porosity), although other limitations such as the detail of the resolution may exist.

Reasonable amplifier linearity is desirable for calibration and discontinuity comparison. Reading accuracies of one part in twenty are adequate because most discrepancies are due to other variables such as coupling and alignment. Precision markers of high sweep linearity are ordinarily not required for discontinuity detection, although one or the other may be necessary for accurate thickness or velocity measurements. In some cases, precision markers are provided as system accessories.

Among the alternative configurations for ultrasonic circuit components are those listed in Table 2.

Special instrumentation needed for some testing applications may include the following: (1) provision for dual-transducer operation, (2) interference elimination circuitry, (3) compensation for long transducer cables, (4) stabilization for extreme line voltage changes, (5) exponential calibrator for attenuation measurements, (6) exceptional portability for field use, (7) remote indicators, (8) frequency range extended above 100 MHz, (9) high resolution and (10) computer interface and on-board digital memory.

B-Scan Presentation

When the shape of large discontinuities or their distribution within a test object cross section is of interest, the B-scan display is the most useful. In addition to the basic components of the A-scan unit, provision must be made for these additional B-scan functions: (1) intensity modulation or brightening of the pixel in proportion to the amplitude of the discontinuity signal, (2) deflection of the display trace in synchronism with the motion of the transducer along the test object and (3) retention of the display image by a long persistence phosphor.

B-Scan Equipment

Often a B-scan display is used with A-scan testing or as an attachment to standard A-scan equipment. Therefore, the system design criteria depend on A-scan equipment and the testing application.

TABLE 2. Alternative circuit components for ultrasonic test systems.

Characteristic	Options
Synchronizer	
pulse repetition rate	fixed, adjustable with fixed range, stepped with sweep range, variable (50 to 1000 Hz)
locking signal	line voltage (or harmonic), internal
Pulser	
wave shape	impulse, spike, gated sine wave, damped wave train
type	tunable, impedance matched, variable amplitude
circuit	thyratron, pulsed oscillator
Amplifier	
Type	tuned radio frequency, wide band
Response	linear, sharp cutoff, logarithmic
Sensitivity	time variable gain or constant
Controls	gain, input attenuation, reject, variable band width
Signal Display	
Type	radio frequency wave train, video
Source	radio frequency output, rectified (envelope), differentiated video
Sweep	
Type	logarithmic, high linearity, conventional
Delay	adjustable, automatic, none
Expansion	fixed, adjustable, related to sweep
Marker	
Type	fixed scale on display, precision electronic, adjustable square wave, movable step mark
Source	crystal oscillator, adjustable multivibrator, precision integrator
Display	superimposed on signals, alternate sweep, separate trace, intensity modulated
Signal Gate	
Type	amplitude proportional
Output	direct current level, modulated, rectangular wave, pulse stretched
System	
Frequency range	single; continuous tuning; low (50 to 200 kHz), intermediate (0.2 to 5 MHz), high (5 to 25 MHz)

Where high speed scanning is required, the longer persistence of the B-scan display may be an advantage to the operator.

Discontinuity Detectability

The effectiveness of the B-scan in showing discontinuity detail depends on the relationship of discontinuity size, beam area and wavelength. Optimum results are obtained with larger discontinuities, smaller transducers and higher frequencies. For other conditions, beam sharpening techniques such as focusing and electronic contrast enhancement may be needed.

C-Scan Presentation

By synchronizing the position of the display spot with the transducer scanning motion along two coordinates, a plan view of the test object can be developed similar to the common plan position indicator (PPI) radar display.

In addition to the circuitry required for a B-scan, provision must be made for eliminating unwanted signals such as the initial pulse, interface echo or back reflection, which obscure internal discontinuity signals. An electronic gate is used to render the display circuits sensitive only for the short intervals of sweep time when signals from the desired depth range occur.

In certain cases, hybrid systems present some data about discontinuity size and location with a sacrifice in discontinuity shape and position detail.

Gated Systems

In general, gating is needed for all automatic C-scan systems that alarm, mark, record, chart or otherwise replace visual interpretation. Such gating circuits may be built into the discontinuity detector or supplied as separate attachments.

