RITEC RAM-5000

Versatile Computer Controlled Ultrasonic System:

- **Modular Approach allows Customization to Specific Experimental Requirements.**

- **High Power RF Burst Outputs as high as 5 kilowatts for frequencies to 7 MHz.**

- **Three Standard Frequency Ranges covering frequencies from 50 kHz to 40 MHz.**

- **Custom Frequency Ranges also available.**

- **Signal Processing Allows Accurate Determination of both Signal Amplitude and Phase.**

- **A phase-sensitive superheterodyne receiver provides the ability to extract otherwise undetectable signals from the noise.**

Powerful Ultrasonic Research Tool

The RITEC RAM-5000 is a complete ultrasonic measurement system designed for ultrasonic research and applications of the nondestructive evaluation of materials properties. Some special capabilities not available in other commercial instruments include:

- The ability to make reproducible measurements using short (down to single cycle) RF burst excitations in composites and other difficult materials,

- High power RF tone burst excitations up to 5 kilowatts, providing ability to drive inefficient transducers,

- A modular approach, (This permits a system to be customized by the user for specific experimental requirements. Standard configurations include a high power tone burst pulser, a broadband pulser/receiver and the complete superheterodyne measurement system.) The RAM-5000 power frame was designed to accept up to five gated amplifier modules; this allows a wider frequency range using two or more gated amplifiers.

- Superior signal processing for amplitude and phase measurements of pulsed RF signals. Measurements of the phase angle are reproducible to within 0.03 degrees and amplitudes are reproducible to within 0.01 dB. For example, in a test sample with a transit time of 5 microseconds with 10 MHz transducers, a resolution of 4 picoseconds is possible.

This ability to measure signals automatically and accurately coupled with software to process these readings into acoustic time of flight and attenuation information combine to make the RAM-5000 a very powerful ultrasonic research tool.

The modular RAM-5000 system consists of the following elements in conjunction with the RAM-5000 power frame:

In our most popular systems, a high quality, fast switching, synthesized frequency source is used to produce the transmitting signal and to process the received signal. This approach enables simultaneous measurements of the phase and the amplitude as well as making the linearity of the system essentially independent of the signal level.

A Modular Approach

The instrumentation for this sophisticated, complete ultrasonic system has been divided into functional modules. Each module performs a specific task and can be understood, tested, and modified individually. This approach offers a number of advantages.

1. Each module can be developed individually and modified for special requirements.

2. Not all applications require the same functional arrangement. For example, some applications require only the broadband receiver, and a pulser/receiver system can purchased without the additional modules for the superheterodyne phase sensitive receiver.

3. New modules may be added to meet the needs of a particular custom application at a fraction of the development cost of a complete system.

4. Modules may be replaced as needed to keep the system current with new developments in measurement technology. This modular approach maximizes RITEC's ability to make state-of-the-art instrumentation available and gives the user the best possibility of keeping his system current.

These advantages result in greatly increased capability, more flexibility, and a lower price as compared with non-modularized stand-alone systems or those created from components purchased from several manufacturers.

I. One or more broadband, high power gated amplifiers for producing RF bursts, derived

from a continuous wave (CW) RF source, to drive various types of transducers, including piezoelectric, air-coupled and electro-magnetic acoustic transducers (EMATs).

II. Timing to produce the gates required to turn the amplifier on and off coherently with the CW source.

III. An accurate direct digital synthesizer (DDS) for high-resolution frequency control and the ability for rapid frequency sweeps.

IV. A broadband receiver stage to amplify ultrasonic signals either from the transmitting transducer, using a diplexer, or from a separate receiving transducer.

V. The broadband receiver is typically followed by superheterodyne phase-sensitive receiver stages to improve the detection of received signals in noisy environments.

VI. A pair of integrators that are gated on and off to process the information from the phase sensitive receiver outputs for precise measurements of the phase and amplitude.

All control and measurement functions are under computer control and software is provided for many of the more standard measurement techniques used in ultrasonics.

Each of the elements listed above can be added to a signal channel system to add increased measurement capabilities to a RAM-5000 system.

Mark I. A Mark I configuration consists of the gated amplifier, element I, and the power frame. For operation, an external RF source and timing gates are required.

Mark II. The Mark II configuration adds the timing functions in element II to the Mark I configuration and can be used with an external CW RF synthesizer.

Mark III. The Mark III, with the addition of the synthesizer, is a complete standalone computer controlled tone burst pulser.

Mark IV. The Mark IV configuration, with the addition of the broadband receiver module, discussed above as element IV, is a computer controlled broadband pulser and receiver.

Mark V. The Mark V configuration adds the superheterodyne mixer and phase sensitive detectors to the broadband Mark IV system for additional processing by digitizing the phase detector outputs.

Mark VI. The complete RAM-5000 superheterodyne phase sensitive measurement system, designated as the Mark VI configuration, utilizes all six elements.

