ARCHIVES OF ACOUSTICS
14, 3–4, 191–202 (1989)

APPLICATION OF THE ELECTRIC PROBE TO THE INVESTIGATION OF SURFACE WAVE IN PIEZOELECTRICS

JERZY FILIPIAK

Instytut Fizyki, Wojskowa Akademia Techniczna (Warszawa)

A system for vizualization of the surface acoustic wave in piezoelectrics is presented. The system for surface wave front amplitude and phase measurement in weak piezoelectrics have been described. The measuring capabilities of the system have been exemplified for the bismuth-germanium oxide and quartz type substrates.

Przedstawiono układ do wizualizacji fali powierzchniowej w piezoelektrykach. Omówiono układy do pomiaru amplitudy oraz fazy frontu fali powierzchniowej w zastosowaniu do słabych piezodielektryków. Pokazano przykłady możliwości pomiarowych układów na podłożach typu tlenku bizmutowo-germanowego oraz kwarcu.

1. Introduction

Having an image of the surface acoustic wave one can estimate the parameters of this wave as well as the quality of the substarte in which it propagates. One of the methods of visualisation of the surface acoustic wave in piezoelectrics is the electric probe method. The probe made of abrasion-resistant conductor is placed on the piezoelectric surface. The electric field related to the propagating wave induces electric potential in the probe. As its magnitude is proportional to the wave amplitude, by changing the position of the probe the information on the surface wave amplitude distribution can be collected. This method was described for the first time by WILLIAMSON [1] who applied it to the piezodielectric with large electromechanic coupling coefficient, $LiNbO_3$. The condition for applying this method to investigations of all practically applied piezodielectrics, including those with small coupling coefficient (e.g. quartz), is the sufficiently large signal received by the probe. This necessitates for the analysis of the entire system in which the probe operates.

2. Analysis of the electric probe

The basic information on the surface acoustic wave distribution are the wave front amplitude and phase cross-sections made perpendicularly to the propagation direction, because of their large ammount these measurements should be carried out automatically. Besides the signal of interest the probe receives other spurious signals. These are, the signal passing directly, the deflected signals and the signals of bulk waves propagating in the investigated substrate. As these signals usually reach the probe at different time than the measured signal, it is possible to eliminate them in the impulse-type system. The main problem that is the increase of the signal received by the probe remains. Therefore, an power flow analysis of the system is necessary. This system can be represented (Fig. 1b) as a voltage source E_g with the internal impedance R_p, loaded with the amplifier input impedance R_{in}. The magnitude of the voltage E_g depends on the surface wave power, piezodielectric substrate properties and the probe geometry.

The investigated surface wave in the piezodielectric is excited with the interdigital transducer. Its power can be equal to the acoustic power in the case of matched

