A useful acoustic measurement system for pulse mode in VHF and UHF ranges

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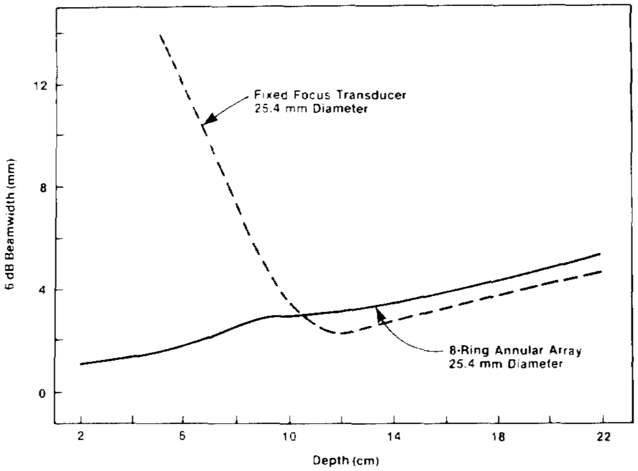

Fig. 18. Comparison of 6-decibel beamwidth of 25.4-mm diameter fixed focus transducer to beamwidth of annular array system.

ducer face as compared to more conventional B-scan approaches. Thus annular array imaging systems represent an attractive approach to high-resolution B-scan imaging over large depths of field.

CONCLUSION

The results presented in this report suggest that substantial improvements in resolution can be obtained in contact B-scans using a simple annular array imaging system. The annular array is driven on transmit to simulate a nonspherical lense approximating a horn. On receive the annular-array is used to approximate an apodized spherically focused transducer. The electronics needed to use an annular array in this fashion is conceptually simple and economically appealing. Thus a practical B-scan imaging system exhibiting good resolving power over a large depth of field may be possible using small annular arrays.

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A Useful Acoustic Measurement System for Pulse Mode in VHF and UHF Ranges

JUN-ICHI KUSHIBIKI, TOSHIO SANNOMIYA, AND NORIYOSHI CHUBACHI

***Abstract*–A useful acoustic measurement system for pulse mode is proposed. This system is developed to automatically measure a frequency response of acoustic properties for a frequency range from 50-1300 MHz with a typical dynamic range of 90 decibels. As an example, characteristics of an acoustic antireflection-coating SiO_2 film formed between a sapphire and water were measured to demonstrate the usefulness and accuracy of this system.**

I. INTRODUCTION

A NUMBER OF acoustic devices and systems utilizing acoustic surface waves as well as bulk waves in very high frequency (VHF) and ultra high frequency (UHF) ranges have been widely developed and demonstrated. In these develop-

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The authors are with the Department of Electrical Engineering, Faculty of Engineering, Tohoku University, Sendai 980, Japan.

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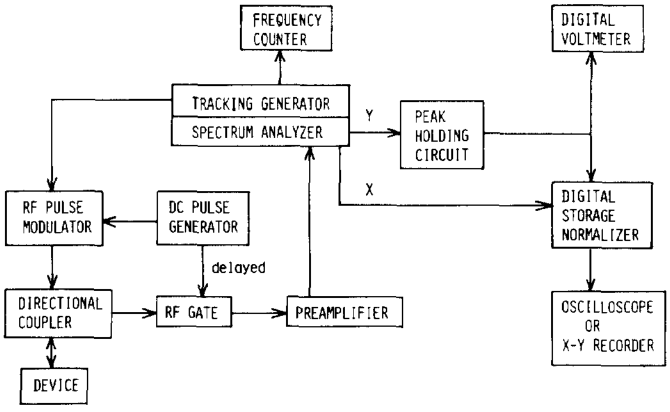

Fig. 1. Basic block diagram of acoustic pulse mode measurement system.

ments and studies it is fundamentally required that acoustic propagation properties, such as sound velocities and attenuation constants, and acoustic transducer properties in relation to generation and detection of acoustic waves, such as conversion loss and insertion loss, can be measured easily and with high accuracy. For the purpose of measuring these acoustic properties, several types of constructions of the basic measurement system, including a pulse mode and a continuous wave (CW) mode, have been made [1]-[10]. In a CW mode the powerful measurement system with an automatic operation has nearly been established using recently developed electronics. However it seems that the pulse mode measurement system, which can automatically measure the frequency response of acoustic properties with high accuracy, stability, and good operation, has not been systematically constructed. This pulse measurement system is frequently more useful than the CW mode measurement system especially in the field of high frequency acoustics.

