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(54) ANALOG DIGITAL CONVERT APPARATUS, ANALOG DIGITAL CONVERT METHOD, CONTROL APPARATUS AND PROGRAM

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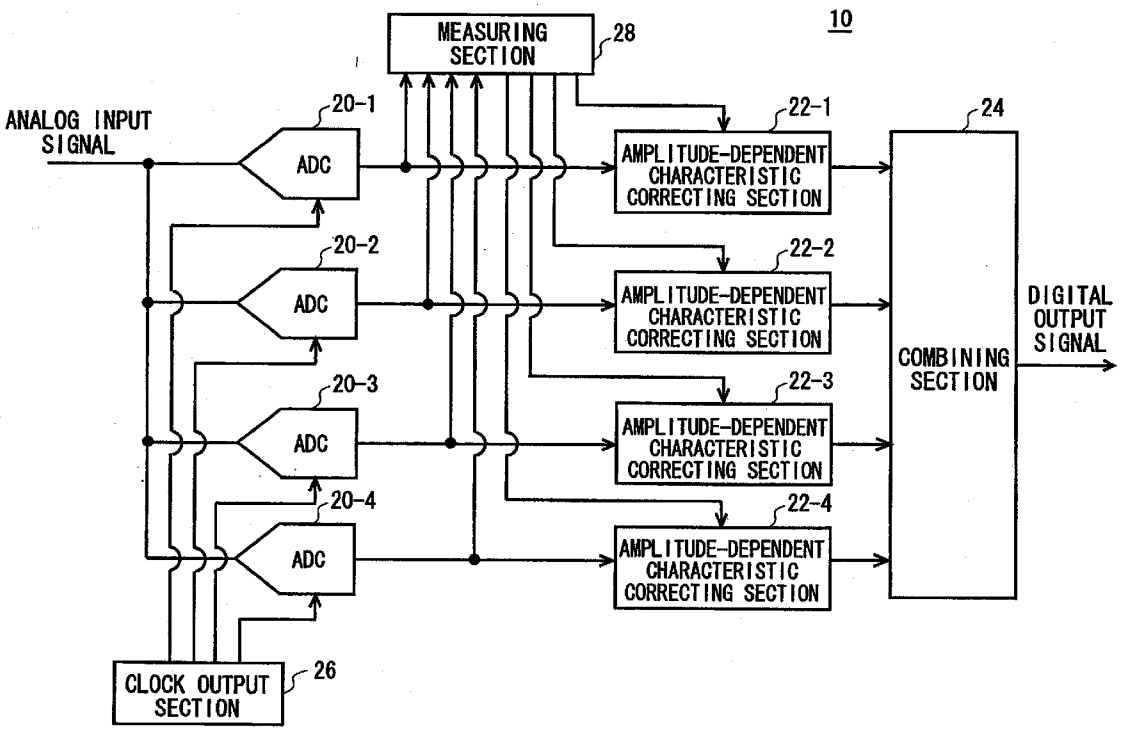
(52) **U.S. Cl.** **341/118**

(57) **ABSTRACT**

Provided is an AD converting apparatus that converts an analog input signal into a digital output signal, comprising a plurality of AD converters supplied with sampling clocks differing from each other by prescribed phase amounts, each AD converter outputting an individual signal obtained by digitizing the input signal according to the supplied sampling clock; a plurality of amplitude-dependent characteristic correcting sections that are provided to correspond to the plurality of AD converters, each amplitude-dependent characteristic correcting section generating a corrected individual signal by correcting the individual signal output by the corresponding AD converter using a correction factor corresponding to an amplitude of the individual signal; and a combining section that generates the output signal by combining a plurality of the corrected individual signals.



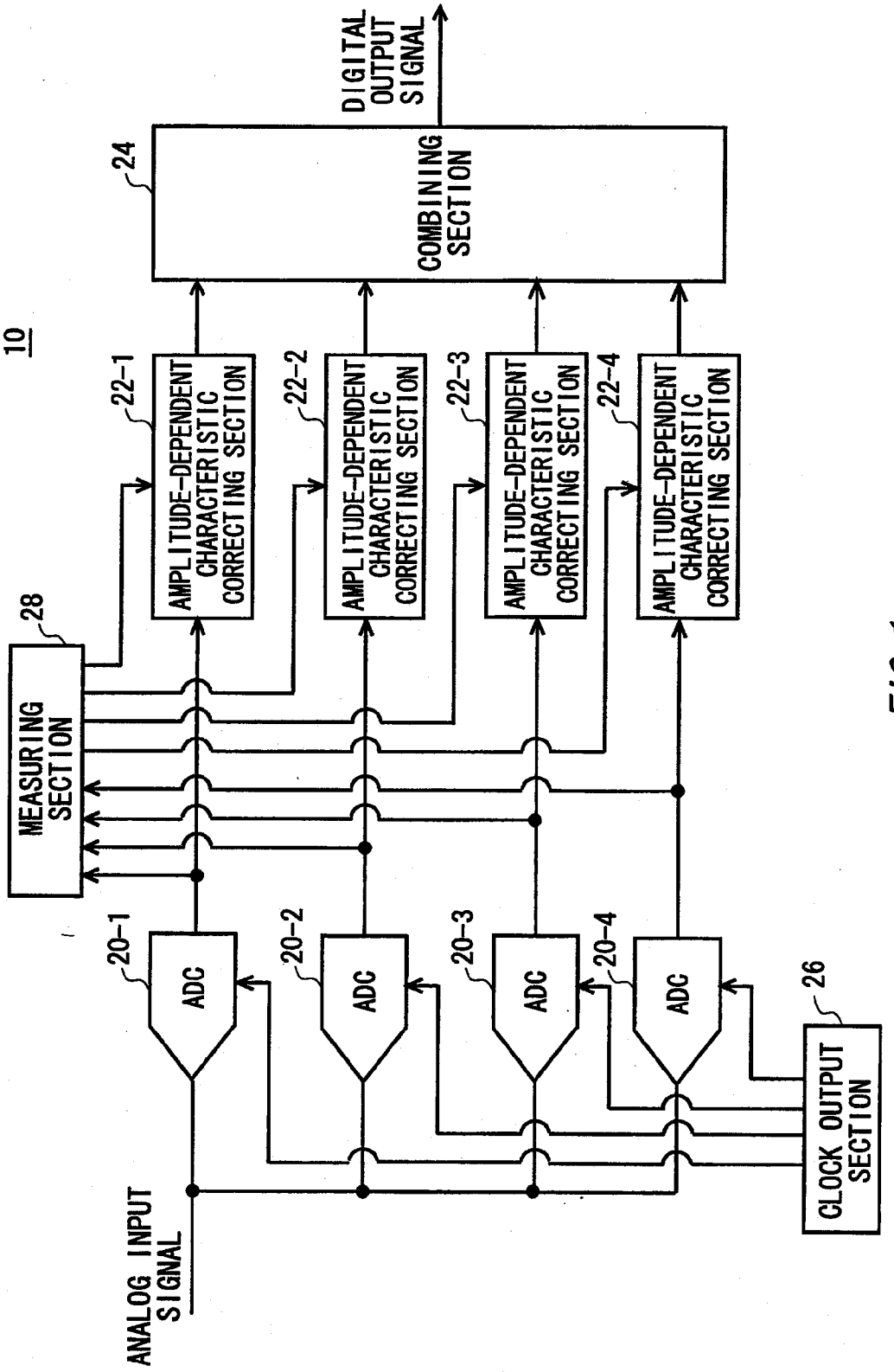

10
ANALOG INPUT SIGNAL
MEASURING SECTION
28
ADC
20-1
ADC
20-2
ADC
20-3
ADC
20-4
CLOCK OUTPUT SECTION
26
AMPLITUDE-DEPENDENT CHARACTERISTIC CORRECTING SECTION
22-1
AMPLITUDE-DEPENDENT CHARACTERISTIC CORRECTING SECTION
22-2
AMPLITUDE-DEPENDENT CHARACTERISTIC CORRECTING SECTION
22-3
AMPLITUDE-DEPENDENT CHARACTERISTIC CORRECTING SECTION
22-4
COMBINING SECTION
24
DIGITAL OUTPUT SIGNAL

FIG. 1

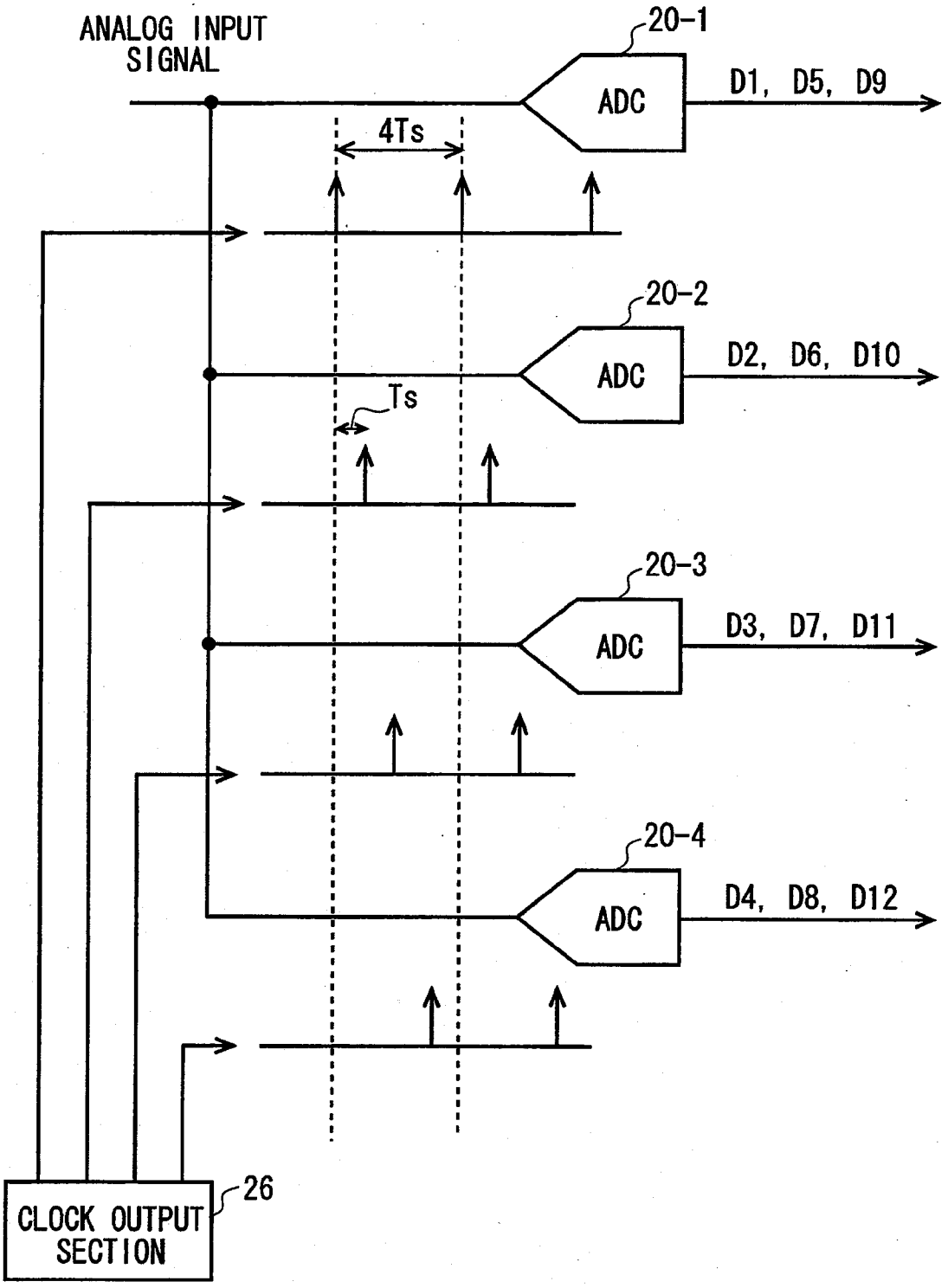

ANALOG INPUT SIGNAL
20-1
ADC
D1, D5, D9
4Ts
20-2
ADC
D2, D6, D10
Ts
20-3
ADC
D3, D7, D11
20-4
ADC
D4, D8, D12
CLOCK OUTPUT SECTION
26