Commercial recording attachments typically provide at least two gates, one to indicate the presence of discontinuities in the test object and the second to show a decrease in back reflection. Some units provide additional discontinuity gates so that two or more alarm levels can be set or so that different depth increments can be tested.

If the cross section of the test object varies during the scanning cycle in an automatic test, the gating periods must be simultaneously adjusted. In addition, other functions such as sensitivity, transducer angle and recorder speed may have to be controlled.

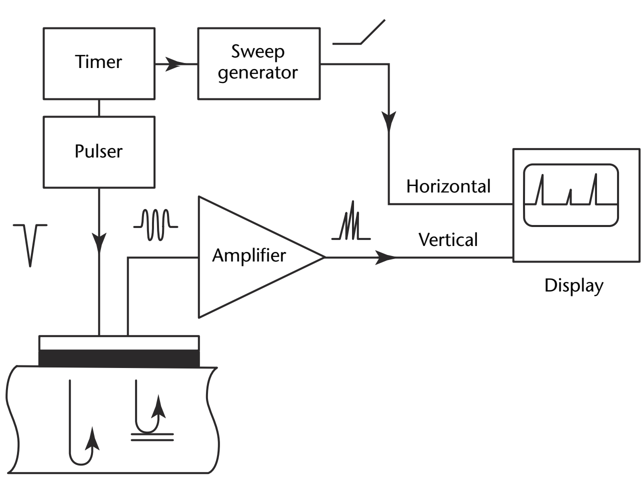
Basic Instrument[2]

The basic electronic instrument used in pulsed ultrasonic testing contains a source of voltage spikes (to activate the sound source — that is, the pulser) and a display mechanism that permits interpretation of received ultrasonic acoustic impulses. Figure 2 shows a block diagram of the basic unit. The display can be as simple as a digital meter for a thickness gage or a multidimensional representation of signals over an extended area of interest.

The timer circuitry triggers the pulser (activates the transducer) and the sweep generator forces the electron beam within the display to move horizontally across the screen. Other special circuits triggered as needed include markers, sweep delays, gates, distance amplitude correction and other support circuits. Pulse signals from the receiver transducer are amplified to a level compatible with the display.

The term *pulse* is used in two contexts in ultrasonic testing. The electronic system sends an exciting electrical pulse to the transducer being used to emit the ultrasonic wave. This electrical pulse is usually a unidirectional spike with a fast rise time. The resulting acoustic wave packet emitted by the transducer is the ultrasonic pulse with both a positive and negative excursion. It is characterized by a predominant central frequency at the transducer's natural thickness resonance.

FIGURE 2. Basic pulse echo system for ultrasonic testing.[2]



The received signals are often processed to enhance interpretation with filters (that limit spurious background noise and smooth the appearance of the pulses), rectifiers (that change the oscillatory radio frequency signals to unidirectional video spikes) and clipping circuits (that reject low level background signals). The final signals are passed on to the vertical displacement circuits of the display unit and produce the time delayed echo signals interpreted by the operator. This type of display is commonly referred to as an A-scan (signal amplitude displayed as a function of time).

Most functions are within the control of the operator, and their collective settings are the setup of the instrument. Table 3 lists the variables under the control of the operator and their impact on the validity of an ultrasonic test. If desired, a particular portion of the trace may be gated and the signal within the gate sent to some external device, an alarm or recording device that registers the presence or absence of echo signals being sought.

Characteristics of the initial ultrasonic, radio frequency pulse (shape and frequency content) are carried forward throughout the system, to the test object, back to the transducer, the receiver (amplifier), the gate and the display. In essence, the information content of the initial electrical pulse is modified by each of these items. It is the result of this collective signal processing that appears on the screen. The initial pulse may range from 100 to 500 V and have a very short rise time.

In some systems, the initial pulse may represent a portion of a sinusoidal oscillation, tuned to correspond to the natural frequency of the transducer. The sinusoidal driving pulses are needed to help penetrate highly attenuative materials such as rubber and concrete.

Signals from the receiving transducer (usually in the millivolt range) may be too small to be directly sent to the display unit. Both linear and logarithmic amplifiers are used to raise signal levels needed to drive the display. These amplifiers, located in the receiver sections of A-scan units, must be able to produce output signals linearly related to the input signals and which supply signal processing intended to assist the operator in interpreting the displayed signals.

