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(54) Title: METHODS AND DEVICES FOR MEASUREMENT OF CABLES HAVING IMPROPERLY TERMINATED FAR END

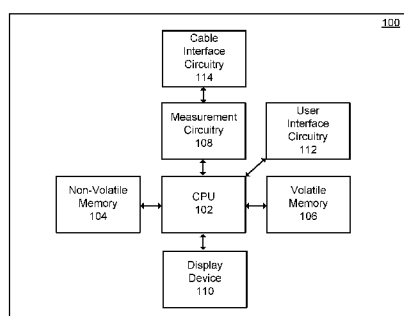


FIG. 1

(57) Abstract: A method for cable measurement includes obtaining frequency-domain signals from a cable; obtaining time-domain data from the signals; determining an estimated length of the cable using the time-domain data; determining a search region of the time-domain data using the estimated length of the cable; determining a first data point having a maximum slope within the search region; determining a second data point corresponding to a point of inflection in relation to the first data point; determining a third data point corresponding to an end point of the cable based on the second data point; modifying the time-domain data by setting to zero data points from the third data point to a last data point of the time-domain data, adjusting a slope of a region of the time-domain data before the third data point, and removing an offset from the time-domain data; and obtaining frequency-domain data from the modified time-domain data.

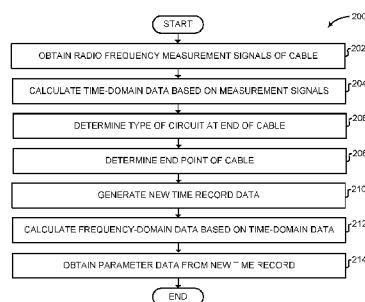


FIG. 3

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METHODS AND DEVICES FOR MEASUREMENT OF CABLES HAVING IMPROPERLY TERMINATED FAR END

BACKGROUND

Technical Field

5 The present disclosure relates to measuring characteristics of a cable, and more particularly to measuring characteristics of a cable using a test device located at the near end of the cable while the far end of the cable is improperly terminated.

Description of the Related Art

Conventionally, radio frequency (RF) measurement systems for copper
10 cabling measure the cable into an impedance matching termination at the far end of the cable. Standards bodies define standards for near end cable measurements made into such a termination. Examples of those standards bodies include Telecommunications Industry Association (TIA), International Organization for Standardization (ISO), and the International Electrotechnical Commission (IEC). Those standards bodies have set
15 values for parameters such as return loss (RL), common mode return loss (CMRL), near end crosstalk (NEXT), common mode to differential mode NEXT (CDNEXT), power sum NEXT (PSNEXT), far-end (ACR-F), power sum ACR-F (PSACR-F), attenuation to crosstalk ratio, near-end (ACR-N), power sum ACR-N (PSACR-N), transverse conversion loss (TCL), and equal level TCTL (ELTCTL), etc. Existing copper cable
20 measurement products by Fluke Networks operate by performing “double ended tests” in which a test device is present on each end of a cable, thereby providing the appropriate termination for the cable. For example, copper certification testing can be performed using products such as the Versiv 2 Mainframe, Versiv 2 Remote, and the DSX-8000 Cable Analyzer Modules manufactured by Fluke Networks.

25 Properly terminating the far end of a cable that is to be tested may be time consuming. For example, a technician may connect test equipment to the near end of the cable, locate the far end of the cable, which may be a considerable distance from the near end of the cable, attach a termination device to the far end of the cable, and then return to the near end of the cable to operate the test equipment. In addition, it

may not be practical to properly terminate the far end of the cable, if the far end of the cable is not easily accessible. For example, the far end of the cable may be buried underground. Accordingly, it is desirable to perform single-ended testing of a cable that may not be properly terminated at the far end thereof.

5 BRIEF SUMMARY

The present disclosure provides methods and devices for performing single-ended testing at a near end of a cable that is not properly terminated at a far end thereof. More particularly, the present disclosure provides methods and devices that obtain measurements from a cable, which has an open circuit or a short circuit at the far end thereof, as if the far end of the cable were properly terminated.

A method according to the present disclosure may be summarized as including: obtaining a plurality of frequency-domain measurement signals from a cable; calculating time-domain data based on the frequency-domain measurement signals, the time-domain data including a plurality of data points; determining an estimated length of the cable based on the time-domain data; determining boundaries of a search region of the time-domain data based on the estimated length of the cable; determining a first data point of the data points of the time-domain data having a maximum slope within the search region of the time-domain data; determining a second data point of the data points of the time-domain data corresponding to a point of inflection within the search region of the time-domain data in relation to the first data point; determining a third data point of the data points of the time-domain data corresponding to an end point of the cable based on the second data point; modifying the time-domain data by: setting to zero a value of each of one or more of the data points of the time-domain data starting from the third data point to a last data point of the data points of the time-domain data; and adjusting a slope of a region of the time-domain data before the third data point of the time-domain data; and removing a direct current (DC) offset from the time-domain data; and calculating frequency-domain data based on the modified time-domain data.

The search region may be centered on a data point of the time-domain data corresponding to the estimated length of the cable. A size of the search region is proportional to the estimated length of the cable. Determining the first data point

having the maximum slope within the search region of the time-domain data may include determining a derivative of a data point in the time-domain data. The method may include determining that an open circuit is present at an end of the cable, and determining the first data point having the maximum slope within the search region of the time-domain data may include determining a data point having a maximum positive slope within the search region of the time-domain data. The method may include determining that a short circuit is present at an end of the cable, and determining the first data point having the maximum slope within the search region of the time-domain data may include determining a data point having a maximum negative slope within the search region of the time-domain data. The first data point of the time-domain data having the maximum slope within the search region of the time-domain data may be at a leading edge of a cable end event in the time-domain data. The second data point may be earlier in time in the time-domain data than the first data point. Determining the third data point of the time-domain data corresponding to the end point of the cable may include subtracting a predetermined time amount from a time value of the second data point of the time-domain data and subtracting a predetermined magnitude amount from a magnitude value of the second data point of the time-domain data. Adjusting the slope of the region of the time-domain data before the third data point of the time-domain data may include: determining a fourth data point of the time-domain data corresponding to a zero crossing point in the time-domain data before the third data point of the time-domain data; determining linear curve fit data based on an end region of the time-domain data from the fourth data point of the time-domain to the third data point of the time-domain data; and subtracting the linear curve fit data from the end region of the time-domain data. Removing the DC offset from the time-domain data may include: determining an average offset value based on the time-domain data; and subtracting the average offset value from each of the data points in a region of the time-domain data from an earliest data point in the time-domain data to the third data point of the time-domain data corresponding to the end point of the cable.