Custom Configurations

The addition of a second high power gated amplifier can be used to extend the frequency range of the system. The addition of a second gated amplifier and a second receiver can be used to drive two transducers in through-transmission or pulse-echo mode. The addition of a special triple synthesizer module allows independent control of the frequency and timing up to three synthesizers and gated amplifiers, resulting in a versatile three channel pulser system.

A block diagram of the single channel Mark VI RAM-5000 measurement system is shown in Figure 1.

RAM-5000 BLOCK DIAGRAM

Figure 1

Block Diagram of the complete RAM-5000 Mark VI System

Each of the various system functions will be briefly described below.

High Power Gated RF Amplifier

The RITEC gated RF amplifier module is designed to derive from an external frequency source the very high power RF bursts needed for modern research studies, with the addition of timing gates produced externally or from the timing module. These RF bursts may then be used to drive various types of ultrasonic transducers, such as piezoelectrics or EMATs. When highly attenuative materials are encountered, long bursts containing numerous cycles may be used to generate very large sound amplitudes. These long tone bursts can also be used to drive the sample into acoustic resonance, which allows the use of inefficient transducers and improves the signal to noise. When the greatest time resolution is required, the unique gating circuitry on the final power amplifier stage allows the amplifier to produce a clean single cycle of RF (up to 2 MHz). Single cycle RF bursts give comparable resolution to spike pulsers in many situations. A block diagram of the gated amplifier is shown in Figure 2.

Block Diagram of Ritec Gated Amplifier

Figure 2

A block diagram of the gated amplifier module.

The high power RF burst is created by selecting a number of RF cycles from a synthesizer running in a continuous mode or in a gated mode. This is accomplished by turning on the amplifier with a gate that is coherent with the RF signal. This low level signal is then split into two signals 180 degrees apart to drive two final amplifier stages. The high power outputs from these final amplifier stages are combined in an output transformer to produce the high power bipolar RF burst. This configuration is known as a "push-pull" configuration. Depending on the transistors used in the final amplifier stages and the frequency range and bandwidth of the output power transformer, the gated amplifier can be customized for specific ranges of frequency.

Two versions of the gated amplifier with different output power levels are available over most frequency ranges. The high power version has a maximum available output pulse power of 5 kilowatts (KW) root-mean-squared (RMS) into a 50 Ohm load. The low power version has a maximum available output pulse power of 1.5 KW RMS into a 50 Ohm load. Please note that these power measurements are RMS measurements, peak pulse power measurements would be double of those RMS power measurements, (10 KW peak and 3 KW peak). Some other amplifier manufacturers quote peak pulse powers.

With the high power version the frequency range where the 5 KW power is available is restricted to 1 decade of frequency up to a maximum frequency of 7 MHz. Typical frequency ranges are 50 kHz to 500 kHz, 250 kHz to 2.5 MHz, and 500 kHz to 5 MHz.

With the standard power version the frequency range where the 1.5 KW power is available is restricted to greater than 1 decade of frequency up to a maximum frequency of 10 MHz. 1KW is typically available to 15 MHz. Typical frequency ranges are 50 kHz to 0.5 MHz, and 500 kHz to 5 MHz. One of the most common frequency ranges is 250 kHz to 10 MHz with a specified output of 1KW at the endpoints.
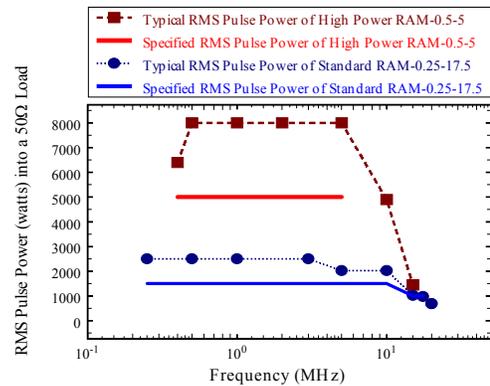
Figure 4

Available powers as a function of frequency for the 1.5 KW amplifier and the 5 KW amplifiers.

The "push-pull" arrangement for the output circuitry of the amplifier results in a lower harmonic content for the even harmonics, even at the maximum output power of 5 KW. The harmonic contents of a 5KW output burst are shown in Figure 5 as a function of frequency.
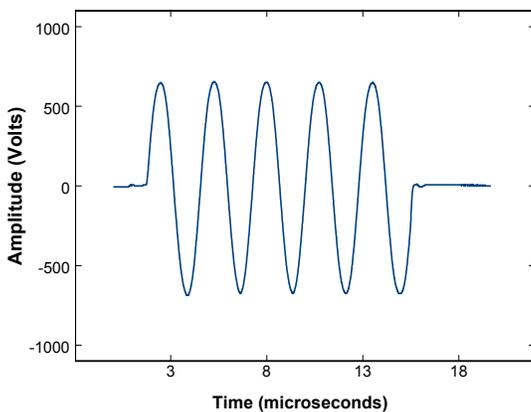
Figure 3

