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A NEW TRIANGULAR ACOUSTIC PULSE -
ITS GENERATION AND UNIQUE
PROPERTIES FOR NDT APPLICATIONS

N. E. Dixon and T. J. Davis

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INTRODUCTION

In the field of nondestructive testing (NDT), much effort has gone into improving range resolution, broadband spectral content, penetration capabilities, and eliminating near-field effects.

Such innovations as destructive lenses, perfectly matched damping members, single surface operation of very thick transducer elements, broadband amplifiers, frequency diffraction gratings, and electronic enhancement of the rising slope of received signals have been developed for obtaining improved resolution response. However, relatively little work has been done to optimize the transmitter pulse for improved response.

This report describes a new triangular-shaped acoustic pulse, see Figure 1, which we have named the "unipolar pulse", that offers significantly improved testing capabilities over conventional pulse methods. We developed the theory and a transducer model on the basis of Redwood's work⁽¹⁻³⁾ which we interpreted for the special unipolar pulse case. Our experimental data verify that unipolar pulses can indeed be transmitted and received. Also included are some specific NDT applications.

a. PULSE-ECHO SIGNAL
USING SHOCKLY DIODE
TRANSMITTER, 100 nsec/cm

b. PULSE-ECHO SIGNAL
USING UNIPOLAR PULSE
TECHNIQUES, BOTH (-)
AND (+) PULSES SHOWN,
100 nsec/cm

c. PULSE-ECHO SIGNAL
USING BOTH (-) AND
(+) UNIPOLAR PULSES
TO FORM BIPOLAR
PULSE, 100 nsec/cm

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FIGURE 1. Received Signal from Medium Damped, 25 MHz, PZT-5 Transducer for a) Conventional Transmitter Received Pulse, b) Unipolar Pulse and c) Unipolar Pulses to Form Bipolar Pulse

SUMMARY AND CONCLUSIONS

An ultrasonic pulse technique has been developed for generating and receiving a triangular-shaped acoustic pulse (which may be either compressional or rarefactional) that exhibits no resonance, as opposed to sinusoidal wave packets, bipolar pulses, or pulses with overshoot. This triangular-shaped acoustic pulse has been named the "unipolar pulse."

Transducer theory describing the generation of the unipolar pulse has been developed and a transducer model has been fabricated which supports the theory. Experimental results with laboratory transducers verify model predictions. The use of the unipolar pulse technique for NDT applications provides the following significant advantages over conventional pulse methods:

- A unipolar acoustic wave inherently providing high range resolution.
- A high range resolution ultrasonic impulse with broad spectral content which significantly increases the amount of information that can be extracted by spectral analysis of received signals.
- Good penetration of, and high resolution in, highly absorbing or attenuating materials such as composites (due partly to the predominant lower spectral content of the unipolar pulse).
- Ease in interpretation and improved correlation of reflected flaw signal information due to the absence of beam field effects and the omnidirectionality of reflected sound without sidelobe patterns, per se, from a flaw.
- Simplified and inexpensive transducer fabrication since transducer requirements are much less stringent for reproduction of the unipolar pulse.

- Due to its broad spectral content, a far-reaching means to further the understanding of acoustic wave propagation including longitudinal, shear, surface and plate waves.

Three distinct development areas for unipolar pulse applications include:

- Transmitter instrumentation
- Transducer design including elimination of element radial modes
- Further theoretical understanding of unipolar pulse propagation.

THEORY

INTRODUCTION

The unipolar pulse (Figure 2) is a single triangular pressure wave radiated from a properly excited ultrasonic transducer. The width, T , of the pulse is equal to one period of the transducer's natural resonant frequency. The pressure amplitude of this pulse will be the same order of magnitude as the maximum half-cycle of an exponentially damped oscillatory burst resulting from rapid excitation of the same transducer.

TRANSDUCER CIRCUIT MODEL

To explain the generation of the unipolar pulse, it is necessary to refer to the exact equivalent circuit of a piezoelectric plate transducer presented by Redwood.⁽¹⁻³⁾ This model appears in Figure 3.

