A brief introduction to terahertz measurement of films, sheets, and coatings.

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-	22/06/2021	JMB	First draft
	11/10/2021	JMB	Modified to extract from longer document
	11/05/2022	JMB	Additional accessories added

'What is a Terahertz?'

Terahertz radiation is in the part of the electromagnetic spectrum which lies between microwaves and the far infrared,

For NDT applications we typically use frequencies around 100 GHz up to about three TeraHertz, this represents frequencies that give a wavelength in free space from around 3mm down to 100 microns, i.e. comparable to the wavelengths that we are used to dealing with for ultrasound

THz radiation penetrates through most non-conductive materials, it can measure thickness and can reveal imperfections such as voids, cracks, and variations in density. A key advantage is that TeraHertz radiation is non-ionizing and involves no safety issues.

When terahertz waves pass through an interface between materials having different dielectric constants some of the energy is reflected. The strength of this reflection will depend primarily on how different the dielectric constants are. With a conductive material none of the energy is transmitted. We can measure the strength and timing of these reflections and we can then calculate the thickness of the material layers and assess whether they are intimately bonded.

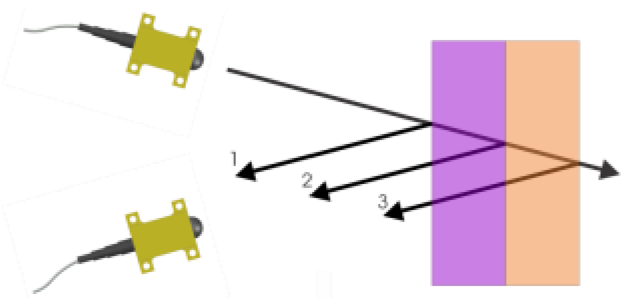

Figure 1 Reflections from layers

Generation and measurement of Terahertz energy

We generate the terahertz radiation by putting an electrical bias across a specialized photoconductive antenna, when we hit this with a very short (around 100 femtosecond) laser light pulse it will conduct, giving a short (2-300 fs) burst of electromagnetic radiation. This transmitter can be packaged like a standard telecom component to make the equipment reliable and robust which of course is important in practical NDT applications.

To detect the reflected or transmitted terahertz energy we use a similar device which becomes conductive when hit with a laser pulse - the resultant current is the product of the laser on off parameter and the energy of the incoming terahertz wave at that instant.

Figure 2 Terahertz transmit and receive transducers

By setting the delay between the transmit and receive laser pulses we can measure a specific point on the waveform, by changing this delay while firing the laser at a high repetition rate (around 80MHz) we can produce a digitized waveform .

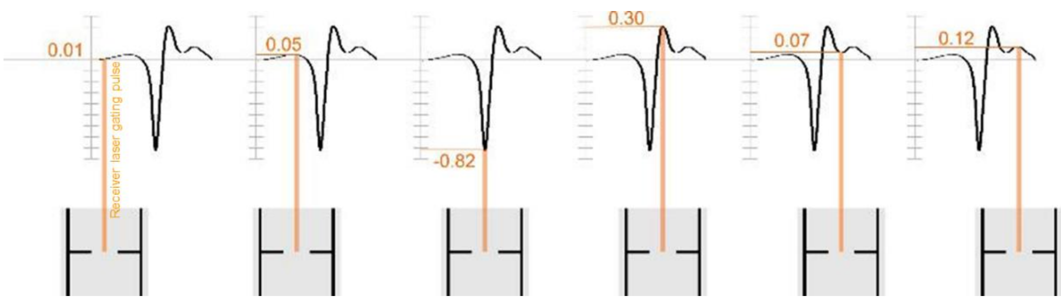

Figure 3 Reconstructing a terahertz signal by moving the measurement point.

In the Terametrix equipment this is done by a rotating multi-faceted mirror which can scan through a time range of several hundred picoseconds at a rate of up to 1000 times a second. This repeating scan is combined with a longer variable delay (multiple reflections) allowing the scanning range to be accurately positioned.