A pulse mode measurement system for a frequency range from 50-1300 MHz with a typical dynamic range of 90 decibels is developed in which a spectrum analyzer, a tracking generator, and microwave components are functionally combined to automatically measure a frequency characteristics of acoustic properties. This system can be widely applied to all the measurements of acoustic properties with a radio-frequency (RF) pulse of arbitrary width. As an example, performance of SiO_2 film as an acoustic antireflection coating for matching the large acoustic discontinuity at the sapphire/water interface was measured to demonstrate the usefulness and accuracy of this system.

II. BASIC SYSTEM FORMATION AND ITS CHARACTERISTICS

The basic block diagram of the acoustic pulse mode measurement system proposed here is shown in Fig. 1. This measurement system is fundamentally a combination of a spectrum analyzer and a tracking generator, which is usually used for the measurement of frequency response in CW signals. For the pulse mode measurement, some functional electrical circuits are newly introduced. By the introduction of these circuits, this system now satisfies three conditions needed for the pulse mode measurement as follows:

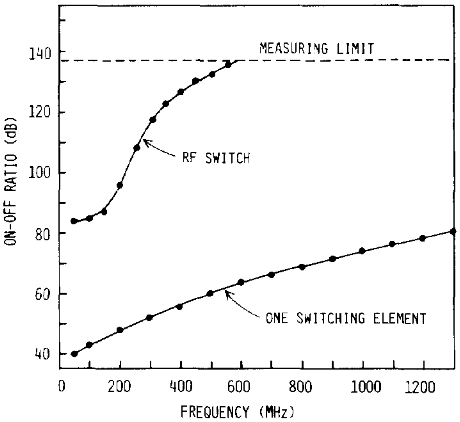

Fig. 2. Frequency dependence of on-off ratio of PIN diode RF switch.

1) generation of RF pulse signal with an arbitrary pulsewidth;
2) arbitrary extraction of RF pulse signal to be measured from a train of acoustic pulses;
3) peak holding of a pulsed video output from a spectrum analyzer so that a conventional measurement can be made.

Here we formed this system from a combination of spectrum analyzer and tracking generator for a frequency range from 0.5-1300 MHz made by Hewlett-Packard Co. As shown in Fig. 1, a CW output signal of a tracking generator which is tuned to a spectrum analyzer is converted into a pulsed RF signal by the RF pulse modulator. In order to assure the dynamic range of the system of more than 90 decibels, the RF pulse modulator with a pulse on-off ratio of greater than about 100 decibels should be selected to be suitable for the measuring frequency range. This selection influences the system possibility. We selected a PIN diode switch of HP-33144A as a switching element. The RF pulse modulator was composed of two p-i-n diode switches connected in series for making an RF pulse signal with an isolation of more than 100 decibels. Fig. 2 shows a frequency response of the modulator's on-off ratio within the frequency range of this system together with that for one switching element. This modulator has a very sufficient on-off ratio, although below a frequency of 200 MHz the on-off ratio decreases to be about 85 decibels. For the lower frequency range, the on-off ratio of more than 100 decibels can be easily achieved by the addition of another RF switch, such as the same p-i-n diode switch or a double-balanced mixer. A high pass filter with 50 MHz cut off is used in order to suppress switching transients of the RF pulse modulator. The minimum pulse width that is limited by a rise and fall time of the modulator and gating DC pulse is about 20 ns in this system.

The measurement can be performed for both a reflection type and a transmission type, although only a reflection type is shown in Fig. 1. The RF pulse signal is applied to acoustic devices to be measured and a directional coupler with a broad bandwidth, that is a HP-778D dual directional 20-decibel coupler with a frequency range from 100-2000 MHz, is employed. Generally a number of acoustic echoes return from the devices to be measured. Therefore the pulsewidth of the pulsed RF signal must be appropriately selected so that the wanted

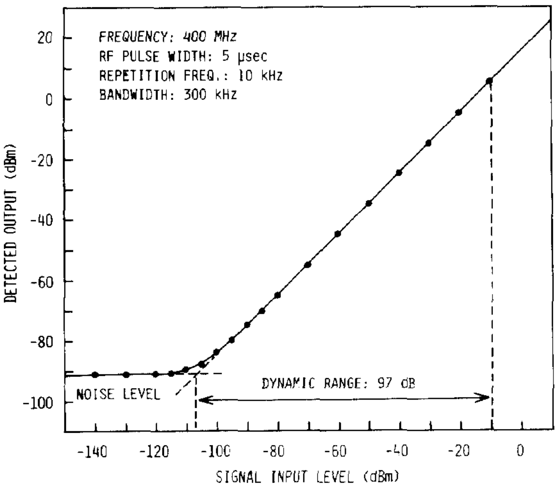

Fig. 3. Dynamic range of system measured at frequency of 400 MHz.

