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Paper Moisture Sensor Based On Microwave Resonator

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Abstract: ***This paper reports use of a non destructive, miniaturized, microwave resonator for moisture sensing application in papers. Advantages offered by this sensor over the prevailing sensors are room-temperature operation, response time in milliseconds, measurements unaffected by dusty environment and ionic conductivity of samples. Samples of eleven types were tested, with grammage (grams per square metre) and thickness varying from 21 to 70 g m^{-2} and 24 to 80 µm respectively. The wet basis moisture normalization (with respect to instantaneous moisture content in the sample) was established to remove scatter and to bring out clearly grammage dependence, thus avoiding error in moisture prediction due to density variations, using only scalar measurements. A single equation for f_r variations is realized in terms of grammage and normalized percentage moisture (M_{ww}) which is valid for all types of tested paper. A model of the wet paper is suggested mainly based on water–dry paper interaction, also considering parameters like thickness and surface roughness, to explain trends of the sensitivity curves. The estimated %M_{ww} shows an error of ±0.9% in the estimated value as compared to the actual value.***

Keywords: quality factor, resonator, frequency, moisture.

1. Introduction

Measurement methodologies using microwave frequencies and RF resonators are considered the most accurate way to obtain measurement data for calculating the weight, moisture, or water content of a variety of materials. Today, microwave frequencies up to 100 GHz are increasingly being used in industrial applications. When used with a special resonator that adapts to the material, one can reliably obtain electrical data that characterize the material, such as its *permittivity* (how the material's electrical properties react to an applied electrical field) and its *permeability* (a measurement of the material's ability to support a magnetic field within itself). With these data one can accurately calculate the weight, moisture, or water content of a given material. Because of the wide range of available microwave frequencies, the measurement method can be customized based on the material. Figure 1shows the permittivity of water with respect to frequency. At frequencies <3 GHz, the permittivity of water is very high; therefore these lower frequencies are ideal for measuring water content. Alternatively, when you wish to minimize the effect of residual moisture, it is better to use a measurement frequency >3 GHz.

Resonators are structures that naturally oscillate at specific (resonant) frequencies. Quality factor (Q factor) is a measure of the resonator's bandwidth relative to its center frequency and is calculated using equation 1
Q factor = f Res loaded/(flo-flu) (1)

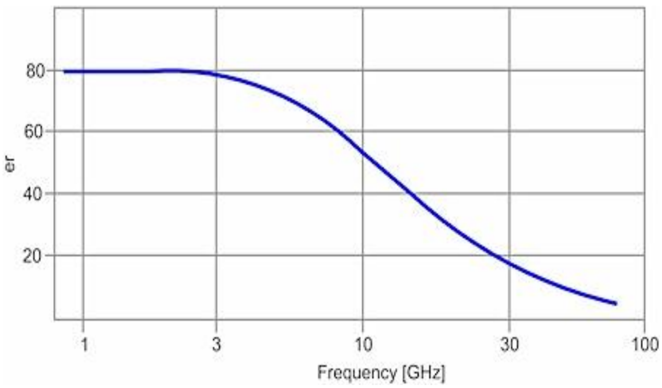

Figure 1: Permittivity (ε_r) of water vs. frequency

where

F Res loaded	=	the resonant frequency of the loaded resonator
flo	=	the frequency beyond f Res loaded that corresponds to an amplitude 3 dB lower than that of the center frequency (see Figure 2)
flu	=	the frequency below f Res loaded that corresponds to an amplitude 3 dB lower than that of the center frequency

When a sample material is inside of the resonator's cavity region, it affects the cavity's center frequency and Q factor. Although several resonator designs are available, to support the different inline production installations, a material's electrical permittivity and permeability are always determined using the frequency shift between the resonant frequency of the unloaded resonator (f Res unloaded) and that of the loaded resonator (f Res loaded). The Q factor is calculated based on the frequencies from 3 dB to the magnitude at resonance. In Figure 2 these are marked as flu/flo and fuu/fuo. Measuring both the shift in resonance frequency and Q factor enables us to determine two corresponding physical qualities, e.g., weight and humidity. In many cases only one physical measurement is required, in which case it is only necessary to measure the shift in resonance frequency or the Q factor, rather than both.

