From August 2006 *High Frequency Electronics*

Experiments with Microwave Coherence Tomography: Part 2

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The second and final part of this article on microwave imaging provides a look at the relatively simple equipment used by the author to determine the validity of this technique at microwave frequencies

As noted in Part 1, Optical Coherence Tomography (OCT) has become practical for medical imaging applications. To explore the possibilities of Microwave Coherence Tomography (MCT), the author developed a relatively simple Michelson interferometer that operates at microwave frequencies.

The introduction to OCT and MCT in Part 1 provided background on the methods used for the MCT test setup. Part 2 now provides additional details on the hardware used for those experiments.

Michelson Interferometer

To review, Figure 1 from Part 1 is repeated below, showing the components of an optical Michelson interferometer [1],[2],[3]. An optical system has a resolution of 2 to 15 µm over the range of optical wavelengths. The longer wavelengths of a microwave system result in resolutions in the cm range, which can be useful in a number of potential applications in industrial process control, imaging the interior of opaque objects, and materials evaluation.

The microwave version of a Michelson interferometer is outlined in the diagram of Figure 2. In an effort to proceed quickly, and with low cost and complexity, the author utilized off-the-shelf components when possible, along with a simplified operational scheme.

Microwave Noise Source

OCT and MCT require partially coherent signal sources for their operation. The term "partially coherent" means that the light or microwave source has a broad bandwidth around the center frequency. The advantage of this type of source is that the interference patterns are generated within a much smaller distance than with coherent sources. With coherent light sources, interference can require meters to be observed. Partially coherent sources have, in essence, multiple signal sources with slightly different interference patterns, the sum of which can be observed at much smaller distances.

In the microwave region, the majority of signal sources are highly coherent, mainly used for information transmission or radar sensors. Noise sources are typically used for testing low-noise receivers. Avalanche-diode noise sources offer a suitable noise output

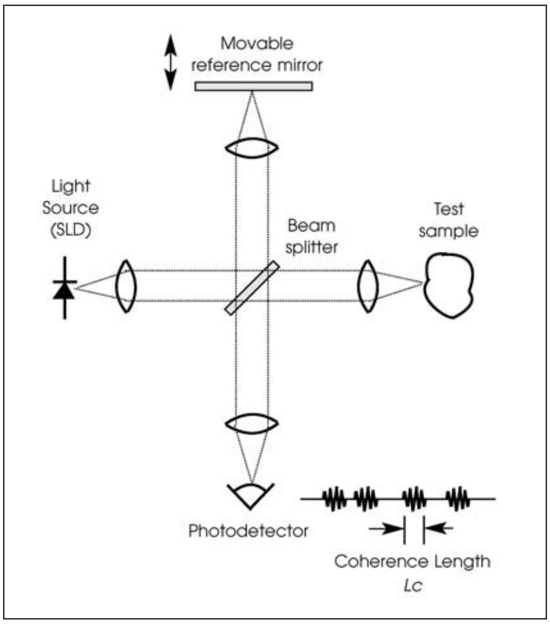

Figure 1 · Typical features of an OCT system.