pulse does not overlap the other acoustic pulse echoes. The RF gate is employed in order to extract the wanted pulse signal from a train of pulse echoes. This RF gate has the same isolation as the RF pulse modulator to ensure the dynamic range of this system. The RF gate is synchronized with the RF pulse modulator and delayed by the required delay time to extract the wanted signal.

Such an extracted RF pulse signal after amplified by the low noise preamplifier (50-decibel gain) is received by the spectrum analyzer. In this pulse mode measurement system, it is fundamental that a peak power detection of the RF pulse signal is made where an intermediate frequency (IF) bandwidth is set at a condition of no pulse desensitization as described later. The video output of the spectrum analyzer is a pulsed video output of which the repetition frequency is the same as that of the gating dc pulse. This pulsed video output is converted into a conventional video output by introducing a peak-holding circuit and then displaying it on an oscilloscope or *X-Y* recorder as a function of frequency. Furthermore a digital storage normalizer is also introduced to remove the unwanted nonuniform frequency response of the measurement system. The acoustic measurement system for pulse mode is thus constructed.

Fig. 3 shows the dynamic range of the system for transmission type measured at following conditions; frequency of $f = 400$ MHz, RF pulsewidth of $\tau = 5\ \mu s$, pulse repetition frequency of PRF = 10 kHz, bandwidth of BW = 300 kHz. A maximum power of transmitting RF pulse of this system is 10 dBm. The dynamic range obtained from the system noise level of -92 dBm and the maximum preamplifier output of 5 dBm is 97 decibels. We can have the maximum measuring range of 117 decibels from the minimum signal input level of -107 dBm to the maximum of 10 dBm. On the other hand, in reflection type the maximum measuring range decreases by the directional coupler's coupling of 20 decibels to 97 decibels. The frequency dependence of the system dynamic range was measured as illustrated in Fig. 4. To keep the system dynamic range more than 90 decibels in a frequency range from 50-1300 MHz, we employed two types of RF switches for the RF gate. One is a Schottky barrier diode switch (Watkins-Johnson Co. model S1) for a frequency range below 700 MHz, and another is the same switch as the RF pulse modulator for a frequency range above 300 MHz. The decrease of the system dynamic range is mainly determined by the decreasing of switching isolation against frequency for each RF switch.

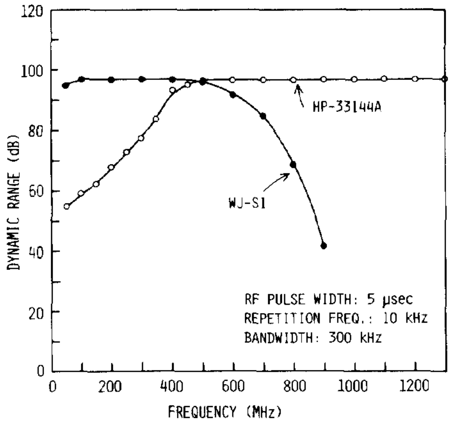

Fig. 4. Frequency dependence of system dynamic range.

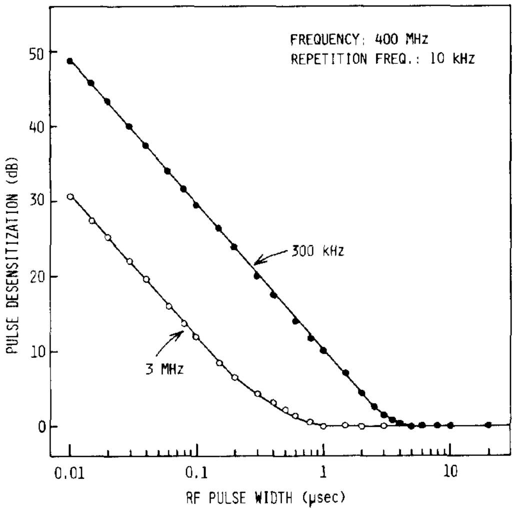

Fig. 5. Pulse desensitization as function of RF pulse width.