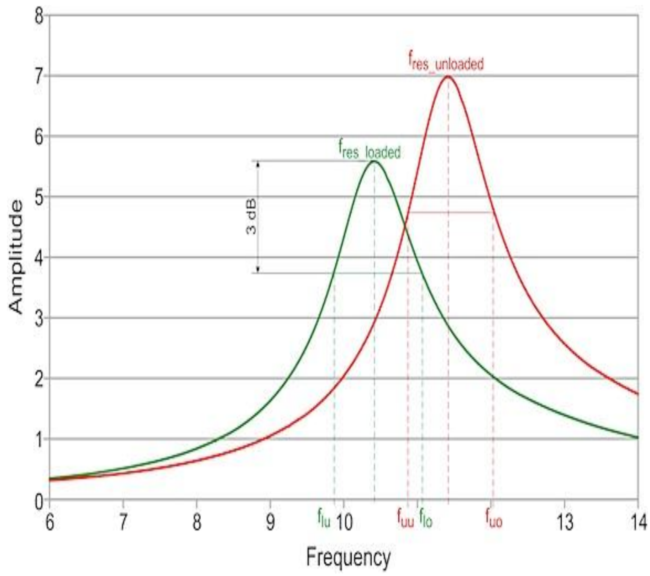

Figure 2: Resonance curve and calculation of Q factor

A typical resonator measurement system using the resonant cavity method consists of a resonator cavity, a signal processing part, and software control by a computer (Figure 3).

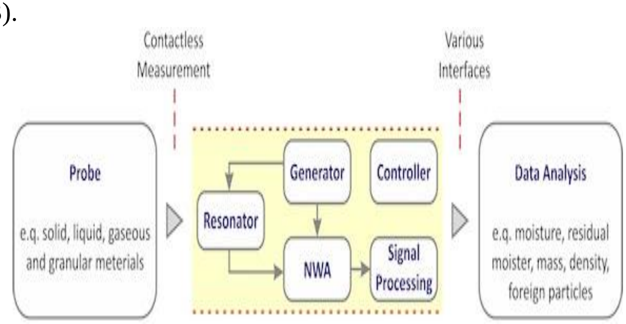

Figure 3: A resonator-based measurement system

Using high-precision sensors based on the microwave resonator technique, manufacturers can measure the moisture content, mass, and density of a wide range of materials as well as identify foreign particles or substances that may have come into contact with those materials. This technology has been particularly useful for determining the water content of paper during the production process. The ability to control the water and wood composition of the pulp helps to optimize the quality, production throughput, and overall manufacturing costs for paper manufacturers.

2. Case Study: Measuring Water Content in Paper

In paper production, if the material becomes too dry or too wet the paper must be discarded. This loss can be prevented by controlling the moisture within a production space. By using microwave resonance sensors, a paper manufacturer can stay within the ideal moisture range of roughly 4%–8%. Sensors can measure the surface conditions as well as the interior of the paper without actually coming into contact with the materials and can also be used to measure glue layers applied to paper and to monitor the drying of printing inks. After a microwave sensor is installed, the device uses a noncontact probe that detects any solid, liquid, gaseous, and granular materials; in this example (Figure 3) it detects the presence of paper.

The paper mass/pulp is transported on a mesh carrier, with a sensor installed directly underneath it, as shown in Figure 4. The resulting resonance frequency is measured with a special vectorial network analyzer configuration, as we see in Figure 5. Using digital signal processing a measurement is taken, typically at speeds of up to 10 Ksps, and then analyzed. These measurements tell the paper manufacturer the moisture content, residual moisture content, mass, density, and whether foreign particles are present. The paper manufacturer then evaluates the results to determine if any adjustments to the production process need to be made.