FIG. 2

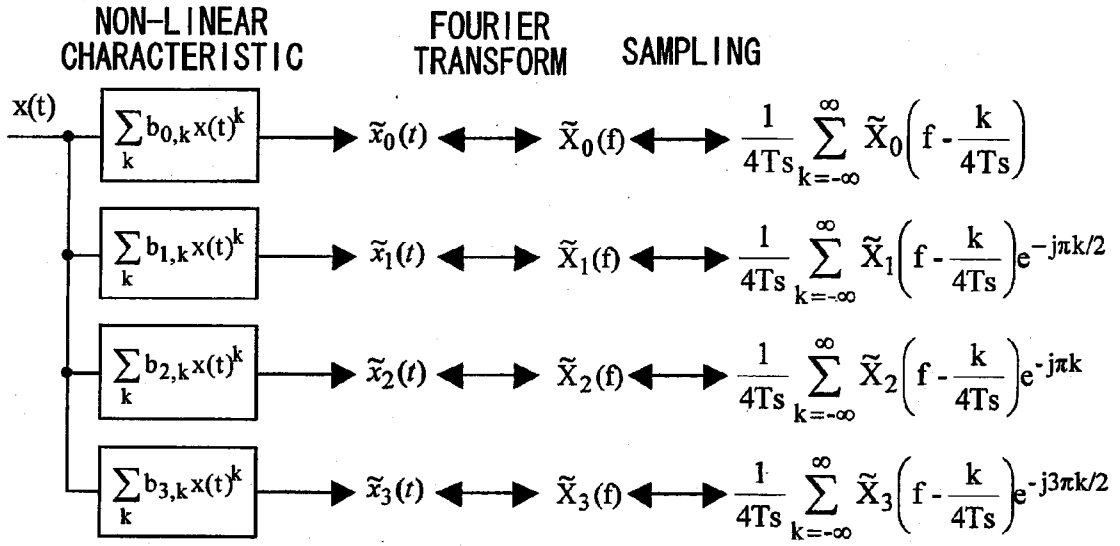

NON-LINEAR CHARACTERISTIC
FOURIER TRANSFORM
SAMPLING
x(t)
$\sum_k b_{0,k}x(t)^k$
$\sum_k b_{1,k}x(t)^k$
$\sum_k b_{2,k}x(t)^k$
$\sum_k b_{3,k}x(t)^k$
$\tilde{x}_0(t) \leftrightarrow \tilde{X}_0(f) \leftrightarrow \frac{1}{4Ts}\sum_{k=-\infty}^{\infty}\tilde{X}_0\left(f-\frac{k}{4Ts}\right)$
$\tilde{x}_1(t) \leftrightarrow \tilde{X}_1(f) \leftrightarrow \frac{1}{4Ts}\sum_{k=-\infty}^{\infty}\tilde{X}_1\left(f-\frac{k}{4Ts}\right)e^{-j\pi k/2}$
$\tilde{x}_2(t) \leftrightarrow \tilde{X}_2(f) \leftrightarrow \frac{1}{4Ts}\sum_{k=-\infty}^{\infty}\tilde{X}_2\left(f-\frac{k}{4Ts}\right)e^{-j\pi k}$
$\tilde{x}_3(t) \leftrightarrow \tilde{X}_3(f) \leftrightarrow \frac{1}{4Ts}\sum_{k=-\infty}^{\infty}\tilde{X}_3\left(f-\frac{k}{4Ts}\right)e^{-j3\pi k/2}$

FIG. 3

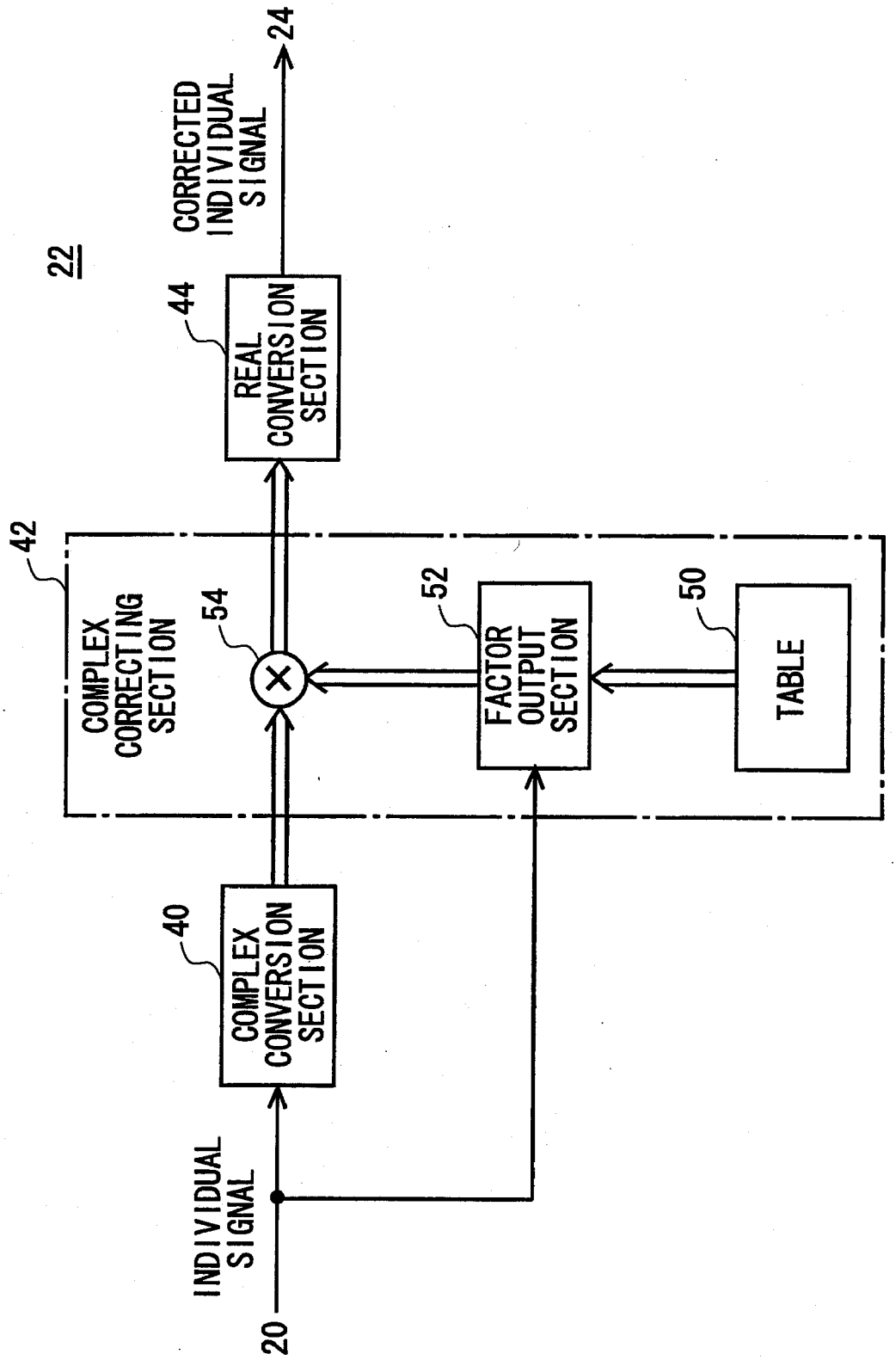

22
INDIVIDUAL SIGNAL
20
COMPLEX CONVERSION SECTION
40
COMPLEX CORRECTING SECTION
42
REAL CONVERSION SECTION
44
CORRECTED INDIVIDUAL SIGNAL
24
54
FACTOR OUTPUT SECTION
52
TABLE
50