A high power RF burst of five cycles at 350 kHz

A typical burst, into a high power 50 Ohm load, is shown in Figure 3. A plot of the available powers as a function of frequency for the two versions of the amplifiers is shown in Figure 4.
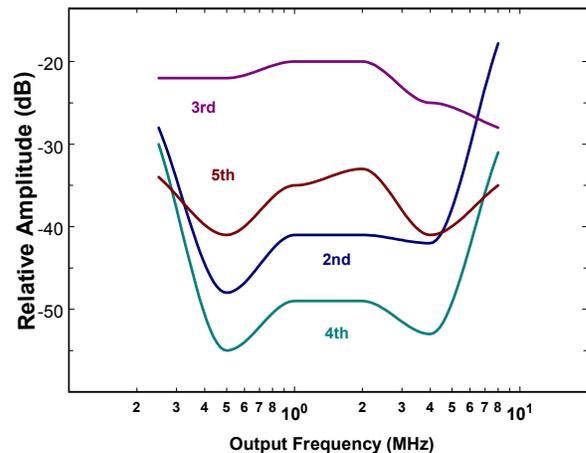
Figure 5

Harmonic Content of Output Pulse as a function of Frequency.

The noise level of the gated amplifier during the receive time is also very low because the

amplifier has been turned off. The ratio of the pulse amplitude to the CW leakage through the amplifier (On-Off ratio) is greater than 140 dB. This high On-Off ratio is important because a very small amount of leakage can overwhelm the receiver input at high gains and cause distortions in the outputs of the quadrature phase sensitive detectors.

This reduction in leakage of the CW signal is a major advantage of using an amplifier that is gated as opposed to an amplifier that operates continuously amplifying externally produced low-level RF bursts. Another advantage is that the amplifier has been turned off and is no longer amplifying any noise that may present on the low level CW input, thus improving the signal-to-noise. Other advantages are the economies realized in size, heat dissipation, and power supply requirements.

Because the amplifier is gated on and off, an important factor to consider when determining the burst width and burst repetition rate or trigger frequency is the duty cycle. This is defined as the time the amplifier is turned on, specifically the burst width multiplied by the repetition rate, expressed as a percentage. For example, as shown above in Figure 3, at an operating frequency of 350 kHz a burst width of five cycles results in a burst 14 microseconds long. At a repetition rate of 100 Hz, the duty cycle would be 0.0014 or 0.14%. At a repetition rate of 1kHz, the duty cycle would be 1.4%.

No appreciable sag in output amplitude will occur as the duty cycle limits are approached at full power. If the limits are exceeded, however, an automatic shutdown circuit will be activated and the power stage will be turned off without damage. (Full power output can be restored by switching the high voltage off, correcting the excessive duty cycle, and turning the high voltage on again.)

The high power available makes it possible to drive very low efficiency transducers such as EMATs and still have reasonable system performance. In addition, when materials exhibiting high ultrasonic losses are to be examined, the use of high power in conjunction with efficient transducers can mean the

difference between meaningful data and no observable signals.

Single Channel Frequency Synthesizer

The frequency source is provided through a direct digital synthesizer that provides instantaneous changes in frequency as contrast to the settling times required in phase locked looped synthesizers. The synthesizer operates up to 40 MHz in the broadband Mark III and Mark IV configurations and up to 64 MHz in the superheterodyne Mark VI configurations. The synthesizer accepts an external clock signal at frequencies up to 25 MHz and processes internally resulting in a system clock as high as 300 MHz. Frequency control is provided through 48-bit control, resulting in a typical resolution of up to 0.5×10^{-6} hertz.

In the broadband Mark III and Mark IV configurations, the synthesizer output is sent to the timing circuitry and to the gated amplifier for gating and amplification. With the super-heterodyne receiver in the Mark VI systems, the output of the frequency synthesizer is used as a "local oscillator" in the superheterodyne receiver. It also is mixed with the quartz intermediate frequency oscillator to produce the CW operating frequency that is sent to the gated amplifier and the timing circuitry.

Signal Channel Timing

All the digital timing functions of the RAM have been made coherent with respect to the CW operating frequency. When a trigger is received from the computer, an external source, or the internal rep-rate generator, the timing circuitry waits for a positive zero crossing of the CW signal before beginning the gating process. The RF cycles are then counted to the desired number to produce a burst with the correct width.

At the same time the gating function begins, a trigger pulse is sent to the trigger output connector and a 10 MHz gated clock oscillator is started. This clock is thus made coherent with respect to the CW and is used to generate the signal processing gate delays and widths. The coherency feature avoids the gate position jitter

that would be evident if a continuous clock were used.