The Terahertz laser system is connected to the transducer element using a precision umbilical cable containing high quality fibre optics, to maintain the laser pulse fidelity a special compensation system, providing a wavelength dependent delay, is required to balance the dispersion within the fibre optic cable.

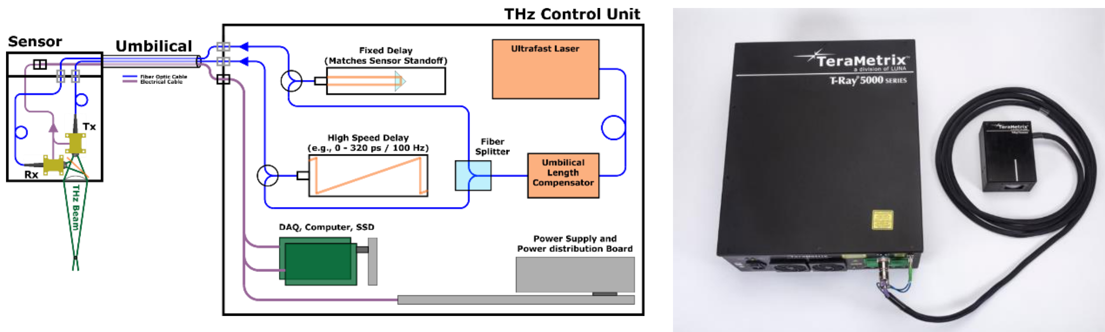

Figure 4 Block diagram of Terahertz system.

To improve resolution and signal clarity of the received signal it can be digitally processed in several ways.

The transmitter device produces energy over a wide spectrum, this can only be altered by changing its physical design., but the digitized signal can be filtered. Generally, the 'Low bandwidth' filtering gives cleaner results, increasing the bandwidth may be required on very thin layers

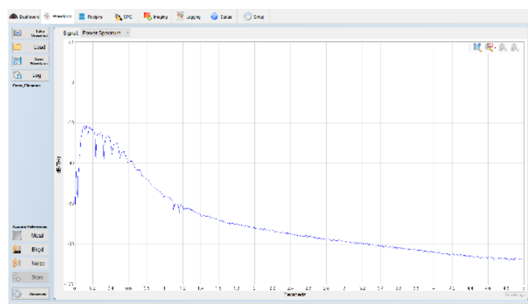

Figure 5 TeraHertz energy spectrum

To improve resolution a 'deconvolution' algorithm processes the signal based on a known signal from a smooth metal surface.

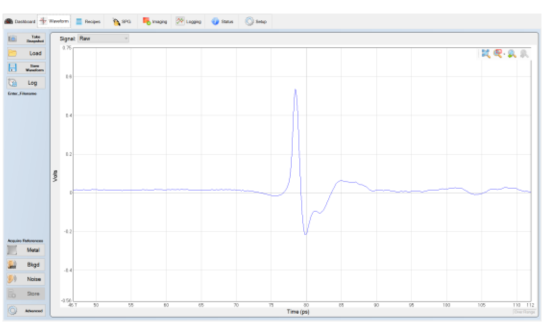

Figure 6 Reference signal from Metal surface

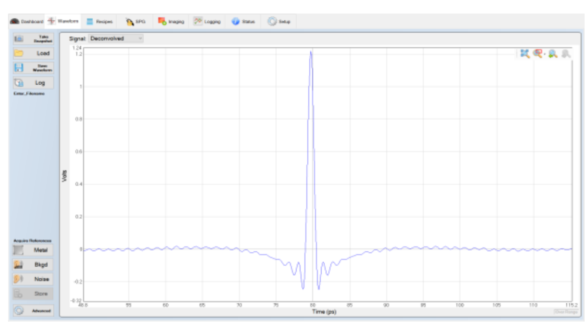

Figure 7 Deconvolved signal from metal surface

Using this deconvolution process generally gives signals which are easier to interpret and gate

Measurement of Films / Sheets

This can be seen in the reflections from a thin plastic shim, normally we will get a positive reflection when passing from air to a material with higher dielectric constant, a negative one when passing back to air

