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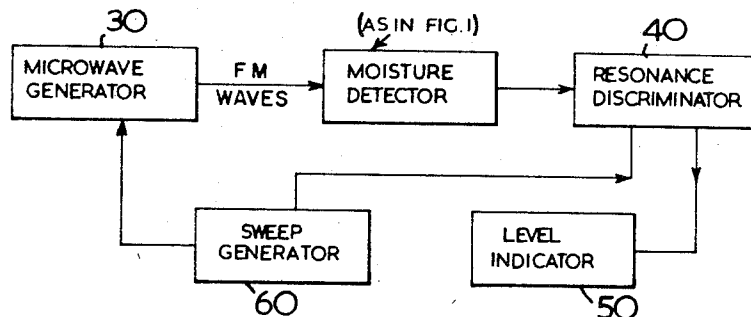
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[54] **MICROWAVE APPARATUS FOR ASCERTAINING
 CHANGES IN DIELECTRIC PROPERTIES
 UTILIZING A SLOW WAVE STRUCTURE**
 8 Claims, 4 Drawing Figs.

[52] U.S. Cl. 324/58.5 C
 [51] Int. Cl. G01r 27/04
 [50] Field of Search 324/58.5 C,
 61

ABSTRACT: This apparatus for the determination of the dielectric properties, including moisture content, of substances utilizes slow wave resonance shift in a slow wave structure due to variations in the dielectric properties of specimen of substances disposed parallel to the axis of the structure. It is not necessary to utilize the prior known techniques involving the measurement of the attenuation of microwave energy.



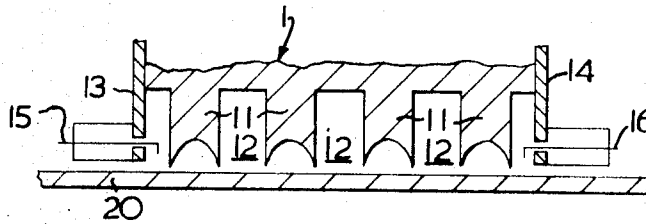


FIG. 1

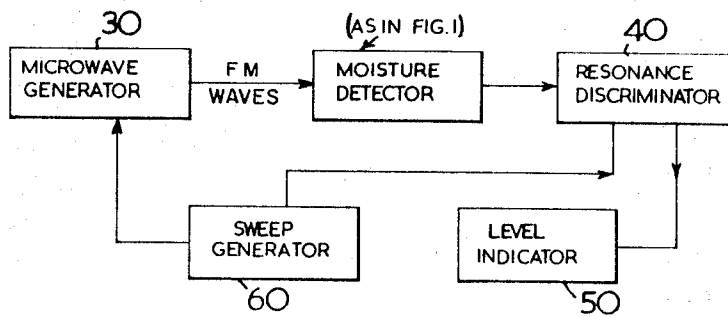


FIG. 2

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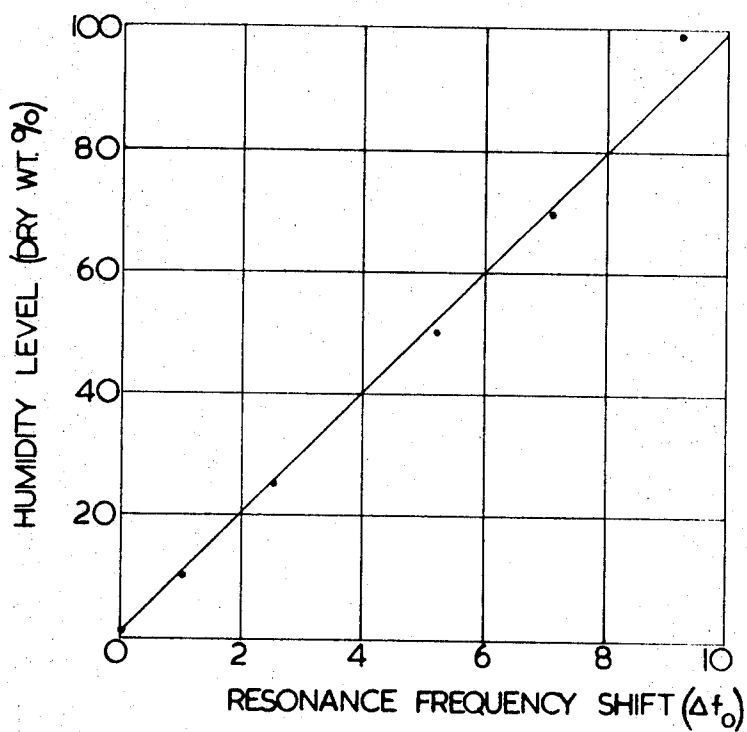