Multiple Gated Amplifier Systems

In some applications, the unique capabilities of the RAM-5000 system to accept multiple gated amplifiers are particularly valuable. The ability to widen the frequency range of a system with two gated amplifiers has already been mentioned. This permits one RAM-5000 system to cover the frequency range of 50 kHz to 7 MHz, maintaining the 5 KW output, between two gated amplifiers. Another configuration, with up to four gated amplifiers, allows the system to fire several transducers simultaneously or in a designated sequence.

Multiple Channel Systems

With the addition of a special triple synthesizer/timing module, it is possible to configure a three channel Mark IV system, with three gated amplifiers driving three transducers and three independently controlled receivers. Such a system has been particularly useful in online industrial applications using electro-magnetic acoustic transducers (EMATS). These transducers are very versatile but have a low efficiency in converting the RF electrical energy into acoustic energy. With the high power, high current output of the RAM gated amplifier and with proper impedance matching in the transmit line, it is possible to produce tens of amperes of current in the EMAT.

With the special triple synthesizer/timing module, it is possible to adjust the relative delay between the outputs of each gated amplifier in 12.5 ns steps, with further control over the relative phases by adjusting the phase of the synthesizer outputs. Unique timing circuitry maintains coherency between each of the synthesizer outputs and therefore between the high power RF bursts.

Superheterodyne Receiver

Superheterodyne circuitry has been used in nearly every radio-frequency receiver manufactured since the 1930s. The concept allows the use of fixed tuning elements at the intermediate frequency (IF), a constant bandwidth independent of the operation frequency, and rejection of out-of-band spurious signals. In RITEC's implementation, the Broadband RF Receiver, Mixer and IF Amplifier, Direct Digital Synthesizer, and IF Oscillator and Quadrature Phase-Sensitive Detectors modules are used in combination to complete the phase sensitive superheterodyne receiver. Selection of the transmitter frequency and receiver tuning are accomplished simultaneously by setting the synthesizer. This feature greatly simplifies the computer control of the receiver, especially in applications requiring the frequency to be swept.

The adjustment of the phase sensitive detection circuitry is also simplified because the multiplication process occurs at the fixed IF frequency. Specifically, the reference outputs from the IF oscillator are adjusted as closely as possible to quadrature (90º) before being applied to the phase sensitive detection multiplier circuits.

Broadband Receiver

The digital control of gain in two dB steps makes possible accurate, repeatable measurements of signal strength, and low noise, high gain external pre-amplifiers are available for use when weak signals are encountered. The addition of adjustable IF band-pass, high-pass, and low-pass filters make this one of the most versatile receiving systems available for ultrasonic research.

Quadrature Phase Sensitive Detection and Analog Integration

One of the significant innovations of the RAM is a signal processing technique that involves the use of both quadrature phase sensitive detection and gated analog integrators. Quadrature detection allows signals to be processed in much the same way as is done with a vector voltmeter. The two detector (multiplier) circuits produce two orthogonal vector components (real and imaginary) of the

signal from which the amplitude and phase angle can be calculated.

To gain more insight into the operation of the phase-sensitive receiver circuitry, it is instructive to consider the received ultrasonic information as a monochromatic signal at frequency (f_r) modulated by a term, which defines the width, amplitude, and shape of the received signal, $A_r(t)$.

$$f(t) = A_r(t)\sin(2\pi\, f_r t + \phi_r) \qquad (1)$$

After conversion to the intermediate frequency, the received signal can be processed in the phase detectors. The output of the Phase Detector No. 1 is given by:

$$D_1(t) = g_3 A_r(t)\sin\phi_r \qquad (2)$$

where the total gain and conversion efficiencies are all included in the term g_3. The output of Phase Detector No. 2 is given by:

$$D_2(t) = g_3 A_r(t)\cos\phi_r \qquad (3)$$

The two phase detector outputs are shown below in Figure 6, along with the broadband receiver echo.
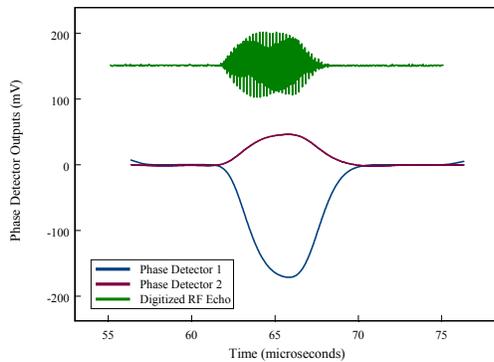
Figure 6

Broadband receiver monitor and the two phase detector outputs.

This type of detection also has the advantage of maintaining excellent linearity even when the received signal is small; this type of detection is also not affected by the presence of noise.

