US007506546B2

(12) **United States Patent**
Cuffe et al.

(10) **Patent No.:** **US 7,506,546 B2**
(45) **Date of Patent:** **Mar. 24, 2009**

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

(75) Inventors: **John Michael Cuffe**, Reedsville, PA (US); **Klaus Peter Busch**, Rodenbach (DE); **Scott Allen Herbster**, Middleburg, PA (US)

(73) Assignee: **GE Inspection Technologies, LP**, Lewistown, PA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **12/104,871**

(22) Filed: **Apr. 17, 2008**

(65) **Prior Publication Data**

US 2008/0202244 A1 Aug. 28, 2008

Related U.S. Application Data

(63) Continuation of application No. 11/266,854, filed on Nov. 4, 2005, now Pat. No. 7,389,692.

(51) **Int. Cl.**
G01N 29/06	(2006.01)
G01N 29/44	(2006.01)
A61B 8/08	(2006.01)
A61B 8/00	(2006.01)

(52) **U.S. Cl.** **73/602**; 600/437; 600/443
(58) **Field of Classification Search** 73/602
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,373,741	A *	12/1994	Volkmann et al.	.... 73/602
6,063,033	A *	5/2000	Haider et al.	.... 600/447
6,932,770	B2 *	8/2005	Hastings et al.	.... 600/443
6,997,875	B2 *	2/2006	Brock-Fisher et al.	...... 600/443
2004/0059218	A1 *	3/2004	Kanda et al.	.... 600/437

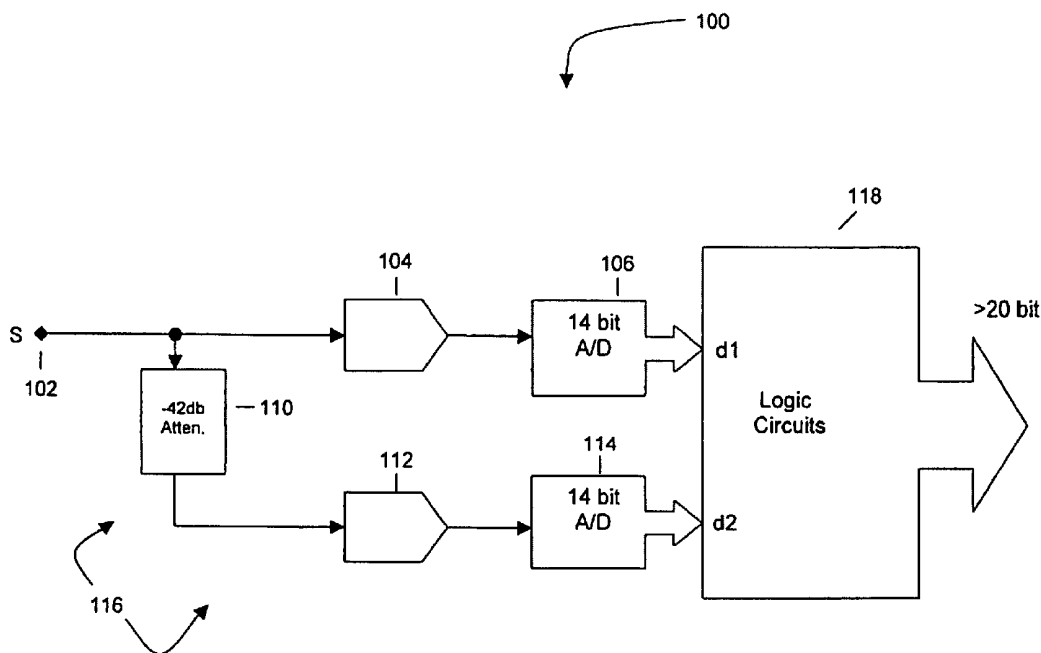* cited by examiner

Primary Examiner—Hezron Williams
Assistant Examiner—Rose M Miller
(74) *Attorney, Agent, or Firm*—Marjama Muldoon Blasiak & Sullivan LL

