimates, a novel hybrid design was developed which provided up to 15 dB more power than an up-converter approach, by driving a multiplier chain from the converter/divider arrangement described schematically in figure 8. The method uses a X36 multiplier chain as the transmitter whilst maintaining the same frequency plan required by the portable VNA architecture. This was achieved by feeding the multiplier chain with a frequency divided by the same multiple, in this case 36, whilst applying a suitable frequency offset from a stable secondary source, phase locked to the VNA reference clock.

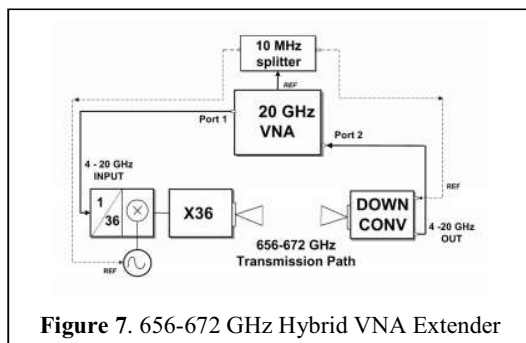


Figure 7. 656-672 GHz Hybrid VNA Extender

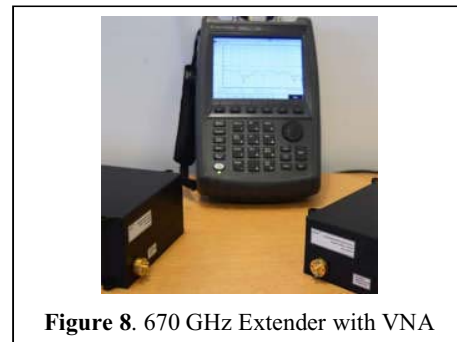


Figure 8. 670 GHz Extender with VNA

In this way an additional 15 dB of transmitter output power was obtained when compared with a mixer up-converter approach. The system produces - 10.5 dBm typical transmit power and has a receiver noise figure of 12 to 14 dB DSB in the band 656 – 672 GHz. These results represent state-of-art performance for wideband transmitter/receiver systems at this wavelength.

7. 670 GHz Water Film Transmission Measurement

The hybrid VNA extender was used to measure 670 GHz transmission losses in thin water films. A theoretical model based on Fresnel theory of reflection and transmission for multilayer structures, air-water-air, was adopted. The complex refractive index of a material $\tilde{n}(f,T) = n - jn$, which depends on both frequency and temperature, will result in reflection of some of the energy at the first medium interface and the rest of the energy will be transmitted through the second medium. The reflection and transmission coefficients of each layer depend on the permittivity, thickness, and shape of the layer. A water film of known thickness may be modelled from its conductivity, magnetic permeability and dielectric permittivity. The experimental test set-up is shown in figure 10, and a comparison between a theoretical model and measurements is shown in figure 11. Results confirm current models provide good estimates of 670 GHz transmission losses for water films in the thickness range 0.1-0.45 mm.

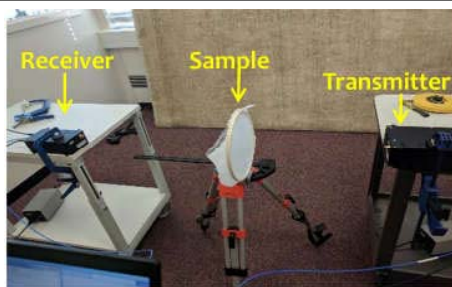


Figure 9. Transmission Test Arrangement

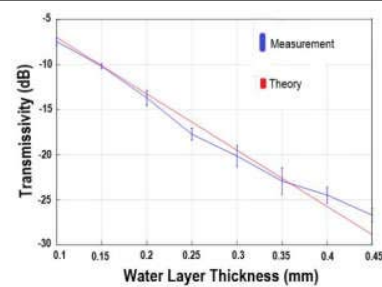


Figure 10. Water Thickness vs. Transmission

8. Conclusion

Following the success of 300 GHz propagation and radar imaging experiments, a 670 GHz hybrid VNA extender has been completed and will be used to (i) make atmospheric transmission measurements under adverse conditions and (ii) test radar performance. The development of this portable 670 GHz radar front end was described along with transmission tests of thin water films.

Acknowledgments

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9. References

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