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(54) **DIGITAL LOG AMPLIFIER FOR ULTRASONIC TESTING**

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(57) **ABSTRACT**

The apparatus and method of the present invention provides a plurality of linear amplifiers simultaneously processing an ultrasonic signal. Each amplifier of the plurality of linear amplifiers has a predetermined gain level suitable for achieving the desired output signal level for input to an analog to digital (A/D) converter for processing. The output of each amplifier is sampled by each respective A/D converter at a very high frequency to convert the analog signal output of each of the linear amplifiers to a digital signal. Logic circuits simultaneously monitor all of the output digital signals from the A/D converters. The logic circuits determine which output of the A/D converters has the greatest linear output and stores the selected output in a memory storage device. The saved output waveforms are subsequently combined into a continuous linear digital output that has a dynamic response range that is approximately the sum of the individual dynamic response ranges of the individual amplifiers and A/D converters. The combined continuous linear digital output waveform may be input to a logarithmic conversion to produce a waveform having a wide dynamic range.

22 Claims, 3 Drawing Sheets
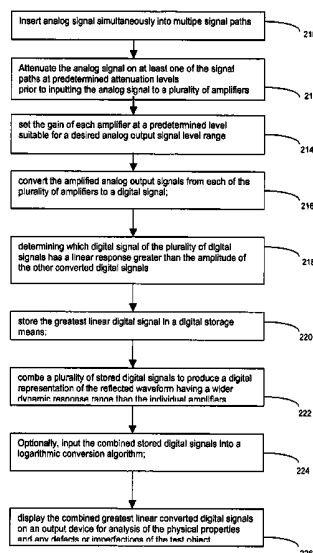
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Fig. 1

Fig. 2

Insert analog signal simultaneously into multipe signal paths — 210

Attenuate the analog signal on at least one of the signal paths at predetermined attenuation levels prior to inputting the analog signal to a plurality of amplifiers — 212

set the gain of each amplifier at a predetermined level suitable for a desired analog output signal level range — 214

convert the amplified analog output signals from each of the plurality of amplifiers to a digital signal; — 216

determining which digital signal of the plurality of digital signals has a linear response greater than the amplitude of the other converted digital signals — 218

store the greatest linear digital signal in a digital storage means: — 220

combe a plurality of stored digital signals to produce a digital representation of the reflected waveform having a wider dynamic response range than the individual amplifiers — 222

Optionally, input the combined stored digital signals into a logarithmic conversion algorithm; — 224