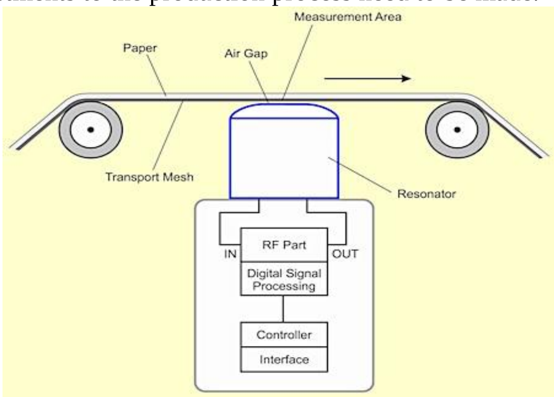

Figure 4: sensor system with one-sided resonator installation

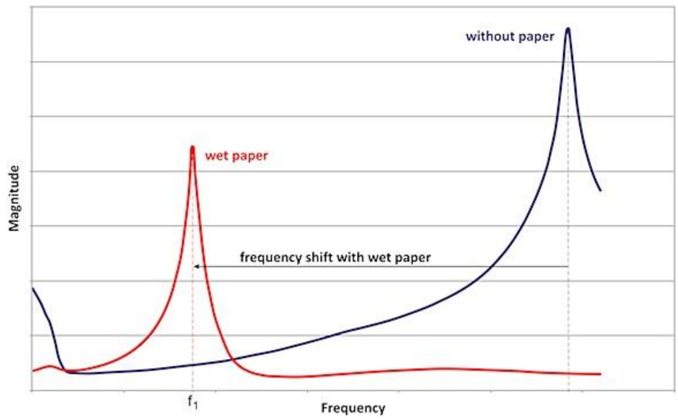

Figure 5: Frequency shift corresponding to the water content of the paper mass.

The blue curve shows the resonator measurement with no paper (for comparison). The red curve shows the resonator measurement with paper. The peak of the red curve indicates the resonator frequency value, which in this instance is equal to f_1.

3. User Interfaces

Microwave-resonator-based sensors such as the one used in this application are compatible with a range of industry standard communication interfaces to monitor and control the sensor's functions. Due to the universal design of the sensor's data interface, communication interfaces and customized interface boards can be added to the sensor for optimal integration of the sensor into a specific environment.

The communication module of the sensor has a standard IEEE 802.3 Ethernet interface so that manufacturers can directly access a sensor's data via a connected computer. The sensor also supports an ISO 11898-compliant CAN 2.0 interface for integration within production environments containing a variety of sensors and actuators. For rough environments, the sensor includes provisions for a DIN 66258 current-loop serial interface.

Any calibration formula or measurement table can be implemented into the sensor's firmware to deliver a direct, accurate reading of the paper's water content (Figure 5). Using the previously identified frequency value of f_1 from Figure 5, the water content can be traced on the calibration curve in Figure 6 to approximately C_1. If C_1 is above or below the optimum water content for high-quality finished paper, then the paper manufacturer can either stop or increase the water flow on the production line to ensure a consistent water content, which will ultimately produce optimum quality paper.

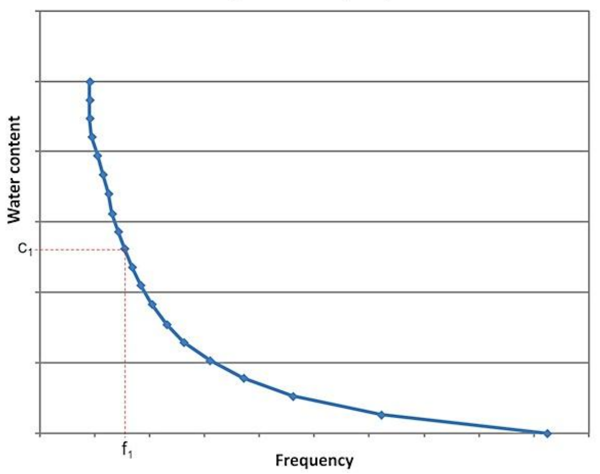

Figure 6: Calibration curve to determine the relationship between the resonator frequency value and the water content

5. Benefits of RF Resonators

In addition to accurately measuring the fiber content of paper pulp, manufacturers employing this technology experience additional benefits. For example, the resonator technique enables manufacturers to measure samples as small as 1 mm^3, with high accuracy and speeds up to 10 Ksps. The high sampling speed makes this method ideal for demanding in-line applications such as paper manufacturing. The high sensitivity of the system enables it to detect very small differences of the unloaded resonator while the probe is on, maximizing the accuracy for materials with a low water content. Repeatability is down to 0.1%.