FIG. 4

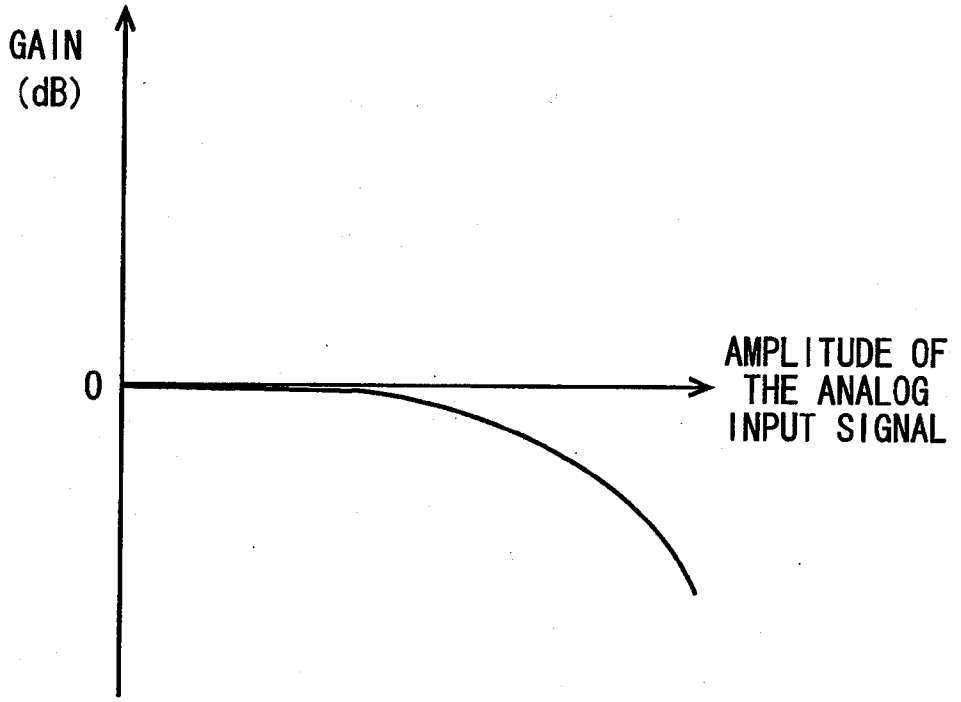

GAIN
(dB)
0
AMPLITUDE OF
THE ANALOG
INPUT SIGNAL

FIG. 5A

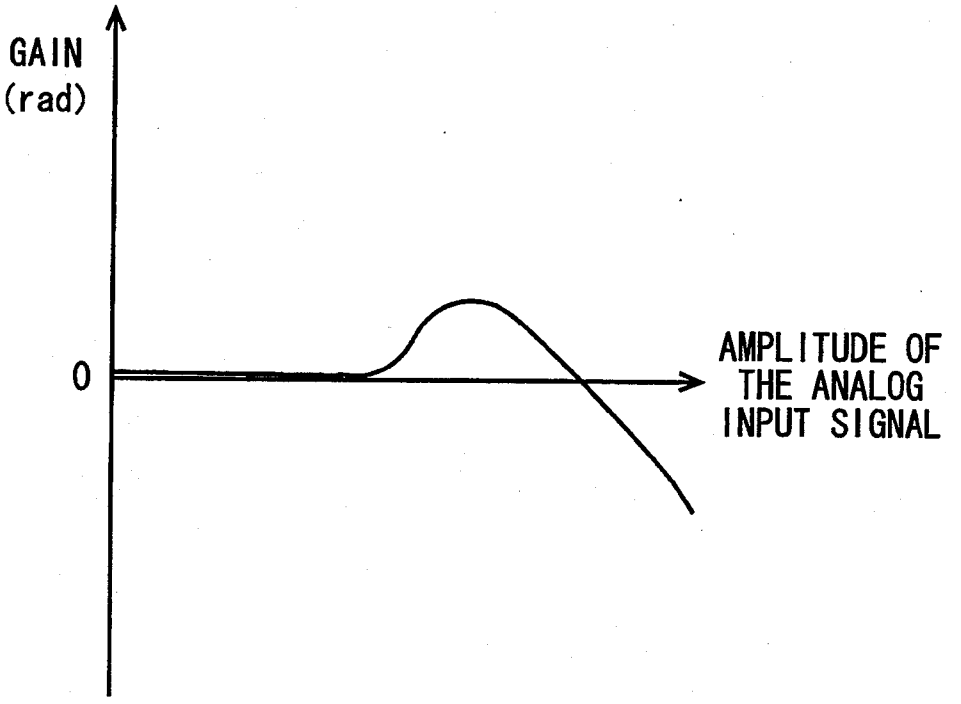

GAIN
(rad)
0
AMPLITUDE OF
THE ANALOG
INPUT SIGNAL

FIG. 5B

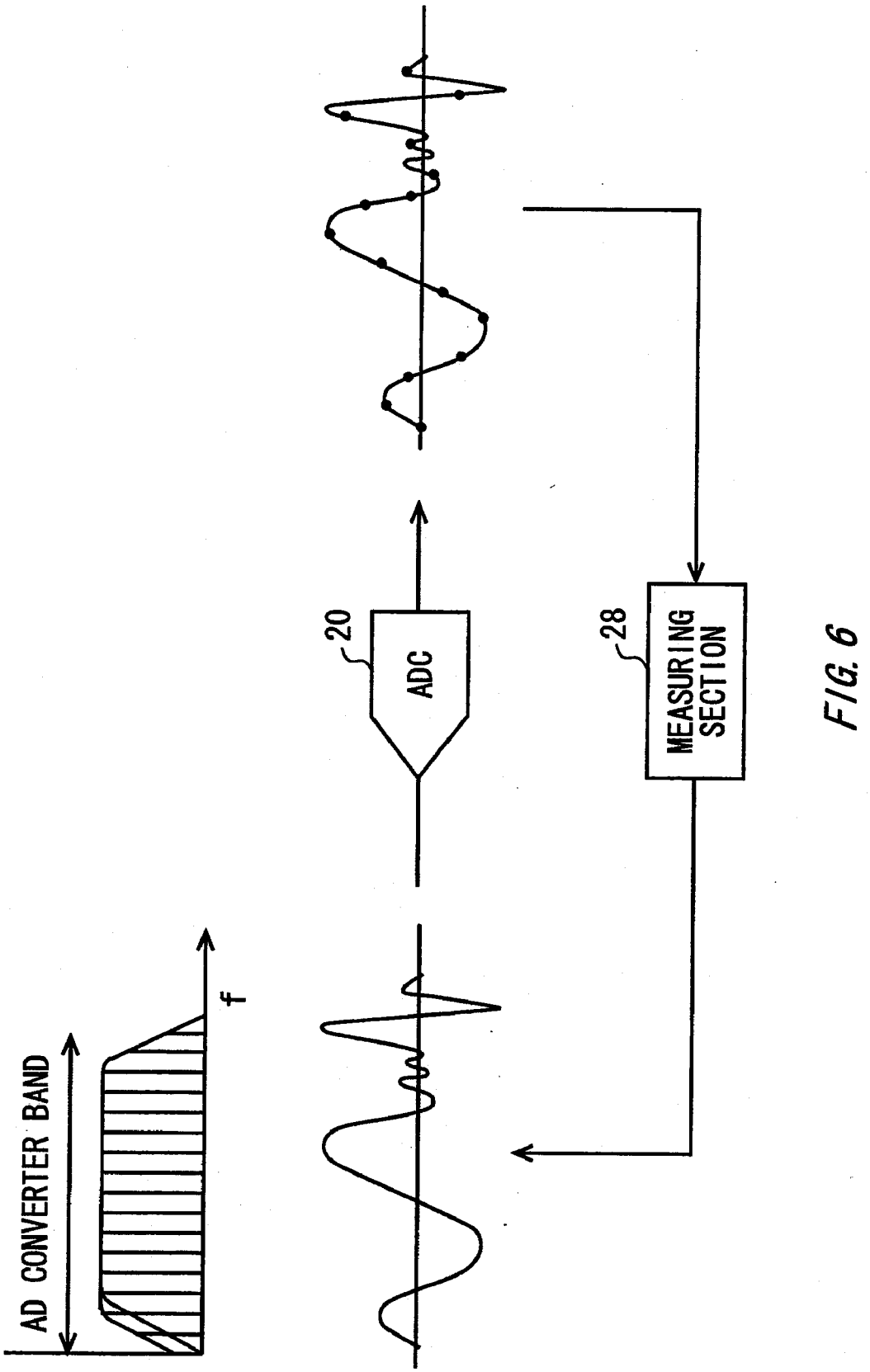


FIG. 6

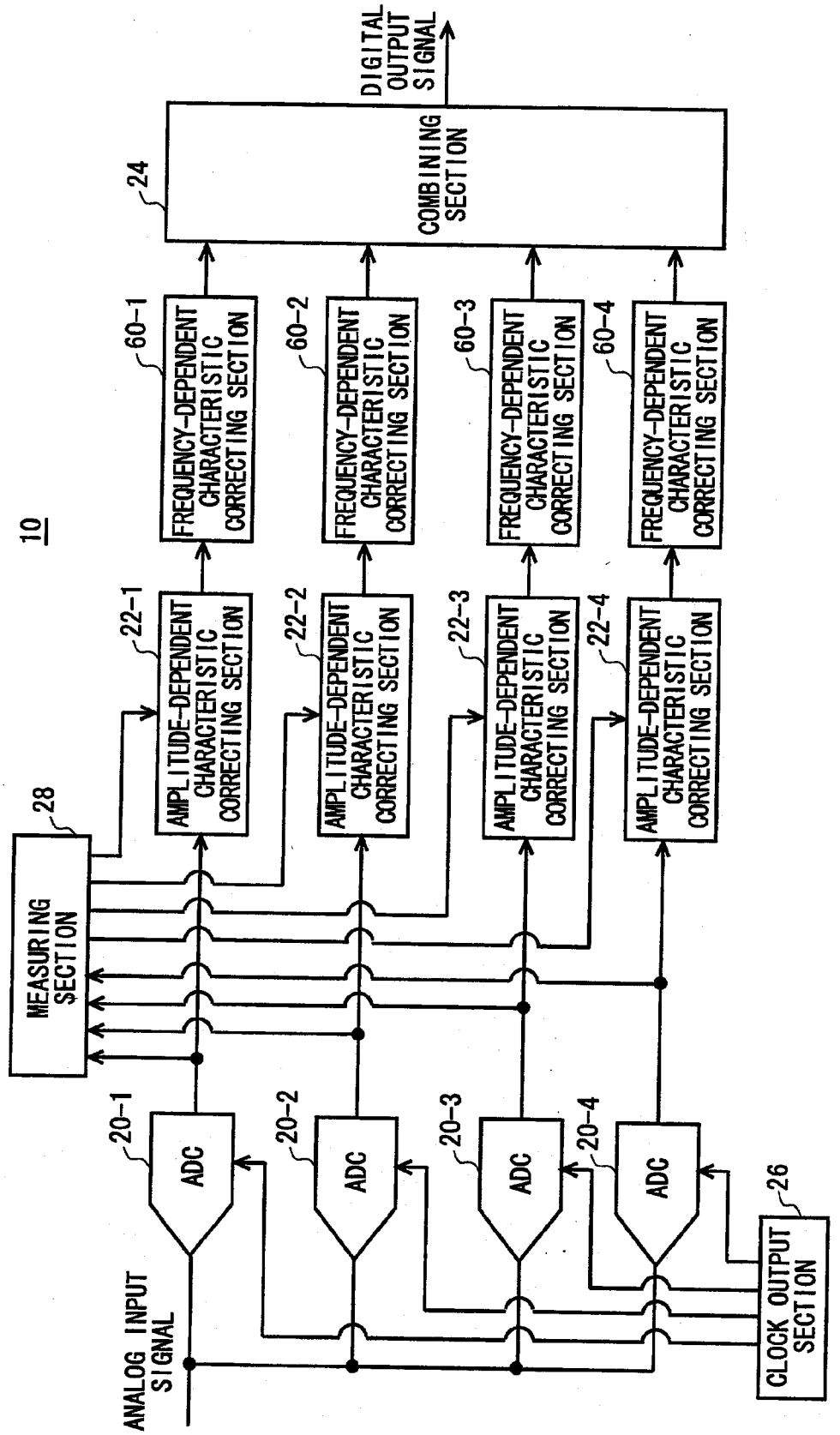

10
ANALOG INPUT SIGNAL
MEASURING SECTION
28
ADC
20-1
20-2
20-3
20-4
CLOCK OUTPUT SECTION
26
AMPLITUDE-DEPENDENT CHARACTERISTIC CORRECTING SECTION
22-1
22-2
22-3
22-4
FREQUENCY-DEPENDENT CHARACTERISTIC CORRECTING SECTION
60-1
60-2
60-3
60-4
COMBINING SECTION
24
DIGITAL OUTPUT SIGNAL