A test device according to the present disclosure may be summarized as including: measurement circuitry which, in operation, obtains a plurality of frequency-domain measurement signals from a cable; at least one processor; and at least one memory device storing instructions that, when executed by the at least one processor,

cause the test device to: calculate time-domain data based on the frequency-domain measurement signals, the time-domain data include a plurality of data points; obtain an estimated length of the cable based on the time-domain data; determine boundaries of a search region of the time-domain data based on the estimated length of the cable;

5 determine a first data point of the data points of the time-domain data corresponding to a maximum slope within the search region of the time-domain data; determine a second data point of the data points of the time-domain data corresponding to a point of inflection within the search region of the time-domain data based on the first data point; determine a third data point of the data points of the time-domain data corresponding to

10 an end point of the cable based on the second data point; modify the time-domain data by: set to zero a value of each of one or more of the data points of the time-domain data starting from the third data point to a last data point of the data points of the time-domain data; adjust a slope of a region of the time-domain data before the third data point of the time-domain data; and remove a direct current (DC) offset from the time-

15 domain data; and calculate frequency-domain data based on the modified time-domain data.

The second data point may be earlier in time in the time-domain data than the first data point. The search region may be centered on a data point of the time-domain data corresponding to the estimated length of the cable. A size of the search

20 region may be proportional to the estimated length of the cable. The test device may include a display device, and the instructions, when executed by the at least one processor, may cause the display device to display the frequency-domain data. The instruction, when executed by the at least one processor, may cause the test device to: determine that an open circuit is present at an end of the cable; and determine the first

25 data point corresponding to the maximum slope as a data point corresponding to a maximum positive slope within the search region of the time-domain data. The instructions, when executed by the at least one processor, may cause the test device to: determine that a short circuit is present at an end of the cable; and determine the first data point corresponding to the maximum slope as a data point corresponding to a

30 maximum negative slope within the search region of the time-domain data. The instructions, when executed by the at least one processor, may cause the test device to adjust the slope of the region of the time-domain data before the third data point of the

time-domain data by causing the test device to: determine a fourth data point of the time-domain data corresponding to a zero crossing point before the third data point of the time-domain data; determine linear curve fit data based on an end region of the time-domain data from the fourth data point of the time-domain to the third data point
5 of the time-domain data; and subtract the linear curve fit data from the end region of the time-domain data. The instructions, when executed by the at least one processor, may cause the test device to remove the DC offset from the time-domain data by causing the test device to: determine an average offset value based on the time-domain data; and subtract the average offset value from each of the data points in a region of the time-
10 domain data from an earliest data point the time-domain data to the third data point of the data points of the time-domain data corresponding to the end point of the cable.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

Figure 1 is a block diagram of a test device, according to one or more embodiments of the present disclosure;

15 Figure 2A is an example of time-domain data obtained based on measurements taken from a properly terminated cable, and Figure 2B is an example of time-domain data obtained based on measurements taken from an improperly terminated cable, according to one or more embodiments of the present disclosure;

Figure 3 is a flowchart of a test method, according to one or more
20 embodiments of the present disclosure;

Figure 4 is a flowchart of a test method, according to one or more embodiments of the present disclosure;

Figure 5 is a flowchart of a test method, according to one or more embodiments of the present disclosure;

25 Figures 6A and 6B are graphs displaying examples of time-domain data, according to one or more embodiments of the present disclosure. For example, the time-domain data shown in Figure 6A may be processed according to the present disclosure to produce the time-domain data shown in Figure and 6B;

Figure 7 is a graph displaying an example of time-domain data,
30 according to one or more embodiments of the present disclosure;

Figures 8A, 8B, and 8C are graphs displaying examples of time-domain data, according to one or more embodiments of the present disclosure;

Figures 9A and 9B are graphs displaying examples of time-domain data, according to one or more embodiments of the present disclosure; and

5 Figures 10A and 10B are graphs displaying examples of frequency-domain data, according to one or more embodiments of the present disclosure.

DETAILED DESCRIPTION

Figure 1 is a block diagram of a test device 100, according to one or more embodiments of the present disclosure. Although the test device 100 is shown
10 having a processor in the form of a Central Processing Unit (CPU) 102, the test device 100 may include multiple hardware processors without departing from the scope of the present disclosure. The CPU 102 is communicatively coupled to non-volatile memory 104, volatile memory 106, measurement circuitry 108, a display device 110, and user interface circuitry 112. The non-volatile memory 104 stores computer-readable
15 instructions that, when executed by the CPU 102, cause the test device 100 to perform the methods described herein. The CPU 102 uses the volatile memory 106 as working memory while executing the instructions stored in the non-volatile memory 104.

The measurement circuitry 108 is communicatively coupled to cable interface circuitry 114. In one or more embodiments, the measurement circuitry 108
20 includes at least one oscillator or signal generator that generates test signals which are provided to a cable under test, and at least one analog-to-digital converter that receives analog measurement signals from the cable and converts those signals into corresponding digital values. The digital values are provided to the CPU 102, which stores those values as measurement data, for example, in the non-volatile memory 104.

25 In one or more embodiments, the cable interface circuitry 114 includes a socket into which a connector of a cable that is to be tested is inserted, and conductors that communicatively couple respective wires of the cable to components of the measurement circuitry 108. The cable interface circuitry 114 may include a shielded RJ45 plug type or a Tera plug type, for example. The cable may include shielded and
30 unshielded Local Area Network (LAN) cabling, for example, TIA Category 3, 4, 5, 5e, 6, 6A: 100 Ω ISO/IEC Class C, D, E, EA, F, and FA: 100 Ω and 120 Ω .

The CPU 102 provides control signals to the measurement circuitry 108, which cause the measurement circuitry 108 to provide corresponding test signals to the cable via the cable interface circuitry 114. In response to the test signals, the measurement circuitry 108 receives measurement signals from the cable via the cable interface circuitry 114, converts those signals into corresponding digital values, and provides the digital values to the CPU 102 as measurement data for further processing, as described in further detail below.

The user interface circuitry 112 includes one or more buttons, dials, knobs, and switches that a user can operate to configure parameters used by the test device 100 to perform testing on a cable. For example, the user interface circuitry 112 includes a power switch. In one or more embodiments, the user interface circuitry 112 includes a touch screen device overlying the display device 110, which can be operated by a user to configure parameters used by the test device 100 to perform testing on a cable.

In one or more embodiments, the hardware components of the test device 100 are the same or substantially similar to those of the DSX-8000 CableAnalyzer™ manufactured by Fluke Networks, except that the test device 100 stores instructions that cause the test device 100 to analyze measurement data and output results differently than the DSX-8000 CableAnalyzer™ such that improperly terminated cables can be tested with high accuracy, which cannot be done using the current version of the DSX-8000 CableAnalyzer™.

Figure 2A is an example of time-domain data obtained based on measurements taken from a properly terminated cable, and Figure 2B is an example of time-domain data obtained based on measurements taken from an improperly terminated cable, according to one or more embodiments of the present disclosure. As can be seen by comparing Figures 2A and 2B, the time-domain data are similar until a point in time that is labeled “L” in Figure 2B. After the point in time labeled “L”, the magnitude of the time-domain data shown in Figure 2A is relatively constant; however, the magnitude of the time-domain data shown in Figure B fluctuates in the form of an end event pulse. The fluctuations in the time-domain data shown in Figure 2B result because the data are based on the measurements taken from the improperly terminal

cable, which causes internal reflections of one or more RF test signals that are provided to the improperly terminated cable to obtain the measurements.