Therefore, signal-averaging techniques may be employed to recover signals from noise. In Figure 7, the signal to noise ratio of the broadband receiver output was purposely reduced to approximately one, but it is relatively to detect the two echoes in the phase detected signals with a reasonable signal to noise ratio.
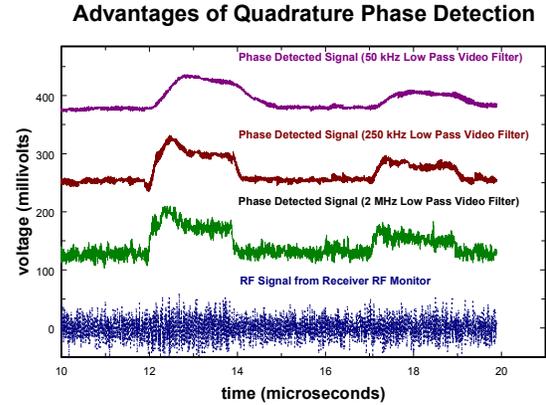
Figure 7

In order to obtain accurate signal amplitude and phase information, the phase-detected signals are processed with analog integration circuits. This method has the value of making the gate position non-critical, removing the RF components, and improving the signal-to-noise ratio. The time limits of the integration are controlled by the integrator gate, and the integrate rate (r_I) is under computer control. The gate is positioned so that it begins before and ends after the signal. The integrator outputs are given by:

$$I_1 = r_I \int_{t_1}^{t_2} D_1(t)dt = \int_{t_1}^{t_2} A(t)\cos\phi_r\, dt \qquad (4)$$

and

$$I_2 = r_I \int_{t_1}^{t_2} D_2(t)dt = \int_{t_1}^{t_2} A(t)\sin\phi_r\, dt \qquad (5)$$

where I_1 and I_2 are the outputs of integrators No. 1 and No. 2, t_1 and t_2 are the start and stop times defined by the integrator gate, and $D_1(t)$ and $D_2(t)$ are the phase sensitive detector outputs. The integrator output voltages are read

by internal 16-bit analog-to-digital converters internal to the RAM and then transmitted back to the data acquisition computer. The phase angle of the received signal can be calculated from the two integrator outputs by:

$$\phi_r = \tan^{-1}\left(\frac{I_2}{I_1}\right) \qquad (6)$$

and the signal amplitude may be obtained from:

$$A = \sqrt{I_1^2 + I_2^2} \, . \qquad (7)$$

Further improvement in the signal to noise can be achieved using the gated integrators. The integrator outputs for the signals shown in Figure 6 are shown below in Figure 8.
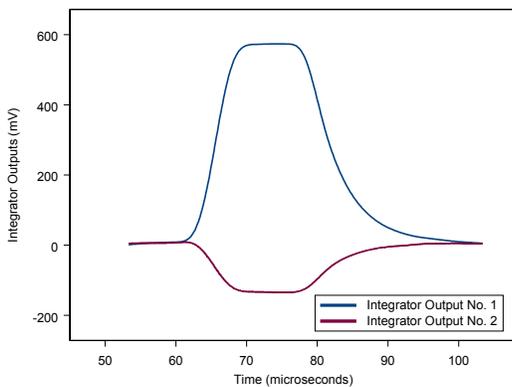
Figure 8

Outputs of the Gated Integrators for the RF Echo and phase detected signals shown in Figure 6.

However, if the signals are a very small number of RF periods wide, measuring the magnitude of the vector components has some experimental difficulties. Typical signals are not flat topped and the peak value may not be the best choice for an accurate measurement of the echo amplitude. In an ideal situation, the RF terms can be completely filtered out, and the amplitude (*A*) and phase (ϕ_r) may be calculated after measuring the instantaneous value of the phase detected outputs at the center of the signal or where steady state conditions have

been achieved. Unfortunately, steady state conditions in the outputs of the phase detectors are sometimes difficult to achieve as shown in the typical situation shown in Figure 9.