FIG. 3

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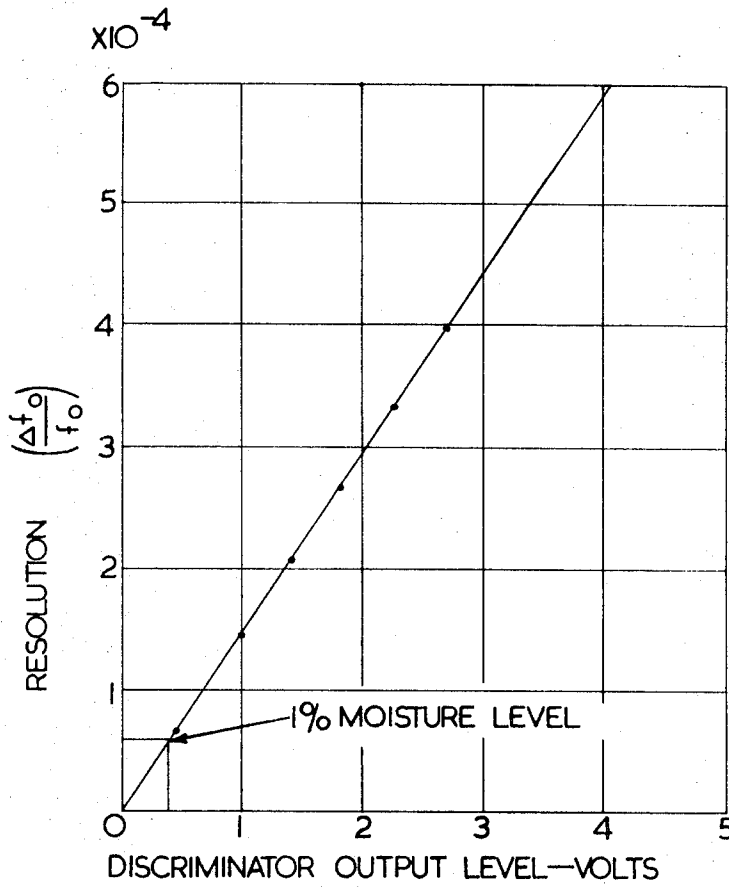


FIG.4

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MICROWAVE APPARATUS FOR ASCERTAINING CHANGES IN DIELECTRIC PROPERTIES UTILIZING A SLOW WAVE STRUCTURE

This invention relates to a method and apparatus utilizing slow waves for the determination of the dielectric properties and moisture content in substances. The invention has particular, but not exclusive use in the determination of the moisture content in sheets of material although it is to be understood that the invention has application to the determination of the moisture content of any material whose dielectric properties change in response to such moisture content. While the invention envisages the determination of moisture content of sheetlike materials, both moving or stationary, it will be obvious to those skilled in the art that the invention would be fully applicable to the indication of relative humidity, in remote or inaccessible environments, by sensing dielectric changes in a hygroscopic element.

The use of microwave techniques in the field of detection of moisture and other parameters is not unknown. Usually, however, such techniques have been dependent on attenuation of the microwave energy by intercepting the wave by the specimen. Such techniques are taught in U.S. Pat. Nos. 2,457,695; 2,659,860, and 3,079,551. Such devices suffer a common disadvantage in that the associated electronics must be of highest quality and be substantially free from drift and further, inevitably require long warmup periods and calibration with specimens having known characteristics. Again, it is generally necessary to build in some sort of impedance matching upstream and downstream of the specimen. Yet another technique typified in the teachings of U.S. Pat. No. 2,455,941 utilizes microwave reflective properties of a specimen and the technique suffers most of the disadvantages of the first three mentioned patents. The only similarity between this prior art and the present invention is in the use of microwaves.