As will be described in greater detail below, the memory 104 stores instructions that cause the test device 100 to perform a signal processing technique that operates in the time domain on near end RF measurement data obtained from an improperly terminated cable. The test device 100 makes measurements in the frequency domain, and then transforms that measurement data into the time domain. The test device 100 then identifies a location of a cable end event with an end finder algorithm.

The end finder algorithm uses a delay estimate, and determines a search region about a data point in the time domain. The end finder algorithm may use several techniques to obtain the delay estimate. In one example, the end finder algorithm uses the phase slope of a measured low-frequency Return Loss signal to produce the delay estimate. For example, in the case of Figure 2B, a measured low-frequency Return Loss phase slope may result in determining the points in Figure 2B labeled “S1” and “S2” which define the boundaries of the search region. Because the measurement was made into an improper terminated cable, this search region will encompass the end event pulse, which the end finder algorithm locates. A point of maximum slope at a leading edge of the cable end event within the search region is then identified. For example, the point in Figure 2B labeled “M” is the point of maximum slope within the search region that encompasses the end event pulse. The end finder algorithm then determines the closest inflection point prior to the point of maximum slope. The determined inflection point prior is the start of the end event pulse. For example, the point in Figure 2B labeled “I” is the inflection point corresponding to the start of the end event pulse. The start of the end event pulse is determined as the cable end location “L”.

After the cable end location is determined using the end finder algorithm described above, the test device 100 uses a time keeping algorithm to transform the time-domain data into a modified time-domain data that resembles data that would have been obtained had the cable been properly terminated. While performing the time keeping algorithm, the test device 100 selects and keeps a region of the measurement signal from the start of the signal to the determined cable end location, and sets to zero

the values of the signal from just after the determined cable end location to end of the signal. The test device 100 also adjusts the measurement signal DC offset to zero, thereby making the signal appear as if it were obtained from a properly terminated cable. For example, after data corresponding to the time-domain data shown in Figure 2B is processed by the time keeping algorithm as described above, the test device 100 produces output data for the time-domain as shown in Figure 2A. Finally, the test device 100 converts the modified time-domain data back into the frequency domain, wherein the resulting frequency domain signal appears as if it resulted from measurements taken from a properly terminated cable. Data obtained using the resulting frequency domain signal can be compared against standards-defined limits that require a proper termination. Accordingly, test device 100 enables “single-ended tests” where a tester on one end of the cable (the “near end”) measures into a cable having an open circuit or a short circuit at the other end (the “far end”) and produces output measurement data as if the tested cable was properly terminated.

A method of performing the above-described signal processing will now be described with reference to Figure 3. Figure 3 is a flowchart of a test method 200, according to one or more embodiments of the present disclosure. In at least one embodiment, the instructions stored in the memory 104 cause the test device 100 to perform the method 200. The method 200 begins at 202.

At 202, radio frequency (RF) measurement signals of a cable are obtained. For example, in response to a user electrically coupling the near end of an improperly terminated cable to the cable interface circuitry 114 and operating a button included in the user interface circuitry 112 of the test device 100, the CPU 102 provides a control signal to the measurement circuitry 108 that causes a signal generator of the measurement circuitry 108 to generate a test signal having a predetermined minimum frequency (*e.g.*, 1 MHz), which is provided to the cable being tested via the cable interface circuitry 114. The test signal is at least partially reflected from within the cable toward the cable interface circuitry 114 of the test device 100, which provides the reflected signal to an analog-to-digital converter of the measurement circuitry 108. The analog-to-digital converter converts an analog value of a power level of the reflected signal to a corresponding digital value, and provides the digital value to the CPU 108. The CPU 108 creates a test record in which the digital value of the reflected signal is

stored as a data point in association with a value of the frequency of the test signal that was provided to the cable. In one more embodiments, the measurement circuitry 108 measures a value of the phase of the reflected signal, and the test record created by the CPU 108 includes the value of the phase of the reflected signal. In one more

5 embodiments, the CPU 108 stores the test record in the memory 104. The CPU 108 then provides to the measurement circuitry 108 a control signal that causes the signal generator to generate a test signal having a frequency that is a predetermined amount (*e.g.*, 1 MHz) greater than the frequency of the test signal previously generated.

 The above-described acts are repeated until the CPU 108 has caused the
10 signal generator of the measurement circuitry 108 to generate a test signal having a predetermined maximum frequency (*e.g.*, 500 MHz or 1200 MHz), thus resulting in storage of measured data points over the range of frequencies of test signals provided to the cable under test. The method 200 then proceeds to 204.

 At 204, time-domain data are calculated based on the measured data
15 points stored in the memory 104. In one more embodiments, the memory 104 stores instructions that cause the CPU to convert the data stored in the test record at 202 from the frequency domain into the time domain. Also, the memory 104 may store instructions that cause the CPU 102 to interpolate the data stored in the test record at 202 in order to determine missing data (*i.e.*, data between the measured data points) and
20 a corresponding new 0 MHz point. For example, the instructions cause the CPU 102 to process the data stored in the test record at 202 by separately using magnitude and phase interpolation, unwrapping the phase, and then determining a correct multiple of a 2-pi phase intercept (*i.e.*, number of times around a unit circle), according to conventional techniques.

25 In addition, to convert the data from the frequency domain into the time domain, the instructions stored in the memory 104 cause the CPU 102 to perform a conventional Inverse Fast Fourier Transform (IFFT) process using the resulting data. In one or more embodiments, the data is converted from the frequency domain into the time domain using 1/8 MHz spacing. In one more embodiments, the CPU 108 stores
30 the resulting time-domain test record data in the memory 104. The method 200 then proceeds to 206.

At 206, a type of circuit at the far end of the cable is determined. In one more embodiments, the memory 104 stores instructions that cause the CPU 102 to determine whether the far end of the cable terminates in an open circuit, a short circuit, or a load. For example, the memory 104 stores instructions that cause the CPU 102 to extrapolate 1-5 MHz magnitude data, extrapolate 1-5 MHz phase data, find the 0 MHz point or Direct Current (DC) point, and use the resulting data to determine whether the far end of the cable includes an open circuit, a short circuit, or a load, according to conventional techniques. An open circuit at the far end of the cable produces positive slope data in an end event pulse in the time domain, e.g., as illustrated in Figure 2B, while a short circuit at the far end of the cable produces an end event pulse with negative slope data. A cable properly terminated with a load at the far end does not produce an end event pulse having a shape as shown in Figure 2B, but rather produces measurement data as shown in Figure 2A. In one or more embodiments, the memory 104 stores instructions that cause the CPU 102 to determine the type of circuit at the far end of the cable in response to a technician operating a touchscreen device of user interface circuitry 112 to initiate a test of the cable. The method 200 then proceeds to 208.