FIG. 7

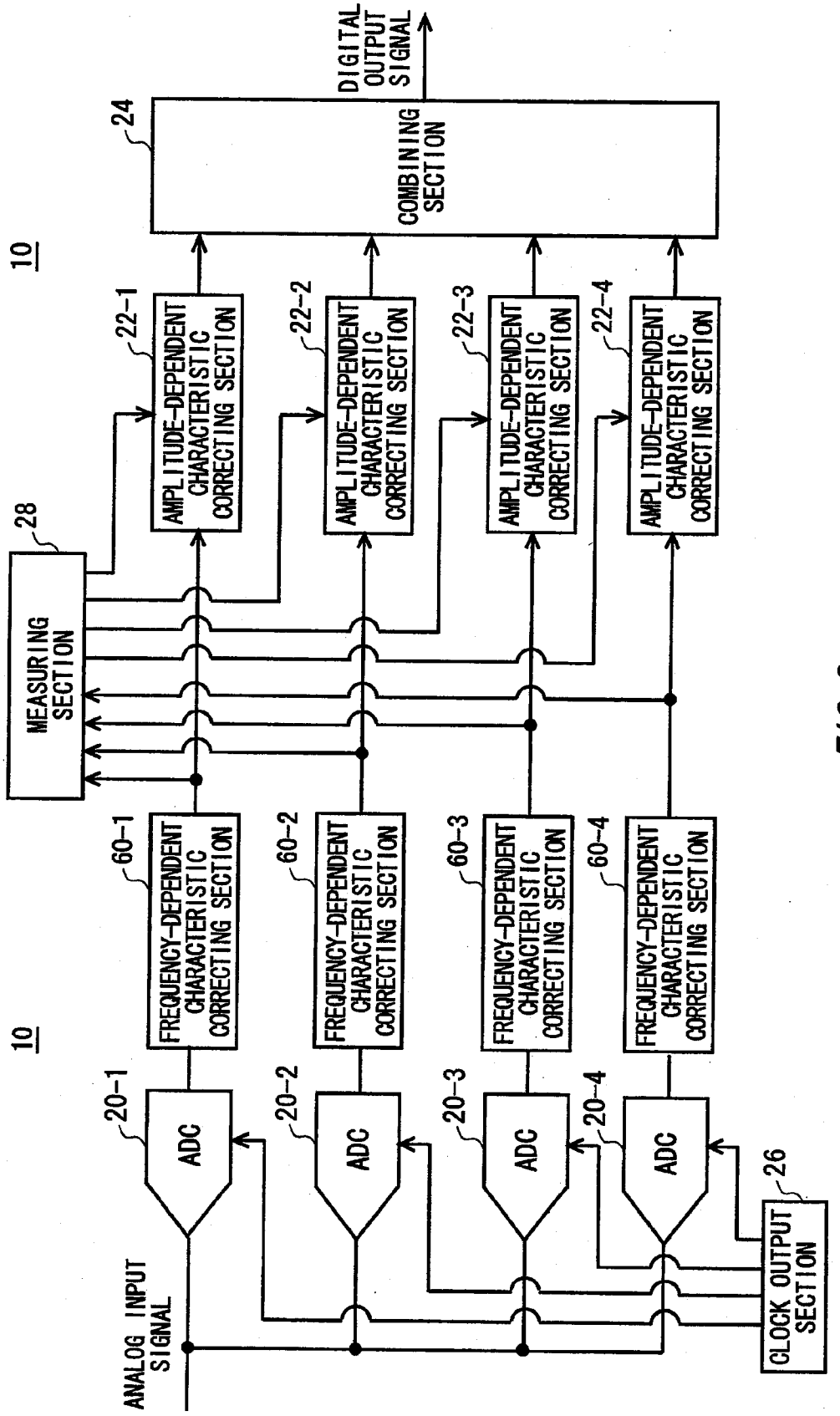

10
10
ANALOG INPUT SIGNAL
ADC
20-1
ADC
20-2
ADC
20-3
ADC
20-4
FREQUENCY-DEPENDENT CHARACTERISTIC CORRECTING SECTION
60-1
FREQUENCY-DEPENDENT CHARACTERISTIC CORRECTING SECTION
60-2
FREQUENCY-DEPENDENT CHARACTERISTIC CORRECTING SECTION
60-3
FREQUENCY-DEPENDENT CHARACTERISTIC CORRECTING SECTION
60-4
MEASURING SECTION
28
AMPLITUDE-DEPENDENT CHARACTERISTIC CORRECTING SECTION
22-1
AMPLITUDE-DEPENDENT CHARACTERISTIC CORRECTING SECTION
22-2
AMPLITUDE-DEPENDENT CHARACTERISTIC CORRECTING SECTION
22-3
AMPLITUDE-DEPENDENT CHARACTERISTIC CORRECTING SECTION
22-4
COMBINING SECTION
24
DIGITAL OUTPUT SIGNAL
CLOCK OUTPUT SECTION
26

FIG. 8

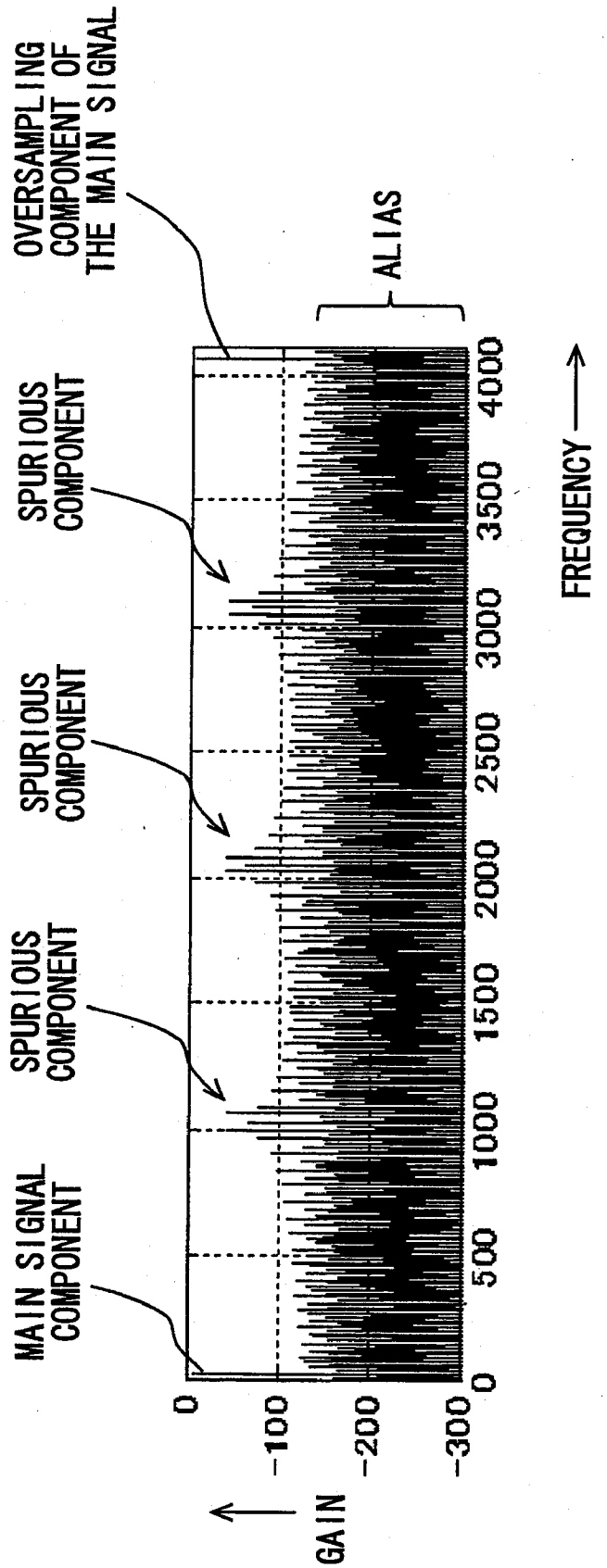

OVERSAMPLING COMPONENT OF THE MAIN SIGNAL
ALIAS
SPURIOUS COMPONENT
SPURIOUS COMPONENT
SPURIOUS COMPONENT
MAIN SIGNAL COMPONENT
FREQUENCY
GAIN
0
500
1000
1500
2000
2500
3000
3500
4000
0
-100
-200
-300

FIG. 9

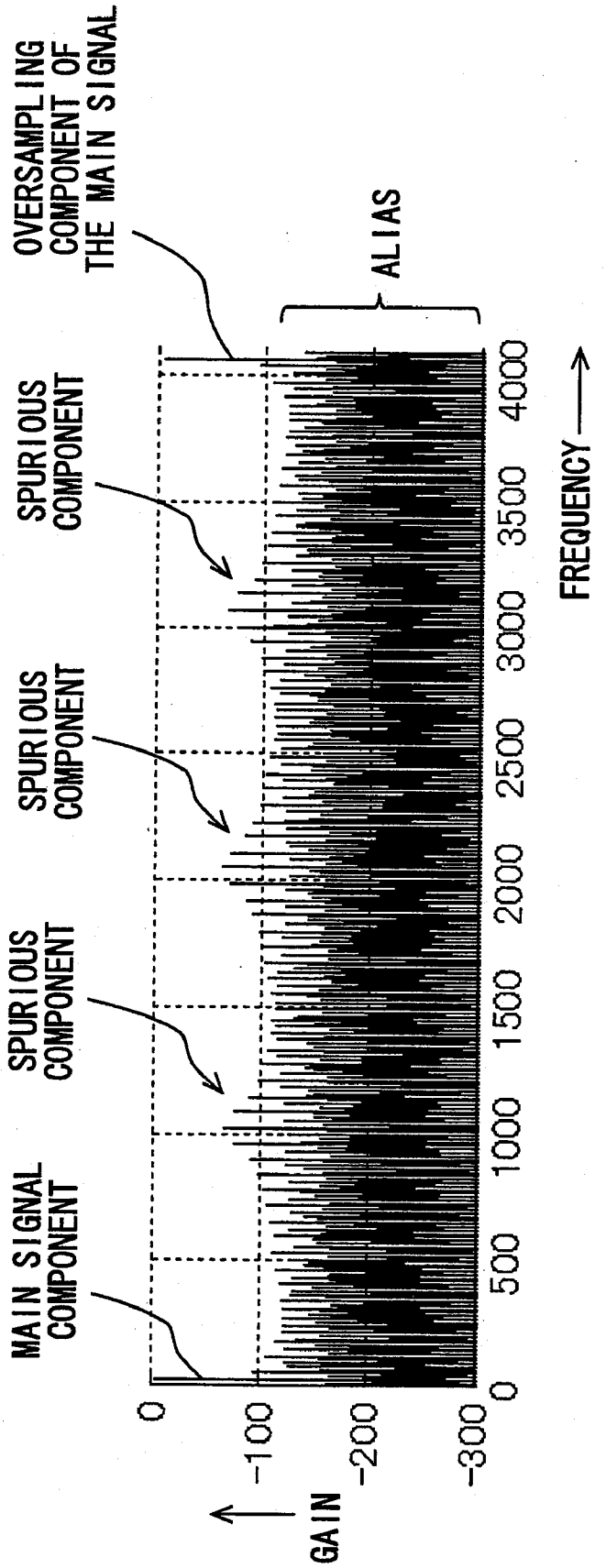

OVERSAMPLING COMPONENT OF THE MAIN SIGNAL
ALIAS
SPURIOUS COMPONENT
SPURIOUS COMPONENT
SPURIOUS COMPONENT
MAIN SIGNAL COMPONENT
FREQUENCY
GAIN
0
500
1000
1500
2000
2500
3000
3500
4000
0
-100
-200
-300

FIG. 10

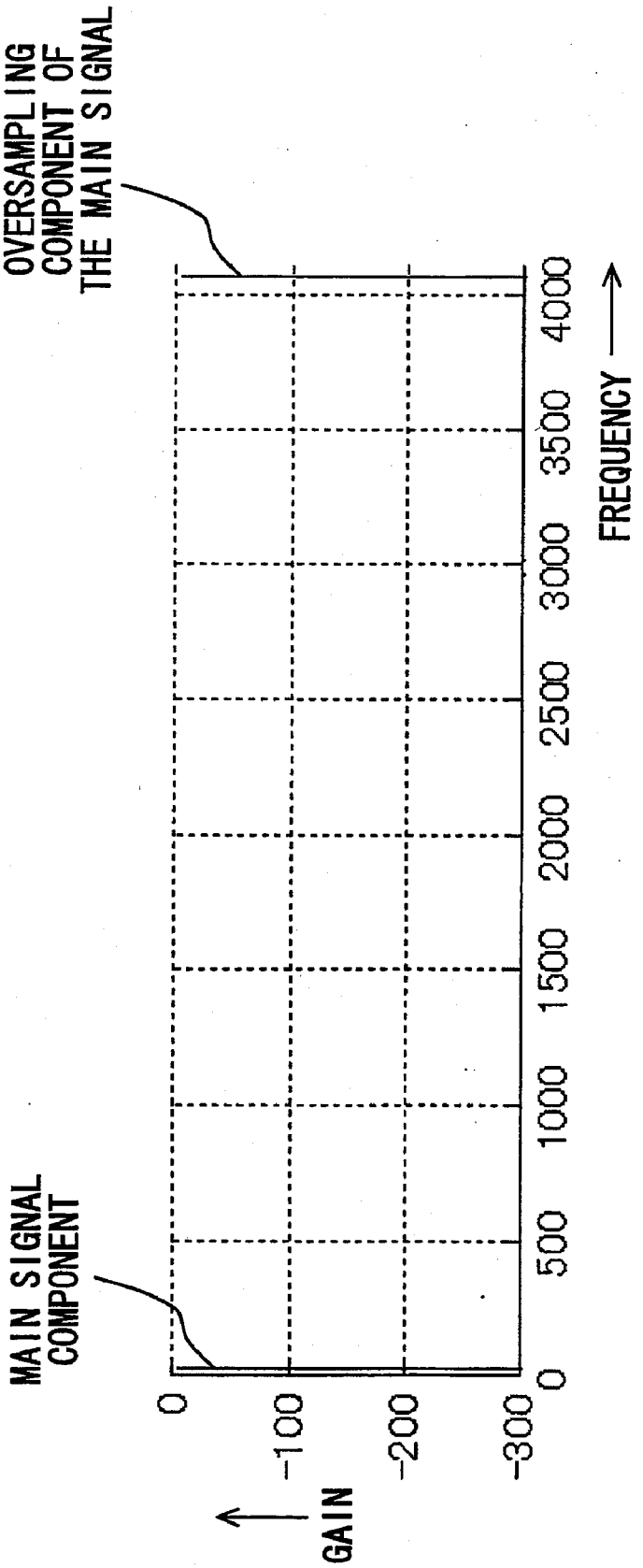

OVERSAMPLING COMPONENT OF THE MAIN SIGNAL
MAIN SIGNAL COMPONENT
0
-100
-200
-300
GAIN
0
500
1000
1500
2000
2500
3000
3500
4000
FREQUENCY