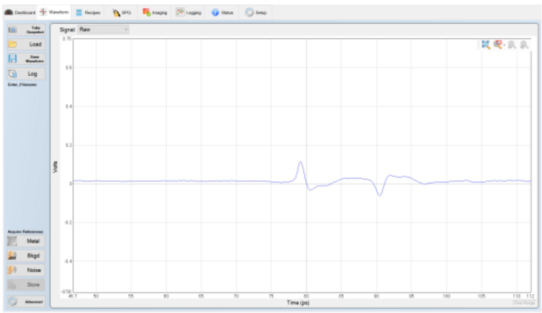

Figure 8 Raw signal from a thin (approx. 1mm) plastic shim

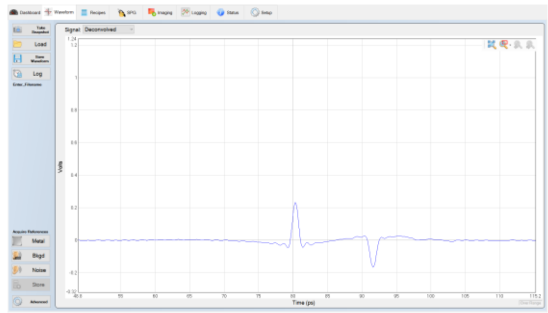

Figure 9 Deconvolved signal from a thin (approx. 1mm) plastic shim

Suitable measurement gates can be applied to this signal, allowing accurate timing, and thus thickness, assessments

We can measure structures having multiple layers. The waveform below shows a three layer plastic sheet.

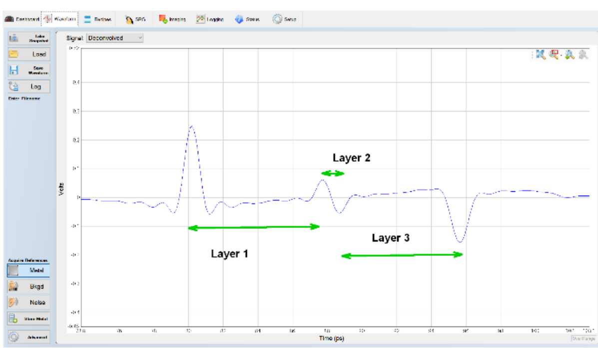

Figure 10 Reflections from three-layer sheet

For thicker materials we will see a similar image, although typically there will be some internal reflections and noise, and in some materials the ‘exit’ signal amplitude will be significantly reduced

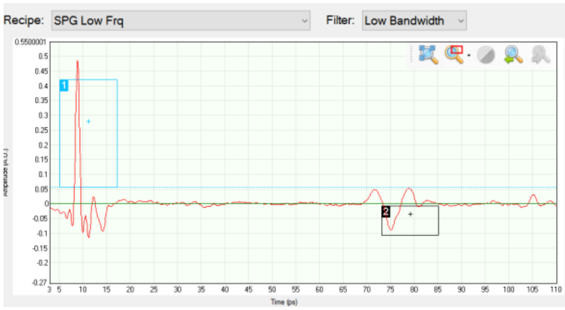

Figure 11 Thicker composite material, showing front and rear reflections.

Where signals are uncertain, a metal 'target' behind the material can be used to confirm that energy is getting through.

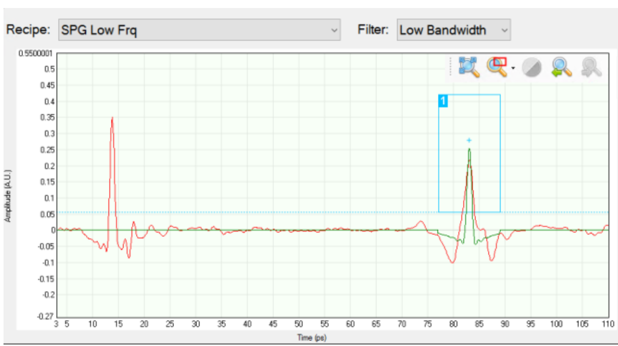

Figure 12 As previous, showing reflection from a far side metal target (coin)

Defects will show as 'extra' reflections, as with ultrasonics.