The body of the transducer is represented by a three-terminal delay line whose time delay is equal to one-half the transducer's period at resonance. The lens and backing member impedances are represented by Z_1 and Z_2 , respectively. An

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FIGURE 2. Unipolar Pressure Wave Resulting from Ramp Excitation of a Piezoelectric Transducer

ideal transformer represents the conversion of electrical energy into mechanical energy. Capacitor C_0 is the output capacitance; the other capacitor has a negative value and has no real electrical equivalent. According to Redwood, the negative capacitance may be ignored because it causes only minor modifications to waveforms. A workable circuit for analysis purposes may be obtained by transforming C_0 , Z_s and V so that the transformer may be eliminated, and by removing the negative capacitance. This circuit is shown in Figure 4.

The voltage appearing at Z_1 is the analog of ultrasonic force (pressure times surface area) radiated into the lens, while that appearing at Z_2 is the analog of force radiated into the backing member. Ease of analysis requires treating the model in two different manners: 1) for injection of electrical energy and 2) for deriving wave shapes of radiated pulses.

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FIGURE 3. Equivalent Circuit of a Piezoelectric Plate Transducer Polarized for the Thickness Compression Mode

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FIGURE 4. Transducer Equivalent Circuit with Negative Capacitance and Transformer Removed

The model analysis holding for injection of electrical energy consists of Z_1 and Z_2 , each tied to the input voltage through line impedance Z_0 as shown in Figure 5. Upon application of voltage, V , the instantaneous voltage appearing at the front face is $(a = hC_0) (V) [Z_1/(Z_0 + Z_1)]$ and that appearing at the rear face is $(hC_0) (V) [Z_2/(Z_0 + Z_2)]$. The voltage appearing across the ends of the delay line will be $hC_0 V$ times one minus the above bracketed quantities. These voltages begin propagating down the line at its velocity, v .

The model analysis for radiated and reflected signals is best served by assuming that the outer shield of the delay line has zero impedance to ground in the circuit of Figure 4. This is legitimate because in practice $a^2 Z_s$ is parallel with C_0/a^2 will be much smaller than Z_0 . Redwood has fabricated this circuit using a source impedance of 50 ohms and delay line with $Z_0 = 900$ ohms. For this work, we fabricated the circuit using

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FIGURE 5. Equivalent Circuit Redrawn for Analysis of Electrical Energy Injection

a characteristic line impedance of 1350 ohms. In this manner the delay line may be treated simply as a transmission line having impedances Z_1 and Z_2 across its ends. At radio frequencies, the line Z_0 will be primarily resistive and in an electrical analog, Z_1 and Z_2 may be replaced with variable resistors.

At ultrasonic frequencies a piezoelectric transducer is effectively damped by its mass with the exception of areas immediately adjacent to the electrodes. Therefore, the only sources of acoustic waves are at the front and back surfaces. Each surface will radiate waves in both the positive and negative X directions. The initial response to a positive Dirac voltage impulse applied at $t = 0$ is shown with forces labelled in Figure 6a. Upon application of the voltage, a positive and negative force will be generated at each surface. The force polarities correspond to a piezoelectric polarized for expansion with application of positive voltages. Magnitudes of the initial forces are apparent from the circuit of Figure 5.

a) INITIAL PULSE RESPONSE OF TRANSDUCER

b) IMPULSE DIAGRAM SHOWING SEVERAL REFLECTIONS

c) RADIATION INTO LOAD Z_1

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FIGURE 6. Response of a Transducer After Application of a Positive Voltage Impulse at $t = 0$

The complete impulse response (Figure 6b) of the transducer can be derived through a transmission line treatment of succeeding reflections and radiations in the delay line. Referring again to the circuit of Figure 4, the reflection coefficient at the front face is

$$\tau_o = (Z_1 - Z_o)/(Z_1 + Z_o) \quad (1)$$

while that at the rear face is

$$\tau_x = (Z_2 - Z_o)/(Z_2 + Z_o). \quad (2)$$

After the initial front face radiation F_1 at $t = 0$, no signal leaves the transducer until the force F_3 originally generated at the rear face reaches the front face. A portion of this wave will leave the front face with magnitude $(1-\tau_o) F_3$. That portion of the wave not radiated will be reflected back into the transducer with magnitude $\tau_o F_3$. By subjecting all signals generated to a similar transmission line treatment, we can draw the complete train of impulses leaving the front face. This impulse train is shown in Figure 6c.

UNIPOLAR PULSE GENERATION

We are now ready to apply these principles to the generation of the unipolar pulse. The simplest case for unipolar pulse generation employs an air-backed transducer with a water or other low impedance lens medium at the front face. Practical values for this case in an actual transducer are $Z_1 = 1/20 Z_o$ and $Z_2 = 0$.