(57) **ABSTRACT**

The invention provides an ultrasonic object inspection system for measuring the physical properties of a test object which includes a pulse generator for sending an electrical pulse signal to a transducer. The transducer then applies an ultrasonic signal to the test object and receives an ultrasonic echo signal from the test object which is then converted by the transducer to an electrical echo signal for sending to a signal processing circuit. The signal processing circuit includes a plurality of signal processing paths with each path scaling the electrical echo signal to a different degree and including a respective analog to digital converter for converting the electrical echo signal to a digital electrical echo signal. The signal processing circuit further includes a logic circuit for selecting the output of the respective analog to digital converter that provides the digital echo signal having the greatest amplitude without exceeding a predetermined saturation threshold.
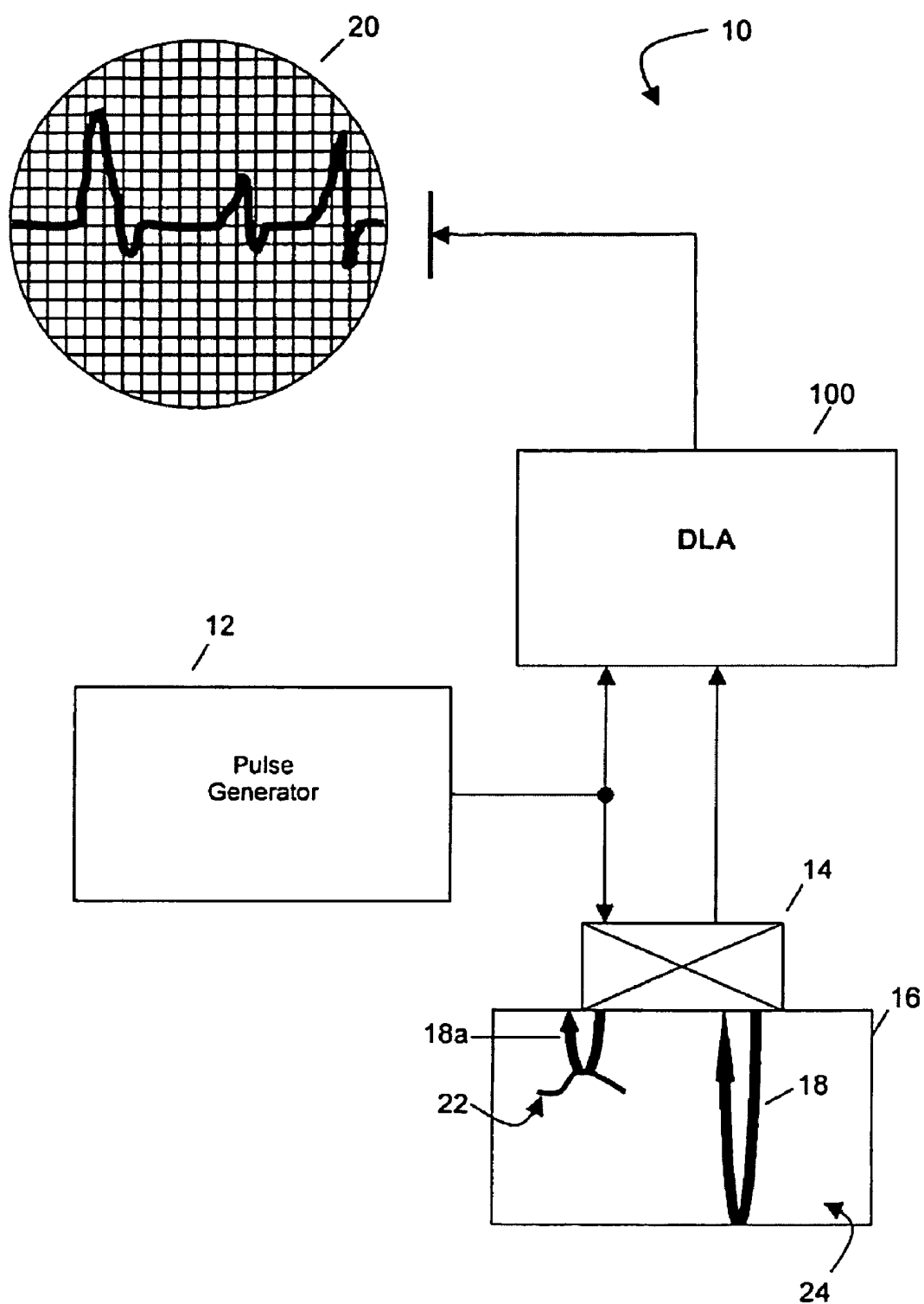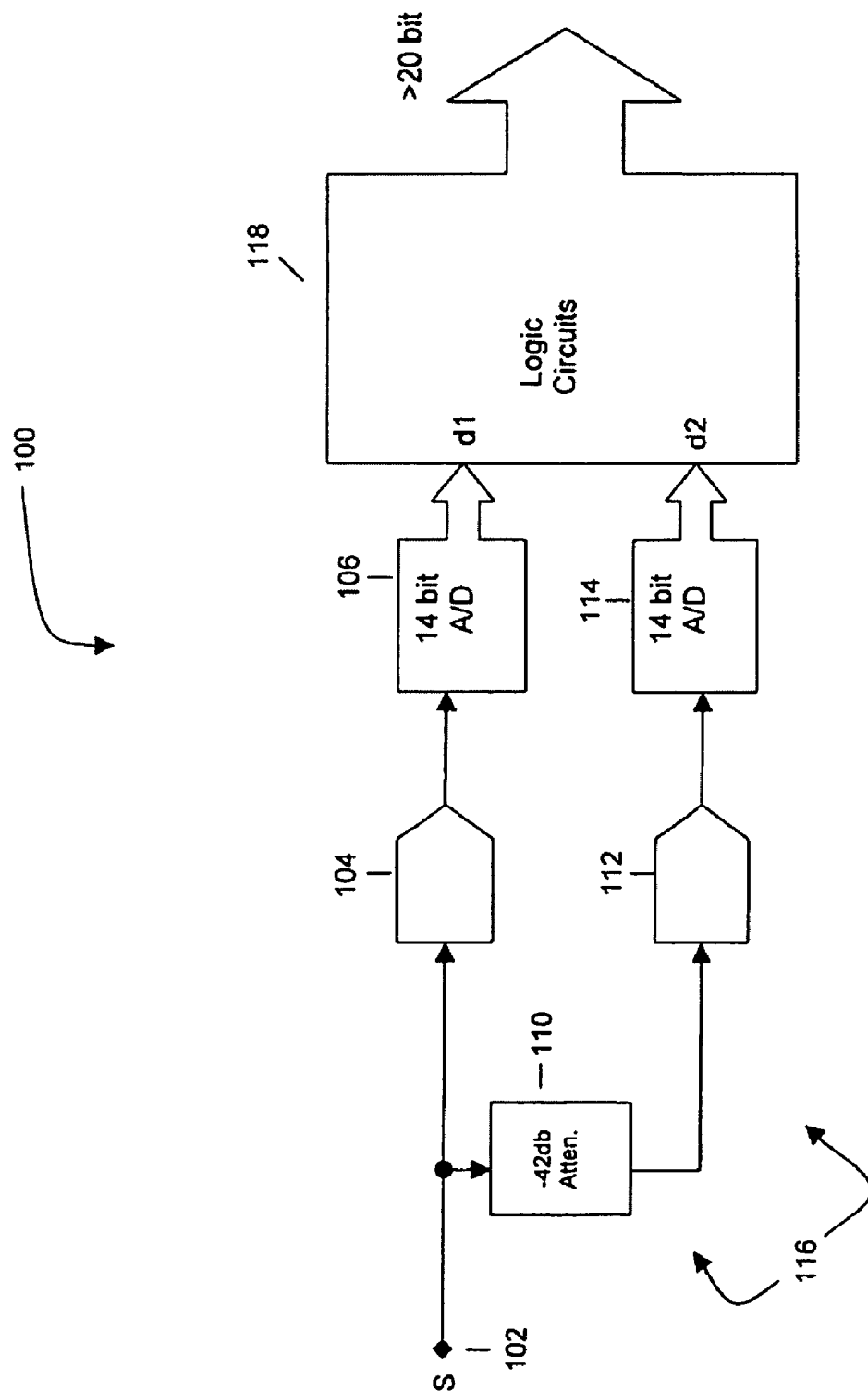
5 Claims, 3 Drawing Sheets