Amplifiers may raise incoming signals to a maximum level, followed by precision attenuators that decrease the signal strength to levels that can be positioned on the screen face — capable of changing amplification ratios in direct response to the gain control.

Discrete attenuators (which have a logarithmic response) are currently used because of their ease of precise construction and simple means for altering signal levels beyond the viewing range of the screen. Their extensive use has made decibel notation a part of the standard terminology used in describing changes in signal levels, such as changes in receiver gain and material attenuation.

The ratio of two pulse amplitudes (A_2 and A_1) and their equivalence can be expressed in decibel notation (N_{dB}):

$$(1) \qquad N_{dB} = 20 \log_{10} \frac{A_2}{A_1}$$

Inversion of this equation results in the useful expression:

$$(2) \qquad \frac{A_2}{A_1} = 10^{\frac{N}{20}}$$

where a change of 20 dB, $N = 20$, makes:

$$(3) \qquad 10^{\frac{N}{20}} = 10^1 = 10$$

Thus 20 dB is equivalent to a ratio of ten to one. Signals may be displayed as radio frequency waveforms, replicating the acoustic wave as detected by the receiving transducer, or as video waveforms, (half-wave or full-wave rectified), used to double the effective viewing range of the screen (bottom to top rather than centerline to top and to bottom) but suppressing the phase information found only in radio frequency presentations.

To enhance the ability to accurately identify and assess the nature of the received ultrasonic pulses, particularly when there exists an excessive amount of background signals, various means of signal processing are used. Both tuned receivers (narrow band instruments) and low pass filters have been used to selectively suppress frequencies of the signal spectrum that do not contain useful information from the test material.

Linear systems, such as the ultrasonic instrument's receiver section (as well as each of the elements of the overall system), are characterized by the manner in which they affect incoming signals. A common approach is to start with the frequency content of the incoming signal (from the receiving transducer) and to describe how that spectrum of frequencies is altered as a result of passing through the system element.

When both useful target information (which may be predominantly contained in a narrow band of frequencies generated by the sending transducer) and background noise (which may be distributed randomly over a broad spectrum of frequencies) are present in the signal entering the receiver, selective passing of the frequencies of interest emphasizes the signals of interest while suppressing others that interfere with interpretation of the display.

When an ultrasonic instrument is described as being broad band, that means a very wide array of frequencies can be processed through the instrument with a minimum of alteration — that is,

Table 3. Effects of instrument controls.

Instrument Control	Comments on Signal Response
Pulser	
Pulse length (damping)	if short, improves depth resolution; If long, improves penetration
Repetition rate	if high, brightens images but may cause wrap-around ghost signals
Receiver	
Frequency response	wide band — faithful reproduction of signal, higher background noise
Frequency response	narrow band — higher sensitivity, smoothed signals, requires matched (tuned) system
Gain	if high, improves sensitivity, higher background noise
Display	
Sweep — material adjust	calibration critical for depth information
Sweep — delay	permits spreading of echo pulses for detailed analysis
Reject	suppresses low level noise, alters opponent vertical linearity
Smoothing	suppresses detailed pulse structure
Output (Alarm, Record) Gates	
Time window (delay, width)	selects portion of display for analysis; gate may distort pulses
Threshold	sets automatic output sensitivity
Polarity	permits positive and negative images, allows triggering on both increasing and decreasing pulses

the signal observed on the screen is an amplified representation of the electrical signal measured at the receiving transducer. Thus both useful signals and background noise are present, and the ratio of signal to noise may be bad. The shape and amplitudes of the signals, however, tend to be an accurate representation of the received response from the transducer.

A narrow band instrument, on the other hand, suppresses incoming frequencies above or below the pass frequency band. With the high frequency noise suppressed, the gain of the instrument can be increased, leading to an improved sensitivity. However, the shape and relative amplitudes of pulse frequency components are often altered.

Instrument Types[3]

Typical ultrasonic test instruments provide basic functions, including the generation of an elastic wave, the reception of ultrasonic signals, signal conditioning and processing, discontinuity signal gating and signal presentation. Depending on the intended application, ultrasonic instruments may incorporate other functions, including multiple-channel capability, additional signal gates, filters, computer interfaces and compensation for signal loss as a function of distance traveled and attenuation. The ultrasonic testing instrument has evolved into several distinct categories: manual instruments (typically portable send/receive units), customized systems (programmed for specific industrial applications) and special purpose systems (typically for the laboratory).