In this example, the RF signal (echo) was produced by transmitting a single cycle RF pulse to the transducer. It is clear that filtering out the RF components in the detected outputs will result in significant degradation of the rise and fall times.
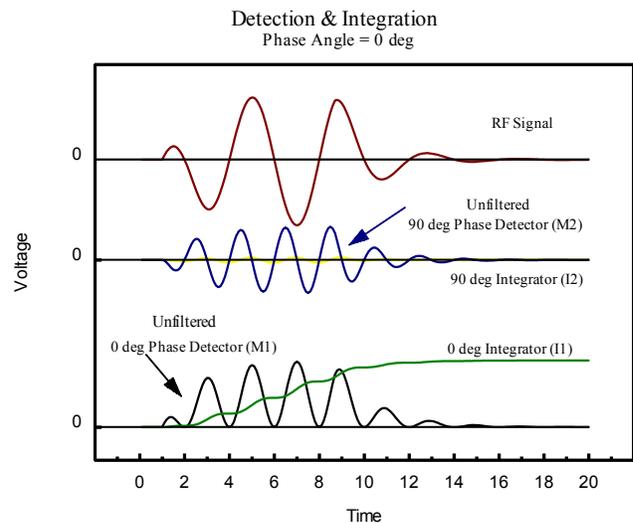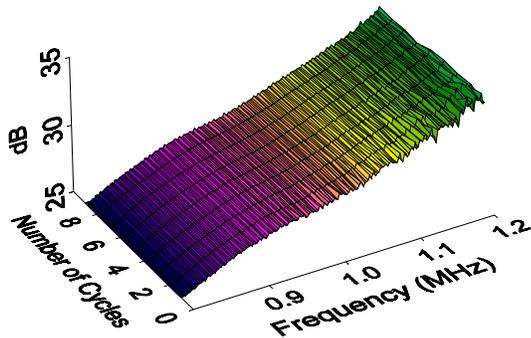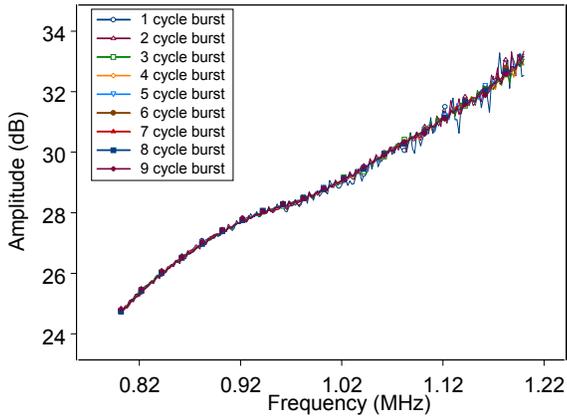

Figure 9

Outputs of the RF Receiver, the Quadrature Phase Sensitive Detectors, and the gated Integrators for a Typical Signal with $\phi_r = 0^o$

The outputs from the two integrators are also shown in Figure 9. Even though it is difficult to determine the steady-state amplitude in the phase-detected signals, it is easy to determine the steady-state amplitude for the outputs of the two phase detectors. In this example, the output of the 0 degree phase detector integrates to a maximum value and the output of the 90 degree phase detector integrates to zero, indicating a phase angle, ϕ_r, of 0 degrees.

In order to illustrate the effectiveness of this signal-processing scheme and to determine if attenuation measurements would be affected by burst width, a simple test was performed with a Plexiglas sample. The logarithmic ratio of the

amplitude of two echoes, which is a measure of the attenuation, was measured as a function of frequency for a number of different transmitter burst widths. The integrator gate width and position remained constant during the investigation. The results are shown in two different formats in Figure 10.

Figure 10

Ratio of the Amplitude of Echo 1 to Echo 2 in decibels as a Function of Frequency and Width

The figure shows that for each frequency a constant value for the attenuation is obtained which is independent of the pulse width. These results could be repeated with a sample-and-hold technique if the gate were placed within the flat-topped portion of a long echo and sufficient filtering were used to remove the RF components from the detected signal. Quite good agreement can be found between the data taken with the maximum burst width of eight cycles and the data taken with the minimum burst width of a single cycle. However, the data taken with a single cycle burst is more sensitive to noise and has a poorer signal-to-noise ratio (SNR) as expected.

The case for phase sensitive detection and integration is made even stronger in this example because the spectrum of the received signal produced from a short burst is dominated by low frequency components. This is true because there is always some low frequency component in the driving pulse and the attenuation is relatively low at this end of the spectrum. The phase sensitive detection and integration process is very effective in rejecting these components. In fact, it can be shown mathematically that the quadrature phase sensitive detection and integration process produces an amplitude equal to the value of the Fourier Transform at the transmit frequency. The conclusion then is that this signal processing technique is the best method known to us for obtaining either amplitude or phase information from pulsed acoustic signals.

Evaluation Tests

In order to illustrate the capabilities of the RITEC RAM system the results of a series of simple tests are presented.

Measurements of the Absolute Transit Time

After determining the slope of the phase versus frequency curve for a signal, the total time of arrival including delays through the electronics and acoustic elements as well as the acoustic time of flight in the sample associated with the group velocity can be determined from the relation:

$$T = \frac{\Delta\phi_r}{2\pi\Delta F} \qquad (5)$$

where $\Delta\phi_r$ is the change in phase and ΔF is the frequency change.