The driving function required to generate a unipolar pulse in an air-backed transducer is merely a linear voltage ramp. The ramp starts at $t = 0$ and must end precisely at

$t = 2X/v$. The duration of the ramp is critical if a clean baseline after $t = 2X/v$ is to be obtained. The amplitude of the unipolar pulse will be directly proportional to the slope of the ramp. The combination of force pulses responsible for generation of the unipolar pulse in this special case is shown in Figure 7.

Referring to Figure 7, we see that ramp waves of force are radiated from the front face with amplitudes as predicted by the impulse diagram of Figure 6. At $t = 0$ a positive force or compression ramp is radiated in-phase with the driving voltage. Its amplitude is established by the values of Z_1 and Z_0 to be $\approx \frac{hC_0V}{20}$ where V is the time function of voltage describing the input ramp. At $t = X/v$ the rarefaction force wave F_3 generated at the rear face reaches the front face and will be radiated with amplitude $\approx \frac{-2hC_0V}{20}$. At $t = 3X/v$, force F_2 will have made a round trip in the transducer and will be radiated with approximate amplitude $\frac{2hC_0V}{20}$. The complete series of radiated pulses can be derived in this manner. The algebraic sum of all these is the total force radiated with time from the front face. As shown in Figure 7 this summation of forces is a unipolar pulse with nearly total cancellation of all radiated signals after $t = 2X/v$.

Since there are losses in the transducer (i.e., propagation losses between faces and some radiation at the front face), the impulse series is not infinite and is damped at a rate determined by the losses. As may be deduced from Figure 7, increased damping or amplitude reduction of succeeding signals, such as would be obtained with increased Z_1 , will degrade integrity of the baseline after $t = 2X/v$.

Actual unipolar response of our transducer equivalent circuit is shown in Figure 8a for $Z_1 = 1/20 Z_0$ and $Z_2 = 0$.

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FIGURE 7. Construction of the Unipolar Pulse in an Air-Backed Transducer

We built this circuit around an R. F. Millen coaxial delay cable having 0.5 μ sec of delay in approximately 1 ft and a characteristic impedance of 1350 ohms. The delay of $X/v = 0.5 \mu$ sec approximates a 1 MHz transducer. A C_0 of 1500 pf was chosen for input capacitance and the circuit was driven from a 50-ohm pulse generator having individually adjustable rise and fall times.

a) $Z_1 = \frac{1}{20} Z_0$, $Z_2 = 0$ (AIR BACKING)

b) $Z_1 = \frac{1}{20} Z_0$, $Z_2 = Z_0$ (MATCHED BACKING)

UPPER TRACE: EXCITATION VOLTAGE, 10 V/DIV

LOWER TRACE: OUTPUT VOLTAGE, 50 MV/DIV

SWEEP RATE = 0.5 MICROSEC/DIV

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FIGURE 8. Unipolar Response of Transducer Equivalent Circuit

Figure 8b shows the response of the model for matched backing; i.e., $Z_2 = Z_0$. In this case the required ramp length is only X/v . This correlates with theory since the unipolar pulse will be the algebraic sum of only two pressure ramps, F_1 and $(1-\tau_0) F_3$, which are equal and out of phase for any value of Z_1 . If they are to generate a unipolar pulse, the ramp must terminate at $(t-X/v)$.

Although it cannot be stated with certainty that Redwood's equivalent circuit with the negative capacitance omitted is representative of all types of transducers, it does serve as a very useful tool for analysis purposes. The equivalent circuit with linear ramp excitation provides a unipolar output for only the two cases mentioned ($Z_1 = \text{very small}$, $Z_2 = 0$ and $Z_1 = \text{any value}$, $Z_2 = Z_0$). In practice, many transducers with epoxy backing of nonzero impedance can be excited in the unipolar mode and many cannot. All air-backed units investigated to date were capable of generating a very clean unipolar response with ramp excitation, thereby conforming to theory.

A simpler means of comprehending generation of the unipolar pulse in some cases is illustrated in Figure 9. The ramp excitation function may be considered as the summation of two separate ramps. One ramp is expressed by $V = kt$ starting at $t = 0$ and the second is $V = -kt$ starting at time $t = 2X/v$. Each of these will excite a damped oscillatory burst in the transducer, and the second burst will be of opposite polarity to the first. The radiated output will be the algebraic sum of these two bursts.