At 208, an end point of the cable is determined. For example, the memory 104 stores instructions that cause the CPU 102 to perform the end finder algorithm mentioned above in order to process the time-domain data generated at 204 to determine the end point of the cable. The processing performed by the CPU 102 at 208 is described in greater detail below with reference to Figure 4. The method 200 then proceeds to 210.

At 210, new time record data is generated. For example, the memory 104 stores instructions that cause the CPU 102 to perform the time keeping algorithm mentioned above in order to process the data determined at 208 to generate a table or other suitable data structure that includes the new time record data. The processing performed by the CPU 102 at 210 is described in greater detail below with reference to Figure 5. The method 200 then proceeds to 212.

At 212, frequency-domain data is calculated based on the time-domain data included in the new time record data that is generated at 210. For example, the memory 104 stores instructions that cause the CPU 102 to perform a conventional Fast

Fourier Transform (FFT) process using the data included in the new time record generated at 210. In one more embodiments, the CPU 108 stores the resulting frequency-domain data in the memory 104. The method 200 then proceeds to 214.

At 214, parameter data is obtained from the frequency-domain data
5 obtained at 212. For example, the memory 104 stores instructions that cause the CPU 102 to obtain frequency-domain data from the new time record that is required to calculate a desired parameter of the cable, such as return loss. In one or more embodiments, the memory 104 stores instructions that cause the CPU 102 to obtain return loss parameter data in decibels by multiplying by ten the log (base 10) of the
10 incident power of the test signal and the reflected power of the measurement signal, for each of the data points in the new test record. The method 200 then ends.

Figure 4 is a flowchart of a test method 300, according to one or more embodiments of the present disclosure. The test method 300 corresponds to at least one embodiment of the end finder algorithm performed by the CPU 102 at 208 of the
15 method 200 shown in Figure 3. The method 300 begins at 302.

At 302, an estimated length of the cable under test is determined. The memory 104 stores instructions that cause the CPU 102 to determine the estimated length of the cable by processing the time-domain data that is obtained at 204 of the method 200. For example, the memory 104 stores a plurality of tables or other suitable
20 data structures that include measured data values resulting from taking an RF sweep, which is similar to the processing described above at 202 of the method 200 shown in Figure 3, of each of a plurality of cables potentially having different lengths. In one or more embodiments, the CPU 102 approximates or interpolates the length of the cable using the time-domain data that is obtained at 204 and the data stored in the tables
25 corresponding to the cables having different lengths. For example, the point in FIG. 2B labeled “E” corresponds to the estimated length of the cable determined at 302. The method 300 then proceeds to 304.

At 304, boundaries of a search region in the time domain are determined. For example, the CPU 102 determines the boundaries of the search region using the
30 estimated length of the cable determined at 302. In one or more embodiments, a size of the search region is proportional to the estimated length of the cable. In other words, the CPU 102 may compute a size of the search region as predetermined percentage

(e.g., 25 %) of the time value corresponding to the estimated length of the cable determined at 302. In one or more embodiments, the search region is centered on a data point of the time-domain data corresponding to the estimated length of the cable. For example, the CPU 102 may determine a value that is half of the size of the search region, determine a first search boundary by subtracting the value that is half of the size of the search region from the time value corresponding to the estimated length of the cable determined at 302, and determine a second search boundary by adding the value that is half of the size of the search region to the time value corresponding to the estimated length of the cable determined at 302. For example, the point in Figure 2B labeled “S1” corresponds to the first search boundary and the point in Figure 2B labeled “S2” corresponds to the second search boundary. The method 300 then proceeds to 304.

A cut-off point is then determined using the estimated length of the cable. More particularly, at 306, a plurality of slope values of the time domain data is determined within the boundaries of the search region determined at 304. For example, the CPU 102 determines a plurality of slope values in the time-domain data that is obtained at 204 of the method 200, within the search the boundaries of the search region determined at 304. In one or more embodiments, for each data point in the search region of the time-domain data, the CPU 102 determines a slope value as a derivative by determining a change in magnitude between the data point and an adjacent data point, determining a change in time between the data point and the adjacent data point, and then dividing the determined change in magnitude by the determined change in time. The method 300 then proceeds to 308.

At 308, a maximum slope value of the time domain data within the search region is determined. For example, the CPU 102 compares the slope values determined at 306 to each other and selects the largest slope value among the slope values. In one or more embodiments, if the CPU 102 determines at 206 of the method 200 that an open circuit is present at the far end of the cable, the CPU 102 selects at 308 a largest positive slope value among the slope values determined at 306. In one or more embodiments, if the CPU 102 determines at 206 of the method 200 that a short circuit is present at the far end of the cable, the CPU 102 selects at 308 a largest negative slope

value among the slope values determined at 306. The method 300 then proceeds to 310.

At 310, a zero-slope point is determined. For example, the CPU 102 selects a time value corresponding to a slope value of zero among the slope values
5 determined at 306, wherein the selected time value is before (*i.e.*, earlier in the time series data) a time value corresponding the maximum slope value determined at 308. The method 300 then proceeds to 312.

At 312, the end point of the cable is determined based on the zero-slope point determined at 310. For example, the CPU 102 subtracts a predetermined amount
10 of time from the time value corresponding to the zero-slope point and subtracts a predetermined percentage value from the magnitude value corresponding to the zero-slope point to determine the end point of the cable. In one or more embodiments, the predetermined amount of time is 10 nanoseconds, and the predetermined percentage value is 5 percent, though in other embodiments, other amounts of time and/or
15 percentage may be used. The method 300 corresponding to the end finder algorithm performed by the CPU 102 at 208 of the method 200 then ends.

Figure 5 is a flowchart of a test method 400, according to one or more embodiments of the present disclosure. The test method 400 corresponds to the time keeping algorithm performed by the CPU 102 at 210 of the method 200 shown in
20 Figure 3 in which the new time record is generated. The method 400 begins at 402.

At 402, time domain data is added to the new time record. For example, the CPU 102 adds some of the time-domain data that is obtained at 204 of the method 200 into the new time record generated at 208 of the method 200. More particularly, the CPU 102 adds values of the time domain data up to a value of the time data
25 corresponding to the end point of the cable determined at 312 of the method 300. The method 400 then proceeds to 404.

At 404, values of the new time record are set to zero. For example, the CPU 102 set to zero the value in the new time record immediately corresponding to the end point of the cable determined at 312 of the method 300, and sets to zero every value
30 in the new time record thereafter until the end of the time record. The method 400 then proceeds to 406.

At 406, a zero cross point in the new time record is determined. For example, the CPU 102 determines the zero cross point as a point in the new time record at which the time-domain values in the new time record transition from a positive value to a negative value, wherein the zero cross point is before (*i.e.*, earlier in the time series data) the end point of the cable determined at 312 of the method 300. The method 400 then proceeds to 408.