This system can be used for the measurement in the frequency range from 50-1300 MHz, and have the typical dynamic range of more than 90 decibels. However it should be noted that the dynamic range depends on the RF pulse width and decreases due to the pulse desensitization, which is caused by the pulse response of the spectrum analyzer's IF amplifier with a finite bandwidth [11]. The maximum bandwidth of the spectrum analyzer in this demonstration is 300 kHz. Fig. 5 shows the pulse desensitization for BW = 300 kHz as a function of RF pulse width. The system dynamic range is reduced by this pulse desensitization in relation to RF pulse width. To make a pulse measurement with no pulse desensitization, an intermediate frequency (IF) bandwidth of $\mathrm{BW} \gtrsim 1/\tau$ (τ equals RF pulse width) is required. Usually the maximum value of the analyzer's IF bandwidth obtained commercially is 3 MHz. The spectrum analyzer with a 3 MHz IF bandwidth should be employed to construct this pulse mode measurement system. In Fig. 5 the pulse desensitization for the another model spectrum analyzer with an IF bandwidth of 3 MHz is also plotted.

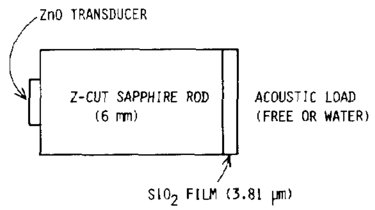

Fig. 6. Sample configuration for measuring effect of SiO_2 film as acoustic antireflection coating at sapphire-water interface.

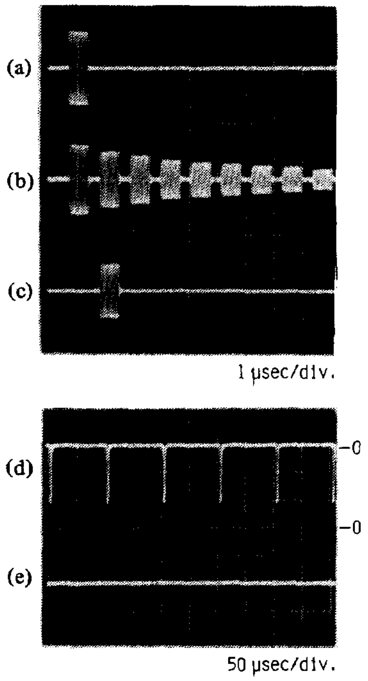

Fig. 7. Oscilloscope traces of wave forms observed at some positions of system operating with RF pulse of 0.7 μs wide, frequency of 400 MHz, and repetition frequency of 10 kHz for sample illustrated in Fig. 6. (a) Transmitting RF pulse. (b) Train of acoustic echoes. (c) RF pulse signal extracted by RF gate. (d) Pulsed video output of spectrum analyzer. (e) Peak holded output of this system.

For an RF pulsewidth of 20 ns, the system dynamic range becomes smaller only by the pulse desensitization of 25 decibels.

III. Measured Example

As an example the measurement with this system of the frequency response of an acoustic antireflection coating of SiO_2 film, which improves effectively the large transmission loss at the interface between a sapphire and water, is described. This antireflection coating is an important subject especially for the development of acoustic microscopy [12]-[14]. The SiO_2 film of 3.81 μm thick was deposited on one side of a *Z*-cut sapphire rod of 5 mm in diameter and 6-mm long by RF sputtering, while the ZnO piezoelectric film transducer was made on the other side of the rod by dc sputtering (Fig. 6). Fig. 7 shows oscilloscope traces of waveforms observed at some positions of this system for this sample. Here we selected an RF pulse of 0.7 μs wide with a frequency of 400 MHz because a train of acoustic echoes occurred in the sapphire rod each 1.07 μs apart. The pulse repetition frequency is 10 kHz. The effect of the acoustic antireflection coating of SiO_2 film was observed by measuring the first acoustic echo. The experimental results for the frequency range from 150-650 MHz are shown in Fig. 8. The two upper traces are the frequency responses of the insertion loss when the surface of SiO_2 film is free and put into water, respectively. The lower trace is the difference between two upper traces, which is equal to the difference of reflection losses at the interface between sapphire and SiO_2 film. Here the difference is defined as the relative reflection loss, which shows the effect of SiO_2 film as an acoustic antireflection coating. A maximum relative reflection loss of 6.9 decibels is obtained at a center frequency of 395 MHz. This value is in good agreement with the theoretical value of 6.990 dB at 392.1 MHz which is calculated by using the bulk values of SiO_2. The minimum relative transmission loss can be calculated to be 1.0 decibels from the maximum relative reflection loss of 6.9 decibels. Therefore it is verified experimentally that the large transmission loss at the interface between sapphire and water (9.0 decibels) is improved more than 8.0 decibels by introducing the SiO_2 film. This effect of SiO_2 film as an acoustic antireflection coating at the sapphire/water interface has been reported elsewhere [14] in detail.