Referring to Figure 9, we see that a unipolar pulse with clean baseline after $t = 2X/v$ will be radiated if the following two conditions are met: 1) the second, negative-going ramp must begin at $t = 2X/v$ and 2) the first half cycle of the second burst must be equal in absolute amplitude value to that of the first half cycle of the first burst.

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FIGURE 9. Alternate Method of Illustrating Construction of the Unipolar Pulse in an Air-Backed Transducer

We have demonstrated these criteria by exciting a lumped circuit model of a piezoelectric transducer. The circuit⁽²⁾ consists of a series RLC network in parallel with a capacitor. Resonance in the RLC branch simulates transducer resonance and the capacitance branch simulates output capacitance. This model only applies for frequencies very near or at resonance, but it is useful in demonstrating the cancellation effect of the unipolar pulse.

If a series RLC circuit is excited with a linear ramp voltage, the current will be of the form

$$I(t) = kC [1 - e^{-Bt} (\cos \omega t + \text{a secondary sin } \omega t \text{ term})] \quad (3)$$

where k is the slope of the ramp, C is the capacitance and ω is 2π times the oscillation frequency. (Derived by Laplace transform techniques, ω is dependent on R in addition to L and C .) If the value of R is chosen correctly, the secondary terms diminish and a very clean, single cycle of current obeying the equation $I \approx kC(1 - e^{-Bt} \cos \omega t)$ flows through the circuit upon application of a voltage ramp terminated at $t = 2\pi/\omega$. A current pulse derived from ramp excitation of a series RLC circuit resonant at 300 kHz is shown in Figure 10. Oscillograms are also included showing the results of terminating the ramp both before and after $t = 2\pi/\omega$.

In effect, the unipolar pulse technique was found to function with electrostatic, piezoelectric, magnetostrictive, inductive or eddy current devices.

PRACTICAL CONSIDERATIONS

The unipolar pulse is not an unmixed blessing. Its main limitations lie in the capabilities required of the pulse

$$L = 92 \mu\text{h}$$

$$C = 3000 \text{ pf}$$

TOP TRACES: EXCITATION VOLTAGE @ 10 V/DIV
 BOTTOM TRACES: RLC CURRENT @ 5 MA/DIV
 SWEEP RATE: 5 MICROSECONDS/DIV

a) $t = 2\pi/\omega$ b) $t > 2\pi/\omega$ c) $t < 2\pi/\omega$

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FIGURE 10. Unipolar Response of Lumped Circuit
 Transducer Model

generator and in the fact that not all transducers can be excited in the unipolar mode with a reasonably clean baseline by a linear ramp.

The minimizing of transducer output capacitance is of prime importance in easing requirements of the pulse generator. For example, a pair of 5 MHz, 3/8 in. diameter lead metaniobate transducers had a measured output capacitance of 2000 pf. To ramp one of these over 100 volts in $2X/v = 200 \text{ nsec}$ requires a

flat-topped current pulse of 1.0 amp amplitude. Much higher capacitances will be obtained with increasing transducer frequency, thereby requiring drives in excess of the capabilities of currently available pulse generators.

We have found that some transducers prefer a nonlinear ramp for maximum baseline clean-up. Redwood's transducer model verifies this and theoretically will radiate a clean unipolar pulse for nonzero, nonmatched backing impedance only if the following conditions are met: 1) that the ramp has a dual slope with a breakpoint at $t = X/v$; 2) the two ramp slopes are of a specific ratio determined by transducer constants; and 3) the impedances Z_1 and Z_2 are equal. Such an excitation ramp is shown in Figure 11.

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FIGURE 11. Excitation Voltage Which Theoretically Can Excite a Clean Unipolar Pulse in any Transducer Whose Front and Rear Impedances are Equal

By requiring that the time derivative of radiated signals occurring in both even and odd time intervals after $t = 2X/v$ is zero, the following relationships hold:

For odd intervals of X/v

$$k_2 + \sigma \left(\frac{Z_1 - Z_0}{Z_2 + Z_0} \right) k_1 = 0 \quad (4)$$

and for even intervals

$$k_2 + \sigma \left(\frac{Z_2 - Z_0}{Z_1 + Z_0} \right) k_1 = 0 \quad (5)$$

where k_1 and k_2 are the ramp slope coefficients as shown in Figure 11, and σ is the attenuation factor for one trip across the transducer in percent/100. For both of these relationships to be true simultaneously, Z_2 must equal Z_1 . The ramp ratio can then be determined to be

$$\frac{k_2}{k_1} = \sigma \left(\frac{Z_0 - Z_2}{Z_0 + Z_2} \right) \quad (6)$$

Funding has not been available to test this theory on either the model or actual transducers. Such action would primarily require considerable modifications to a pulse generator.