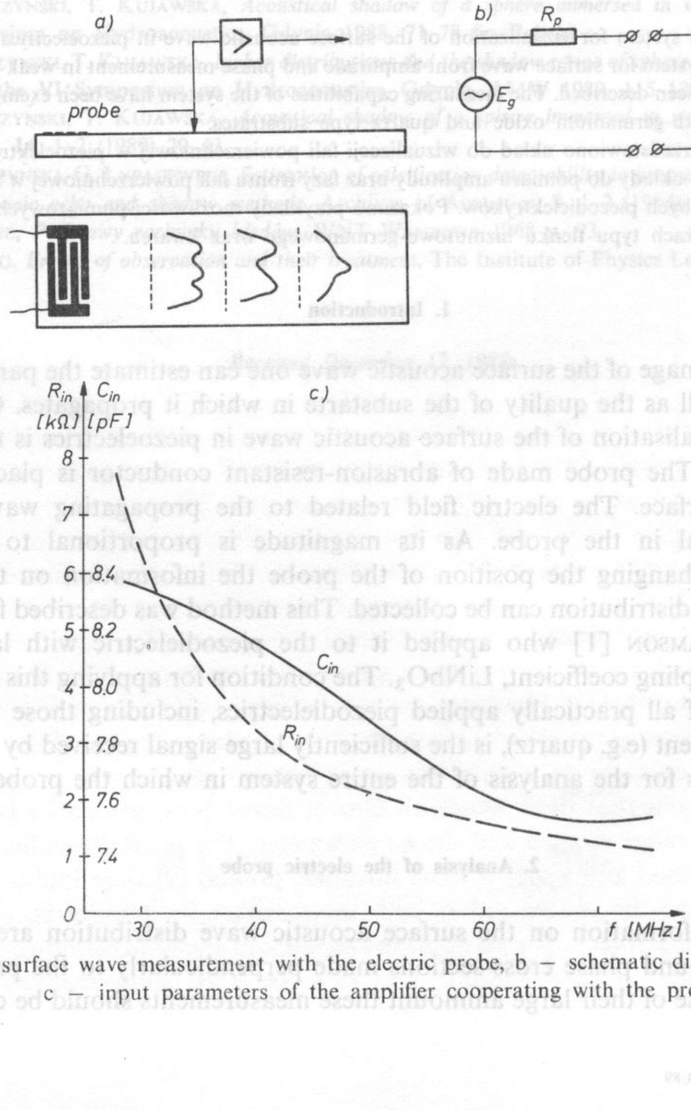


Fig. 1. a — surface wave measurement with the electric probe, b — schematic diagram of the probe, c — input parameters of the amplifier cooperating with the probe

transducer and supply generator. For a given frequency the transducers with arbitrary geometry can be matched irrespective of the piezodielectric substrate.

The power P of the amplifier cooperating with the probe (e.g. Fig. 1b) depends mainly on matching of the amplifier and the internal impedance of the source with very high resistance. Regarding this, the power increase will be proportional to the increase of the input resistance of the amplifier.

The probe geometry can be optimised for a given wave length. However for various probe geometries the received voltages differ a little [1]. As the system should work by a variety of wave lengths it is reasonable to omit the probe geometry influence, and make the probe as thin as possible.

From the above considerations it results that the increase of the signal received by the probe can be obtained in practice in the following ways:

a – by previously matching the wave exciting transducer with the supply generator;

b – by applying the amplifier with the possibly greatest input resistance.

The input parameters of the amplifier co-operating with the probe are shown in Fig. 1c. In the practically implemented system (Fig. 2) the probe output has been connected directly to the high-resistance input of the amplifier. The input capacitance of the amplifier (8 pF) and the input one of the probe (4 pF) have been eliminated with the variable-inductance coil connected with the amplifier input. Avoiding the