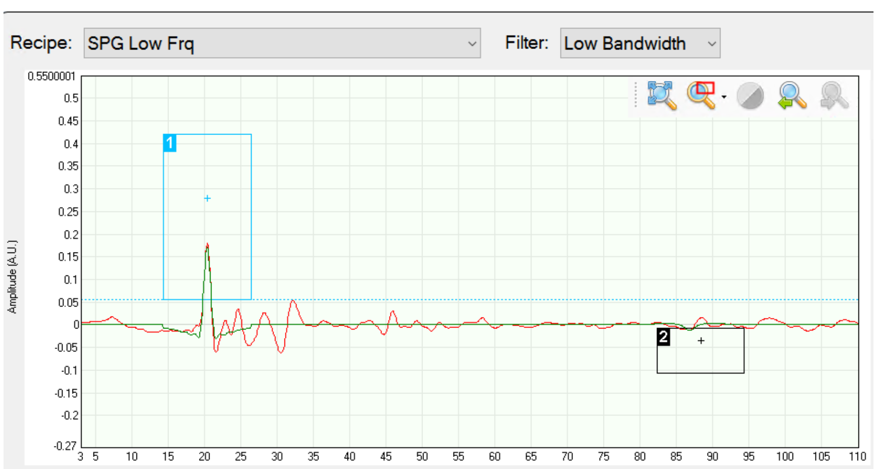

Figure 13 Extra reflections from damaged area.

Measurement of coatings

The reflections from coatings on conductive surfaces are similar, the relative strength and polarity of the reflections will depend on the thickness and dielectric constants on the materials involved, examples:

Paint on metal, using a high bandwidth filter, the paint layer is around 100 um, combined with the low dielectric constant this gives a short transit time, making the reflections relatively hard to distinguish.

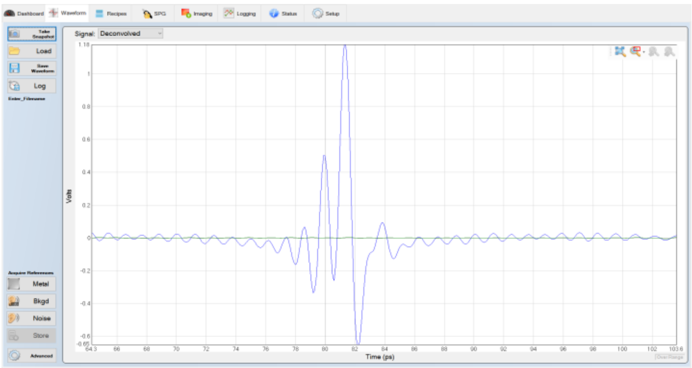

Figure 14 Terahertz signals from paint on metal

Plastic coating on metal – low dielectric constant, thicker, so easier to measure. Note the second reflection – reflected twice through the coating

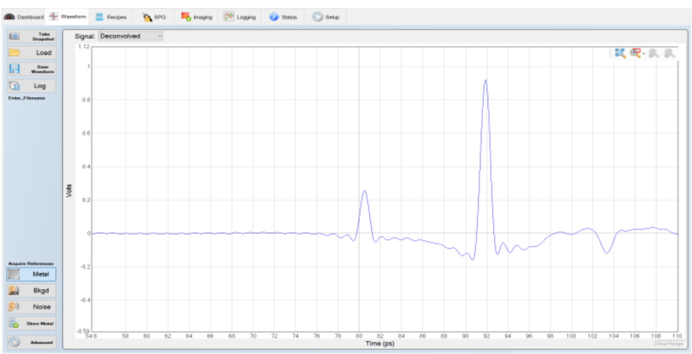

Figure 15 Terahertz signals from thick plastic coating on metal

Ceramic coating – High dielectric constant – Much more of the energy is reflected at the surface of the coating, so the fraction of energy penetrating to the metal substrate is much less. The initial signal is larger than the reflection from the ceramic-metal interface. Again, multiple reflections are visible.