display the combined greatest linear converted digital signals on an output device for analysis of the physical properties and any defects or imperfections of the test object — 226
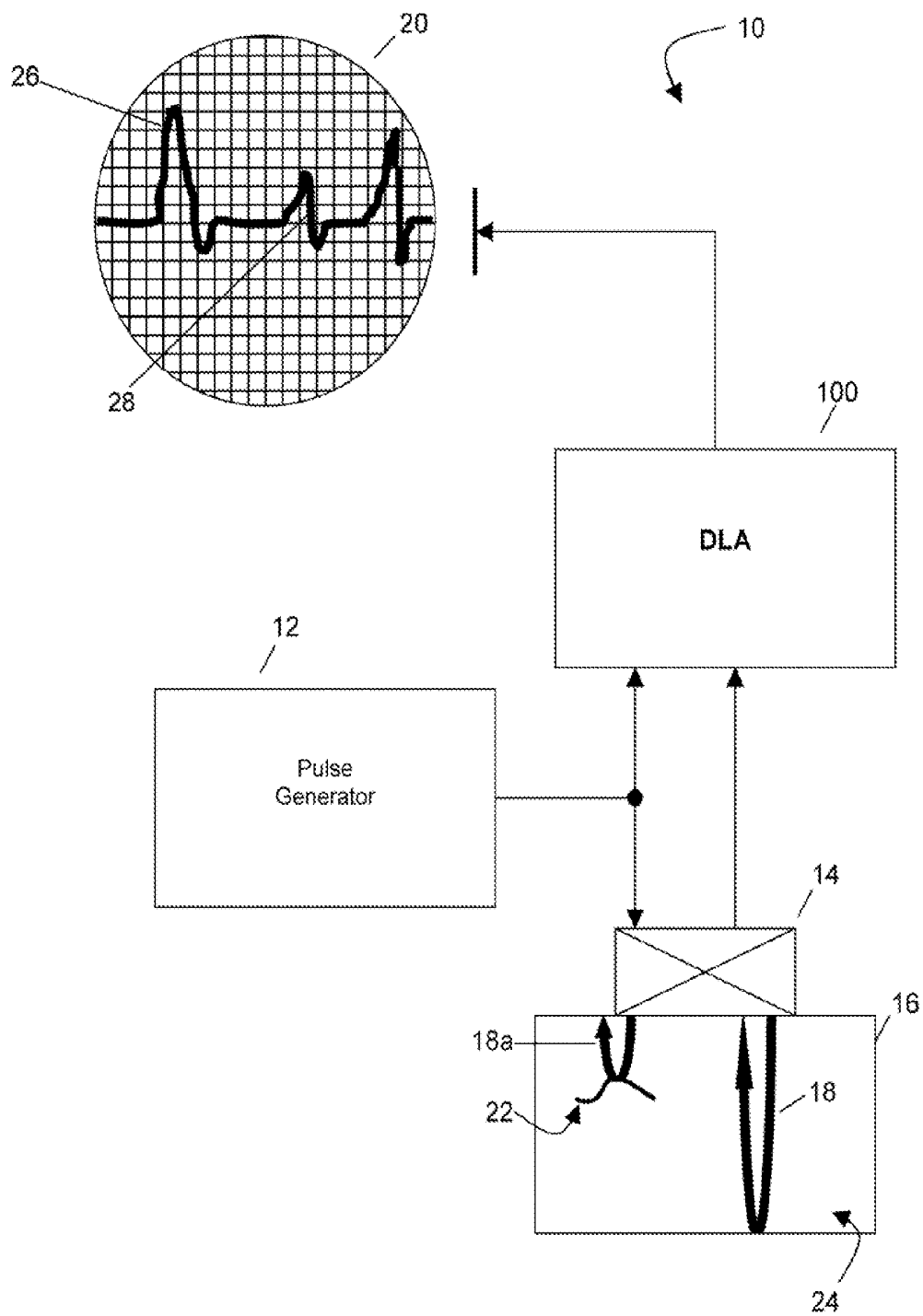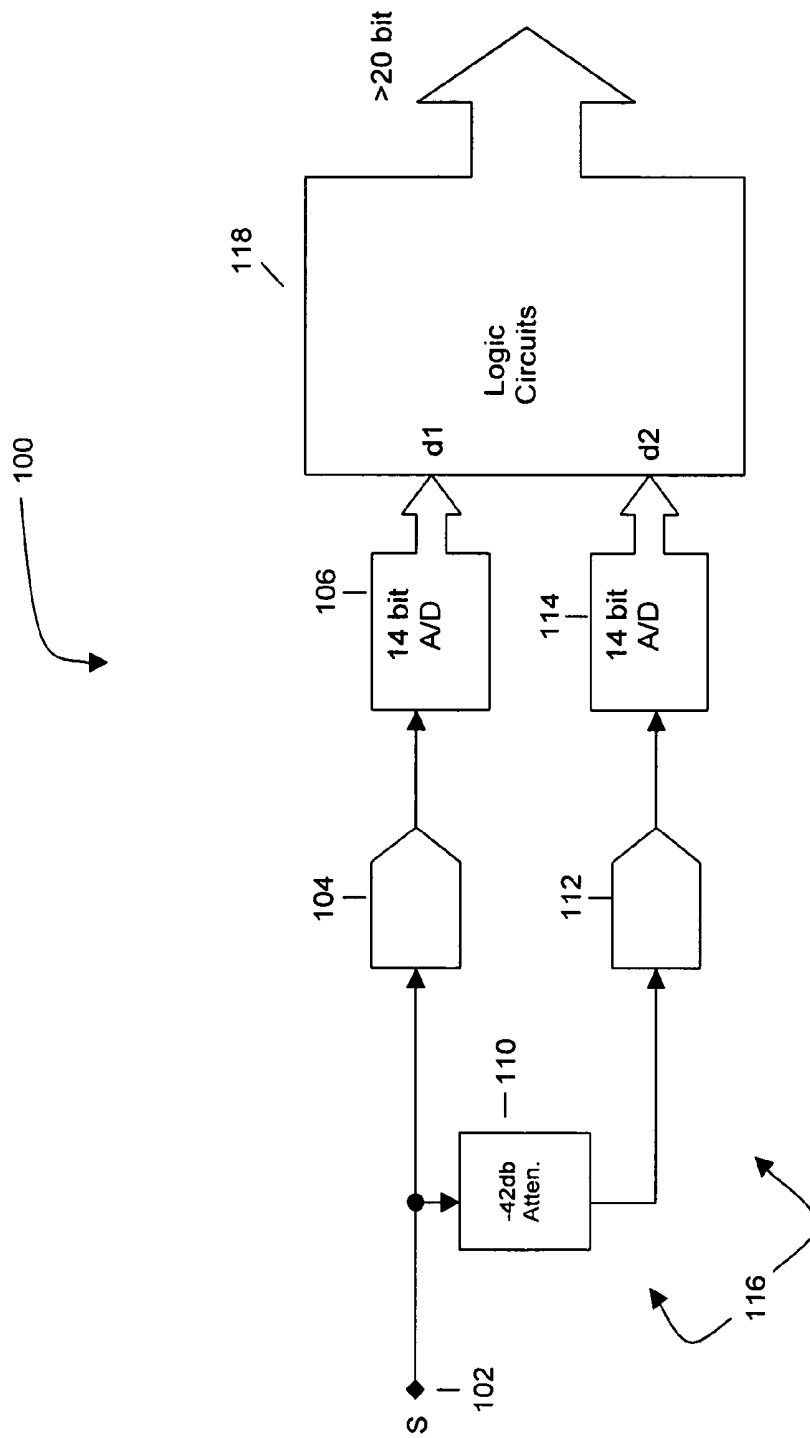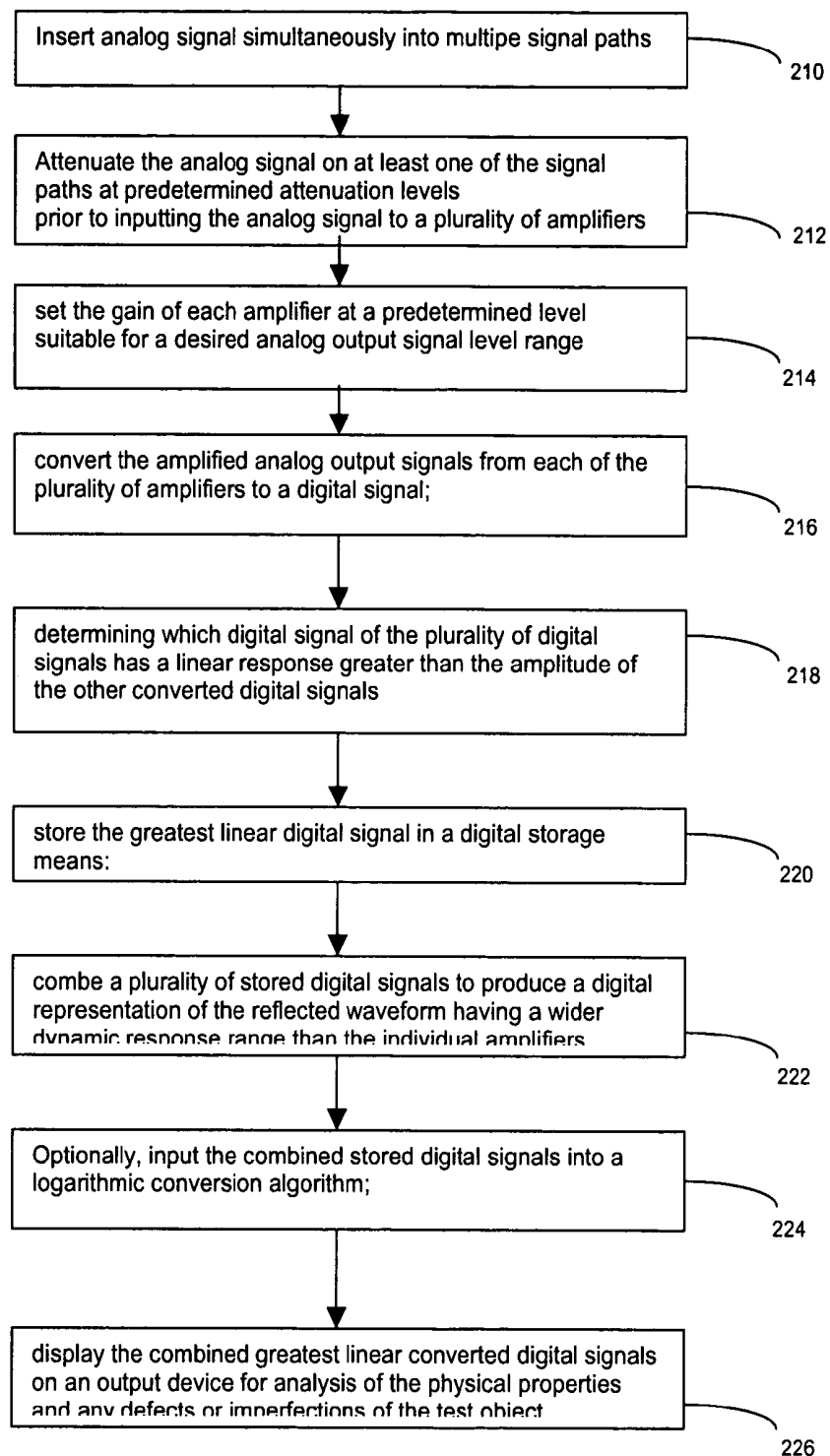
Figure 3