At 408, linear curve fit data is determined based on the zero cross point determined at 406. In one or more embodiments, the memory 104 stores instructions that cause the CPU 102 to perform a conventional linear curve fitting algorithm that constructs an adjustment curve that best fits the data in a region of the time record from the data point corresponding to the zero cross point determined at 406 to the data point corresponding to the end point of the cable determined at 312 of the method 300. The method 400 then proceeds to 410.

At 410, the linear curve fit data obtained at 408 is subtracted from a region of the time-domain data. In one or more embodiments, the memory 104 stores instructions that cause the CPU 102 to subtract the linear curve fit data determined at 408 from the region of the time record from the data point corresponding to the zero cross point determined at 406 to the data point corresponding to the end point of the cable determined at 312 of the method 300. By subtracting the linear curve fit data from the region of the time-domain data, the CPU 102 adjusts a slope of the region of the time-domain data. The method 400 then proceeds to 412.

At 412, an average offset value in a region of the time-domain data is determined. For example, the memory 104 stores instructions that cause the CPU 102 to add together all of the magnitudes of the time-domain data in the region starting from the first (*e.g.*, earliest) data point of the time-domain data to the data point corresponding to the end point of the cable determined at 312 of the method 300, and determine the average of the resulting value. The method 400 then proceeds to 414.

At 414, the average offset value determined at 412 is subtracted from each data point in the region. For example, the memory 104 stores instructions that cause the CPU 102 to subtract the average offset value determined at 412 from each data point in the region of the time record from the data point corresponding to the first

(*e.g.*, earliest) data point of the time-domain data to the data point corresponding to the end point of the cable determined at 312 of the method 300. The method 400 then ends.

The method 400 may optionally include applying time gate processing to a portion of the measurement data near the end of the new time record. For example,
5 the memory 104 stores instructions that cause the CPU 102 to apply conventional time gate processing to a portion of the measurement data in a defined window preceding the end of measurement data in the new time record.

Figures 6A and 6B are graphs displaying examples of time-domain data, according to one or more embodiments of the present disclosure. The time domain data
10 shown in the graph of Figure 6A is an example of time-domain data that may be obtained at 204 of the method 200 shown in Figure 3. The time-domain data shown in the graph of Figure 6B is an example of data that may be included in the new time record that is generated at 210 of the method 200 shown in Figure 3. As can be seen by comparing the time-domain data shown in Figures 6A and 6B, the time-domain data
15 shown in Figure 6A includes an end event pulse that begins at approximately 2120 nanoseconds; however, the end event pulse is not present in the time-domain data included the new time record shown in Figures 6B. More particularly, the processing described above removes the end event pulse that results from the cable under test not being properly terminated. The time-domain data shown in the graph of Figure 7 is an
20 enlarged version of a portion of the time-domain data shown in Figure 6A that includes the end event pulse.

Figures 8A, 8B, and 8C are graphs displaying examples of time-domain data, according to one or more embodiments of the present disclosure. The time-domain data shown in the graph of Figure 8A is an example of data in a region of the
25 new time record from which linear curve fit data is determined at 408 of the method 400 shown in Figure 5. The time-domain data shown in the graph of Figure 8B is an example of an adjustment curve that is used to determine the linear curve fit data at 408 of the method 400 shown in Figure 5, in the region of the time series data shown in Figure 8A. The time-domain data shown in the graph of Figure 8C is an example of
30 data that results at 410 of the method 400 shown in Figure 5 from subtracting the linear curve data determined at 408 of the method 400 from the region of the time series data shown in Figure 8A.

Figures 9A and 9B are graphs displaying examples of time-domain data, according to one or more embodiments of the present disclosure. The time-domain data shown in the graph of Figure 9A is an example of time-domain data in the region of the new time record to which the average offset is subtracted at 414 of the method 400 shown in Figure 5. The time-domain data shown in the graph of Figure 9B is an example of data in the new time record after the average offset is subtracted at 414 of the method 400 shown in Figure 5.

Figures 10A and 10B are graphs displaying examples of frequency-domain data, according to one or more embodiments of the present disclosure. The frequency-domain data shown in the graph of Figure 10A is an example of return loss parameter data that is obtained from the RF measurement signals obtained at 202 of the method 200 shown in Figure 3. The frequency-domain data shown in the graph of Figure 10B is an example of return loss parameter data that is obtained at 214 of the method 200 shown in Figure 3. In one or more embodiments, the memory 104 stores instructions that cause the display device 110 to display the frequency-domain data shown in Figure 10B.

As can be seen from comparing Figures 10A and 10B, the return loss parameter data shown in Figures 10A and 10B is considerably different at frequencies below approximately 120 MHz, and is similar at higher frequencies. The differences in return loss parameter values at lower frequencies result from reflections within the cable that are caused by improper termination of the cable. By performing the processing described above associated with the method 200, 300, and 400, the test device 100 is able to produce more accurate return loss parameter values at lower frequencies (*e.g.*, below 120 MHz) in the context of cables. Thus, the test device 100 can produce more accurate measurements of return loss parameter values even though the cable is not properly terminated. The test device 100 can be used to certify that return loss parameter values of the cable under test adhere to a standard that is prepared for testing properly terminated cables, even though the cable under test is improperly terminated.

The various embodiments described above can be combined to provide further embodiments. Although the embodiments above are described in the context

cables that are used to transmit data signals, the present disclosure may be applied to cables that are used to transmit other types of signals, for example, power signals.

These and other changes can be made to the embodiments in light of the above-detailed description. In general, in the following claims, the terms used should
5 not be construed to limit the claims to the specific embodiments disclosed in the specification and the claims, but should be construed to include all possible embodiments along with the full scope of equivalents to which such claims are entitled. Accordingly, the claims are not limited by the disclosure.

CLAIMS

1. A method comprising:
 - obtaining a plurality of frequency-domain measurement signals from a cable;
 - calculating time-domain data based on the frequency-domain measurement signals, the time-domain data including a plurality of data points;
 - determining an estimated length of the cable based on the time-domain data;
 - determining boundaries of a search region of the time-domain data based on the estimated length of the cable;
 - determining a first data point of the data points of the time-domain data having a maximum slope within the search region of the time-domain data;
 - determining a second data point of the data points of the time-domain data corresponding to a point of inflection within the search region of the time-domain data in relation to the first data point;
 - determining a third data point of the data points of the time-domain data corresponding to an end point of the cable based on the second data point;
 - modifying the time-domain data by:
 - setting to zero a value of each of one or more of the data points of the time-domain data starting from the third data point to a last data point of the data points of the time-domain data; and
 - adjusting a slope of a region of the time-domain data before the third data point of the time-domain data; and
 - removing a direct current (DC) offset from the time-domain data;
 - and
 - calculating frequency-domain data based on the modified time-domain data.
2. The method according to claim 1 wherein the search region is centered on a data point of the time-domain data corresponding to the estimated length of the cable.