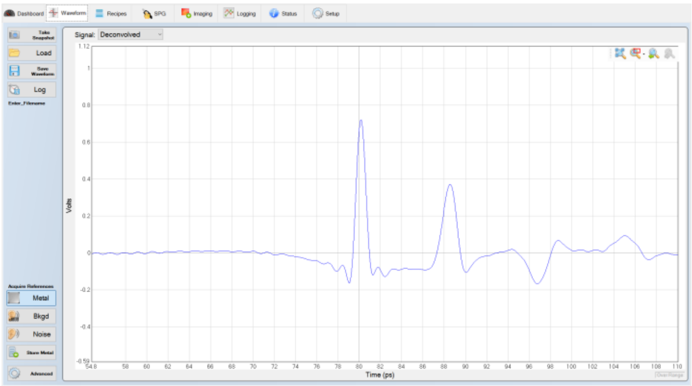

Figure 16 Terahertz signals from ceramic coating on metal

Paint on Carbon fiber composite – while much of the energy is reflected at the paint to carbon interface some is transmitted into the composite and absorbed.

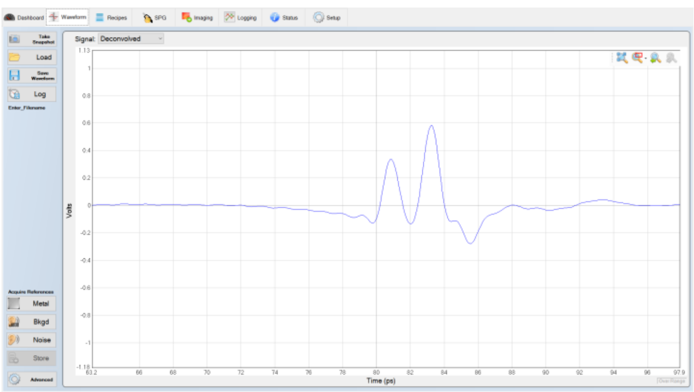

Figure 17 Terahertz signals from paint on carbon composite

Sensor Heads

For coating and film thickness measurement a colinear geometry sensor (internal beam splitter) is used. These contain:

- Transmitter module
- Receiver module
- Beam splitter
- Lens

The lenses are made from a polymer material and have a fixed focus, normally 25, 75 or 150mm, the test head must be accurately positioned at the correct distance to obtain a small focal spot size, typically around 2mm. The Terahertz control unit delay line should be adjusted so that the reflection comes to around the mid-point of the display range.

There are three standard test head configurations available, all have essentially identical performance.

Online sensor Head HXC50yn

- Designed for mounting on process equipment or on a scanner system
- 178 x 128 x 64mm, 1.6 kg
- 25, 75 or 150mm focus
- Sealed design – dust resistant
- Cleanable
- 5, 10 or 30m umbilical
- High resolution transmitter option available.
- Lowest cost option.

Figure 18 Online sensor head.

Explosion Proof online Sensor CID1- SCS500n

- Designed for mounting on spray system in Paint Booth or similar – allows precise monitoring and control of coating thickness.
- Low profile design to minimize mechanical interference
- 114mm fixed focus option.
- Safe in explosive atmospheres
- Solvent resistant design
- High resolution transmitter option available.
- Designed to be steam-cleanable
- 10m umbilical with Barrier junction box and 5m extension. (20m option)

Figure 19 Explosion-proof sensor

Separate transmit receive heads

A variety of transmit and receive heads, optimized for different applications, are available.

They can be mounted on a rail, combined on a suitable scanner, or used in conjunction with a 'collinear adapter' for reflection mode.