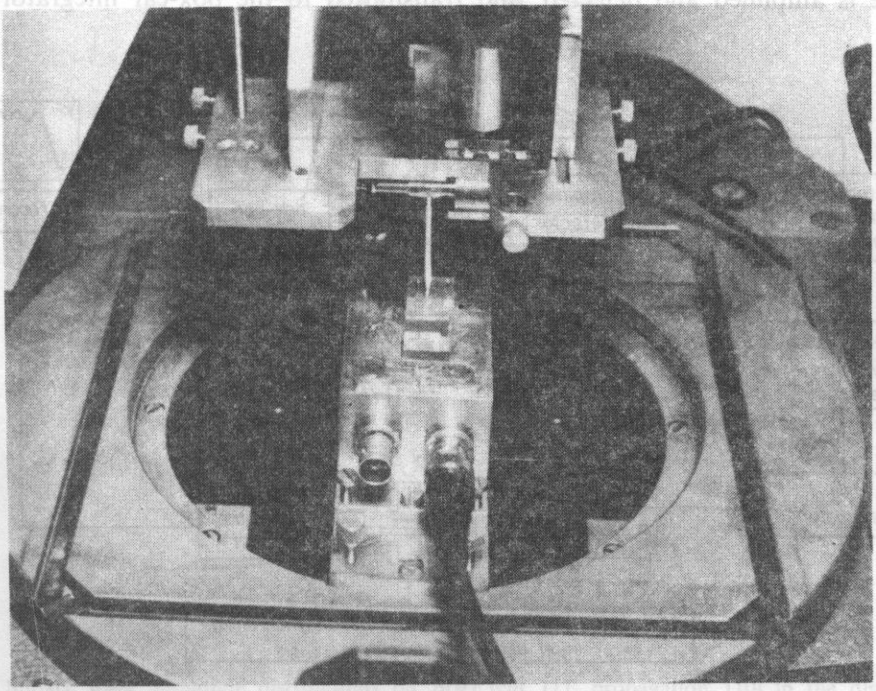


Fig. 2. The stand for surface wave measurement with the electrical probe

signal coming directly from the supply generator to the amplifier input is a problem. For this reason the whole useful signal channel has been thoroughly electricaly isolated.

The existance of backlashes, or the probe movement along the path different from the set pre-set one, can be the reason of considerable measurement errors. This is particularly important in wave front phase measurements. For example, in the case of the bismuth-silicon oxide (BGO) for the frequency equal to 30 MHz, the surface wave length is 56 μm and the 1 μm backlash limit the phase measurement accuracy to 6°.

In the system shown in Fig. 2, the probe has been mounted in two spherical holders and pressed to the tested specimen with a spring. The probe is fixed to a workshop microscope type FK 40 × 40. The specimen is placed on its table. The surface of the specimen is levelled with help of the workshopmicrometric probe. The table turn mechanism provides for precision setting of the required specimen direction.

3. System for surface wave amplitude distribution measurement

The layout of the surface wave amplitude measurement system has been shown in the Fig. 3. The surface wave is excited by the interdigital transducer supplied with a wave form of the length equal to several μs. The electric signal received by the probe is amplified and detected, and transmitted to the box-car integrator. This

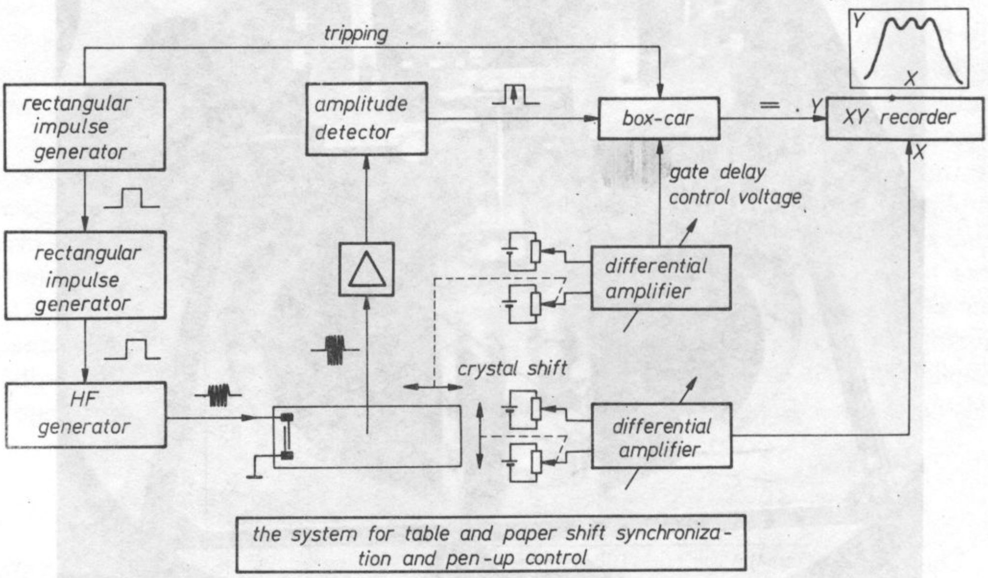


Fig. 3. The diagram of the system for surface wave amplitude distribution measurement

system transforms the received signal magnitude by the probe into the direct current signal, which is recorded in the digital or analog form. The system significantly improves the signal-to-noise ratio.