3. The method according to claim 1 wherein a size of the search region is proportional to the estimated length of the cable.
4. The method according to claim 1 wherein determining the first data point having the maximum slope within the search region of the time-domain data includes determining a derivative of a data point in the time-domain data.
5. The method according to claim 1, further comprising:
determining that an open circuit is present at an end of the cable,
wherein determining the first data point having the maximum slope within the search region of the time-domain data includes determining a data point having a maximum positive slope within the search region of the time-domain data.
6. The method according to claim 1, further comprising:
determining that a short circuit is present at an end of the cable,
wherein determining the first data point having the maximum slope within the search region of the time-domain data includes determining a data point having a maximum negative slope within the search region of the time-domain data.
7. The method according to claim 1 wherein the first data point of the time-domain data having the maximum slope within the search region of the time-domain data is at a leading edge of a cable end event in the time-domain data.
8. The method according to claim 1 wherein the second data point is earlier in time in the time-domain data than the first data point.
9. The method according to claim 1 wherein determining the third data point of the time-domain data corresponding to the end point of the cable includes subtracting a predetermined time amount from a time value of the second data point of the time-domain data and subtracting a predetermined magnitude amount from a magnitude value of the second data point of the time-domain data.

10. The method according to claim 1, wherein adjusting the slope of the region of the time-domain data before the third data point of the time-domain data includes:

determining a fourth data point of the time-domain data corresponding to a zero crossing point in the time-domain data before the third data point of the time-domain data;

determining linear curve fit data based on an end region of the time-domain data from the fourth data point of the time-domain to the third data point of the time-domain data; and

subtracting the linear curve fit data from the end region of the time-domain data.

11. The method according to claim 1, wherein removing the DC offset from the time-domain data includes:

determining an average offset value based on the time-domain data; and

subtracting the average offset value from each of the data points in a region of the time-domain data from an earliest data point in the time-domain data to the third data point of the time-domain data corresponding to the end point of the cable.

12. A test device comprising:

measurement circuitry which, in operation, obtains a plurality of frequency-domain measurement signals from a cable;

at least one processor; and

at least one memory device storing instructions that, when executed by the at least one processor, cause the test device to:

calculate time-domain data based on the frequency-domain measurement signals, the time-domain data include a plurality of data points;

obtain an estimated length of the cable based on the time-domain data;

determine boundaries of a search region of the time-domain data based on the estimated length of the cable;

determine a first data point of the data points of the time-domain data corresponding to a maximum slope within the search region of the time-domain data;

determine a second data point of the data points of the time-domain data corresponding to a point of inflection within the search region of the time-domain data based on the first data point;

determine a third data point of the data points of the time-domain data corresponding to an end point of the cable based on the second data point;

modify the time-domain data by:

set to zero a value of each of one or more of the data points of the time-domain data starting from the third data point to a last data point of the data points of the time-domain data;

adjust a slope of a region of the time-domain data before the third data point of the time-domain data; and

remove a direct current (DC) offset from the time-domain data; and

calculate frequency-domain data based on the modified time-domain data.

13. The test device according to claim 12 wherein the second data point is earlier in time in the time-domain data than the first data point.

14. The test device according to claim 12 wherein the search region is centered on a data point of the time-domain data corresponding to the estimated length of the cable.

15. The test device according to claim 12 wherein a size of the search region is proportional to the estimated length of the cable.

16. The test device according to claim 12, further comprising:
a display device,

wherein the instructions, when executed by the at least one processor, cause the display device to display the frequency-domain data.

17. The test device according to claim 12 wherein the instructions, when executed by the at least one processor, cause the test device to:

- determine that an open circuit is present at an end of the cable; and
- determine the first data point corresponding to the maximum slope as a data point corresponding to a maximum positive slope within the search region of the time-domain data.

18. The test device according to claim 12 wherein the instructions, when executed by the at least one processor, cause the test device to:

- determine that a short circuit is present at an end of the cable; and
- determine the first data point corresponding to the maximum slope as a data point corresponding to a maximum negative slope within the search region of the time-domain data.

19. The test device according to claim 12 wherein the instructions, when executed by the at least one processor, cause the test device to adjust the slope of the region of the time-domain data before the third data point of the time-domain data by causing the test device to:

- determine a fourth data point of the time-domain data corresponding to a zero crossing point before the third data point of the time-domain data;

- determine linear curve fit data based on an end region of the time-domain data from the fourth data point of the time-domain to the third data point of the time-domain data; and

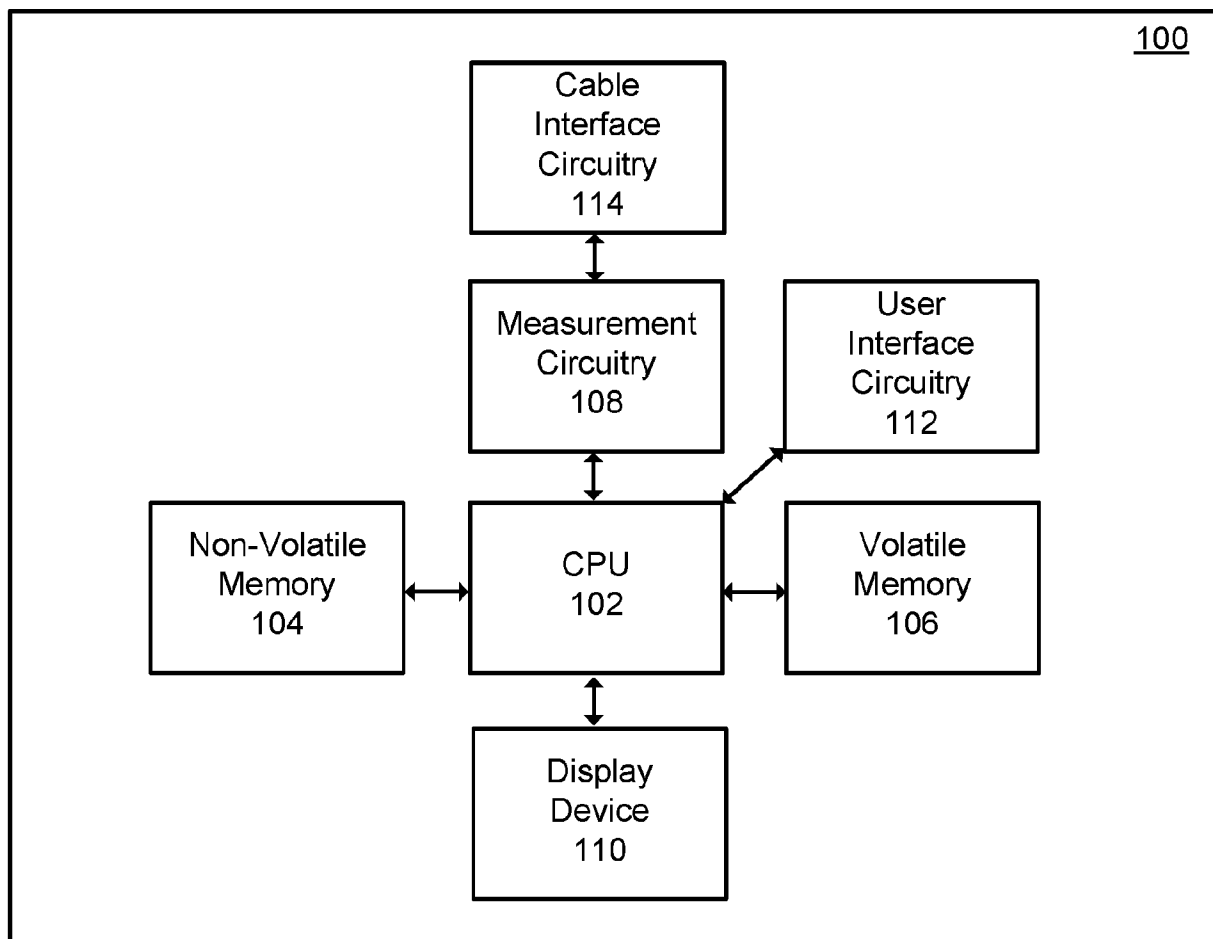
- subtract the linear curve fit data from the end region of the time-domain data.