When two echoes are measured, an accurate measure of the acoustic transit time can be obtained by taking the difference between the results and dividing by the appropriate number

of transits for the echoes chosen. In the example shown in Figure 11, the first two echoes were measured.
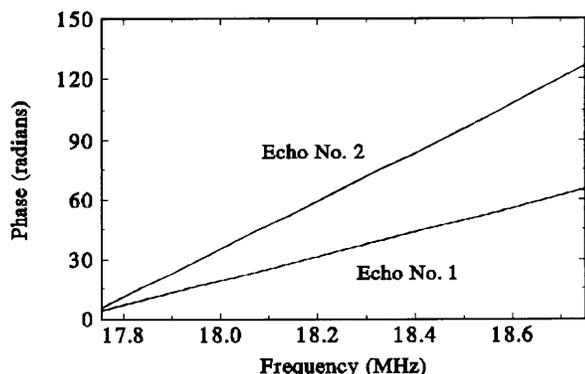

Figure 11

Acoustic Phase Measurements in a Fused Silica Rod.

A least squares data fit produced values for the phase versus frequency slopes of 61.533 and 121.489 radians per MHz, and the acoustic transit time was than calculated as 4.771 microseconds. *It is not difficult to obtain better than four-place <u>reproducibility</u> in data of this type. However, the researcher must be careful to include all relevant acoustic effects, such as diffraction and phase shifts at the bond-transducer-sample interface, if he wishes to claim this level of <u>absolute accuracy</u>.*

Changes in Acoustic Transit Time

Many investigations are more concerned with changes in acoustic velocity or time as a function of some other parameter such as temperature or pressure than they are with absolute times. These changes can also be determined with more accuracy and precision than absolute measurements. The calculations are made from the relation:

$$\textbf{Change in Time} = \frac{\Delta\phi_r}{2\pi\ \textbf{F}} \qquad (6)$$

Note that the frequency remains constant during these investigations. This eliminates problems with frequency dependent phase shifts, which

may occur in the electronics or the acoustic bond. However, the acoustic bond must remain stable over the course of the readings.

In order to document the system's ability to measure small changes in signal arrival time, a test was devised using an adjustable length air dielectric coaxial line. Because the dielectric is air, the increase in time may be easily calculated using the speed of light and the change in line length. The block diagram of the test is shown in Figure 12.
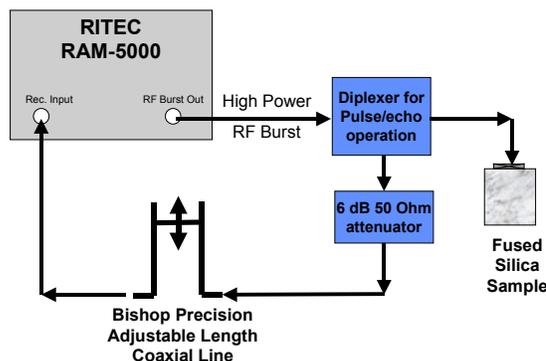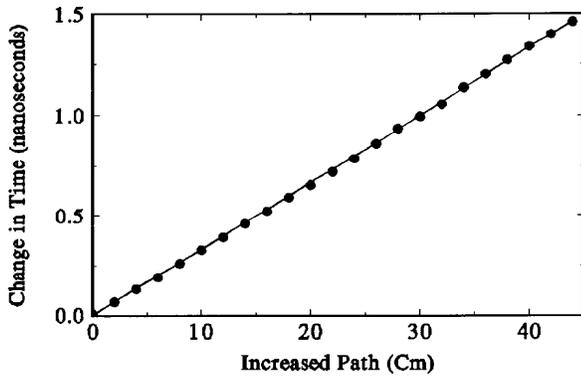

Figure 12

System for Delaying the Arrival of an Acoustic Echo by a Known Amount.

In order to have confidence in delay produced by the adjustable line, it is necessary to insure that the delay line is terminated in 50 Ω in both directions. To terminate the input to the adjustable delay line, the 6 dB attenuator was added between the diplexer and the delay line; this attenuator would not be required in an actual acoustic application. The results of a test performed at 18.312 MHz are shown in Figure 13.
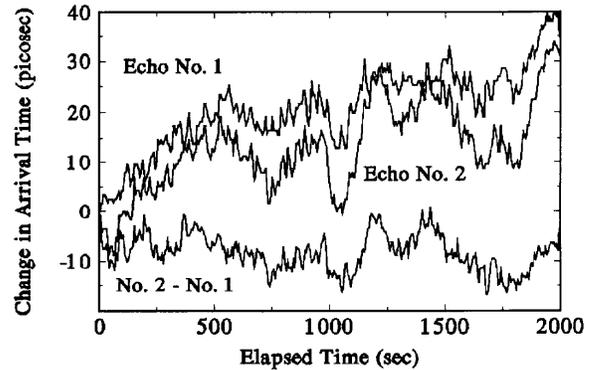
Figure 13

Experimental Measurements of Echo Delays and Line Showing the Theoretical Delay Calculated Using the Speed of Light.
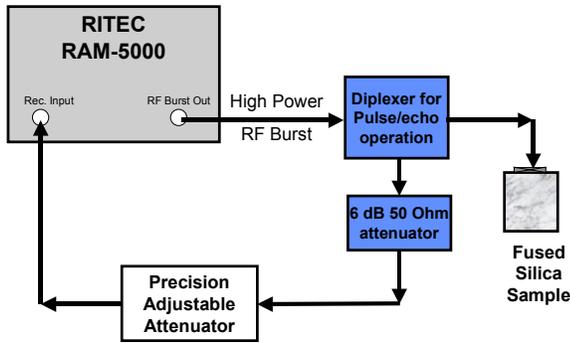

Figure 14

Changes in the Arrival Times for the First Two Echoes in a Silica Rod and Changes in the Round Trip Time Calculated from This Data.