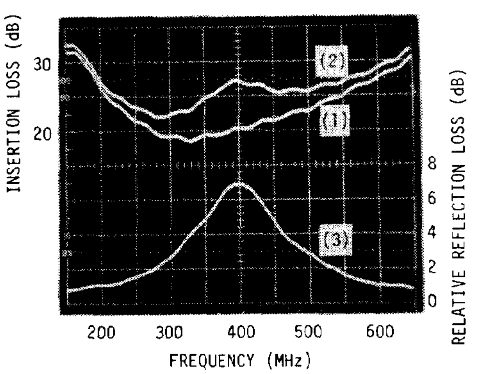

Fig. 8. Measurement of effect of acoustic antireflection coating of SiO_2 film (3.81 μm) at sapphire-water interface. (1) Insertion loss trace with acoustic load free. (2) Insertion loss trace with acoustic load of water. (3) Relative reflection loss trace equal to difference between (1) and (2).

IV. Conclusion

The acoustic pulse mode measurement system proposed here was constructed for a frequency range from 50-1300 MHz with a large dynamic range of more than 90 decibels. By applying this system to measure the effect of SiO_2 film as an acoustic antireflection coating at the sapphire/water interface, it was proved that this system has a high accuracy and usefulness. The distinctive feature of this system is that it can easily and automatically measure the frequency response of acoustic properties with a large dynamic range and a variable pulse width of RF pulse signal. This system can be readily expanded to both higher and lower frequencies. The pulse mode measurement system developed here can be used as a powerful tool for measuring the performance of acoustic devices and systems in VHF and UHF ranges. This system is also expected to be used for measuring the acoustic characteristics of materials in the field of physical acoustics.

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Visualization and Quantification of Acoustic Beams in Echo-Graphic Real-Time Systems

MASSIMO PAPPALARDO AND ENRICO D'OTTAVI

***Abstract*–For many years wires of small diameter, compared to the wavelengths, have been used to test echographic B-mode systems for medical diagnostic applications. The image generated on the display of a real-time linear scanning system by an array of such wires is analyzed. A two-dimensional mathematical interpretation of this particular image, which appears to be related to the acoustic beam of the multielement transducer employed, is given.**

I. INTRODUCTION

FOR MANY years wires of small diameter, compared to the wavelengths, have been employed to test echographic B-mode systems. A variety of test objects consisting of thin wires have been used and a standard "phantom" developed by the American Institute of Ultrasound in Medicine's Standards Committee [1] is commercially available. Recently Hefner *et al.* [2] proposed a simple test-object consisting of a linear array of wires which generate an image on the display of a B-mode system, which appears to be related to the pulsed acoustic beam of the particular transducer in use.

Independently of the above we recognized the validity of such a "phantom" to test real-time multielement systems [3]. In addition to the applications described by Hefner for single element B-scan systems, we pointed out the possibilities of such a "phantom" for a simple evaluation of the performances of the dynamic focusing techniques employed in the majority of commercial linear or sector scanning systems.

Schlieren images of the pulsed acoustic beam have been used in order to characterize multielement transducers [4], [5], [6], [7] but a good quality optical system is required for this purpose. In fact the signal-noise ratio, i.e., the ratio between diffracted and undiffracted light, is not very good because the acoustic perturbation takes place for a short time and the repetition rate and the central frequency of the pulse are not very high. The kind of images obtained with this test object are comparable, as far as the quality is concerned, to that given by the Schlieren method but they are obtained without the aid of an optical system.

In this paper we will analyze the images obtained by this "phantom" and we will give a two-dimensional mathematical interpretation of the acoustic beam image formation. We point out the similarity and the difference between the images generated by the "phantom" and the acoustic beam of the

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The authors are with Consiglio Nazionale delle Ricerche, Istituto di Acustica "O.M. Corbino," Via Cassia, 1216-00189 Rome, Italy.

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