Another factor which should be considered in future work is that some transducer materials may require a finite time to establish a field gradient between electrodes. This would result in an electric excitation which lags the input voltage, thereby causing the transducer to deviate from performance as predicted by the model.

It should be added that the calculated frequency spectrum of both bipolar and unipolar pulses are in agreement with the measured spectrums of Figure 12.

a. TRANSMITTER PULSE WITHOUT TRANSMISSION CABLE ATTACHED, 20 nsec/div., BIPOLAR CONDITION

b. PULSE-ECHO RECEIVED BIPOLAR PULSE, 20 nsec/div

c. SPECTRAL POWER DENSITY OF PULSE SHOWN IN b, 25 MHz CENTER SCALE, 5 MHz/div

d. TRANSMITTER PULSE WITHOUT TRANSMISSION CABLE ATTACHED, 20 nsec/div., UNIPOLAR CONDITION

e. UNIPOLAR (+) PULSE, RECEIVED, GATED, 20 nsec/div

f. SPECTRAL POWER DENSITY OF PULSE SHOWN IN e, 25 MHz CENTER FREQUENCY, 5 MHz/div

g. UNIPOLAR (-) PULSE, GATED RECEIVED, 20 nsec/div

h. SPECTRAL POWER DENSITY OF PULSE SHOWN IN g, 25 MHz CENTER FREQUENCY, 5 MHz/div

30 MHz PZT-5 TRANSDUCER. SHOWS TRANSMITTER, RECEIVED PULSE AND SPECTRAL POWER DENSITY OF BOTH THE BIPOLAR AND UNIPOLAR 30 MHz PERIOD PULSES.

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FIGURE 12. 30 MHz PZT-5 Transducer. Shows transmitter, received pulse and spectral power density of both the bipolar and unipolar 30 MHz period pulses.

EXPERIMENTAL RESULTS

Experimental data were obtained to establish the validity of the transducer behavior with respect to the transducer model as well as to elucidate the more obvious characteristics of the unipolar pulse wave propagation.

In most instances the experimental equipment satisfied the requirements of the transducer model. Transmitters terminated for 50 ohms (such as the Tektronix 115, Datapulse 108L, or Chronetics PG-13A) with individually variable rise, length, and fall times were used with 50 ohm coaxial cable terminated in 50 ohms at the transducer housing. Amplifiers such as Tektronix scope or Keithly pulse were used to condition the received signal for display or gating. Gating and time measurements to ± 1 nsec was accomplished by using the EG&G M-100 system; spectral analysis was made using the H/P 8552/8553L spectrum analyzer. The transducers were fabricated in our BNW transducer fabrication facilities with tungsten powder loaded epoxy backing members and exposed front electrodes except when lenses were used which were made of resin. Special care was taken to keep the center lens thickness to less than $1/4$ of the period propagation time of the active element thickness period. Attempts were made to damp the radial mode excited by the transmitter pulse which can be bothersome when a decreasing diameter to thickness approaches the ratio of 10 to 1 or in some cases even 15 or 20 to 1. Further work remains to be done to silence the radial mode, particularly in lead zirconate-lead titanate materials with strong cross mode generation.

