PHASE METHOD FOR MONITORING THE PERMITTIVITY OF
DIFFERENT MEDIA

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A nondestructive method was developed for rapidly monitoring the permittivities of solid, liquid, and gaseous
materials, based on measuring the phase difference of signals passing along two transmission lines and
comparing the parameters of the "standard" and "investigated" media. The design of a volume-integral
microwave transducer is considered together with its operating principle and its range of application.

The development of microelectronics has required the use of a large number of natural materials not previously used
and also the creation and use of new synthetic materials not encountered in nature. This in turn has led to a study of the
properties of the new materials and the development of new measurement methods and instruments for investigating their
physical properties, particularly the electrophysical properties of dielectric materials, and this has made it necessary to create
sufficiently efficient methods of measurement based on highly sensitive transducers.

Of special importance here is the science-intensive field of microelectronics, which has absorbed a large volume of
knowledge in the fields of physics, chemistry, biology, mathematics, and materials science. This field utilizes a large number
of diverse materials and the most modern achievements in the interaction of materials with each other and also with high-energy
streams of matter, for example with plasma streams, laser radiation, beams of accelerated particles, and electromagnetic fields
[1-3].

Solid, liquid, and gaseous dielectric materials are important among these since they are widely used for making
products of microelectronic technology. Many publications have been devoted to a study of the properties of dielectric materials
[1-7]. The expansion of the range of operation of microelectronic products in the microwave region and the extremely
high-frequency (EHF) range and their widespread introduction into the national economy, space and military technology, has
imposed more rigorous requirements on the original materials. Solid dielectrics which act simultaneously as structural materials
performing the role of mechanically bearing the structure and as microwave materials operating in electromagnetic fields are
doubtless of special importance among the dielectric materials used in microelectronics in the microwave range [8, 9]. Materials
forming components of airborne apparatus which are transparent to radio waves are a striking example. These act as a
protective envelope for on-board antenna systems and simultaneously give the airborne apparatus its necessary aerodynamic
shape [10].

The properties of dielectrics, including those operating in the microwave region, are usually estimated in terms of their
basic electrical parameters, namely their permittivity, loss tangent, and breakdown voltage. No theory presently exists which
makes it possible to establish a clear analytical dependence between the electrical characteristics of dielectrics and external
influencing factors which include the frequency of the external electromagnetic field, the temperature, and the pressure. It
therefore remains important to monitor directly the parameters of dielectric media at different stages during the manufacture
of microelectronic products. Methods are known which have become classic for measuring the resonance, waveguide, optical,
calorimetric, and ponderometric parameters of dielectric media [1-26].

Waveguide bridge methods have come into extensive use in recent years. These are based on measuring the phase shift
and damping of a wave [27]. The amplitude and phase characteristics have also been measured when investigating the properties
of microwave dielectrics under high-temperature conditions. A scheme was given in [8] of a complex system for measuring
the electrical parameters of dielectrics at high temperatures using a two-channel microwave phase meter. Schemes with phase
detectors make it possible considerably to increase the experimental accuracy, especially for investigations at millimeter wave-
lengths. Values of the low-frequency output signals from a phase detector which are proportional to the sine and cosine of the measured phase difference can be recorded separately. In finding the phase difference it is then necessary to calculate the tangent of the phase difference by taking the ratio of these signals. For this purpose it is most promising to replace the two-channel line with a two-mode transmission line [28]. In this case the "standard" and measurement channels are subject to identical external conditions. We consider below a method of measurement and the construction of a transducer made using circuitry utilizing microwave volume (3D) integrated circuits.

The fundamental parameters of the substrates of microstrip plates for hybrid integrated circuits and those of the external medium are directly related to the output parameters of microelectronic microwave instruments. It is therefore important to select the most accurate and the fastest methods for measuring the permittivity of the materials employed in their circuitry. It becomes especially important to acquire a nondestructive method for rapidly monitoring the parameters of materials directly during the industrial manufacturing cycle of microcircuits. It is well known that resonance methods are used for this purpose. These are based on changing the resonance frequency of a ring microstrip resonator by introducing the investigated material into its field [18, 28].

The proposed phase method is based on the principle of comparing the phase of microwave signals propagating along two transmission lines. One of the lines is the "standard" line and the other is the measurement line. The electromagnetic fields of the lines are decoupled by more than 60 dB. The microwave signals from the outputs of the lines enter a measuring device which converts the phase shift into a dc current.

The method of measurement is as follows. When the dielectric being measured (solid, liquid, or gaseous) is introduced into one of the transmission lines there is a change in its electrical length (signal phase velocity) and this leads to an additional phase shift of the signal which is resolved by the detector. The current at the output of the phase detector is a function of the phase difference between the signals from the transmission lines.

The time taken to measure the permittivity is reduced by using a microprocessor which employs an analog—digital converter to perform the function of controlling the microwave oscillator, the amplification of the output signal from the phase-shift measuring device, the comparison of the signals with previous measurements (the elimination of random errors), the calculation of the permittivity, and the outputting of the measured results to a digital meter.

The transducer was manufactured with a 3D integrated circuit utilizing the "circuitry optimization principle" [19] in which the choice of input—output line (a symmetric strip line) and the measurement line (an asymmetric strip line) is determined by the condition for the best matching to the electromagnetic field. This considerably reduces the experimental error (Fig. 1).

The transducer contains two dielectric substrates 1 and 2 between which input 3 and output 4 asymmetric strip lines are coaxially positioned on opposite sides. The narrow conductors of the asymmetric strip line are galvanically connected to the common metalized layer of the asymmetric strip lines 5 and 6. The narrow conductors of the asymmetric strip lines mounted on the outer sides of substrates 1 and 2 are also galvanically connected to the metalized layers of the symmetric strip.