Basic Instruments

A distinction is made between basic, manual (portable) and laboratory instruments because their internal designs and external interfaces are considerably different. Portable instruments are generally self-contained in terms of their internal functions. Laboratory instruments often require peripheral components not normally found in nondestructive testing production environments: signal sources and processors, displays, desk top computers and other components.

Portable and industrial production instruments are calibrated differently than laboratory instruments. For example, the vertical and horizontal axes of portable instruments are generally calibrated in relative units with respect to known distances and reflector sizes. Furthermore, portable instruments are intentionally designed to allow adjustments and calibration by a human operator at the job site. Laboratory instruments are typically calibrated in absolute units (volts and microseconds).

A general purpose instrument designed for research laboratory applications has functions similar to a basic portable instrument but with different operator interfaces. The external and internal differences between manual and laboratory instruments reflect different user requirements. Basic, portable instruments are configured to satisfy the practical needs of an inspector whose test assignments may vary daily. Laboratory instruments are intended primarily for use by material research engineers and scientists who require ultrasonic frequency data in terms of highly reproducible engineering units. Industrial production systems are generally intended for special purpose, factory floor installations operated under computer control.

Industrial Production Systems

Industrial production systems are often modular and offer multiple-channel capabilities. Such systems can be easily optimized for a particular production environment through plug-in modules and changes in computer control software.

To accommodate different test requirements, modular systems typically use a general purpose enclosure internally compatible with a broad range of special function, plug-in modules. Each module is designed to perform a specific function. This approach offers the user the flexibility of designing a custom instrumentation package. As the requirements change, new modules can be added to the system at incremental cost. Maintenance of modular systems is facilitated by this approach. The initial cost of a basic modular system may be higher than that of a portable system.

Special Purpose (Laboratory) Systems

The category of special purpose systems includes all instruments designed to perform a specific ultrasonic test that cannot, for cost or performance reasons, be carried out with a portable, laboratory or modular system. This category includes bond testers, velocity determination instruments, high powered drivers for air coupled and special purpose electromagnetic acoustic transducers, scanners, imaging equipment and acoustic microscopes. The cost of installing a special purpose system can vary widely. Thickness gages are generally less expensive than portable ultrasonic instruments whereas acoustic microscopes can be much more expensive than modular systems.

Low frequency (less than 100 MHz) acoustic microscope systems are suited for ultrasonic tests of complex aerospace structures and electronic packages. High power laboratory instruments can be used with unconventional ultrasonic transducers, including air coupled and electromagnetic acoustic transducers. Using front panel controls, it is possible to reconfigure this instrument to generate a variety of pulse shapes, including spike, square wave and tone burst pulses.

Below, the principles of ultrasonic test instruments and auxiliary equipment are explained by using the operation of a portable instrument as an example. The special features of laboratory and modular industrial production instruments are explained and some basic modes of data presentation are discussed.

Portable Instruments[3]

Portable ultrasonic instruments are battery operated and principally used as discontinuity detectors. Some such instruments are designed for handheld operation and offer a limited range of functions. Other instruments are suitable for most remote or laboratory production applications and for procedure development. Such instruments are generally larger and heavier than handheld discontinuity detectors but offer many additional functions.

Basic portable instruments are most often operated in the pulse echo mode (described elsewhere in this volume) by using the same ultrasonic transducer for generating and receiving the ultrasonic signals. This mode of operation was first demonstrated by Firestone around 1940.[4] However, portable instruments may also be operated in a pitch catch or through-transmission mode, using separate transducers for generating and receiving ultrasonic signals.

Instrument Functions

Portable test systems typically offer a minimum range of basic functions: (1) pulse echo and pitch catch modes, (2) spike or square wave pulse generation, (3) adjustment of pulse amplitude and harmonic content, (4) selection of test frequencies, typically 1 to 50 MHz, (5) coarse and fine receiver amplifier gain adjustment, (6) signal gating, (7) signal detection and filtering, (8) accept/reject threshold setting and alarm and (9) display of received ultrasonic signals.