By coupling the microscope table shifts in the direction perpendicular or paralel to the wave propagation direction the sampling time before passing the signal to the box-car, should be properly changed when the probe moves allong the wave propagation direction. This way full automisation of measurements on the whole piezodielectric surface has been obtained. To ilustrate the measuring capability of the system the typical diffraction phenomenon which accompanies the surface wave propagation has been presented in Figs. 4–6. In the Fig. 4 the surface wave amplitude cross-sections perpendicular to the propagation direction is shown. They have been obtained for the bismuth-germanium oxide (*BGO* int 111, propagation 110) in

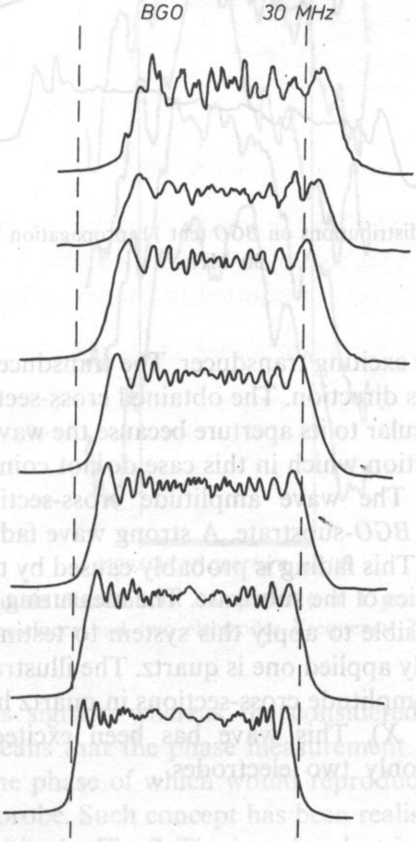


Fig. 4. Surface wave amplitude distributions on *BGO* (cut 111, propagation 110) in the distances 2, 4, 6, ... mm from the transducer. Frequency 30 MHz

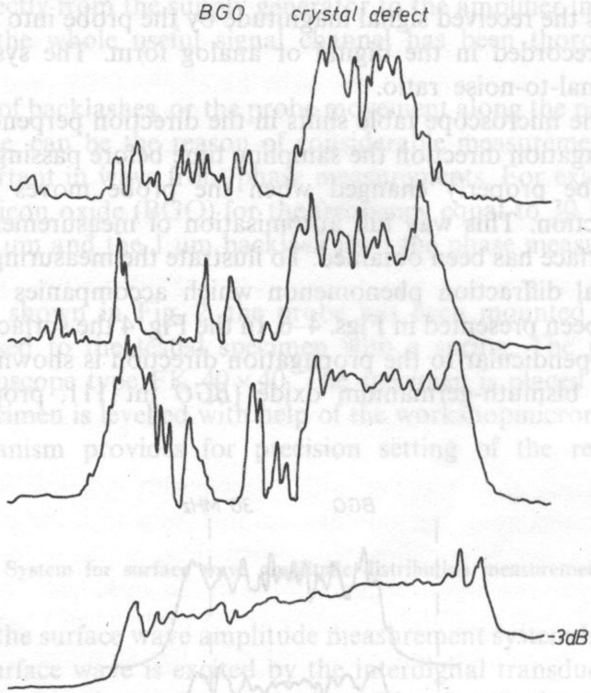


Fig. 5. Surface wave amplitude distributions on *BGO* (cut 11, propagation 110) with a defect. Frequency 30 MHz

various distances from the exciting transducer. The transducer is not placed precisely in the crystallographic axis direction. The obtained cross-sections come out from the channel which is perpendicular to its aperture because the wave propagates in near the crystallographic axis direction which in this case do not coincide with the symmetry axis on the transducer. The wave amplitude cross-sections presented in Fig. 5 illustrate a defect of the *BGO*-substrate. A strong wave fading, non-uniform in the cross-section, can be seen. This fading is probably caused by the local perturbation of the piezodielectric properties of the substrate. The measuring sensitivity of the system is high what makes it possible to apply this system to testing weak piezodielectrics. Among them the frequently applied one is quartz. The illustration of the above is the Fig. 6 in which the wave amplitude cross-sections in quartz have been presented (cut *Y*, propagation direction *X*). This wave has been excited with the interdigital transducer consisting of only two electrodes.