20. The test device according to claim 12 wherein the instructions, when executed by the at least one processor, cause the test device to remove the DC offset from the time-domain data by causing the test device to:

determine an average offset value based on the time-domain data; and

subtract the average offset value from each of the data points in a region of the time-domain data from an earliest data point the time-domain data to the third data point of the data points of the time-domain data corresponding to the end point of the cable.

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**FIG. 1**

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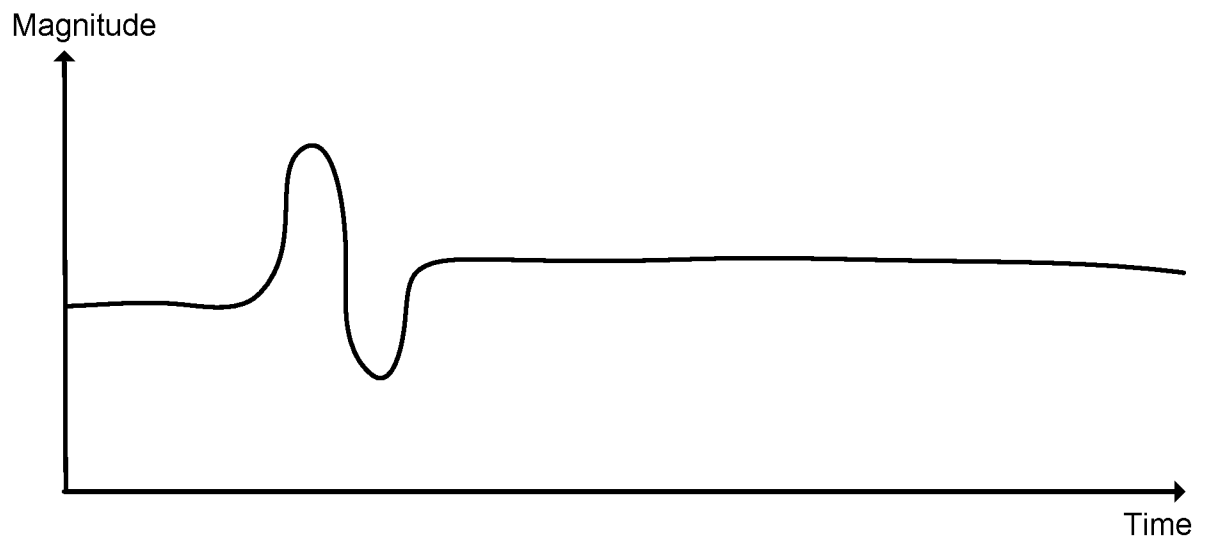