The present invention is directed to the novel concept of using slow wave resonance shift experienced in a slow wave structure due to variations in the dielectric characteristics of a substance disposed parallel to the axis of the structure.

It will be immediately apparent that while three of the above-discussed prior art utilized waveguides, such waveguides were incorporated as at least parts of fast wave transmission lines and that, as such, the properties and advantages of microwave resonant shift were not appreciated. It will be shown that while the inherent and unavoidable absorption of microwave energy in the present invention, must exist, it ceases to be important although for obvious reasons should be unnecessarily high.

It is an object of one feature of the invention to provide a method of measuring the dielectric properties of a specimen.

In accordance with this feature, the method comprises a method of ascertaining changes in the dielectric property, K , of a substance, said method comprising the steps: establishing a slow wave RF field of frequency modulation f to f_2 , disposing a specimen of said substance, having a first dielectric property K_0 , in said RF field, adjusting the frequency limits f_1 and f_2 of said slow wave to span the resonant condition f_0 for a selected mode of resonance; disposing, in succession, differing specimens of said substances, having varying dielectric properties $K_1, K_2 \dots K_n$, in said RF field; measuring the shift in resonant frequency Δf_0 , in the same selected mode of resonance for each of said specimens; from the immediately preceding step deriving the relationship $\Delta f_0 / \Delta K$, and from the immediately preceding step ascertaining said changes.

It is an object of another feature of the invention to provide apparatus for the detection of the dielectric properties of a specimen.

In accordance with this other feature the invention comprises an apparatus for ascertaining changes in the dielectric property K of a substance, said apparatus comprising: a periodic slow wave structure whose RF field lines, in operation, link into said substance; means for feeding a microwave

signal into said slow wave structure, and to extracting said signal therefrom; means for adjusting the frequencies f_1 and f_2 of the microwave signal to span the resonant frequency f_0 , for a selected mode of resonance, upon linking the RF field lines with a specimen of said substance having a predetermined value of K ; means for frequency-modulating said signal through a selected frequency deviation from f_0 , and means for measuring changes in the resonance frequency Δf_0 , for the same mode of resonance, in response to different specimens of said substance having individual values of $K_1, K_2 \dots K_n$.

A preferred embodiment of the invention will now be described with reference to the accompanying drawings, in which:

FIG. 1 is a diagram illustrating the basic configuration of a resonant slow wave structure alongside which there is disposed a specimen of dielectric material.

FIG. 2 is a block diagram of associated equipment for use with the slow wave structure shown in FIG. 1.

FIG. 3 is a graph showing typical response of a moisture detector.

FIG. 4 is a graph showing typical discriminator resolution.

By way of introduction, the invention when applied to the detection of moisture or wetness in a specimen, depends upon the determination of the dielectric constant of the nondry specimen. The constant is then compared with that determined with a perfectly dry sample of the specimen. Since water has a very high dielectric constant the technique may be used with a very large variety of moisture-absorbent or hygroscopic materials. In the exemplary embodiment, paper will be discussed as a reference.

Referring now to FIG. 1, the detection element comprises a slow wave structure generally indicated at 1. The element includes a plurality of anodes 11, each separated from its neighbor by a resonant gap or cavity formed by gaps or slots 12. Thus the anode plane is slotted periodically and has an overall length of N periods, the length being terminated at each end by half period planes defined by end walls 13, 14. The exciting microwave signal is loosely applied across probes 15, 16 with which the resultant frequency shift is also detected. In order to concentrate the RF field lines fringing the gaps, the anodes 11 may have concave ends as shown.

A specimen, as for example, a sheet 20 is positioned beneath and parallel to the anode plane, and sufficiently close thereto to permit the RF electric field lines to link into the specimen.

Let it now be assumed that in the presence of say a dry specimen the resonant frequency of the structure is f_0 for a particular mode pattern. In the presence of a moist or wet specimen, i.e. of a different dielectric strength, the resonant frequency for the same mode will change by amount Δf_0 , the change being due to dielectric loading on the RF fields. It is therefore necessary to measure Δf_0 in order to derive the desired moisture content of the sample.