4. System for surface wave phase measurement

The surface wave phase measurement is much more complex than the amplitude measurement. The main problem results from the fact the available phase meters

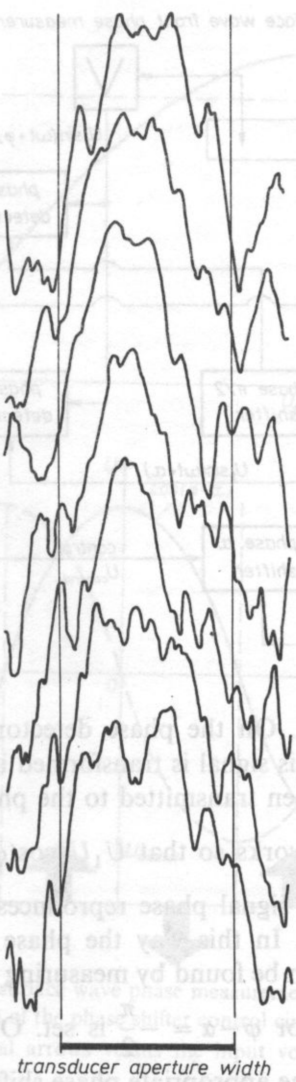
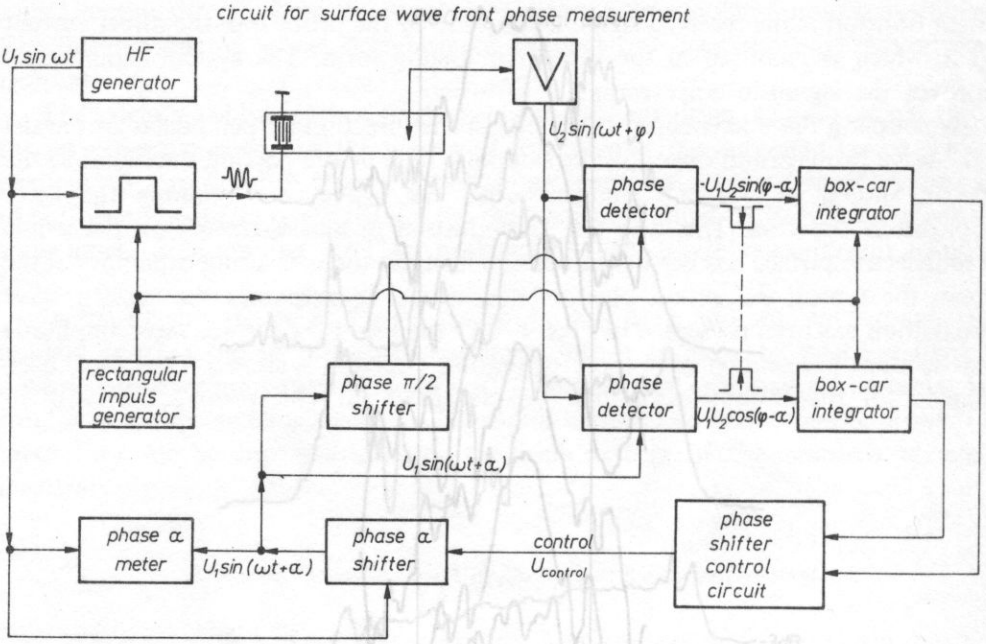


Fig. 6. Surface wave amplitude distributions on quartz (cut *Y* propagation *X*). The wave exciting transducer had two electrodes Frequency 20 MHz

operate on continuous signals, whereas the considered measuring system works impulse mode. This means that the phase measurement should be carried out with a continuous signal, the phase of which would reproduce the phase of the impulse signal received by the probe. Such concept has been realised in the measuring circuit schematically presented in the Fig. 7. The impulse electric signal $U_2 \sin(\omega t + \varphi)$ in the form of a few μs wide wave packet, received by the probe after amplification is transmitted to one of the two inputs of the phase derector. A continuous reference signal $U_1 \sin(\omega t + \alpha)$ previously transformed by the voltage controlled phase shifter is