These functions typically satisfy most contact ultrasonic test requirements. However, additional functions are needed in applications such as contact tests of thick sections and immersion tests. Some of these additional functions are available in portable instruments but are usually standard in laboratory and production systems.

If properly configured, a portable instrument can be used in immersion testing in the pulse echo and through-transmission modes. It can also be used to test many thick section materials and structures. In addition, when used with data logging and scanning, the instrument offers B-scan and C-scan presentations. Other useful functions include interface triggering of gate and display, distance amplitude correction and simultaneous display of both video and radiofrequency signals.

Although nearly all portable instruments are compatible with piezoelectric ceramic transducers in the 1 to 50 MHz frequency region, they may not operate properly with special transducers. In particular, most piezoelectric polymer and low frequency (typically 0.5 MHz and lower) piezoelectric ceramic transducers will not operate properly if the equipment is not designed for these materials and frequencies.[5]

It is not generally recommended that portable instruments be used to drive unconventional transducers, including air coupled transducers and electromagnetic acoustic transducers. However, specialized high power drivers[6] and low noise preamplifiers are available for such transducers.[7]

Operation

Low cost, portable instruments are intended primarily for discontinuity detection and thickness gaging. The instrument provides a video display of the ultrasonic signals. Figure 3 illustrates the main functions of the instrument and shows representative internal and displayed waveforms.

Internally, the basic instrument is a display whose horizontal deflection (sweep) voltages are synchronized with the transmitted ultrasonic pulses. Two modes of operation are possible: pulse echo and pitch catch. The pulser excites an ultrasonic transducer with a high voltage spike or square wave pulse and has controls for adjustment of the amplitude (energy) and shape (harmonic content) of the transmitted ultrasonic pulses. The system's receiver processes ultrasonic signals returned from the test object (Fig. 4). Only the most elementary controls are provided for adjusting the

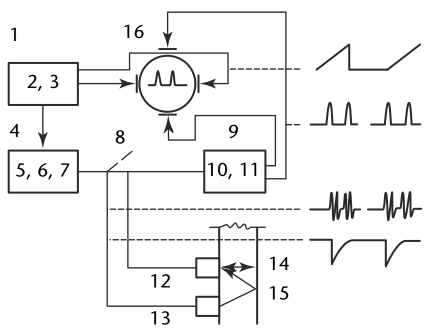


FIGURE 3. Block diagram of portable ultrasonic instrument (see also Fig. 4).

Legend

1. Timing section
2. Pulse repetition frequency
3. Sweep rate
4. Pulser
5. Pulse amplitude
6. Pulse frequency
7. Damping
8. Transmit/receive switch
9. Receiver
10. Gain
11. Frequency
12. Receiver
13. Transmitter
14. Pulse echo
15. Pitch catch
16. Display

frequency domain (filtering) and time domain (gain) parameters of the received signals. In addition, such a basic instrument has front panel controls for adjusting the sweep rate, usually calibrated in units of length or velocity. The sweep rates are made adjustable because ultrasonic propagation velocities vary with the test material. A signal gate, enabling the operator to set an alarm level, is provided as a standard function.

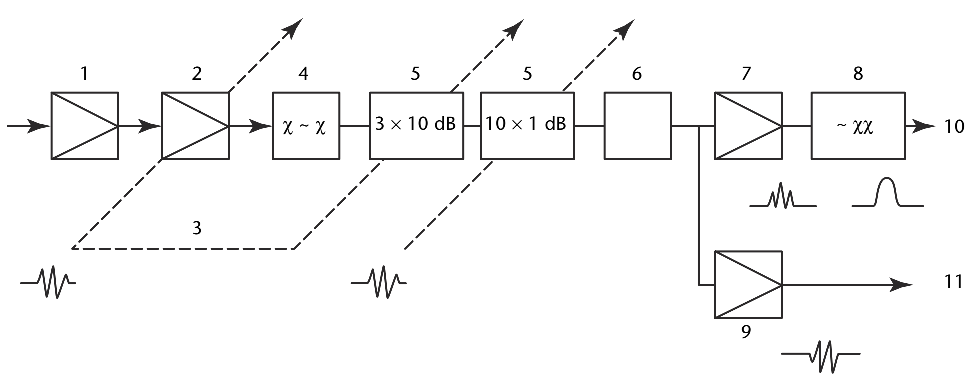
Timing and Synchronization

The operation of a basic instrument is timed and synchronized by the so-called *timing section*, which controls the system's pulse repetition frequency. The timing section also generates the internal sweep rate signals which determine the separation between the received ultrasonic signals on the instrument's display.