DIGITAL LOG AMPLIFIER FOR ULTRASONIC TESTING

FIELD OF THE INVENTION

The present invention is directed to a method and system for processing acoustic signals for use in ultrasonic inspection and testing, and more particularly to simultaneously processing an acoustic signal with multiple linear amplifiers to obtain a combined linear digital output signal having a dynamic response range that is greater than the individual ranges of the amplifiers.

BACKGROUND OF THE INVENTION

Ultrasonic inspection employs high frequency, ultrasonic waves generated by a transducer to examine test objects and make measurements. Ultrasonic inspection can be used for detection of flaws in test objects, and for performing evaluation, dimensional measurements, material characterization, and more on objects. Measurement procedures initially developed for metals have been extended to engineered materials such as composites, where such characteristics as anisotropy and inhomogeneity are of concern. Advances in digitization and computing capabilities have changed the types of instruments and algorithms that are used in processing the resulting data. High-resolution imaging systems and multiple measurement modalities for characterizing a flaw have emerged. Of interest are detecting, characterizing, and sizing defects, as well as characterizing the materials in which they are found. The objectives of ultrasonic testing range from the determination of fundamental microstructural characteristics such as grain size, porosity, texture and preferred grain orientation, to material properties related to failure mechanisms such as fatigue, creep, and fracture toughness.

In ultrasonic testing, a transducer containing a piezoelectric element is excited by an electrical pulse to transmit an ultrasonic pulse into a test object. The sound wave propagates through the test object and is reflected. The transducer receives the reflected wave and the reflected wave is converted by the transducer into an electrical signal and analyzed to determine whether a discontinuity exists in the test object. A flaw or discontinuity in the test object is characterized by certain anomalous profiles in the electrical signal that are viewable on an analog display, such as an oscilloscope or a recording device.

The electrical signal from a transducer representing the reflected sound wave must be amplified for input into a display or recording device. In order to be displayed, the amplified signal must fall within a certain dynamic response range that is defined by the maximum and minimum operating parameters of the respective display device. In many cases, the signal representing the acoustic wave includes multiple components. For example, in the case of a flaw occurring near the surface of an object, the echo caused by the near-surface defect is received within the interval of the initial pulse. In that case the flaw is not detectable by a visual display, or a recording device, since the amplitude of the echo is small relative to the initial pulse. Since the instrument receives them concurrently, the relatively small-magnitude echo signal from the near-surface flaw is essentially superimposed on the larger initial pulse or interface signal. The large difference in amplitude of the two simultaneous signals makes the smaller signal very difficult to detect.

Previously, analog logarithmic amplifiers have been used in attempts to compress the dynamic response range, but analog amplifiers are not particularly well suited to perform

this due to the limited bandwidth and dynamic response range of analog logarithmic amplifiers. Analog techniques are limited by noise and accuracy problems.

Therefore there is a need for a device for digitally processing simultaneous ultrasonic signals having widely varying amplitudes and combining them for display into a continuous linear digital signal having a wide dynamic range.