Referring now to FIG. 2 the moisture detector is shown connected to ancillary equipment comprising a microwave generator 30 which feeds an FM signal into the detector. The generator 30 has a sufficient frequency deviation to cover the expected resonance shift. The output from the detector is fed into a resonance discriminator which converts the variation Δf_0 into a voltage signal which may be read on a level meter 50 or fed into a suitable recording instrument. In order to scan the interested range of frequency modulations a sweep generator 60 feeds common control signals into both the microwave generator 30 and the resonance discriminator 40.

It will be appreciated by those skilled in the art that the microwave generator 30, resonance discriminator 40, sweep generator 60, and level indicator 50 are items of standard electronics hardware and as such require no detailed description.

In the present example the slow wave structure 1 was 12 periods long. With a dry sheet of paper placed alongside the structure the resonant frequency for the $\pi/2$ mode was 1.561 mHz. The present operating frequency of 1.5 GHz. was chosen

for convenience only. A wide range of frequencies can be used by varying the size of the detector.

FIG. 3 shows the relationship between water content, expressed as percentage of dry weight, versus resonance frequency shift Δf_0 , derived from the described apparatus. FIG. 4 shows the resolution, expressed as $\Delta f_0/f_0$, plotted against the discriminator output level in volts.

The sensitivity of this instrument may be evaluated from FIGS. 3 and 4 by using the 1 percent moisture level as a reference value. A linear interpolation of the 1 percent moisture reference level, from FIG. 3 shows that a resonance deviation of about 90 kHz. is obtained for this moisture reference level. Thus the resolving power $\Delta f/f_0$ required for a 1 percent moisture content is $90 \times 10^3 / 1.5 \times 10^9$ or about 0.60×10^{-4} . From FIG. 4 the output signal level of the discriminator is in the order of 0.4 v. for the reference moisture level. Such a signal level can be easily detected and recorded.

It will be appreciated that the above-described technique and apparatus can also be used to measure the thickness of plastic sheets or of any other dielectric material where handling becomes difficult due to inaccessibility or high production speeds, etc. It is further envisaged that the invention may be used for investigating those properties of materials which are related to dielectric characteristics thereof. Similarly, the apparatus may be directly calibrated in terms of relative dielectric strength or electrostatic capacitance as a function of frequency shift by which graphs depicting $\Delta f_0/K$, $\Delta f_0/C$ or any other denominational function to which the electrostatic dielectric varies, may be plotted. The material or substance to be investigated may be of any suitable shape and may be moving or stationary relative to the slow wave structure.

Other variants of the disclosed techniques and apparatus falling within the terms of the appended claims will occur to those skilled in the art.

I claim:

1. Apparatus for ascertaining changes in the dielectric prop-

erty K of a substance, said apparatus comprising:

- i. a periodic slow wave structure comprising a detector head having one side electrically open to said substance whose RF field lines, in operation, link into said substance,
 - ii. means producing a microwave signal,
 - iii. means for feeding said microwave signal, consisting essentially of frequency-modulated electromagnetic waves, into said slow wave structure, and to extract said signal therefrom,
 - iv. means for sweeping the microwave signal through a resonant frequency f_0 , for a selected mode of resonance, upon linking the RF lines with a specimen of said substance having a predetermined value of K, and
 - v. means for measuring changes in the resonance frequency Δf_0 , for the same mode of resonance, in response to different specimens of said substance having individual values of $K_1, K_2 \dots K_n$.
2. Apparatus as defined in claim 1 wherein said microwave signal is derived from a microwave generator.
3. Apparatus as defined in claim 2 wherein the frequency of said generator is varied in response to a sweep generator connected thereto.
4. Apparatus as defined in claim 3 wherein said means for measuring changes in the resonant frequency Δf_0 comprises a resonance discriminator.
5. Apparatus as defined in claim 4 further including output level indicator means connected to said discriminator.
6. Apparatus as defined in claim 1, wherein said detector head has only one side electrically open to said substance.
7. Apparatus as defined in claim 1, wherein said detector comprises a plurality of anodes disposed between end walls, said anodes being separated by gaps.
8. Apparatus as defined by claim 7, wherein said anodes define a plane, said substance being disposed substantially parallel to said anode plane.

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