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
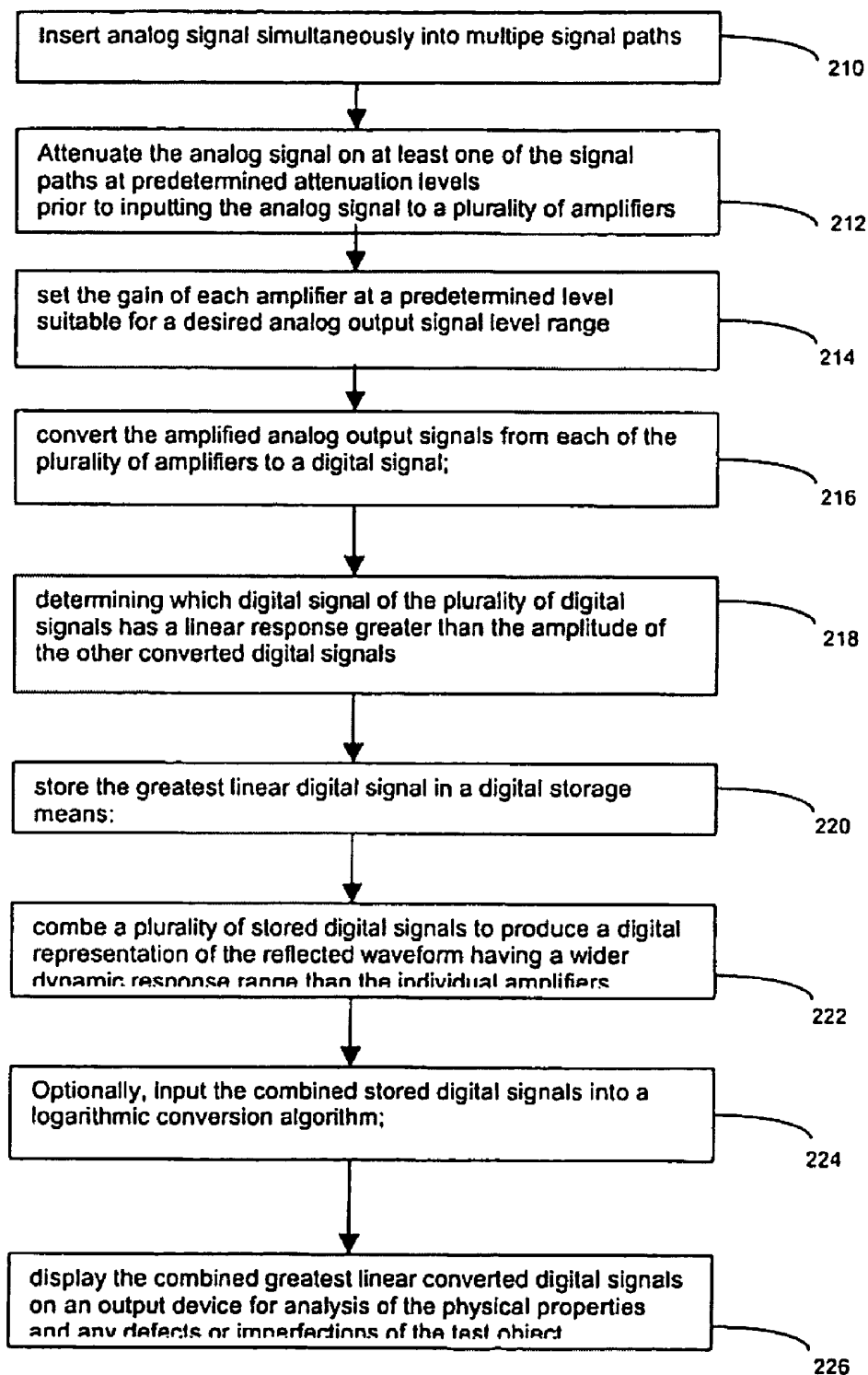
226

Figure 3

DIGITAL LOG AMPLIFIER FOR ULTRASONIC TESTING

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 11/266,854, filed Nov. 4, 2005.