supplied to the second input. On the phase detector output the $U_1U_2\cos(\varphi-\alpha)$ impulse signal is obtained. This signal is transformed into a direct-current signal by the box-car integrator, and then transmitted to the phase shift control input. If the phase shifter control circuit works so that $U_1U_2\cos(\varphi-\alpha)=0$; hence $\varphi-\alpha=\pm\frac{\pi}{2}$ and the continuous reference signal phase reproduces the phase φ of the impulse signal received by the probe. In this way the phase φ change during the probe movement in any direction can be found by measuring the phase α, provided that an unique relation $\varphi-\alpha=+\frac{\pi}{2}$ or $\varphi-\alpha=-\frac{\pi}{2}$ is set. Obtaining the unique relation necessitates for working out the appropriate phase shift control signal in the control circuit. The phase shift control circuit characteristic has been shown in the Fig. 7b. It can be seen that the control voltage increase causes the phase shift α increase. In the Fig. 7c the arrows indicate the direction of changes with respect to the value of $\varphi-\alpha$. The up arrow indicate the control voltage increase, and the down arrow the decrease. From the Fig. 7c it is apparent that the needed character of changes of this voltage coincides with the sign of the product of $-\operatorname{sign}(\varphi-\alpha)$ and $\cos(\varphi-\alpha)$. To obtain this product an additional voltage, proportional to $\sin(\varphi-\alpha)$ should be generated. In the diagram presented in Fig. 7 a this voltage is obtained by applying an additional loop consisting of the phase detector and the box-car integrator in which the reference voltage is shifted by the phase $\alpha+\frac{\pi}{2}$. The shift is made by a supplementary phase

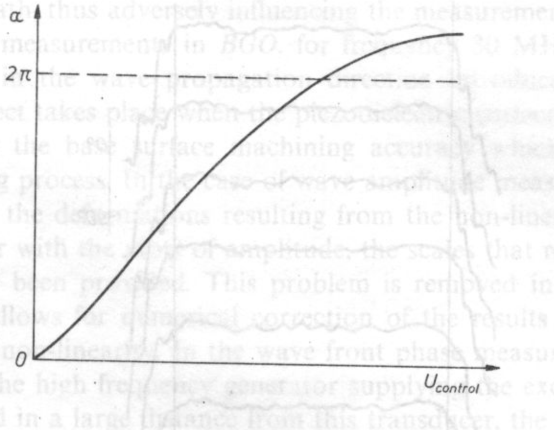


Fig. 7. a — diagram of the circuit for surface wave phase measurement, b — characteristic of the voltage driven phase shifter, c — input voltage of the phase shifter control circuit and the requires shifter control voltage change direction vertical arrows versus the input voltage phase difference range

shifter (by $\pi/2$) introduced in the reference signal circuit. The phase shift control system in the Fig. 7a generates the voltage changes dependent on the sign of the product $-\sin(\varphi-\alpha)\cdot\cos(\psi-\alpha)$. This voltage applied to the phase shifter forces the shift which allows for unique phasing on the continuous signal $U_1\sin(\omega t+\alpha)$ with the impulse signal $U_2\sin(\omega t+\varphi)$ received by the probe in the range $0\div 2\pi$. Then, the phase φ measurement is carried out by meas ring the phase α of the continuous signal with the use of a phase meter. In the system under consideration the Wiltron phase meter, model 31 OB, has been used. The surface wave front phase distribution for quartz (cut *Y*, propagation *X*) presented in the Fig. 8, illustrates the measuring capability of the discribed system.