FIG. 11

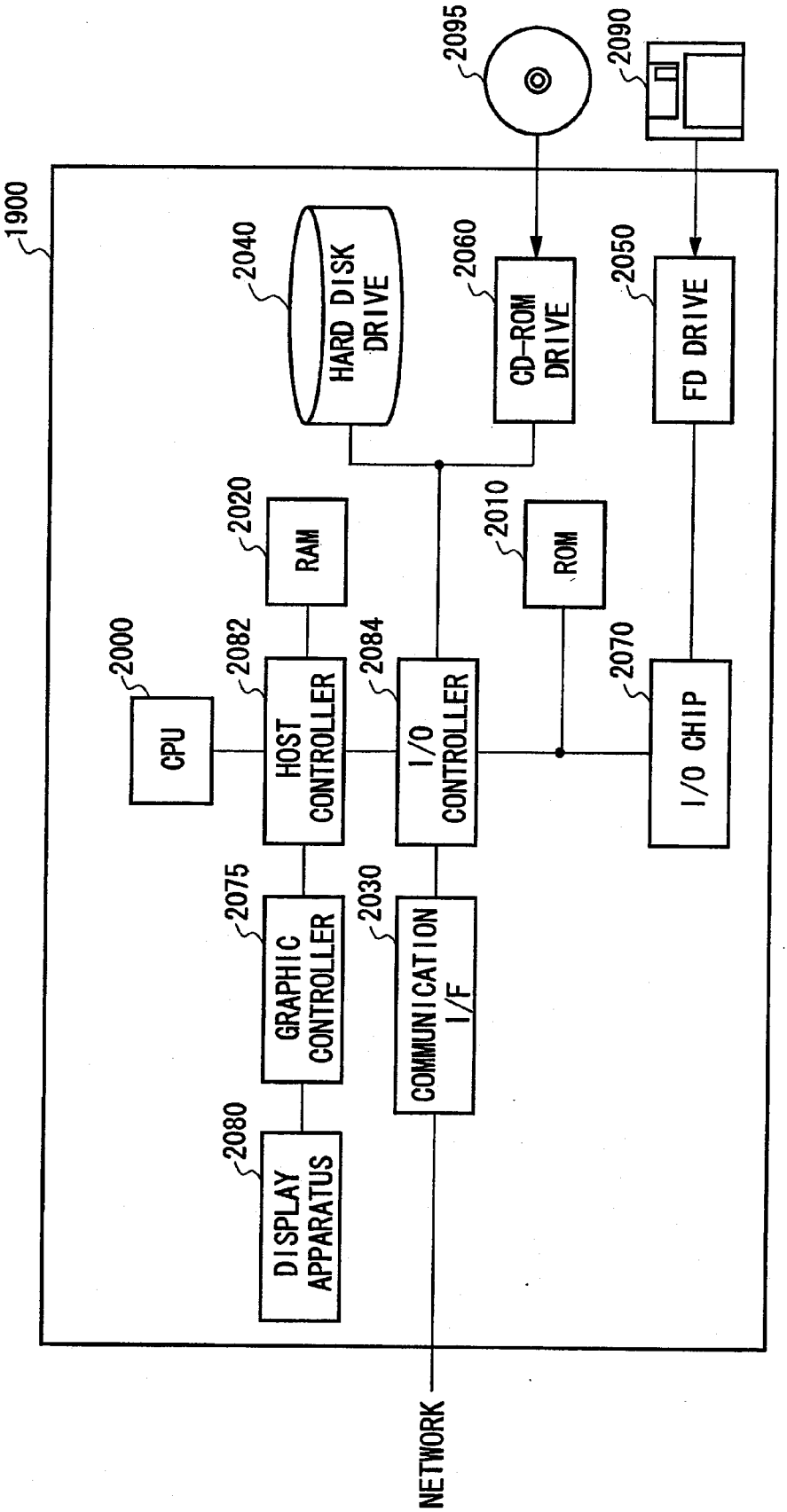

1900
2095
2090
2040
HARD DISK DRIVE
2060
CD-ROM DRIVE
2050
FD DRIVE
2020
RAM
2010
ROM
2000
CPU
2082
HOST CONTROLLER
2084
I/O CONTROLLER
2070
I/O CHIP
2075
GRAPHIC CONTROLLER
2030
COMMUNICATION I/F
2080
DISPLAY APPARATUS
NETWORK

FIG. 12

ANALOG DIGITAL CONVERT APPARATUS, ANALOG DIGITAL CONVERT METHOD, CONTROL APPARATUS AND PROGRAM

CROSS REFERENCE TO RELATED APPLICATION

[0001] The present application claims priority from a Japanese Patent application No. 2007-338228 filed on Dec. 27, 2007, the contents of which are incorporated herein by reference.

BACKGROUND

[0002] 1. Technical Field

[0003] The present invention relates to an AD converting apparatus, an AD converting method, a control apparatus, and a program. In particular, the present invention relates to an AD converting apparatus, an AD converting method, a control apparatus, and a program for converting an analog input signal into a digital output signal using a plurality of AD converters.

[0004] 2. Related Art

[0005] An interleave-type AD converting apparatus with a high sampling rate is known as in, for example, Japanese Patent Application Publication No. 2005-347967. The interleave-type AD converting apparatus is provided with a plurality of AD converters that are supplied with sampling clocks that differ from each other by a prescribed phase, and a combining section that sequentially selects one sample at a time of the signals output by the AD converters and combines these sampled signals.

[0006] The AD converting apparatus described above corrects each of a plurality of signals output by a plurality of AD converters, where each signal is corrected according to a frequency characteristic of the corresponding AD converter. In this way, the AD converting apparatus can accurately convert an analog input signal into a digital output signal, even when each AD converter has a different frequency characteristic.

[0007] However, each AD converter has an error that causes a curve representing the relation between the amplitude of the input signal and the data value of the AD-converted output signal to deviate from the ideal curve, e.g. a straight line. The characteristic that causes the curve representing the relation between the amplitude of the input signal and the data value of the AD-converted output signal to deviate from the ideal curve is known as the "non-linear characteristic." An interleave-type AD converting apparatus causes spurious components to be included in the output signal when the AD converters have different non-linear characteristics, and this decreases the dynamic range of the output signal.

SUMMARY

[0008] Therefore, it is an object of an aspect of the innovations herein to provide an AD converting apparatus, an AD converting method, a control apparatus, and a program, which are capable of overcoming the above drawbacks accompanying the related art. The above and other objects can be achieved by combinations described in the independent claims. The dependent claims define further advantageous and exemplary combinations of the innovations herein.

[0009] According to a first aspect related to the innovations herein, one exemplary AD converting apparatus may include an AD converting apparatus that converts an analog input signal into a digital output signal, comprising a plurality of AD converters supplied with sampling clocks differing from each other by prescribed phase amounts, each AD converter outputting an individual signal obtained by digitizing the input signal according to the supplied sampling clock; a plurality of amplitude-dependent characteristic correcting sections that are provided to correspond to the plurality of AD converters, each amplitude-dependent characteristic correcting section generating a corrected individual signal by correcting the individual signal output by the corresponding AD converter using a correction factor corresponding to an amplitude of the individual signal; and a combining section that generates the output signal by combining a plurality of the corrected individual signals.

[0010] According to a second aspect related to the innovations herein, one exemplary AD converting method may include an AD converting method that uses a plurality of AD converters to convert an analog input signal into a digital output signal, comprising supplying the plurality of AD converters with sampling clocks differing from each other by prescribed phase amounts, and causing each AD converter to output an individual signal obtained by digitizing the input signal according to the supplied sampling clock; generating a corrected individual signal for each AD converter by correcting the individual signal output by the AD converter using a correction factor corresponding to an amplitude of the individual signal; and generating the output signal by combining a plurality of the generated corrected individual signals.

[0011] According to a third aspect related to the innovations herein, one exemplary control apparatus may include a control apparatus that uses a plurality of AD converters to function as an AD converting apparatus that converts an analog input signal into a digital output signal, comprising a clock output section that supplies the plurality of AD converters with sampling clocks differing from each other by prescribed phase amounts, causing each AD converter to output an individual signal obtained by digitizing the input signal according to the supplied sampling clock; a plurality of amplitude-dependent characteristic correcting sections that are provided to correspond to the plurality of AD converters, each amplitude-dependent characteristic correcting section generating a corrected individual signal by correcting the individual signal output by the corresponding AD converter using a correction factor corresponding to an amplitude of the individual signal; and a combining section that generates the output signal by combining a plurality of the corrected individual signals.

[0012] According to a fourth aspect related to the innovations herein, one exemplary program may include a program that causes a control apparatus to function as an AD converting apparatus that uses a plurality of AD converters to convert an analog input signal into a digital output signal, the program causing the control apparatus to function as a clock output section that supplies the plurality of AD converters with sampling clocks differing from each other by prescribed phase amounts, causing each AD converter to output an individual signal obtained by digitizing the input signal according to the supplied sampling clock; a plurality of amplitude-dependent characteristic correcting sections that are provided to correspond to the plurality of AD converters, each amplitude-dependent characteristic correcting section generating a corrected individual signal by correcting the individual signal output by the corresponding AD converter using a correction factor corresponding to an amplitude of the individual signal;

and a combining section that generates the output signal by combining a plurality of the corrected individual signals.

[0013] The summary clause does not necessarily describe all necessary features of the embodiments of the present invention. The present invention may also be a sub-combination of the features described above. The above and other features and advantages of the present invention will become more apparent from the following description of the embodiments taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] FIG. **1** shows an exemplary configuration of an AD converting apparatus **10** according to an embodiment of the present invention.

[0015] FIG. **2** shows an exemplary sampling clock provided to each AD converter **20**.

[0016] FIG. **3** describes the effect that an error in the non-linear characteristic of each AD converter **20** has on the output signal of the AD converting apparatus **10**.