The pulse repetition frequency timing signals are fed directly to a pulser that drives the ultrasonic transducer through a manually selectable diplexer. Diplexers are also known as *transmit/receive switches*.

Following a propagation delay corresponding to the ultrasonic time of flight between the transducer and an internal reflector, the back scattered ultrasonic signals are received by the same transducer. These signals are then detected by the receiver preamplifier.

FIGURE 4. Principal functions of portable instrument's receiver and their effect on the received ultrasonic signals.



Legend

1. Preamplifier
2. First radiofrequency amplifier (gain block)
3. Gain adjust
4. Filters
5. Attenuators
6. Second radiofrequency amplifier
7. Video detector
8. Low pass filters
9. Buffer amplifier
10. Video out
11. Radiofrequency out

However, before the received signals can be processed and displayed, additional signal processing steps are needed. Processed signals are displayed for evaluation by inspectors or automatic detectors. It is assumed that the travel time is long enough to keep signals of different transmitter pulses from overlapping.

Receiver Gain Adjustment

After preamplification to help establish the best electrical signal-to-noise ratio, the amplitudes of the received signals on the display can be adjusted using a combination of fixed and variable attenuators. The overall gain of the amplifier can be selected by switching in two or three 20 dB gain circuits. Generally, this selection can be accomplished using controls at the front panel of the instrument. Receiver gains might be adjusted also through an external controller.

After amplification, band pass filtering and video detection (rectification and low pass filtering), the signals are amplified again by the video amplifier. This amplification is often followed by an adjustable low pass filter and the output of the filter is then applied to the vertical axis of the display, as function of time (horizontal axis of the display). The final detected and filtered signal is called the *video display* or *A-scan*. In some designs, it is possible to display radiofrequency waveforms directly.

Sweep, Signal Filtering and Display

The horizontal axis of the display device is driven by the sweep signals generated in the system's timing section. Generally, the start of each sweep signal is delayed with respect to the transmitter pulse or by an interface trigger. This delay is used to offset the start of the display to some convenient interface echo.

The amplitude of the displayed signals are determined principally by the receiver gain and frequency filter settings. They can also be affected by the low pass filter in the detector circuit. In addition, the setting of the transmitter pulse amplitude and pulse damping controls can affect the amplitude and the appearance of the displayed ultrasonic signals.

Signal Gating and Threshold Selection

Among the essential functions of a basic instrument are the signal gate and the alarm threshold controls. These functions enable the operator to isolate a specific portion of the received signal train and to compare its peak amplitude with a preset threshold level.

The signal gate delay, width parameters and alarm threshold level typically can be selected from the front panel. To ensure reliable results, receiver gain levels and the alarm threshold level within the gate interval should be adjusted before the test using an appropriate ultrasonic reference standard and an instrument calibration procedure.

Pulse Repetition Frequency

Battery powered discontinuity detectors can be operated at relatively high pulse repetition frequencies (500 Hz and higher) to ensure a bright display. Thickness gages can achieve even higher pulse repetition frequencies. However, high pulse repetition frequencies use more power and so make the instrument less portable. High pulse repetition frequencies can cause interference of ultrasonic signals generated by different transmitter pulses, in turn producing undesirable fluctuations in signal amplitude. Interference must be avoided because of its detrimental effect on test reliabilities.

In many advanced instruments, fast digital sampling, storage techniques and advanced display technologies increase display brightness while reducing power consumption. In these designs, pulse repetition frequencies can be as low as 40 Hz. Lower frequencies could result in perceptible flicker and make real time scanning inadvisable because of wide intervals between adjacent pulses.

Pulse Amplitude and Shape Control

Most portable ultrasonic instruments use relatively simple pulse circuitry. In the twentieth century, spike pulser designs were common. In the twenty-first century, many designs incorporate square wave pulsers.