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.sub.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.sub.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 d1, d2 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.sub.1, N.sub.2, N.sub.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.sub.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.sub.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

5   6

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. An ultrasonic object inspection system for measuring the physical properties of a test object comprising:

a pulse generator for generating and transmitting an electrical pulse signal to a transducer;

said transducer for receiving and converting said electrical pulse signal to an ultrasonic signal, applying said ultrasonic signal to said test object, receiving an ultrasonic echo signal from said test object, and converting said ultrasonic echo signal to an electrical echo signal, and transmitting said electrical echo signal to a signal processing circuit;

said signal processing circuit for receiving and processing said electrical echo signal;

said signal processing circuit comprising a plurality of signal processing paths, each of said signal processing paths scaling said electrical echo signal to a different degree and comprising a respective analog to digital converter for converting said electrical echo signal to a digital electrical echo signal; and

said signal processing circuit further comprising a logic circuit for selecting the output of said respective analog to digital converter that provides the digital electrical echo signal having the greatest amplitude without exceeding a predetermined saturation threshold.

2. The ultrasonic object inspection system of claim **1**, further comprising a display for displaying said selected output as a signal representative of said electrical echo signal.

3. The ultrasonic object inspection system of claim **1**, wherein each of said plurality of signal processing paths comprises an amplifier.

4. A method of ultrasonic object inspection testing for measuring the physical properties of a test object comprising the steps of:

generating and transmitting an electrical pulse signal;

receiving and converting the electrical pulse signal to an ultrasonic signal;

applying said ultrasonic signal to said test object;

receiving an ultrasonic echo signal from said test object;

converting said ultrasonic echo signal to an electrical echo signal;

transmitting said electrical echo signal;

receiving and processing said electrical echo signal in a plurality of signal processing paths;

scaling said electrical echo signal to a different degree in each of said signal processing paths;

converting said electrical echo signal to a digital electrical echo signal in each of said signal processing paths; and

selecting the digital electrical echo signal having the greatest amplitude without exceeding a predetermined saturation threshold.

5. The method of ultrasonic object inspection testing of claim **4**, further comprising the step of converting said selected digital electrical echo signal to a logarithmic scale to compress the amplitude of the continuous linear digital waveform over a wide dynamic range.

* * * * *

专利名称(译)	用于超声波测试的数字对数放大		
公开(公告)号	US7506546	公开(公告)日	2009-03-24
申请号	US12/104871	申请日	2008-04-17
申请(专利权)人(译)	GE检测TECHONOLOGIES，LP		
当前申请(专利权)人(译)	GE检测科技，LP		
[标]发明人	CUFFE JOHN MICHAEL BUSCH KLAUS PETER HERBSTER SCOTT ALLEN		
发明人	CUFFE, JOHN MICHAEL BUSCH, KLAUS PETER HERBSTER, SCOTT ALLEN		
IPC分类号	G01N29/06 G01N29/44 A61B8/00 A61B8/08		
CPC分类号	G01N29/36 G01N29/44 H03M1/1235 G01N2291/02854		
其他公开文献	US20080202244A1		
外部链接	Espacenet USPTO		

摘要(译)

本发明提供一种用于测量测试对象物理特性的超声波物体检查系统，该系统包括用于将电脉冲信号发送到换能器的脉冲发生器。换能器然后将超声信号施加到测试对象并从测试对象接收超声回波信号，然后由换能器将其转换成电回波信号以发送到信号处理电路。信号处理电路包括多个信号处理路径，每个路径将电回波信号缩放到不同的程度，并包括相应的模数转换器，用于将电回波信号转换成数字电回波信号。信号处理电路还包括逻辑电路，用于选择相应模数转换器的输出，该输出提供具有最大幅度的数字回波信号，而不超过预定的饱和阈值。