[0017] FIG. **4** shows an exemplary configuration of one of the plurality of amplitude-dependent characteristic correcting sections **22** according to the present embodiment.

[0018] FIG. **5**A shows an example of a non-linear characteristic, i.e. an amplitude component, of an AD converter **20**.

[0019] and FIG. **5**B shows an example of a non-linear characteristic, i.e. a phase component, of an AD converter **20**.

[0020] FIG. **6** shows an example of a measured signal supplied to an AD converter **20** for calculating a correction factor.

[0021] FIG. **7** shows a configuration of the AD converting apparatus **10** according to a first modification of the present embodiment.

[0022] FIG. **8** shows a configuration of the AD converting apparatus **10** according to a second modification of the present embodiment.

[0023] FIG. **9** shows the result of a simulation of a frequency characteristic of an output signal output by an interleave-type AD converting apparatus provided with four AD converters, when supplied with an input signal having a single frequency.

[0024] FIG. **10** shows the result of a simulation of a frequency characteristic of an output signal output by an interleave-type AD converting apparatus provided with four AD converters and four correcting sections that respectively correct the frequency characteristics of the four AD converters, when supplied with an input signal having a single frequency.

[0025] FIG. **11** shows the result of a simulation of a frequency characteristic of an output signal output by the AD converting apparatus **10** according to the modification shown in FIG. **7**, when supplied with an input signal having a single frequency.

[0026] FIG. **12** shows an example of a hardware configuration of a computer **1900** according to the present embodiment.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0027] Hereinafter, some embodiments of the present invention will be described. The embodiments do not limit the invention according to the claims, and all the combinations of the features described in the embodiments are not necessarily essential to means provided by aspects of the invention.

[0028] FIG. **1** shows an exemplary configuration of an AD converting apparatus **10** according to an embodiment of the present invention. The AD converting apparatus **10** converts an analog input signal into a digital output signal. The AD converting apparatus **10** is provided with a plurality of AD converters **20** (in the present embodiment there are four AD converters **20-1** to **20-4**), a plurality of amplitude-dependent characteristic correcting sections **22** (in the present embodiment there are four amplitude-dependent characteristic correcting sections **22-1** to **22-4**), a combining section **24**, a clock output section **26**, and a measuring section **28**.

[0029] Each AD converter **20** is supplied with an input signal to be AD converted. Each AD converter **20** is supplied with a sampling clock, the phase of which differs by a prescribed amount for each AD converter **20**. The sampling clock is described in detail in FIG. **2**. Each AD converter **20** samples the analog input signal according to the sampling clock supplied thereto, and outputs a digitized individual signal.

[0030] The plurality of amplitude-dependent characteristic correcting sections **22** are provided to correspond respectively to the plurality of AD converters **20**. Each amplitude-dependent characteristic correcting section **22** generates a corrected individual signal by correcting the individual signal output by the corresponding AD converter **20** using a correction factor based on the amplitude of the individual signal.

[0031] For example, each amplitude-dependent characteristic correcting section **22** corrects the individual signal output by the corresponding AD converter **20** such that the corrected individual signal approaches a reference value, e.g. such that the corrected individual signal matches a reference value. The reference value may be a data value that should be output when a reference AD converter AD converts the analog input signal. The reference AD converter may cause the amplitude of the input signal and the data value of the output signal to have an ideal linear relationship. As another example, the reference AD converter may cause the amplitude of the input signal and the data value of the output signal to have a non-linear relationship, e.g. the reference AD converter may be any one of the AD converters **20** provided to the AD converting apparatus **10**.

[0032] Each amplitude-dependent characteristic correcting section **22** may perform the correction by multiplying the individual signal output from the corresponding AD converter **20** by the correction factor based on an inverse characteristic of a non-linear characteristic of the AD converter **20**. Here, the non-linear characteristic indicates the ratio of the individual signal output from the AD converter **20** to a signal expected to be output by the reference AD converter.

[0033] Each amplitude-dependent characteristic correcting section **22** may acquire, in advance, a function expressing the inverse of the non-linear characteristic of the corresponding AD converter **20**, where the amplitude of the individual signal is a variable in the function. Each amplitude-dependent characteristic correcting section **22** may use, as the correction factor, a result obtained by substituting the amplitude of the individual signal output by the corresponding AD converter **20** into the function.

[0034] Each amplitude-dependent characteristic correcting section **22** may store, in advance, the correction factor for each amplitude of the individual signal in a table or the like. In this case, each amplitude-dependent characteristic correcting section **22** may select one correction factor from the table that is associated with the amplitude of the individual signal output by the corresponding AD converter **20**, and correct the individual signal using the selected correction factor.

[0035] The combining section **24** generates an output signal by combining the plurality of corrected individual signals output by the plurality of amplitude-dependent characteristic correcting sections **22**. More specifically, the combining section **24** may generate a single data sequence by sequentially selecting, cyclically for each sample, the corrected individual signals output by the amplitude-dependent characteristic correcting sections **22**. The combining section **24** selects the corrected individual signals sequentially, beginning with the AD converter **20** supplied with the sampling clock having the earliest phase. The combining section **24** outputs the generated data sequence as the output signal.

[0036] After combining the plurality of corrected individual signals corrected to have a characteristic matching that of a certain AD converter, the combining section **24** may correct each data value in the output signal to be equal to an ideal value. For example, the combining section **24** may correct each data value in the output signal to be equal to an ideal value by performing, on the combined signal, the process performed by the amplitude-dependent characteristic correcting sections **22**. In this way, the combining section **24** can cause the relation between the amplitude of the input signal and the data value of the output signal to have the ideal direct relationship, even when the amplitude-dependent characteristic correcting sections **22** output corrected individual signals that are corrected with data values output by non-ideal AD converters.

[0037] The clock output section **26** supplies each AD converter **20** with a sampling clock, each sampling clock having the same frequency and a phase differing by a prescribed amount. In this way, the clock output section **26** can cause the AD converters **20** to output digitized individual signals by causing the AD converters **20** to sample the input signal at timings shifted relative to each other by a prescribed amount but having the same frequency.

[0038] The measuring section **28** measures in advance the characteristic of the individual signal of a single AD converter **20** output for each amplitude of the input signal. The measuring section **28** then generates a correction factor corresponding to the single AD converter **20**, based on the measurement result, and supplies this correction factor to the corresponding amplitude-dependent characteristic correcting section **22**. For example, the measuring section **28** supplies a predetermined analog measurement signal instead of the input signal to each AD converter **20**, and measures the individual signal output by each AD converter **20**. The AD converter **20** may then calculate the non-linear characteristic of each AD converter **20** based on the measurement results, and generate correction factors based on the calculated non-linear characteristics. The measuring section **28** can set the correction factor in each amplitude-dependent characteristic correcting section **22** during manufacturing or during calibration.

[0039] The AD converting apparatus **10** need not be provided with the measuring section **28**. In this case, the AD converting apparatus **10** may use an external measuring device to measure in advance the characteristic of the individual signal output by each AD converter **20** for each amplitude of the input signal, and may set a correction factor in each amplitude-dependent characteristic correcting section **22** from an external section.

[0040] The AD converting apparatus **10** described above can eliminate spurious components included in the output signal, even when the plurality of AD converters **20** have different non-linear characteristics. In this way, the AD converting apparatus **10** can widen the dynamic range of the output signal.

[0041] FIG. **2** shows an exemplary sampling clock provided to each AD converter **20**. If the AD converting apparatus **10** is provided with N AD converters, where N is an integer greater than 1, the clock output section **26** supplies the sampling clock with a phase of (N×Ts) to each of the N AD converters **20**, such that the phase of the sampling clock changes by Ts for each AD converter **20**. In the present embodiment, the AD converting apparatus **10** is provided with four AD converters **20**, and therefore the clock output section **26** generates a sampling clock with a phase of 4×Ts obtained by changing the phases by the time Ts in relation to each other. In this way, the AD converting apparatus **10** can output an output signal at a rate N times that of the sampling clock.

[0042] FIG. **3** describes the effect that an error in the non-linear characteristic of each AD converter **20** has on the output signal of the AD converting apparatus **10**. The input signal input into each AD converter **20** is represented by x(t). A signal obtained by adding the effect on the non-linearity of one of the AD converters **20** to the input signal x(t) is defined below in Expression 1. A result obtained by performing a Fourier transform on the signal obtained by adding the effect on the non-linearity of one of the AD converters **20** to the input signal x(t) is defined as the signal expressed by the right-hand portion of Expression 2.

$$\tilde{x}_m(t) = \sum_k b_{m,k} x(t)^k \tag{1}$$

$$\tilde{x}_m(t) \Leftrightarrow \tilde{X}_m(f) \tag{2}$$

[0043] Here, t represents time, m is a value designating one of the AD converters **20** and can be an integer greater than or equal to 0 and less than or equal to N−1, $b_{m,k}$ represents a k-th order non-linear characteristic in one of the AD converters **20**, and k represents an order.

[0044] One of the AD converters **20** samples the signal expressed by the right-hand side of Expression 2 using a sampling clock with a period of N×Ts that has a phase shifted by m×(2π/N). Accordingly, the individual signal output by the one AD converter **20** can be expressed by Expression 3.

$$\tilde{X}_m(f) = \frac{1}{N \cdot T_S} \sum_{k=-\infty}^{\infty} \tilde{X}_m\left(f - \frac{k}{N \cdot T_S}\right) e^{-j2\pi mk/N} \tag{3}$$

[0045] The AD converting apparatus **10** outputs a signal obtained by combining a plurality of individual signals output from the plurality of AD converters **20**. The signal obtained by combining the plurality of individual signals output from the plurality of AD converters **20** can be calculated by adding together the signal expressed by Expression 3 from m=0 to m=(N−1). For example, a signal obtained by combining the signals output from four AD converters **20** can be expressed by Expression 4. From Expression 4 it is understood that, when each AD converter **20** has a different non-linear characteristic, the signal obtained by combining the plurality of individual signals output by the plurality of AD converters **20** includes an image component, e.g. a spurious component or a

spurious alias component, at each 1/N periods of the apparent sampling clock, which is Ts/4 periods in the case of Expression 4.

$$\tilde{X}(f)=\frac{1}{4Ts}\sum_{k=-\infty}^{\infty}\left[\begin{array}{l}\tilde{X}_0\left(f-\frac{k}{4Ts}\right)+\tilde{X}_1\left(f-\frac{k}{4Ts}\right)e^{-j\pi k/2}+\\ \tilde{X}_2\left(f-\frac{k}{4Ts}\right)e^{-j\pi k}+\tilde{X}_3\left(f-\frac{k}{4Ts}\right)e^{-j3\pi k/2}\end{array}\right[\quad (4)$$

[0046] Here, if the non-linear characteristic of each AD converter **20** is the same, each signal obtained by adding the effect of the non-linear characteristic of one of the AD converters **20** to the input signal x(t) is the same, as shown in Expression 5.

$$\tilde{X}_1(f)=\tilde{X}_2(f)=\tilde{X}_3(f)=\tilde{X}_4(f)=\tilde{X}_n(f)=\tilde{X}(f) \quad (5)$$

[0047] When Expression 5 is substituted into Expression 4, the exponential terms cancel out, resulting in Expression 6. In this way, when the non-linear characteristic of each AD converter **20** is the same, it can be seen from the signal obtained by combining the plurality of individual signals output by the plurality of AD converters **20** that the image components at each period of 1/N in the apparent sampling clock are eliminated.

$$\tilde{X}(f)=\frac{1}{T_S}\sum_{k=-\infty}^{\infty}\tilde{X}\left(f-\frac{k}{T_S}\right) \quad (6)$$

[0048] The AD converting apparatus **10** combines the individual signals output by the AD converters **20** after multiplying each individual signal by a correction factor corresponding to the inverse of the non-linear characteristic. In other words, the output signal of the AD converting apparatus **10** is the same as a signal obtained by combining individual signals output from AD converters **20** having the same non-linear characteristics. Accordingly, the AD converting apparatus **10** can output a signal that does not include the spurious components, in the same way as shown by Expression 6.