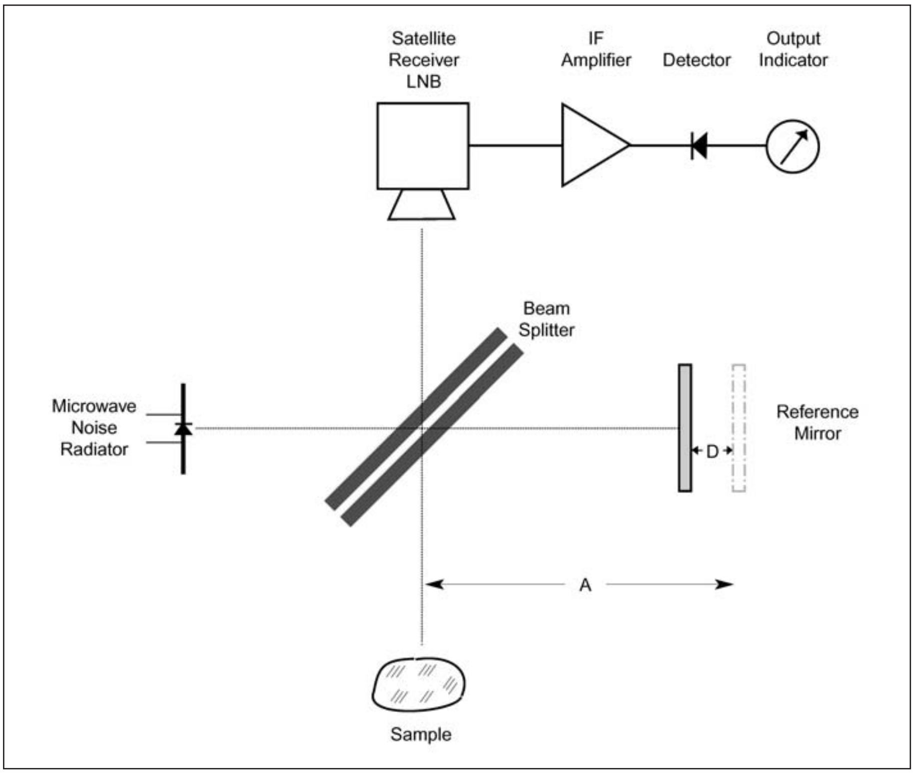

Figure 2 · Michelson interferometer setup for use in Microwave Coherence Tomography.

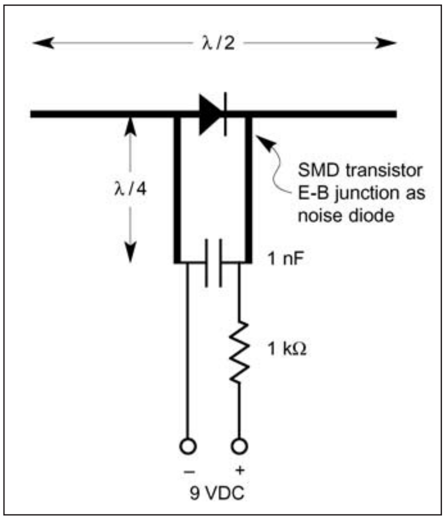

Figure 3 · The partially coherent source is provided by a noise diode (E-B junction of a transistor) connected directly to an antenna.

power, and as described in numerous papers, may be combined with dipoles or other antennas to make noise radiators. Such noise radiators exhibit partly- or non-coherent properties comparable to similar light sources used in OCT.

The author developed such a noise source for this project using a single active device [5], [6]. The emitter-base junction of an SMD transistor is used as a noise diode, and is connected directly to the terminals of a half-wave dipole antenna, which provides filtering action to concentrate the noise energy around a center frequency where the dipole is resonant ($\lambda/2$). A quarter-wave section is used to isolate the antenna from the DC connection that provides power to the transistor/diode (Figure 3).

The Beam Splitter

The beam splitter is a device not too familiar in microwave work. In optics, beam splitters utilize various materials and structures, typically one or two dielectric (glass) plates. Several structures were developed and tested to create a suitable beam splitter for the wavelength of approximately 2.5 cm for which the microwave radiometer and noise radiator were available.

Using two parallel dielectric plates as shown in Figure 2, the desired properties were experimentally verified: this beam splitter is lossless and splits the noise beam in two with equal intensities.

Moving Reference Mirror

The reference mirror in the interferometer controls the scan of the object being tested so that its reflective features may be mapped according to depth. At microwave frequencies a good mirror is a flat aluminum plate. To move it as desired a motorized-screw mechanism from a CD-player was used that offers 3 cm movement range. This movement should be used as X axis on the X-Y recorder, so a 10-turn potentiometer was linked to the mirror as shown in the diagram of Figure 4.

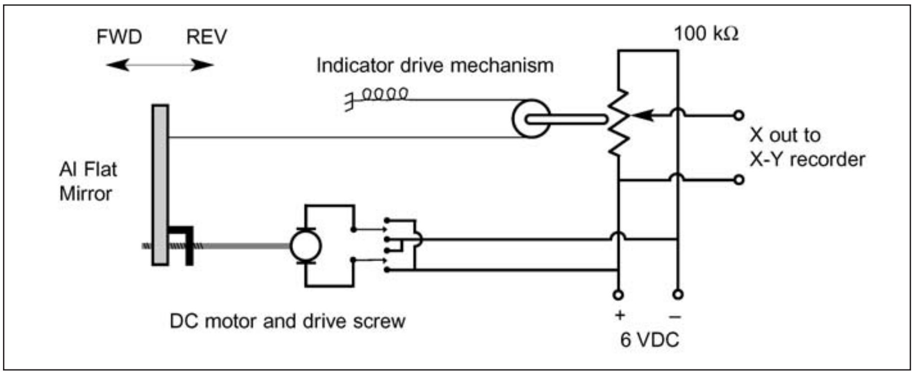

Figure 4 · Construction of the moving reference mirror assembly, with position indication for an X-Y recorder.