One method of generating the unipolar pulse is as follows. The use of a relatively slow rise or charge rate on the element effectively eliminates the transmission of detectable acoustic energy. At some time after the transducer has been fully

charged, the linear discharge ramp can be applied which functions as the unipolar pulse generator and simultaneously leaves the transducer element at ground potential. This is in preparation for a scheme of switching "off" the transducer all transmitter internal noise, capacitance, and termination circuitry including receiver limiting circuitry, and switching "on" pre-selected or optimized receiver mode termination, transmission cable, and amplifier for the echo portion period of interest of the pulse-echo sequence. After the echo period of interest has passed, the receiver mode instrumentation is switched off the transducer, and the transmitter is switched on, thereby completing the pulse-echo cycle, unipolar pulse operation.* Should through-transmission application be desired, no switching of transmit-to-receive modes is necessary. Should a bipolar pulse be tolerable, the transmitter pulse can be made to charge the transducer, thereby producing a unipolar pulse output of either compression or rarefaction polarity. Immediately following the generation of the first unipolar pulse, the transmitter can be made to discharge the transducer thereby generating a second unipolar pulse which is opposite in phase both electrically and acoustically. Figure 12 illustrates the relationship between the transmitter pulse, unipolar pulse, bipolar pulse and spectral power distribution.

In Figure 12 a through h, data are presented from a 30 MHz, PZT-5, medium damped, 1/4 in. diameter element. The spectral power distribution data agree quite well with Fourier transform theory.

Data for confirming the pulse-echo response of a transducer were taken using a well damped, higher frequency receiver. Figure 13 shows a simulated 15 MHz period unipolar pulse

* *This instrumentation system is being filed on by the USAEC patent office under Case No. S-38297.*

a. SIMULATED 15 MHz PERIOD
LINEAR RISE-LINEAR FALL UNIPOLAR
PULSE, 100 nsec/div

b. SPECTRAL POWER DENSITY OF
SIMULATED PULSE SHOWN IN
a, 10 MHz CENTER FREQUENCY,
2 MHz/div

c. GATED (+) UNIPOLAR PULSE, 100
nsec/div., PULSE ECHO

d. SPECTRAL POWER DENSITY
FOR PULSE SHOWN IN c,
10 MHz CENTER FREQUENCY,
2 MHz/div

e. GATED (+) UNIPOLAR PULSE, 15
MHz TRANSMITTER, 35 MHz
RECEIVER, 100 nsec/div

f. SPECTRAL POWER DENSITY
FOR PULSE SHOWN IN e,
10 MHz CENTER FREQUENCY,
2 MHz/div

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FIGURE 13. Comparison of Pulse Shapes and Spectral Power Distribution Curves for Pulses from a Simulated 15 MHz Unipolar Period, a 15 MHz Period Unipolar Pulse-Echo, and a 35 MHz Receiver to 15 MHz Period Transmitted

compared with the gated pulse-echo data from a 15 MHz, PZT-5 transducer and the gated data from a 35 MHz highly damped receiver response of the 15 MHz unit transmitted pulse. Spectral power density patterns show minor differences; however, all data approach the theoretical spectral distribution curves for triangular shaped pulses. Some overshoot is noticeable on both the pulse-echo and high frequency receiver transducer data and is typical of some damping member-to-couplant medium acoustic impedance ratios which may be simulated with the transducer model described in the theory section of this report. It is useful to have a transducer model available for thorough evaluation and comparison of commercially available transducers. Individual transducer variations become readily apparent when a model and variable transmitter parameters are available. Further work in the evaluation of transducer quality using these techniques may provide a superior method for obtaining nearly identical units.

Figures 14 a and b, illustrate the range resolution on aluminum of a unipolar pulse received pulse-echo. The longitudinal velocity for this aluminum was near 0.250 in./ μ sec (6,420 m/sec). Most materials are considerably lower in velocity than aluminum, resulting in even better resolution with an equivalent thickness and period transducer. Experimental data have been taken in the transducer element period band from 500 kHz through 35 MHz and it appears that the range resolution of the unipolar pulse technique is primarily limited by the element period, the transmitter capability and the propagation distance.

Figure 15 shows a topographical, three-dimensional distance - amplitude beam plot: 15a shows the presence of field effects in a pseudo-continuous wave at the Y_2 (second near field minimum) of a 5 MHz, 3/4 in. diameter, PZT-5 transducer,

a. PULSE-ECHO SIGNAL
TRAIN FROM 0.034 IN.
Al, 200 nsec/cm

b. T-T SIGNAL TRAIN
FROM 0.010 IN. Al,
50 nsec/cm

c. T-T SIGNAL TRAIN
FROM 0.005 IN. Al,
50 nsec/cm

NOTE: THE BASELINE NOISE IS DUE TO TRANSMITTER GENERATED NOISE
AND A TRANSMITTER PULSE OF ONLY 10V APPLIED

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FIGURE 14. Example of Typical Signal Trains Showing Range
Resolution Capabilities of a High Frequency
Transducer Element