[0049] FIG. **4** shows an exemplary configuration of one of the plurality of amplitude-dependent characteristic correcting sections **22** according to the present embodiment. The amplitude-dependent characteristic correcting section **22** may include a complex conversion section **40**, a complex correcting section **42**, and a real conversion section **44**.

[0050] The complex conversion section **40** converts the individual signal output by the corresponding AD converter **20** into a complex individual signal represented by a complex number. For example, the complex conversion section **40** may use a Hilbert transformation to convert the individual signal expressed as a real number into the complex individual signal expressed as a complex number.

[0051] The complex correcting section **42** corrects the complex individual signal using a correction factor expressed as a complex number to generate a complex corrected individual signal. The complex correcting section **42** may include a table **50**, a factor output section **52**, and a complex multiplying section **54**.

[0052] The table **50** stores a correction factor for each amplitude of the individual signal. The table **50** may store a correction factor corresponding to the inverse of the non-linear characteristic of the corresponding AD converter **20**, in association with an amplitude of the individual signal. In this case, the non-linear characteristic of the AD converter **20** may be a characteristic that expresses a ratio between (i) the phase and the amplitude of the complex individual signal resulting from the complex conversion of the individual signal output by the AD converter **20** and (ii) the phase and the amplitude of the signal resulting from the complex conversion of the signal output by the reference AD converter.

[0053] The factor output section **52** outputs the correction factor according to the amplitude of the individual signal output by the corresponding AD converter **20**. More specifically, the factor output section **52** reads, from the table **50**, the correction factor corresponding to the amplitude of the individual signal output by the AD converter **20**, and supplies the correction factor to the complex multiplying section **54**.

[0054] The complex multiplying section **54** performs a complex multiplication between the complex individual signal output by the complex conversion section **40** and the correction factor supplied from the factor output section **52**. The complex multiplying section **54** then outputs the complex multiplication result as the complex corrected individual signal. In this way, the complex correcting section **42** can generate the complex corrected individual signal.

[0055] The real conversion section **44** converts the complex corrected individual signal output by the complex correcting section **42** into a corrected individual signal expressed as a real number. For example, the real conversion section **44** may use an inverse Hilbert transformation to convert the complex corrected individual signal expressed as a complex number into a corrected individual signal expressed as a real number.

[0056] The real conversion section **44** may instead use an FFT (Fast Fourier Transform) and an inverse FFT to convert the complex corrected individual signal into the corrected individual signal. In other words, the real conversion section **44** performs an FFT on the complex corrected individual signal. Next, the real conversion section **44** generates a reflection component, which is a component obtained by reflecting a complex conjugate of the FFT result around a frequency of 0, and adds this reflection component to the FFT result. More specifically, the reflection component is obtained by converting the component at each positive frequency in the FFT result to a negative frequency such that the complex conjugate of each positive component has the same frequency and absolute value as each negative frequency component. The real conversion section **44** may then generate the corrected individual signal by performing an inverse FFT on a result obtained by adding together the FFT result and the reflection component.

[0057] The amplitude-dependent characteristic correcting section **22** described above can more accurately correct the individual signal output by the corresponding AD converter **20**, even when the phase and amplitude of the individual signal changes according to the amplitude of the input signal. In this way, the AD converting apparatus **10** can more accurately eliminate the spurious components included in the output signal.

[0058] FIG. **5**A shows an example of a non-linear characteristic, i.e. an amplitude component, of an AD converter **20**. FIG. **5**B shows an example of a non-linear characteristic, i.e. a phase component, of an AD converter **20**.

[0059] The measuring section **28** may calculate the amplitude component and the phase component non-linear characteristics by measuring, for each AD converter **20**, the amplitude and phase of the complex individual signal

corresponding to each amplitude of the input signal. For example, the measuring section **28** calculates the amplitude component and the phase component non-linear characteristics based on a measurement result obtained by supplying each AD converter **20** with a measurement signal having a changing amplitude, e.g. a triangular wave or a sinusoidal wave, and measuring the phase change and amplitude change of the resulting complex individual signal.

[0060] The measuring section **28** may calculate a correction factor expressed as a complex number for each amplitude of the individual signal, according to an inverse of the non-linear characteristic, and store the correction factors in the table **50** shown in FIG. **4**. In this way, the measuring section **28** can generate correction factors for correcting the complex individual signals.

[0061] FIG. **6** shows an example of a measured signal supplied to an AD converter **20** for calculating a correction factor. For example, the measuring section **28** supplies the AD converter **20** with a predetermined measurement signal that includes a frequency component over the entire operational frequency band of the AD converter **20**. In this way, the measuring section **28** can calculate the non-linear characteristic averaged over the entire operational frequency band of the AD converter **20**.

[0062] FIG. **7** shows a configuration of the AD converting apparatus **10** according to a first modification of the present embodiment. Components in the AD converting apparatus **10** according to the present modification that have the same configuration and function as components of the AD converting apparatus **10** shown in FIG. **1** are given the same numerals, and the following description includes only differing points.

[0063] The AD converting apparatus **10** of the present modification is further provided with a plurality of frequency-dependent characteristic correcting sections **60**, i.e. four frequency-dependent characteristic correcting sections **60-1** to **60-4**. The plurality of frequency-dependent characteristic correcting sections **60** are provided to correspond to the plurality of AD converters **20**. Each frequency-dependent characteristic correcting section **60** corrects the individual signal output by the corresponding AD converter **20**, according to a frequency characteristic of the AD converter **20**.

[0064] The plurality of frequency-dependent characteristic correcting sections **60** may correct the individual signal output by the corresponding AD converter **20** by using a technique disclosed in Japanese Patent Application Publication No. 2005-347967 (U.S. Pat. No. 3,947,185). In this case, the plurality of frequency-dependent characteristic correcting sections **60** perform a Fourier transform step and a correction step. In the Fourier transform step, each frequency-dependent characteristic correcting section **60** performs a Fourier transform on the data sampled by the corresponding AD converter **20** to generate a frequency domain signal. In the correcting step, each frequency-dependent characteristic correcting section **60** multiplies the frequency domain signal by a correction factor based on the frequency characteristics of all of the AD converters **20**, to convert the frequency domain signal into a frequency domain signal acquired when the frequency characteristic of the corresponding AD converter **20** is ideal.

[0065] More specifically, in the correction step, the frequency-dependent characteristic correcting sections **60** begin by dividing the frequency band of the digital signal to be calculated according to the number of AD converters **20**. Next, for each divided frequency band, the frequency-dependent characteristic correcting sections **60** calculate first correction factors based on the frequency characteristics of all of the AD converters **20**. Each first correction factor, when multiplied by the corresponding frequency domain signal, causes the spurious components in the frequency domain signal caused by the frequency characteristic of the corresponding AD converter **20** to cancel out. Next, for each divided frequency band, the frequency-dependent characteristic correcting sections **60** calculate second correction factors based on the first correction factors and the frequency characteristics. Each second correction factor corrects an error in the phase of the signal component in the frequency domain signal that is caused by the multiplication by the first correction factor. The frequency-dependent characteristic correcting sections **60** then multiply each frequency domain signal by the corresponding first correction factor and the corresponding second correction factor.

[0066] In the present modification, the combining section **24** generates a frequency spectrum of the digital signal by combining each frequency domain signal obtained as a result of the correction step. In this way, the AD converting apparatus **10** according to the present modification can generate a frequency spectrum in which the spurious components are eliminated.

[0067] In the AD converting apparatus **10** of the present modification, the frequency-dependent characteristic correcting sections **60** may multiply the frequency domain signals by the corresponding first correction factors in the correction step, the combining section **24** may combine the resulting frequency domain signals, and the combined signal may then be multiplied by the second correction factor. In this order as well, the AD converting apparatus **10** according to the present modification can generate a frequency spectrum in which the spurious components are eliminated.

[0068] Each frequency-dependent characteristic correcting section **60** may be provided behind the corresponding amplitude-dependent characteristic correcting section **22**. In other words, each frequency-dependent characteristic correcting section **60** may correct the corrected individual signal generated by the corresponding amplitude-dependent characteristic correcting section **22** according to the frequency characteristic of the corresponding AD converter **20**. The combining section **24** may then generate the output signal by combining the plurality of corrected individual signals corrected by the plurality of frequency-dependent characteristic correcting sections **60**, instead of the plurality of corrected individual signals generated by the plurality of amplitude-dependent characteristic correcting sections **22**.

[0069] The AD converter is provided with a sample/hold circuit and a conversion processing section such as a DA converter and comparator. In the AD converter, the sample/hold circuit has a bigger impact than the conversion processing section on an error dependent on the frequency of the input signal. On the other hand, the conversion processing section has a bigger impact than the sample/hold circuit on an error dependent on the amplitude of the input signal.

[0070] Here, the sample/hold circuit is provided in front of the conversion processing section. In other words, the error dependent on the frequency of the input signal is added to the output signal of the AD converter first, and then the error dependent on the amplitude of the input signal is added. Therefore, when eliminating the errors from the output signal of the AD converter, the errors are desirably eliminated in the opposite direction, i.e. the error dependent on the amplitude

of the input signal is eliminated first, and then the error dependent on the frequency of the input signal is eliminated. In this way, by providing the frequency-dependent characteristic correcting sections **60** behind the amplitude-dependent characteristic correcting sections **22**, the AD converting apparatus **10** according to the present modification can efficiently eliminate the errors added by the AD converters **20**.

[0071] FIG. **8** shows a configuration of the AD converting apparatus **10** according to a second modification of the present embodiment. Components in the AD converting apparatus **10** according to the present modification that have the same configuration and function as components of the AD converting apparatus **10** according to the first modification shown in FIG. **7** are given the same numerals, and the following description includes only differing points.

[0072] In the present modification, each frequency-dependent characteristic correcting section **60** is provided behind the corresponding AD converter **20**, and in front of the corresponding amplitude-dependent characteristic correcting section **22**. In other words, each frequency-dependent characteristic correcting section **60** corrects the individual signal output by the corresponding AD converter **20** according to the frequency characteristic of the AD converter **20**. Then, each amplitude-dependent characteristic correcting section **22** generates the corrected individual signal by correcting the signal output by the corresponding frequency-dependent characteristic correcting section **60**, instead of the individual signal output by the corresponding AD converter **20**.

[0073] The AD converting apparatus **10** according to the present modification can generate a frequency spectrum in which the spurious components are eliminated. Furthermore, the AD converting apparatus **10** according to the present modification may be provided with a plurality of first frequency-dependent characteristic correcting sections **60** provided in front of the plurality of amplitude-dependent characteristic correcting sections **22** and a plurality of second frequency-dependent characteristic correcting sections **60** provided behind the plurality of amplitude-dependent characteristic correcting sections **22**. In this way, the AD converting apparatus **10** according to the present modification can more accurately eliminate the spurious components.

[0074] FIG. **9** shows the result of a simulation of a frequency characteristic of an output signal output by an interleave-type AD converting apparatus provided with four AD converters, when supplied with an input signal having a single frequency. FIG. **10** shows the result of a simulation of a frequency characteristic of an output signal output by an interleave-type AD converting apparatus provided with four AD converters and four correcting sections that respectively correct the frequency characteristics of the four AD converters, when supplied with an input signal having a single frequency. FIG. **11** shows the result of a simulation of a frequency characteristic of an output signal output by the AD converting apparatus **10** according to the modification shown in FIG. **7**, when supplied with an input signal having a single frequency.