The fact that the data fall on the theoretical line clearly support the ability of the apparatus to measure changes in time; the small deviations are ascribed to the difficulty of setting the line length exactly.

Everything else being equal, this resolution is directly proportional to the operating frequency. However, the accuracy of acoustic amplitude and phase measurements depends on many experimental factors other than the quality of the electronic instrumentation.

Some measure of the stability of the instrumentation and the value of using two echoes for the measurement of time change is illustrated when the changes in arrival time for the first two echoes in the Silica rod are plotted over a longer period of time. For this test, the sample was placed on the table without any effort to maintain temperature stability in any part of the apparatus. The results are shown in Figure 14.

The upward drifts of the arrival time of the two echoes follow each other closely. This general drift cannot be explained by a change in either the sample dimensions or sound velocity because that effect would cause the two lines to diverge. The major portion of the effect must come from changes in the instrumentation. Therefore, the difference calculations of the changes in round trip time are clearly superior because the upward drift is canceled and the remaining effects are either noise or real changes in the sample. Note: these extremely small changes in transit time were observed using signal-averaging techniques.

Changes in Acoustic Attenuation

In order to precisely determine the acoustic attenuation or relative changes in attenuation, accurate measurements of the amplitude must be performed. Some discussion of this requirement has previously been made and results shown in Figure 4. The following tests were designed to show the linearity of the instrumentation and check measured values of amplitude change against the precision attenuators responsible for this change. The block diagram of the setup is shown in Figure 15.

Figure 15

*Setup for Producing Calibrated Changes in Echo Amplitude*

In the first test, the attenuator was a precision adjustable wave-guide operating beyond cut-off with an insertion loss of 34 dB and a resolution of .02 dB. The data shown in Figure 16 fall close to the theoretical line and agree within the resolution of the attenuator.
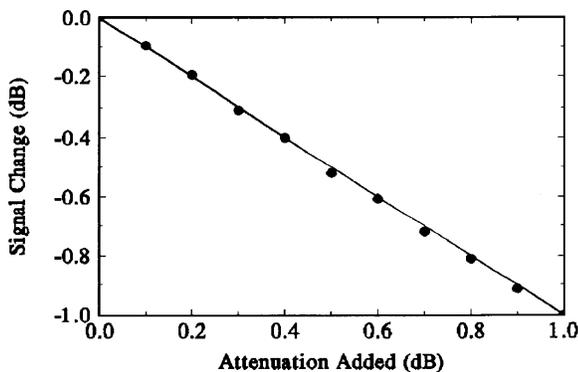
Figure 16

Measured Signal Change and Line Showing Expected Result over a 1 dB Range.

The second test was performed using switched attenuators with 10 dB steps and a 0 dB
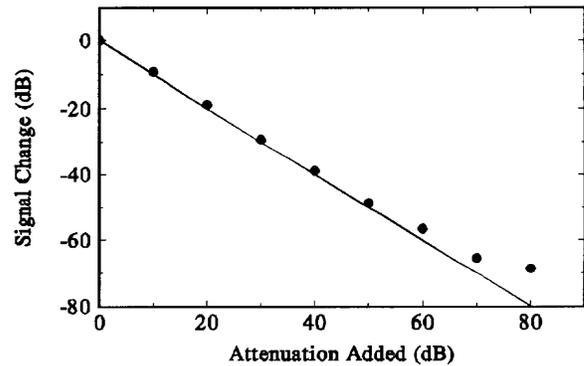
Figure 17

Measured Signal Change and Line Showing Expected Result over an 80 dB Range.

In this case, the data deviates from what is theoretically expected when a large attenuation is switched into the system. The reason for this discrepancy is most likely improper compensation for CW leakage. However, the signal size with 80 dB inserted is more than an order of magnitude smaller than the bit size of the A/D converter and even with averaging some error is expected.

Every effort was made to anticipate the questions of potential users in this descriptive sheet. However, it is recognized that it is not possible to predict all the possible uses of the RITEC RAM-5000 system or even the concerns of researchers wishing to use it for standard applications. If there are any questions about the applicability of this instrumentation for a specific or general requirement, please contact Bruce Chick, Gary Petersen, Michael Ragosta or Mark McKenna and they will endeavor to be of assistance.