A microwave resonator method can also be used to characterize low-loss materials and materials with a low dielectric constant, which are extremely difficult to measure using other electrical measurement techniques. Substances with a low dielectric constant include a perfect vacuum; dry air; and most pure, dry gases such as helium and nitrogen. Materials with moderate dielectric constants include ceramics, distilled water, paper, mica, polyethylene, and glass. Metal oxides, in general, have high dielectric constants.

4. Comparison with other method/technology

Until recently, nuclear-based sensors have been the standard for measuring the water content of paper (**Figure 7**). New sensors based on RF technology eliminate the need for handling nuclear sensors, enabling manufacturers to avoid the time and costs involved in specialized training for employees in the handling of nuclear sensors. Because nuclear sensors always contain a certain amount of radioactive material, manufacturers face restrictions when distributing the equipment to certain countries and may have to apply for special approval to export the devices. RF-based sensors are unaffected by those restrictions. Nuclear-based sensors also require a stringent waste-disposal process that is heavily regulated by the government. An RF-based sensor allows manufacturers to reduce potential environmental contamination.

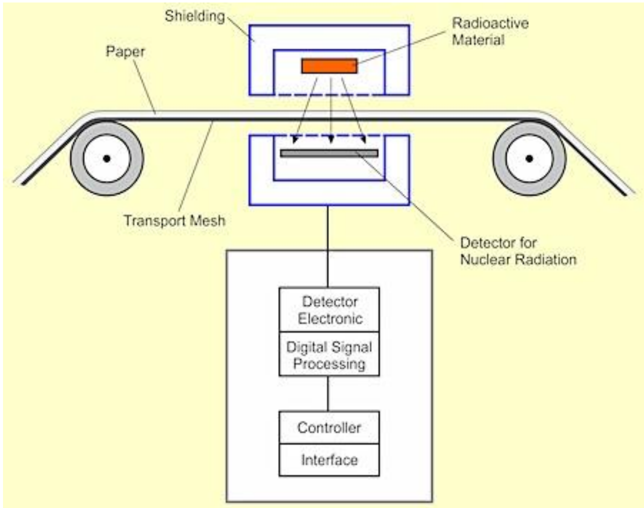

Figure 7: A schematic of a nuclear sensor

Manufacturers can also use either a flow-through resonator or a one-sided resonator measurement, both of which are noncontact systems. Sensors with a flow-through resonator are usually used for measuring powders, liquids, granulate, or pellets up to a certain size; the size of the material is the main limitation for flow-through resonators. In applications such as paper production, where a piece of paper in the production line can be up to 6 m wide, such a sensor wouldn't work, in most cases, and would be extremely expensive to design and manufacture. For this application, a sensor that makes one-sided measurements is an appropriate choice. Single-sided sensors are also suitable in applications where the thickness of the material is subject to larger variations during the production process. This sensor type can be integrated into an existing system.

6. Conclusion

Using a sensor based on the resonator measurement technique, a paper manufacturer can determine an optimum frequency range for the resonator thus ensuring—with extreme accuracy—that the paper maintains the required low water content. This ultimately leads to improved product quality and increased productivity. Sensors using this technique are flexible enough to maintain both low and high water constants and present a cost-effective solution, because manufacturers can employ one sensor for two purposes. The microwave resonator measurement technique also ensures the slow removal of moisture from the paper, which is essential to producing superior paper.

RF sensors based on the microwave resonator technique can also be applied in other industries, such as the food, tobacco, pharmaceutical, automotive, recycling, and chemical industries where they can be used to measure moisture, mass, and density, as well as to identify foreign particles and measure dielectric properties. Because quality assurance is so critical in any manufacturing industry, the RF sensor gives companies the peace of mind that their materials meet and exceed quality expectations, allowing them to deliver the best product to their customers.