SUMMARY OF THE INVENTION

The apparatus and method of the present invention provides a plurality of linear amplifiers simultaneously processing an ultrasonic signal. Each amplifier of the plurality of linear amplifiers has a predetermined gain level suitable for achieving the desired output signal level for input to an analog to digital (A/D) converter for processing. The output of each amplifier is sampled by each respective A/D converter at a very high frequency to convert the analog signal output of each of the linear amplifiers to a digital signal. Logic circuits simultaneously monitor all of the output digital signals from the A/D converters. The logic circuits determine which output of the A/D converters has the greatest linear output and stores the selected output in a memory storage device. The saved output waveforms are subsequently combined into a continuous linear digital output that has a dynamic response range that is approximately the sum of the individual dynamic response ranges of the individual A/D converters. The combined continuous linear digital output waveform may be accurately converted by corresponding computing to logarithmic scaling to produce a waveform having a wide dynamic range comparable to the output of a logarithmic amplifier.

An advantage object of the present invention is that the device can detect small defects near the surface of a test object by eliminating the constant wave signal reflected from the top surface of the test object and detecting the small signals that are normally masked by the constant wave signal reflected from the top surface.

Another advantage of the present invention is that simultaneous reflected waveforms can be measured and recorded having a wide dynamic response range with no distortion of the respective waveforms.

Yet another advantage of the present invention is that a wide dynamic response range is provided for the measurement of signals reflected from various depths in a material characterized by high signal attenuation.

Other features and advantages of the present invention will be apparent from the following more detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings which illustrate, by way of example, the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of a test arrangement using the digital log amplifier of the present invention;

FIG. 2 is a schematic diagram of the digital log amplifier; and

FIG. 3 is a flow chart of the method of converting an analog signal into a plurality of digital components representing a reflected ultrasonic waveform.

Wherever possible the same reference numbers will be used throughout the drawings to refer to the same or like parts.

DETAILED DESCRIPTION OF THE INVENTION

Referring to FIG. **1**, a test inspection arrangement **10** includes a pulse generator circuit **12** that transmits a pulse to a transducer **14** for propagating an ultrasonic acoustic wave **18** through a test object **16**. Wave **18** is reflected back to the transducer **14**. In the example shown in FIG. **1**, one transducer both transmits and receives the acoustic wave, however, other test configurations may also be employed with multiple transducers, some that transmit, some that receive, and some that perform both transmitting and receiving functions. The transducer **14** receives the reflected acoustic wave and converts it back into an electrical signal, which is input to the digital log amplifier (DLA) **100** of the present invention. The DLA **100** processes the electrical signal representing the reflected waveform, as discussed in further detail below. The output waveform of the DLA **100** is displayed on an oscilloscope **20** or other similar peripheral display or storage device (not shown). Many other test arrangements may be substituted for the arrangement of FIG. **1**, as are well known to those skilled in the art. The arrangement of FIG. **1** is therefore presented as an example, and the invention is not limited to the particular arrangement of this example.

As indicated in FIG. **1**, a defect **22** in the test object **16** will reflect the waveform **18** at a point different from a backwall **24** of the test object **16**, resulting in different wave propagation times that may be shown on the screen of the oscilloscope **20**. The smaller the defect **22**, the smaller the magnitude of the reflected wave, so that in some instances, the sensitivity of the output device or the non-linearity of the amplifier, may cause a small reflected signal to be lost. Also, where the defect **22** is very near to the surface, the reflected wave **28** associated with the defect **22** may be received by the amplifier and output to the display **20** at approximately the same time as the initial pulse **26** or the interface signal. When displayed on an analog display the initial pulse **26** is very large in relation to the near-surface reflected wave **28**, the small reflected signal **28** is also lost in the larger waveform.

Referring to FIG. **2**, signal S representing a reflected waveform propagated through a test object is applied to the input **102** of the DLA **100**. An amplifier **104** has a gain suitable for processing the unattenuated signal S, and amplifies the signal S for input to an analog-to-digital (A/D) converter **106**. Preferably, all of the A/D converters used in the present invention are 14-bit converters with a high-dynamic response range but the invention can principally perform on each type of analog to digital (A/D) converter. The output of amplifier **104** is inserted into the A/D converter **106** and sampled at a very high rate, to provide a digitized representation, d_1, of the analog signal S. The sampling frequency must be at least twice that of the analog signal frequency, and preferably in practice should be at least three times the frequency of analog signal S. The preferred sampling frequency for low signal frequency applications is around 50 MHz and for high signal frequency applications is around 100 MHz, but may be more or less depending on the frequency of the analog signal S.

