STATE OF ART IN MICROWAVE SENSORS FOR MEASURING NONELECTRICAL QUANTITIES

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Abstract

Use of microwave sensors for measuring nonelectrical quantities in laboratory, industrial and field environments is outlined along with salient specifications imposed by diversification of modern technology. The basic principles of operation and typical applications of common microwave sensors are presented and new concepts for possible future implementation are suggested.

Summary

Microwave sensors have been of growing interest in research and industry because they possess many intriguing capabilities and offer many attractive technical and commercial possibilities. This could be of special interest to microwave researchers and industries seeking diversification or new directions in non-military products.

One of the most important applications of microwave sensors is for the measurement of nonelectrical quantities for laboratory, industrial and field uses.[1,2,3] Their attractive features are mainly due to the fact that they are nondestructive, contactless, continuous and have a low time constant, high reliability and are free of radiation hazards. However, their practical implementation imposes certain specifications which are significantly different from radar and communication systems as emphasized in this paper.

The choice of microwave frequencies for any particular nonelectrical quantity is based on a critical comparison with other techniques utilizing other frequencies in the electromagnetic spectrum (e.g. rf, infrared and optical bands) or utilizing ionizing radiation. The criteria for this comparison are outlined and results of comparison for particular cases are presented on basis of accuracy, precision, sensitivity, reliability, time constant, investment cost, radiation hazard and maintenance. These results point to the necessity for a new approach and philosophy to meet challenging specifications and exploit potential applications.

The basic physical phenomena utilized in relating nonelectrical to electrical quantities at microwave frequencies are presented in the form of transducer response. This response relates electromagnetic wave quantities (field intensity, polarization, wave velocities and impedance) to desired nonelectromagnetic physical quantities (e.g. dimensions, speed, etc.) or electromagnetic properties of the medium (e.g. permittivity, permeability, etc.) to desired nonelectromagnetic physical properties of the medium (e.g. moisture, density, etc).[4] The first group employs such electromagnetic phenomena as diffraction and scattering which may be treated by geometrical optics, physical optics, geometrical theory of diffraction, boundary value, perturbation or variational techniques depending on the characteristic dimension of the object under test in comparison to the wavelength. The response in the second group is basically derived from generalized mixture theory. The usual microwave response quantities are amplitude ratio, phase shift, frequency shift (doppler effect), polarization shift, resonant frequency shift and Q factor ratio. These quantities are normally measured using an S-parameter meter, doppler frequency meter, polarimeter and Q factor meter.

In order to illustrate the principles of sensor operation, some established applications of microwave sensors are summarized from an extensive bibliography comprising more than 200 papers and patents. These applications include the measurement of mechanical quantities (e.g. distance, speed, acceleration, vibrations, displacements, torque, surface roughness, flow rate, solid and liquid levels,[5,6] geometrical dimensions (e.g. thickness, length, width, profile shape),[7,8,9] physical properties of materials (e.g. moisture, density, granulation, degree of cure, solidification, setting, percentage of contaminations, phase of water and other liquids).[10,11] Further applications are found in plasma diagnostics as well as diagnosis of voids, cracks, inclusions and impurities in nonconducting media.[12]

Finally, new concepts for future development are presented (e.g. application of time domain reflectometry for determination of moisture, temperature and density profiles, multifrequency microwave moisture-temperature-density meter) based on recent work by the authors.

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