[0075] As shown in FIGS. **9**, **10**, and **11**, each output signal output from an AD converting apparatus includes a main signal component of the input signal at a frequency position corresponding to the frequency of the input signal, i.e. a position near the frequency **0** in FIGS. **9** to **11**. Furthermore, these output signals include an oversampling or undersampling component of the input signal at a frequency position at a distance of n times the sampling frequency Fs (where n is an integer) from the frequency of the input signal, i.e. a position at a frequency around 4000 in FIGS. **9** to **11**.

[0076] The output signal shown in FIG. **9** includes a plurality of spurious components at substantially every quarter frequency of the sampling frequency Fs, i.e. frequencies of Fs/4. This output signal also includes aliases of the spurious components over the entire band. Accordingly, the output signal shown in FIG. **9** has a narrow dynamic range due to the effect of the spurious components and aliases.

[0077] The output signal shown in FIG. **10** includes a plurality of spurious components and aliases of these spurious components. However, the spurious components in this output signal are suppressed more than those in the output signal shown in FIG. **9**, and therefore the output signal of FIG. **10** has a wide dynamic range.

[0078] The output signal of the AD converting apparatus **10** according to the present modification, as shown in FIG. **11**, does not include spurious components or aliases. Therefore, the output signal of the AD converting apparatus **10** according to the present modification has a wider dynamic range than the output signals shown in FIGS. **9** and **10**.

[0079] FIG. **12** shows an example of a hardware configuration of a computer **1900** according to the present embodiment. The computer **1900** according to the present embodiment is provided with a CPU peripheral including a CPU **2000**, a RAM **2020**, a graphic controller **2075**, and a displaying apparatus **2080**, all of which are connected to each other by a host controller **2082**; an input/output section including a communication interface **2030**, a hard disk drive **2040**, and a CD-ROM drive **2060**, all of which are connected to the host controller **2082** by an input/output controller **2084**; and a legacy input/output section including a ROM **2010**, a flexible disk drive **2050**, and an input/output chip **2070**, all of which are connected to the input/output controller **2084**.

[0080] The host controller **2082** is connected to the RAM **2020** and is also connected to the CPU **2000** and graphic controller **2075** accessing the RAM **2020** at a high transfer rate. The CPU **2000** operates to control each section based on programs stored in the ROM **2010** and the RAM **2020**. The graphic controller **2075** acquires image data generated by the CPU **2000** or the like on a frame buffer disposed inside the RAM **2020** and displays the image data in the displaying apparatus **2080**. In addition, the graphic controller **2075** may internally include the frame buffer storing the image data generated by the CPU **2000** or the like.

[0081] The input/output controller **2084** connects the communication interface **2030** serving as a relatively high speed input/output apparatus, the hard disk drive **2040**, and the CD-ROM drive **2060** to the host controller **2082**. The communication interface **2030** communicates with other apparatuses via a network. The hard disk drive **2040** stores the programs and data used by the CPU **2000** housed in the computer **1900**. The CD-ROM drive **2060** reads the programs and data from a CD-ROM **2095** and provides the read information to the hard disk drive **2040** via the RAM **2020**.

[0082] Furthermore, the input/output controller **2084** is connected to the ROM **2010**, and is also connected to the flexible disk drive **2050** and the input/output chip **2070** serving as a relatively high speed input/output apparatus. The ROM **2010** stores a boot program performed when the computer **1900** starts up, a program relying on the hardware of the computer **1900**, and the like. The flexible disk drive **2050** reads programs or data from a flexible disk **2090** and supplies the read information to the hard disk drive **2040** via the RAM

2020. The input/output chip 2070 connects the flexible disk drive 2050 to each of the input/output apparatuses via, for example, a parallel port, a serial port, a keyboard port, a mouse port, or the like.

[0083] The programs provided to the hard disk drive 2040 via the RAM 2020 are stored in a storage medium, such as the flexible disk 2090, the CD-ROM 2095, or an IC card, and provided by a user. The programs are read from storage medium, installed in the hard disk drive 2040 inside the computer 1900 via the RAM 2020, and performed by the CPU 2000.

[0084] The programs installed in the computer 1900 to make the computer 1900 function as a control apparatus of a plurality of AD converters 20 are provided with a plurality of amplitude-dependent characteristic correcting modules, a combining module, a clock output module, and a measuring module. These programs and modules prompt the CPU 2000 or the like to make the computer 1900 function as the plurality of amplitude-dependent characteristic correcting sections 22, the combining section 24, the clock output section 26, and the measuring section 28. The programs installed in the computer 1900 to make the computer 1900 function as a control apparatus of a plurality of AD converters 20 may be further provided with a frequency-dependent characteristic correcting module. In this case, these programs and modules prompt the CPU 2000 or the like to make the computer 1900 function as the plurality of frequency-dependent characteristic correcting sections 60.

[0085] The programs and modules shown above may also be stored in an external storage medium. The flexible disk 2090, the CD-ROM 2095, an optical storage medium such as a DVD or CD, a magneto-optical storage medium, a tape medium, a semiconductor memory such as an IC card, or the like can be used as the storage medium. Furthermore, a storage apparatus such as a hard disk or RAM that is provided with a server system connected to the Internet or a specialized communication network may be used to provide the programs to the computer 1900 via the network.

[0086] While the embodiments of the present invention have been described, the technical scope of the invention is not limited to the above described embodiments. It is apparent to persons skilled in the art that various alterations and improvements can be added to the above-described embodiments. It is also apparent from the scope of the claims that the embodiments added with such alterations or improvements can be included in the technical scope of the invention.

[0087] The operations, procedures, steps, and stages of each process performed by an apparatus, system, program, and method shown in the claims, embodiments, or diagrams can be performed in any order as long as the order is not indicated by "prior to," "before," or the like and as long as the output from a previous process is not used in a later process. Even if the process flow is described using phrases such as "first" or "next" in the claims, embodiments, or diagrams, it does not necessarily mean that the process must be performed in this order.

What is claimed is:

1. An AD converting apparatus that converts an analog input signal into a digital output signal, comprising:

a plurality of AD converters supplied with sampling clocks differing from each other by prescribed phase amounts, each AD converter outputting an individual signal obtained by digitizing the input signal according to the supplied sampling clock;

a plurality of amplitude-dependent characteristic correcting sections that are provided to correspond to the plurality of AD converters, each amplitude-dependent characteristic correcting section generating a corrected individual signal by correcting the individual signal output by the corresponding AD converter using a correction factor corresponding to an amplitude of the individual signal; and

a combining section that generates the output signal by combining a plurality of the corrected individual signals.

2. The AD converting apparatus according to claim 1, wherein

each amplitude-dependent characteristic correcting section corrects the individual signal output by the corresponding AD converter such that the corrected individual signal approximates a prescribed value.

3. The AD converting apparatus according to claim 2, wherein

each amplitude-dependent characteristic correcting section generates the corrected individual signal by multiplying the individual signal by the correction factor, which corresponds to an inverse of a characteristic representing a ratio of (i) the individual signal output by the corresponding AD converter to (ii) a signal expected to be output from a reference AD converter.

4. The AD converting apparatus according to claim 1, wherein each amplitude-dependent characteristic correcting section includes:

a complex conversion section that converts the individual signal output by the corresponding AD converter into a complex individual signal expressed as a complex number;

a complex correcting section that generates a complex corrected individual signal by correcting the complex individual signal using the correction factor expressed as a complex number; and

a real conversion section that converts the complex corrected individual signal into the corrected individual signal expressed as a real number.

5. The AD converting apparatus according to claim 4, wherein each complex correcting section includes:

a factor output section that outputs, according to an amplitude of the individual signal output by the corresponding AD converter, the correction factor corresponding to an inverse of a characteristic representing a ratio of (i) a phase and an amplitude of the complex individual signal obtained by performing the complex conversion on the individual signal output by the corresponding AD converter to (ii) a phase and an amplitude of a signal obtained by performing the complex conversion on an individual signal expected to be output by a reference AD converter; and

a complex multiplying section that outputs the complex corrected individual signal obtained as the result of a complex multiplication between the complex individual signal and the correction factor.

6. The AD converting apparatus according to claim 5, wherein

each complex correcting section includes a table that stores the correction value for each amplitude of the individual signal, and

each factor output section reads, from the table in the corresponding complex correcting section, the correction factor corresponding to the amplitude of the indi-

vidual signal output by the corresponding AD converter, and supplies the read correction factor to the complex multiplying section.

7. The AD converting apparatus according to claim **1**, further comprising a measuring section that measures a characteristic of an individual signal output by a certain AD converter at each amplitude of the input signal, and generates the correction factor for the certain AD converter based on a result of the measurement.

8. The AD converting apparatus according to claim **1**, further comprising a plurality of frequency-dependent characteristic correcting sections that are provided to correspond to the plurality of AD converters, each frequency-dependent characteristic correcting section correcting the individual signal output by the corresponding AD converter according to a frequency characteristic of the corresponding AD converter.

9. The AD converting apparatus according to claim **8**, wherein

each frequency-dependent characteristic correcting section corrects the corrected individual signal generated by the corresponding amplitude-dependent characteristic correcting section, according to the frequency characteristic of the corresponding AD converter, and

the combining section generates the output signal by combining the plurality of corrected individual signals generated by the plurality of frequency-dependent characteristic correcting sections, instead of the plurality of corrected individual signals generated by the plurality of amplitude-dependent characteristic correcting sections.

10. An AD converting method that uses a plurality of AD converters to convert an analog input signal into a digital output signal, comprising:

supplying the plurality of AD converters with sampling clocks differing from each other by prescribed phase amounts, and causing each AD converter to output an individual signal obtained by digitizing the input signal according to the supplied sampling clock;

generating a corrected individual signal for each AD converter by correcting the individual signal output by the AD converter using a correction factor corresponding to an amplitude of the individual signal; and

generating the output signal by combining a plurality of the generated corrected individual signals.

11. A control apparatus that uses a plurality of AD converters to function as an AD converting apparatus that converts an analog input signal into a digital output signal, comprising:

a clock output section that supplies the plurality of AD converters with sampling clocks differing from each other by prescribed phase amounts, causing each AD converter to output an individual signal obtained by digitizing the input signal according to the supplied sampling clock;

a plurality of amplitude-dependent characteristic correcting sections that are provided to correspond to the plurality of AD converters, each amplitude-dependent characteristic correcting section generating a corrected individual signal by correcting the individual signal output by the corresponding AD converter using a correction factor corresponding to an amplitude of the individual signal; and

a combining section that generates the output signal by combining a plurality of the corrected individual signals.

12. A program that causes a control apparatus to function as an AD converting apparatus that uses a plurality of AD converters to convert an analog input signal into a digital output signal, the program causing the control apparatus to function as:

a clock output section that supplies the plurality of AD converters with sampling clocks differing from each other by prescribed phase amounts, causing each AD converter to output an individual signal obtained by digitizing the input signal according to the supplied sampling clock;

a plurality of amplitude-dependent characteristic correcting sections that are provided to correspond to the plurality of AD converters, each amplitude-dependent characteristic correcting section generating a corrected individual signal by correcting the individual signal output by the corresponding AD converter using a correction factor corresponding to an amplitude of the individual signal; and

a combining section that generates the output signal by combining a plurality of the corrected individual signals.

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