and 15b shows the distance-amplitude plot for the same water path in a unipolar pulse from the same transducer. The received signal was taken with a 0.050 in. diameter 22 MHz, lead metaniobate, damped transducer. The complete absence of field effects is obvious with the unipolar pulse technique. Note, however, the aberration in the amplitude plot near the center of the beam. This was due to the leadwire solder spot on the back electrode appearing as an impedance variation in the backing member. Frequency dispersive effects were measurable and are visible in the beam dimension spreading at this

a. TOP TRACE-RECEIVED
PSEUDO-CONTINUOUS
WAVE PULSE,
 1μ sec/cm
BOTTOM - DISTANCE -
AMPLITUDE
SHOWING FRESNEL FIELD.

b. TOP TRACE-RECEIVED
UNIPOLAR PULSE,
 0.5μ sec/cm
BOTTOM - DISTANCE -
AMPLITUDE
SHOWING ABSENCE
OF FRESNEL FIELD.

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FIGURE 15. Topographical Beam Amplitude Map Showing a) Near or Fresnel Field Effects in a Sinusoidal Wave Packet Pulse, and b) the Absence of Field Effects in the Unipolar Pulse

water path and pulse-period, beam-diameter condition. In other work with smaller diameter elements, frequency dispersive beam spreading became more pronounced; the high spectral components were more directional, thus lows show spreading.

Other observations noted in the use of the unipolar pulse technique included good penetration characteristics. This was noted in flaw detection and velocity measurements in composites and concrete. Improved penetration with resolution is likely due to the prevalent lower frequency spectral content of the unipolar pulse. It also appears that spectral attenuation information is easily obtained, by spectral analysis techniques, which is related to material acoustic attenuation. This information may also be usable for velocity correction factoring when accurate velocities are required from pulses which have been reshaped due to material attenuation effects. To be more specific, broadband pulses are affected in shape because of material attenuation and generally imply a slower velocity than is actually the case. With the spectral attenuation curves obtained by spectral analysis techniques, it becomes possible to relate the attenuation reshaping to pulse peak amplitude-time, thereby correcting for peak amplitude time delay caused by attenuation pulse reshaping. Further work is necessary before conclusive results on velocity correction can be stated. This pulse velocity correction capability would be very valuable in composite, graphite and other highly attenuating materials testing.

Another effect noted in the use of unipolar pulse-echo work included the omnidirectionality of reflected acoustic energy from flaws smaller than the beam dimension. No field effects or side lobes were noted in the reflected wave; however, there were considerable spectral and amplitude variations for various shaped flaws and their respective orientation.

In general, total spectral power related to flaw dimension with the spectral distribution pattern and curve correlating with flaw shape and orientation. Very promising results were obtained for relating spectral information to individual flaw evaluation. Certain test applications such as pulse-echo and pitch-catch or the so-called delta technique for weld testing appear to be ideally suited for inclusion of the unipolar pulse technique to obtain improved test capabilities.

Some interesting effects were noted in the use of unipolar pulsed longitudinal and shear waves in large thick steel plates. Mode conversion, dispersion, and plate wave formation become resolvable and are useful in elucidating wave propagation behavior. For instance, the dispersion or spreading rate of shear along the particle motion direction axis is significantly greater than in the normal to the particle motion direction axis and it is greater than the equivalent pulse period longitudinal wave which is longer because of the higher velocity mode. Normally, one associates the shorter wave with higher directionality.

Surface or Rayleigh waves were readily generated using the unipolar pulse technique. This presents some interesting possibilities since surface wave depth of penetration is related to frequency and, for instance, cold work and grain size or orientation information might be readily separated by spectral analysis techniques.

An effect noted in the pulse-echo signal from scintered material was the obvious spectral change in the surface reflected signal from varying degrees of scintering in powdered metals.

Topographical mapping using the unipolar pulse and time measuring systems such as the EG&G M-100 system has been accomplished to ± 1 nsec precision using low velocity couplant

fluids. This corresponds to 10 μ in. accuracy and can be used for applications such as radius measurements, topographical plots, absolute thickness measurements, absolute velocity measurements, and dimensional contour mapping regardless of total dimensional size.

Further understanding of the behavior of the unipolar wave propagation is obviously needed before all new application potentials can be established.

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