Noise versus coherency in mm-wave material characterization

B. Kapilevich(1), J.Polivka(2)

(1)Department of Electrical and Electronics Engineering, The Ariel University Center of Samaria, Ariel – 40700, Israel. (2) Spacek Labs. Inc., Santa Barbara, CA, U.S.A.

***Abstract* — Comparison of coherent and noise probing is described in order to formulate the criteria for characterization of materials on mm-wave and microwave frequencies. Double-layers dielectric structure having Fabry-Perot resonator properties is employed to develop accurate mathematical model and to predict transmittances for both coherent and noise illuminations. Experiments have proved the basic modeling predictions as well as the role of noise bandwidth in averaging process used in material characterizations.**

I. Introduction And Background

Microwave and mm-wave sensors employed for material characterization have basically used a CW (or modulated) signals. However, incoherent (noise-like) signal may provide some advantages [1]. But noisy EM fields require development sensitive wideband detectors as noise sources deliver a power measured in nanowatts. These detectors must be designed and installed so that interfering signals cannot disrupt there operations. Using EM noise in sensors allows the tested objects and materials to move while with a CW signal any movement or spatial instability > 0.1 wavelengths is extremely disturbing. The situation is becoming more critical when coherent signals are used for characterization of dense inhomogeneous materials like various dielectric granules [2]. In this case, strong depolarization and undesirable interference are typical for backward-forward scattering. The latter is more essential for mm and sub-mm wavelength when dimensions of irregularities are comparable with wavelength. The paper presents an attempt of formulating the criteria of application of noise and coherent signals in material characterization based on the suggested model verified by experiments.

II. Modeling Intereference in Presence of Noise

Multi-layers plane-parallel dielectric structure, Fig.1, is a good candidate for comparison interference-noise averaging effects. Indeed, when the distance between layers is varied, a spatial distribution of the interference maxima (minima) is taking place. A periodicity, swing and height of interference maxima (minima) depend on both real and imaginary parts of refractive index n and k (or complex dielectric constant $\varepsilon'=n^2-k^2$, $\varepsilon''=2nk$). By recording the transmitted signal we can easily compare interferogram for coherent and noise illuminating fields.

The plane-parallel cell employed in the experiments consists of the two dielectric plates of thickness t separated by air gap. The transmitted energy is captured by wideband detector. In order to create a transmittance interferogram the adjustable air gap L is introduced. When illuminating signal is frequency limited noise field we need to introduce some assumptions:

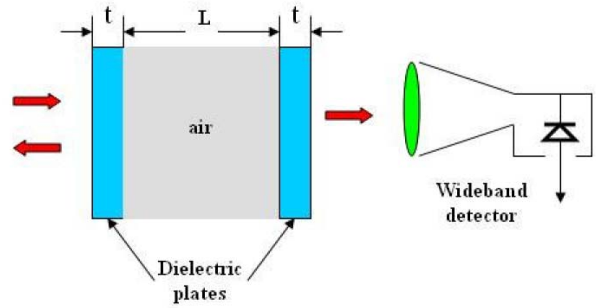

Fig. 1. Configuration of the measuring cell used in THz experiments.

1. Noise waveform occupies the band $f_c - BW/2$ to $f_c + BW/2$, where BW is the bandwidth of the frequency limited noise signal;
2. Power spectral density is uniform randomly distributed function within the specified BW.

Following [3], the total averaged transmitted power transmittance T_{av} will be given by the following expression

$$T_{av} = \int_{f_c+BW/2}^{f_c+BW/2} T_p(f)D(f)df \qquad (1)$$

where $D(f)$ is the normalized uniform random distribution spectral density.

Figure 1 illustrates calculated transmittances as a function of distance for dielectric plates fabricated from alumina (t = 2.19mm, ε_{rt}= 9.6 and $tan\delta$ = 0.001) when they are illuminated by coherent (at f = 95 GHz) and incoherent signals, plots (A) and (B) respectively. Beginning from the value of the noise bandwidth Δ =30% and more the noise averaged power transmittance tends to its weighted median value near T_{av} = 0.45.

III. Experimental setups

The two experimental setups in W- and K_u bands were designed and tested. The block diagram of the W-band setup is depicted Fig.3. It consists of W-band coherent source (1) and full W-band (75-110 GHz) noise source (2) with ENR 13-15 dB. The output power of the coherent source is quite high and direct reading attenuator (3) is added to avoid overloading of the pyroelectric detector (8). On the other hand, the output power of the noise source is low in order to be directly measured by the detector. Therefore, the LNA (4) with gain 30dB is added to its output. Both coherent and incoherent sources are connected alternately to the horn antenna (5) whose aperture is overlapping by the chopper (6) needed for AM modulation with frequency 10 Hz. The programmable micro-stepper is used for changing distance L between the two dielectric plates (7) with accuracy about 2 μm. The slabs of thickness t = 2.19mm were fabricated from Al_2O_3 . One of the plates is fixed on the optical table while the second one is mounted directly on the input window of the detector so that both detector and the second plate are moving in longitudinal

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direction simultaneously varying the distance *L* between the dielectric plates. The detected signal is filtered by BPF (9) with the central frequency *f = 10 Hz* and amplified by operational amp (10). The digital scope (11) is used for recording the detected signal.