If the instrument uses a spike pulser, then the operator may be able to modify the pulse amplitude by adjusting the energy of the pulse. Pulse energy is adjusted by selecting the value of the energy storage capacitor. In addition, an adjustment of the damping resistor value may be made to minimize transducer ringing.

If the instrument uses a square wave pulser, the operator is generally required to adjust pulse width individually for each transducer to exactly match the frequency characteristics. In addition, the value of the damping resistor should be adjusted to match the impedance characteristics. To protect the transducers from the effects of voltage overdrive, pulser voltages seldom exceed 400 V.

Avoidance of Receiver Saturation

Most ultrasonic testing procedures require the operator to adjust the gain of the input amplifier and attenuator to ensure that none of the components in the receiver amplifier chain are in saturation. Typically, the maximum displayed signal level is adjusted to the saturation value, about 80 percent of the full display. Such an adjustment can be made using front panel controls. The overall gain of a typical receiver may be adjustable over a range of 100 dB in discrete steps of 1, 2, 6 and 10 dB.

Signal Gate and Alarm Level Settings

The gain adjustment and signal gate functions are important because they can be used to control accept/reject thresholds. If the amplitude of the signal in a discontinuity gate exceeds a preestablished threshold, then the discontinuity alarm feature is activated. The discontinuity alarm is usually built-in and can be audible or visual.

Operation in Pitch Catch or Through-Transmission Modes

If the diplexer or transmit/receive switch is set in the open position, then it is possible to operate in the pitch catch or through-transmission modes. In this configuration, separate transducers are used to generate and receive the ultrasonic signals.

General Purpose Ultrasonic Test Equipment[3]

Portable ultrasonic systems intended for the field and laboratory can incorporate more functions than basic instruments, including distance amplitude correction, interface triggering, display of radiofrequency waveforms, multiple signal gates, interfaces to external control and others.

Distance Amplitude Correction

Distance amplitude correction helps control the gain of the instrument receiver section as a function of sweep time. This function is often used in contact testing of thick sectioned materials where signal attenuation as a function of depth can be severe. Distance amplitude correction allows signals reflected from similar discontinuities at different depths to be evaluated concurrently.

Interface Triggering

The interface triggering function is typically needed when the transducer separation from the front surface of the test object cannot be precisely controlled, as in immersion testing. This situation often occurs in pulse echo, water immersion testing of thin, flexible laminates. If the time delay of the signal gate is synchronized with the initial pulse, variations in distance between the transducer and the front surface cause the position of the gate to vary as well. In effect, on the basis of elapsed time, the gate position has remained constant, but the position of the test object has shifted from the original setup. This is highly undesirable because many potential discontinuities may be missed.

To ensure that the ultrasonic signals returned from the interior of the laminate always arrive within the signal gate, the beginning of each signal gate and display sweep waveform can be synchronized to the signal reflected from the front face of the laminate. This procedure is called *interface triggering*.

Interface triggering permits automatic tracking of the signal gate with respect to a selected portion of the ultrasonic sweep. When using interface triggering, the relative positions of the signals on the display remain unchanged as the transducer separation from the test object is varied (Fig. 5).

In practice, the signal gate and the sweep delays can be synchronized to other ultrasonic signals when a blocking gate is part of the equipment. Signals are disregarded at the blocking gate. Examples of such signals include those from the back faces of thick laminates, thick metal sections and other thick test objects.

In traditional instrument designs, the interface triggering function is realized using analog circuits. However, by using analog-to-digital converters, interface triggering also can be accomplished with digital signal processing techniques.[8]