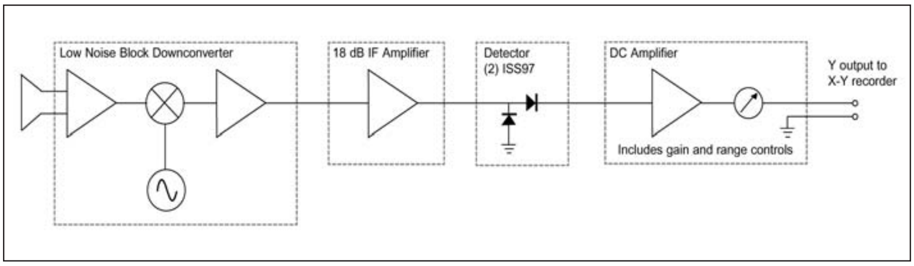

Figure 5 · Block diagram of the microwave radiometer constructed from low cost components.

The Microwave Radiometer

In OCT technology, the light source is usually capable of a high output power, so to detect the light at interferometer output, a simple photodetector is suitable.

At microwaves, noise source output power is weaker by several orders of magnitude. This disadvantage must be balanced by using a more sensitive detector. To accomplish this, a multistage amplifier must be used before a broadband detector. For this project, common satellite-TV low-noise block converters (LNBs) offer excellent sensitivity performance at low cost. An additional in-line IF amplifier is added before the IF detector. A DC operational amplifier and indicator is connected to indicate the relative amplitude of the detected signal. A block diagram of the radiometer assembly is shown in Figure 5. For MCT sample tests, an X/Y recorder was connected as shown.

Experiments

First the noise radiator and microwave radiometer had to be tested. The noise radiator is biased from a 9 to 15 VDC source, controlled by either the source voltage or the series resistor. Diode current was set to obtain a maximum response in the radiometer. A typical current is between 5 and 10 mA.

Figure 2 in Part 1 shows a set of test results with several readily-available objects. Signatures are well expressed with the mirror distance moved from 9 to 8 cm from the beam splitter. At closer distances, the signatures are weak. The explanation may be the LNB sensitivity to close objects. This indicates that for a particular interferometer, an optimum range of reference-mirror movement must be found.

In those experiments, the width of the beam at sample location was not focused by any lens, so no third-dimension resolution was seen. Like in OCT, lenses will have to be designed and tested to narrow the probing beam at the sample.

According to the equations presented in Part 1, the coherence length, and the longitudinal resolution in OCT is

$$Lc = 0.44\ \lambda/\Delta\lambda$$

or 2 to 15 µm for visible light. $\Delta\lambda$ is the amount of wavelength spreading.

For the microwave noise radiator, Lc ~ 0.046 cm from this formula, but ~1.7 cm from author's independent Lc measurement using a correlation function test [4]. The observed signatures, however, appear to demonstrate that the actual depth resolution is shorter than 1 cm.

The lateral resolution by focusing optics can be 1-10 µm for visible light. In the MCT experiment, no such optics were used, so the lateral resolution was not observed. It is planned to design a microwave dielectric lens for this purpose.

Conclusion

The presented experiment and its results indicate that the successful development of OCT in optical region can be extended into microwave and mm-wave region. A new class of sensors may emerge which can probe various objects in depth.

Applications

Like OCT, medical applications are also possible with MCT. The cm-range resolution may be improved to mm-range at frequencies higher than the experimental system described here. At these resolutions, real-time imaging of the internal organs of the human body may be possible, similar to ultrasound, but without the need for physical contact.

Additional applications are possible in industrial process control, evaluation of materials, or observations into optically opaque, but microwave translucent, objects.

References

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