Analog signal S is simultaneously processed by at least one attenuators. FIG. **2** illustrates only one attenuation path **116**, but it is understood that the DLA **100** of the present invention may typically include multiple parallel paths with different attenuation values. Each attenuation path **116** includes an attenuator **110**, an amplifier **112** and an A/D converter **114** connected in series, similar to attenuation path **116**. In the example of FIG. **2**, attenuator **110** attenuates signal S for input to amplifier **112**. Attenuation values are preferably selected in increments of −6 db (e.g., −24 db, −30 db, −36 db, et. seq.), which conveniently correspond to an additional sampling bit

for every 6 db of attenuation, however any magnitude of signal attenuation may be substituted if desired. In the example shown in FIG. **2**, minus (−) 42 db signal attenuation is provided by the attenuator **110** before amplification. Amplifier **112** has a gain suitable for the dynamic response range of the attenuated signal S for providing a desired output level of the amplified signal. The output of the amplifier **112** is inserted into A/D converter **114** and simultaneously sampled at the same rate as A/D converter **106** to provide a second digitized representation, d_2, of the signal S. Any number of attenuator paths may be used to process signal S simultaneously for input to a corresponding number of amplifiers. Attenuation values are selectively assigned to match desired response levels, and each amplifier has a gain level designed with respect to the associated attenuator to provide the desired output signal level for the associated A/D converter.

Logic circuits **118** analyze the signal levels of the digitized outputs d**1**, d**2** of the A/D converters **106**, **114** or if additional paths are used the digitized outputs of all paths. The logic circuits **118** determine which of the converters **106**, **114** has the greatest output, which is linear, as the amplitude of signal S fluctuates. The logic circuits **118** determine whether the digitized output signal from each converter falls between a predetermined saturation threshold and a predetermined minimum signal level. Those outputs falling outside the desired band are eliminated—i.e., outputs above the predetermined saturation level or below the minimum signal level. The selected converter output waveforms that fall between the saturation threshold and minimum levels are saved to a digital memory storage device (not shown). The saved output waveforms of signals with different amplitudes are subsequently combined by logic circuits **18** to form a continuous linear digital output for display on an oscilloscope **20** or other peripheral device connected to the amplifier output. At each sample point, N_1, N_2, N_3 etc., which occur every 20 nanoseconds at 50 MHz sample rate, the outputs from multiple A/D converters are available. Thus for sample point N_1, logic circuits **18** decide which output is within range and this amplitude is used in the logic circuit output. Next for sample point N_2, logic circuits **18** decide which A/D output to use in the logic circuit output. This process is continued for each sample point. Every 6 dB of attenuation (approximately) at the input to the 14-bit A/D converter **114** corresponds to an extra bit of sensitivity and a doubling of response range of the resulting logic circuit output signal. The dynamic response range of the resulting logic circuit output signal is greater than 20-bit, which corresponds with the sum of the multiple dynamic response ranges of individual amplifier and A/D converter combinations. The digitized signal may be converted to a logarithmic scaling by a corresponding conversion algorithm implemented in the logic circuits **18** for compressing the dynamic response range of the combined output signal to a screen or recorder presentation. This conversion algorithm produces logarithmic output that is more accurate over a greater dynamic range than can be produced by existing techniques.

The method, for converting an analog signal into a plurality of digital components representing a reflected ultrasonic waveform for testing objects, is set forth in FIG. **3**. The flowchart, generally designated **200**, begins at step **210**, processing a reflected analog signal by amplifying the analog signal simultaneously through a plurality of different amplifiers. Then, at step **212**, the analog signal is attenuated at a plurality of predetermined attenuation levels prior to inputting the analog signal to at least one of the plurality of amplifiers. Next, at step **214**, the gain of each of the plurality of amplifiers is set at a predetermined level suitable for a desired

predetermined analog output signal level range. At step **216**, the amplified analog output signals from each of the plurality of amplifiers are converted to a digital signal. Then, at step **218**, the system determines which converted digital signal has a response that is (1) linear and (2) greater than the amplitude of the other converted digital signals. Following step **218**, at step **220**, that greatest linear converted digital signal is stored in memory or other digital storage means. Then at step **222** a plurality of the stored converted digital signals is combined to produce a digital representation of the reflected waveform, the digital representation of the reflected waveform has a wider dynamic response range than the response range of the separate individual amplifiers. At step **224**, which is optional, the combined stored greatest linear converted digital signals is input to a logarithmic conversion algorithm. Then, at step **226**, the combined greatest linear converted digital signals are displayed on an output device for analysis of the physical properties and any defects or imperfections of the test object.