References

[1] He, X.-J.; Wang, Y.; Wang, J.-M.; Gui, T.-L. Thin film sensor based tip-shaped splits ring resonator metamaterial for microwave application. Microsyst. Technol. 2010, 16, 1735–1739. [Google Scholar]

[2] Driscoll, T.; Andreev, G.O.; Basov, D.N.; Palit, S.; Cho, S.Y.; Jokerst, N.M.; Smith, D.R. Tuned permeability in terahertz split ring resonators for devices and sensors. Appl. Phys. Lett. **2007**, 91, 062511:1–062511:3. [Google Scholar]

[3] Yogi, R.A.; Parolia, R.S.; Karekar, R.N.; Aiyer, R.C. Microwave Microstrip ring resonator as a paper moisture sensor: Study with different grammage. Meas. Sci. Technol. **2002**, 13, 1558–1562. [Google Scholar]

[4] Pattnaik, P.K.; Vijayaaditja, B.; Srinivas, T.; Selvarajan, A. Optical MEMS Pressure Sensor Using Ring Resonator on a Circular Diaphragm. Proceedings of the 2005 International Conference on MEMS, NANO and Smart Systems (ICMENS'05), Banff, AB, Canada, 24–27 July 2005; pp. 277–280.

[5] Liu, X.; Xue, C.; Yan, S.; Xiong, J.; Zhang, W. Integrated High Sensitivity Displacement Sensor Based on Micro Ring Resonator. Proceedings of the 2009 4th IEEE International Conference Nano/Micro Engineered and Molecular Systems, Shenzhen, China, 5–8 January 2009; pp. 1000–1003.

[6] Pendry, J.B.; Holden, A.J.; Robbins, D.J.; Stewart, W.J. Magnetism from conductors and enhanced nonlinear phenomena. IEEE Trans. Microw. Theory Tech. 1999, 47, 2075–2084. [Google Scholar]

[7] Martín, F.; Falcone, F.; Bonache, J.; Marqués, R.; Sorolla, M. A new split ring resonator based left handed coplanar waveguide.Appl. Phys. Lett. **2003**, 83, 4652–4654. [Google Scholar]

[8] Falcone, F.; Martin, F.; Bonache, J.; Marqués, R.; Sorolla, M. Coplanar waveguide structures loaded with split ring resonators.Microw. Opt. Technol. Lett. **2004**, 40, 3–6. [Google Scholar]

[9] García-García, J.; Martín, F.; Baena, J.D.; Marques, R.; Jelinek, L. On the resonances and polarizabilities of split rings resonators. J. Appl. Phys. **2005**, 98, 033103:1–033103:9. [Google Scholar]

[10] Mandel, C.; Kubina, B.; Schüßler, M.; Jakoby, R. Passive Chipless Wireless Sensor for Two-Dimensional Displacement Measurement. Proceedings of the 41st European Microwave Conference, Manchester, UK, 10–13 October 2011; pp. 79–82.

[11] Stray field ring resonators and a novel trough guide resonator for precise microwave moisture and density measurements Reinhard Knöchel *et al* 2007 *Meas. Sci. Technol.* **18** 1061

[12] Naqui, J.; Durán-Sindreu, M.; Martín, F. Novel sensors based on the symmetry properties of Split Ring Resonators (SRRs).Sensors **2011**, 11, 7545–7553. [Google Scholar]

[13] Cubukcu, E.; Zhang, S.; Park, Y.-S.; Bartal, G.; Zhang, X. Split ring resonator sensors for infrared detection of single molecular monolayers. Appl. Phys. Lett. **2009**, 95, 043113:1–043113:3. [Google Scholar]

[14] Martín, F.; Falcone, F.; Bonache, J.; Marqués, R.; Sorolla, M. A new split ring resonator based left handed coplanar waveguide.Appl. Phys. Lett. **2003**, 83, 4652–4654. [Google Scholar]

[15] Microwave microstrip ring resonator as a paper moisture sensor: study with different grammage R A Yogi *et al* 2002 *Meas. Sci. Technol.* 13 1558

[16] Humidity/Moisture Microwave Resonator Based Sensors: An Accurate Solution for Measuring the Water Content in PaperAugust 1, 2012By: Hinrich Römhild, WORK Microwave GmbHSensors