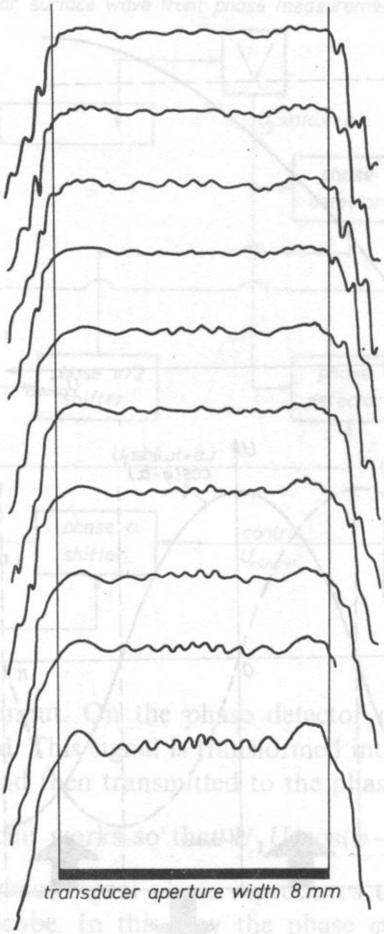


Fig. 8. Surface wave phase cross-sections for quartz (cut *Y*, propagation *X*). Frequency 30 MHz

5. Measuring technique

The probe practically does not interfere with the propagating surface wave. It receives a very small part of the wave energy, the probe diameter being of the magnitude about 20 μm, in comparison with the surface beam width usually equal to several millimeters. Therefore the measurement accuracy is concerned with accuracy of receiving and processing the signal received by the probe i.e. with the manufacturing quality and tuning of the measuring circuits, and the technique of the measurement itself.

During the measurements, particular attention should be paid to precise levelling of the tested piezodielectric. This is done with the use of screws. Levelling checking is carried out with the mechanical probe of 1 μm accuracy. Inaccurate levelling deforms the probe travel path, thus adversely influencing the measurements. For example, in wave front phase measurements in *BGO*, for frequency 30 MHz, the 1 μm probe travel path error in the wave propagation direction introduces the 6° error.

The similar effect takes place when the piezodielectric surface is not planar. This is concerned with the base surface machining accuracy which can be estimated during the levelling process. In the case of wave amplitude measurements, attention should be paid to the deformations resulting from the non-linearity of the system. Therefore, together with the plots of amplitude, the scales that represent the system non-linearity have been provided. This problem is removed in the case of digital recording which allows for numerical correction of the results accounting for the measuring system non-linearity. In the wave front phase measurements one should be cautions with the high frequency generator supplying the exciting transducer. If the probe is placed in a large distance from this transducer, the surface wave phase changes several hundred times. Then, a small frequency change during the measurement totally deforms its result. In the presented system the TESLA programmable generator, type *BM*-406, with short-term stability 10^{-7}, has been applied.

In the phase measurements an important task is to eliminate the spurious bulk-wave signals received by the probe. Part of them can be received in the same time as the useful signal. As the measurement takes place for zeroed phase detector output signal even a small spurious signal can considerably reduce the measurement accuracy. The working frequency of the rectangular impulse generator which synchronizes the operation of the whole system should also be properly chosen. This is in connection with the box-car system which is an integrating circuit. For greater noise-to-sigmal ratio of the useful signal, the RC constant should be increased. While increasing the RC constant, however, the repeating frequency should be decrased, so that the direct-current output voltage from the box-car integrator would precisely reproduce the useful signal sample value set to its input.

6. Conclusion

The presented method of measuring the surface wave distribution can be applied to all piezodielectrics applied in practice. It provides for simple, fully automatic measurements of the surface wave amplitude and phase. The obtained accuracy is entirely enough for piezoelectric substrate quality inspection as well as for wave parameters calculation. The impulse type operation of the system makes it possible to investigate numerous physical effects which take place in microwave acoustic systems, as e.g. wave reflection phenomenon. In comparison with the systems utilizing the wave interaction with light, the features of the described system are simplicity and better accuracy. The restriction is the applicability of the probe only to the free surfaces of the piezodielectrics, as only from such surfaces the probe is capable of receiving a signal.

Acknowledgements

The author wants to express his gratitude to Dr E. DANICKI for his encouragement and constructive discussions in the course of the presented work.

References

[1] R. C. WILLIAMSON, *Improved electrostatic probe for measurement of elastic surface waves*, IEEE Trans. Sonics Ultrasonics, vol. SU-12, 536–441, (1972).

Received June 5, 1988.