It is known that small defects present near the surface of a test object are difficult to detect. The reflected waveform from the near-surface defect is very small, relative to the interface signal or surface reflection. The magnitude of the interface signal may be on the order of one hundred times the magnitude of the signal from the defect. Thus the larger signal overloads the amplifier, and the signal from the defect is contained within the larger waveform signal and is lost or undetectable. The interface may be subtracted from the amplifier output, since the magnitude and waveform of the interface signal is known. By eliminating the interface signal, smaller signals such as the near-surface flaw are selectively displayed, allowing the tester to obtain more accurate inspection results of near-surface defects. Also, where ultrasonic inspection techniques are employed to measure thickness of a test object, wide variations in amplitude may be eliminated by capturing the waveforms over a wide dynamic response range, allowing greater accuracy in thickness measurements.

Another advantage of the present invention is realized in the ultrasonic inspection of composite components which are characterized by high attenuation. The wide dynamic response range of the DLA permits accurate amplitude measurements of signals from various depths in test objects of composite materials, as well as testing composite objects with wide variations in thickness.

Finally, the DLA allows the combined outputs of the stored waveforms to be easily processed into logarithmic scaling without the noise and accuracy limitations normally associated with the analog logarithmic amplifiers.

While the invention has been described with reference to a preferred embodiment, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

We claim:

1. Apparatus for measuring physical properties of a test object using ultrasonic inspection techniques comprising:

a pulse generator to generate an electrical pulse having predetermined characteristics;

an ultrasonic wave generator, the ultrasonic wave generator receiving the electrical pulse from the pulse generator; the ultrasonic wave generator being configured to con-

vert the electrical pulse to an ultrasonic wave and propagate the ultrasonic wave at an object, the ultrasonic wave generator being configured to receive a reflected ultrasonic wave from a test object and convert the reflected ultrasonic wave to an analog signal;

a digital log amplifier for processing the analog signal comprising:

at least one unattenuated processing path, each unattenuated processing path including amplifier means for amplifying the analog signal to a desired level and a converter means for digitally sampling the amplified analog signal to convert the analog signal to a digitized representation of the analog signal;

at least one attenuated processing path, each attenuated processing path including attenuation means for attenuating the analog signal, amplifier means for amplifying the attenuated analog signal to a desired level and converter means for digitally sampling the amplified attenuated analog signal to form a digitized representation of the analog signal;

a logic device receiving each digitized representation of the analog signal from both the at least one unattenuated and at least one attenuated signals, thereby receiving a plurality of digitized signals,

the logic device comprising means for selecting one digitized signal of the plurality of digitized signals the selected digitized signal being the most linear and having the greatest amplitude of the plurality of digitized signals;

storage means for storing a plurality of selected digitized signals;

combining means for combining the stored plurality of digitized signals to form a continuous linear digital waveform; and

display means for displaying the combined continuous linear digital waveform.

2. The apparatus of claim **1**, wherein the combining means is a set of logic circuits configured to convert the plurality of digitized signals to a logarithmic scale to compress the amplitude of the continuous linear digital waveform over a wide dynamic range.

3. The apparatus of claim **2**, wherein the analog signal is a low frequency signal and the converter means has a digital sampling rate of about 50 MHz.

4. The apparatus of claim **2**, wherein the analog signal is a high frequency signal and the converter means has a digital sampling rate of about 100 MHz.

5. The apparatus of claim **2**, wherein the converter means is a 14-bit analog-to-digital signal converter.

6. The apparatus of claim **1**, wherein the analog signal is a low frequency signal and the converter means has a digital sampling rate of about 50 MHz.

7. The apparatus of claim **1**, wherein the analog signal is a high frequency signal and the converter means has a digital sampling rate of about 100 MHz.

8. The apparatus of claim **1**, wherein the converter means is a 14-bit analog-to-digital signal converter.

9. The apparatus of claim **1**, wherein the attenuating means of the at least one attenuated path is an attenuator, and each of the attenuated paths has an attenuator of a different attenuation value.