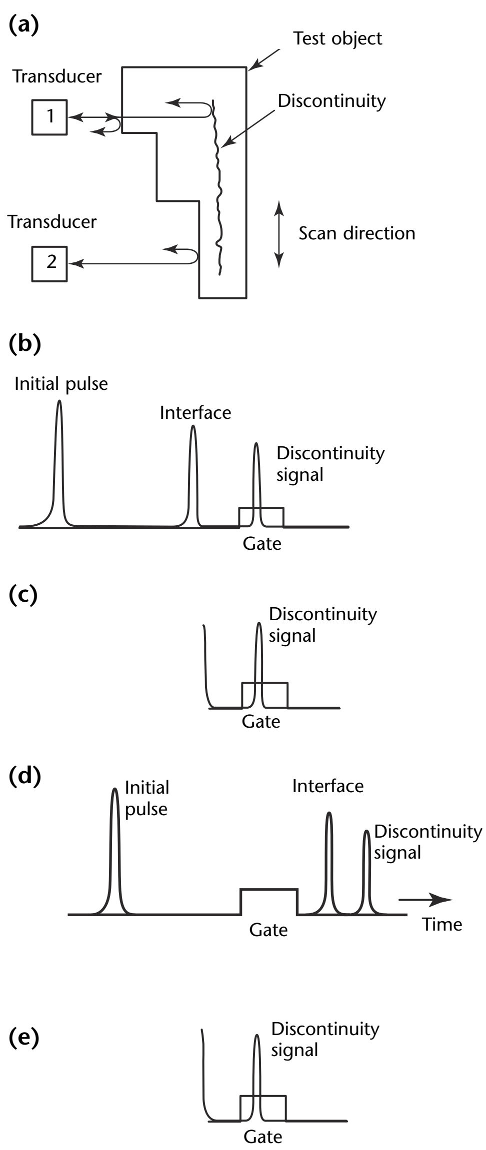
Digital signal processing is generally superior to the traditional analog techniques, particularly in terms of near surface resolution. This capability is particularly important in the study of impact damage in polymer composites.

To isolate and process characteristic features of radiofrequency waveforms is increasingly important in discontinuity evaluation and material characterization. It is now widely recognized that radiofrequency waveforms can contain significant material information. Processing of radiofrequency waveforms is of particular interest in the study of polymer composite materials.[9] However, to fully exploit the information in a radiofrequency waveform, digital signal processing must be used.

Modular Ultrasonic Instruments[3]

Instruments in ultrasonic testing research are designed to be used with other high performance instrumentation in the laboratory: display screens, desktop computers, data logging equipment and other components. Equipment intended for production testing and procedure development is typically self-contained. By contrast, laboratory instruments can delegate many functions to other more efficient laboratory systems. This trend is reflected in the designs of many ultrasonic instruments that can be interfaced with other laboratory instruments by high speed computer interfaces.

FIGURE 5. Interface triggering function for automatic tracking of ultrasonic signal gate: (a) test configuration; (b) initial pulse triggering for transducer 1; (c) interface triggering for transducer 1; (d) initial pulse triggering for transducer 2; (e) interface triggering for transducer 2.



Multiple Channels

A waveform digitizer, of 100 MHz for example, can be designed to allow custom integration of laboratory instruments by using an industry standard architecture bus. In combination with an ultrasonic transducer that interfaces with the same bus, the digitizer can form the nucleus of a flexible system for ultrasonic testing research.

Multiple-channel capabilities can be achieved by adding more pulser/receiver and digitizer boards. The instrument also can be adapted to different measurement needs by changing the control and signal processing software of the host computer. The data display functions are provided by the computer and its output devices.

Digital signal processing offers many advantages over analog techniques. Most importantly, digital processing allows expansion of the dynamic range of the ultrasonic signals. Digital instruments with high dynamic range are more easily calibrated and can acquire and record more data than analog instruments. Furthermore, setup information, including pulser/receiver and transducer parameters, can be stored in the headers of data files. This feature may facilitate comparison and standardization of results obtained with different instruments or at different times.

Modularity

Modules are used to configure an ultrasonic instrument for a specialized application: a multiple-channel preamplifier, a high energy pulser, a receiver module and a gate. The modules are integrated with a proprietary electrical back plane design that can accommodate both analog and digital signals. The operation of the instrument is controlled by a dedicated module that interprets digital control signals generated by an external computer. Generally, modules designed by one manufacturer are not compatible with instruments designed by other manufacturers.

Conceptually, the functions offered by modular instruments are similar to those of general purpose ultrasonic systems. However, modular instruments can be configured for concurrent, multiple-channel operation with the parameters of each channel optimized to perform a specific ultrasonic test. Thus, one channel can be configured for pulse echo testing while another channel is configured for pitch catch testing. In many designs, the setup parameters can be dynamically modified under computer control. This feature of modular instruments facilitates testing of complex structures.