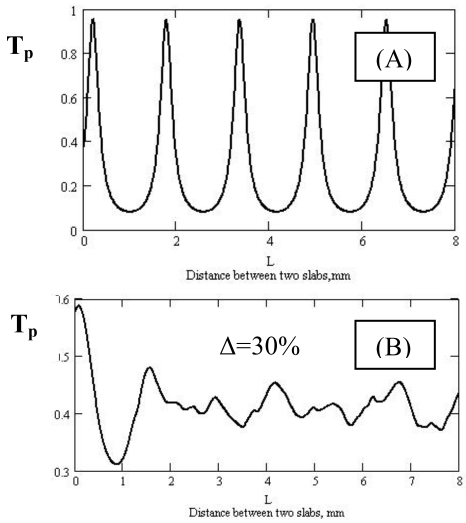

Fig. 2. Calculated transmittance for the double-layer cell illuminated by coherent signal (A) and by frequency limited noise with 30%.bandwidth (B).

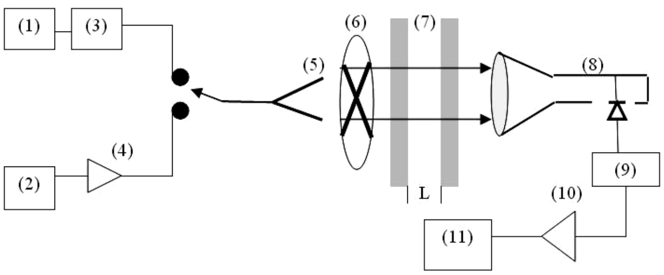

Fig. 3 Block-diagram of the W-band experimental setup using for noise versus coherency comparison.

Using the radiometer described in [1], twin-dielectric-plate Fabry-Perot resonators with varying L were tested under a CW and noise illuminations in K_u - band. Also, bandpass filter with ~ 0.8 GHz bandwidth was added in some experiments to increase the noise coherence.

IV. Experimental results: noise versus coherency

Figure 4 shows the measured transmittance interferogram as a function of the distance between them for coherent illumination at frequency 96.5 GHz. Similar measurements were performed with incoherent illumination of the same plates and depicted in Fig. 5. It can be seen that the variation of magnitude of transmitted signal is much more less compared with coherent illumination proving the concept of noise averaging.

Using the suggested model we have estimated the averaged power transmittance 0.4 with 20-30% noise bandwidth. The measured transmittance was about 0.38 – 0.42 for noise illumination with same bandwidth.

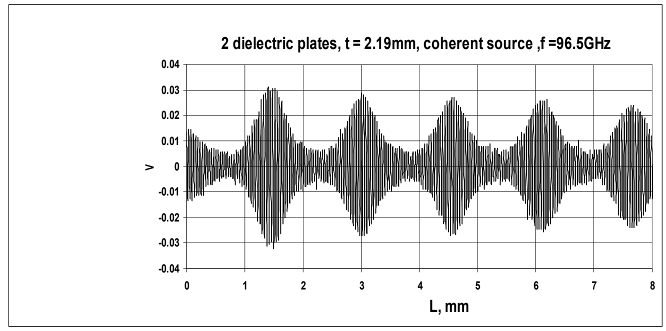

Fig. 4. The detector's output as a function of the distance between the two dielectric plates for coherent illumination at frequency 96.5 GHz.

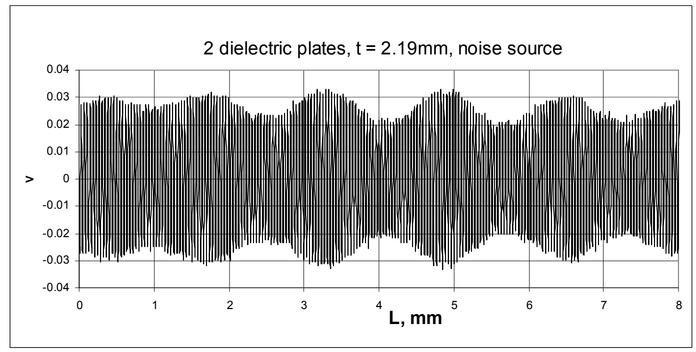

Fig. 5.The detector's output as a function of the distance between the two dielectric plates for incoherent illumination with 20% bandwidth.

The experiments in Ku-band were performed under the following conditions:

- A CW signal at 11.5 GHz, fully coherent, produced an interferogram with well pronounced maxima and minima, like in Fig. 2A;
- A noise from a source with ENR~30 dB, and a bandwidth of ~1.8 GHz produced a "flat" interferogram like in Fig.5;
- A bandpass filter with ~0.8 GHz bandwidth was used to increase the noise coherence; the interferogram was similar to Fig.4.

The experiments with different degrees of coherence confirmed, in principle, the results expected by the theory of coherence in optics

V. Conclusion

Based on modeling and experiments we have determined that the "good-of-fit" confidence level of the frequency limited noise is about 25% of the CW carrier. This level is recommended as a criterion of noise versus coherency competition in mm waves and microwave characterizations of inhomogeneous materials.

References

[1] Polivka, J.: Noise Can Be Good, Too, Microwave Journal, March 2004, pp.66-78

[2] B.Kapilevich, B.Litvak, T.Ben Yehuda and O.Shotman, Comparative characteristics of coherent and incoherent microwave scattering in dense inhomogeneous layers, Russian Physics Journal, Vol.49, no.9, 2006, pp.913-916.

[3] M.Ghavami, L.B.Michael, R.Konho, *Ultra Wideband Signals and Systems in Communication Engineering,* John Wiley & Sons, 2004, p.108-110.

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