10. The apparatus of claim **9**, wherein the different attenuation values are comprised of –6 dB increments.

11. A method for converting an analog signal into a plurality of digital components representing a reflected ultrasonic waveform for testing the physical characteristics of an object, comprising the steps of:

providing a plurality of parallel amplifier paths, each of the paths having an amplifier with a predetermined gain level suitable for a desired predetermined analog output signal level range;

attenuating the analog signal at a plurality of predetermined attenuation levels prior to inputting the analog signal to at least one of the amplifier paths; amplifying the analog signal simultaneously through the plurality of amplifier paths;

converting the amplified analog output signals from each of the plurality of amplifiers to a digital signal;

determining which converted digital signal of the plurality of converted digital signals has a linear response greater than the amplitude of the other converted digital signals;

storing the linear converted digital signal with the greatest amplitude in a digital storage means; combining a plurality of stored digital signals to produce a digital representation of the reflected waveform having a wider dynamic response range than the sum of the plurality of amplifiers; and

displaying the combined greatest linear converted digital signals on an output device for analysis of the physical properties and any defects or imperfections of the test object.

12. The method of claim **11** above, also including the step of, inputting the combined linear converted digital signals into a logarithmic conversion means, and displaying the combined greatest linear converted digital signals on an output device for analysis of the physical properties and any defects or imperfections of the test object.

13. A digital log amplifier for processing an ultrasonic analog signal representative of a reflected wave, the amplifier comprising:

at least one unattenuated processing path including amplifier means for amplifying the analog signal to a desired level;

converter means for digitally sampling the amplified analog signal to convert the analog signal to a digitized representation of the analog signal;

at least one attenuation processing path, each attenuation processing path including attenuation means for attenuating the analog signal, amplifier means for amplifying

the attenuated analog signal to a desired level; and converter means for digitally sampling the amplified attenuated analog signal to form a digitized representation of the analog signal;

logic circuit means for selecting one digitized signal of the plurality of digitized signals which is linear and which has the greatest amplitude of the plurality of digitized signals;

storage means for storing a plurality of selected digitized signals; and

combining means for combining the stored plurality of digitized signals to form a continuous linear digital waveform.

14. The digital log amplifier of claim **13**, wherein the combining means is a set of logic circuits configured to convert the plurality of digitized signals to a logarithmic scale to compress the amplitude of the continuous linear digital waveform over a wide dynamic range.

15. The digital log amplifier of claim **14**, wherein the analog signal is a low frequency signal and the converter means digital sampling rate is about 50 MHz.

16. The apparatus of claim **14**, wherein the analog signal is a high frequency signal and the converter means digital sampling rate is about 100 MHz.

17. The apparatus of claim **14**, wherein the converter means is a 14-bit analog-to-digital signal converter.

18. The digital log amplifier of claim **13**, wherein the analog signal is a low frequency signal and the converter means digital sampling rate is about 50 MHz.

19. The apparatus of claim **13**, wherein the analog signal is a high frequency signal and the converter means digital sampling rate is about 100 MHz.

20. The apparatus of claim **13**, wherein the converter means is a 14-bit analog-to-digital signal converter.

21. The apparatus of claim **13**, wherein the attenuating means of the at least one attenuated path is an attenuator, and each of the attenuated paths has an attenuator of a different attenuation value.

22. The apparatus of claim **21**, wherein the different attenuation values are comprised of –6 dB increments.

* * * * *

专利名称(译)	用于超声波测试的数字对数放大

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摘要(译)

本发明的装置和方法提供了多个同时处理超声信号的线性放大器。多个线性放大器中的每个放大器具有预定的增益电平，该增益电平适于实现所需的输出信号电平，以输入到模数（A / D）转换器以进行处理。每个放大器的输出由每个相应的A / D转换器以非常高的频率进行采样，以将每个线性放大器的模拟信号输出转换为数字信号。逻辑电路同时监控来自A / D转换器的所有输出数字信号。逻辑电路确定A / D转换器的哪个输出具有最大线性输出并将所选输出存储在存储器存储设备中。保存的输出波形随后组合成连续线性数字输出，其动态响应范围大约是各个放大器和A / D转换器的各个动态响应范围的总和。组合的连续线性数字输出波形可以输入到对数转换以产生具有宽动态范围的波形。