Figure 20 Transmitter (or receiver, appearance is identical)

Figure 21 colinear adapter

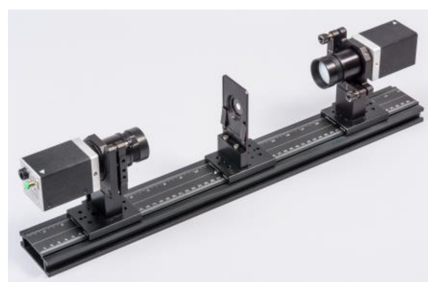

Figure 22 Spectroscopy Rail (60cm long)

Single Point Gauge SPG500n

- Handheld unit
- Ergonomic design for use without fatigue
- Touchscreen control
- Works with custom software module for TCU
- Screen can show single, dual, or three-layer measurements
- Trigger operation
- 25mm or 75mm focus, interchangeable without tools
- Conical tip for accurate positioning
- Sensing area can be swapped from 'front' to 'top' without tools

Figure 23 Single point Gauge

Line Scan Gauge

The line scan gauge includes an internal scanner, capable of shifting the terahertz beam back and forth across a width of up to 75mm at 4 times per second, or up to 8 times per second. for a shorter Sweep. This allows a B-scan image to be produced, and programming can simultaneous measure spacing between features.

The Line Scan Gauge requires appropriate software to be installed on the TCU.

- One hand operation
- Ergonomic design for use without fatigue, 1 kg weight
- Touchscreen control
- Works with custom software module for TCU
- Screen can show colour B-Scan or calculated measurements
- Trigger operation
- 50mm or 75mm scan width. By changing lens assembly
- Up to 8 scans per second.
- Interchangeable feet – accessories for e.g. inspection on tunes can be fitted.
- Up to 30m umbilical.

Figure 24 Line Scan Gauge

T-Image Scanner

The T-Image scanner is a portable 'C-scan system' suitable for laboratory or field work.

It is a highly versatile design which can be:

- Used vertically or horizontally
- Used in Reflection or through transmission mode.
- Used in conjunction with an external rotation support / motor to inspect cylindrical components.

It features an embedded motion controller which is linked to the secondary network interface on the TCU. The system can (with a suitable TCU) acquire up to 1000 pixels / second, moving at up to 150mm/s with a minimum resolution of 30 microns.

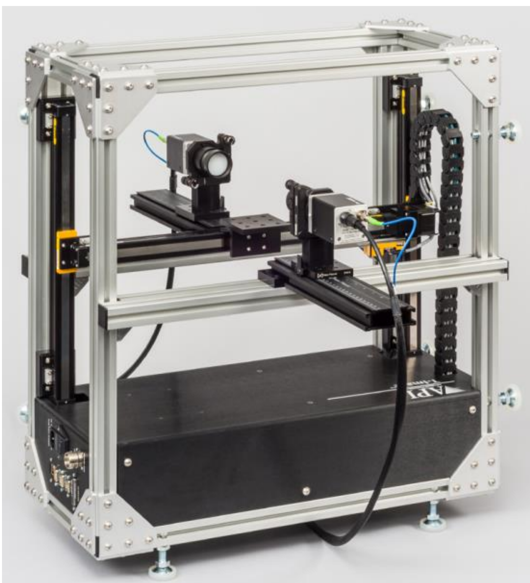

Figure 25 T-Image system configured for through-transmission with separate transmit and receive heads

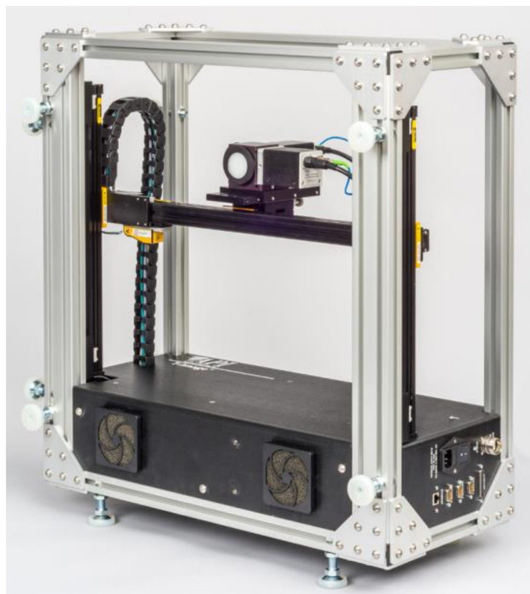

Figure 26 T-Image system configured for through-transmission with separate transmit and receive heads fitted to a colinear adapter – The online sensor can alternatively be used for reflection mode. The feet for use horizontally are visble here.

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