FIG. 2A

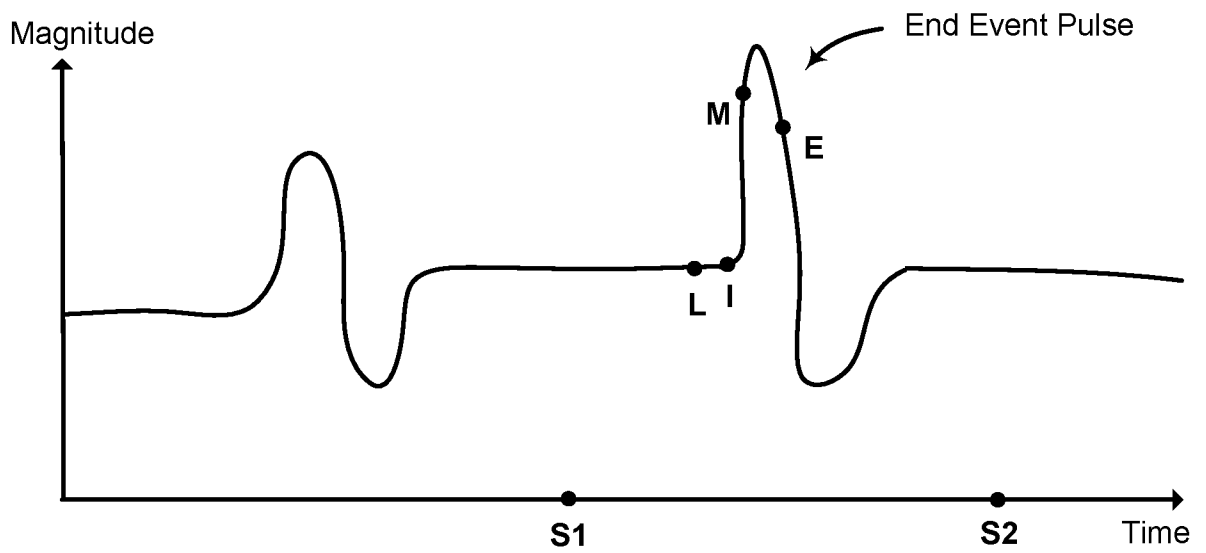
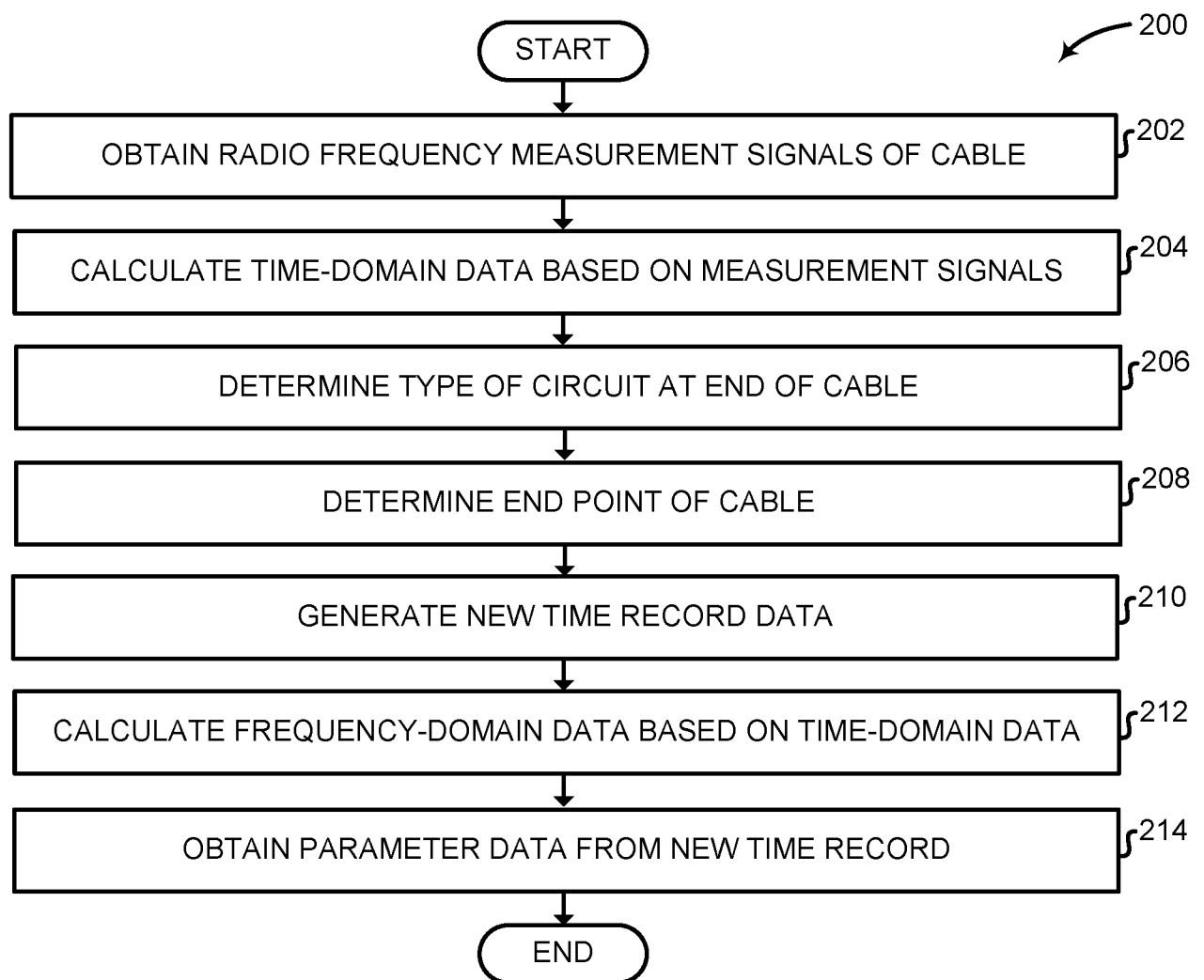
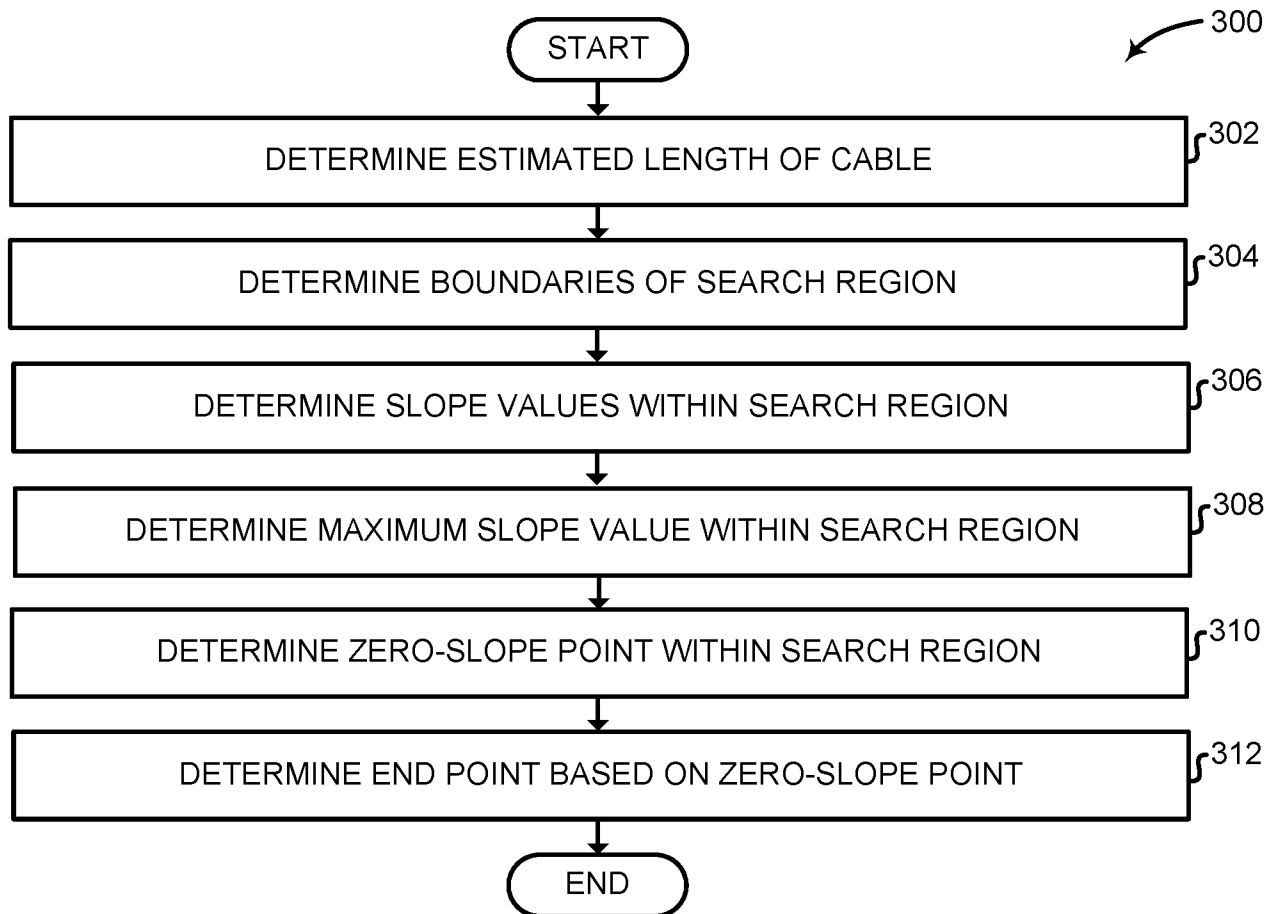


FIG. 2B

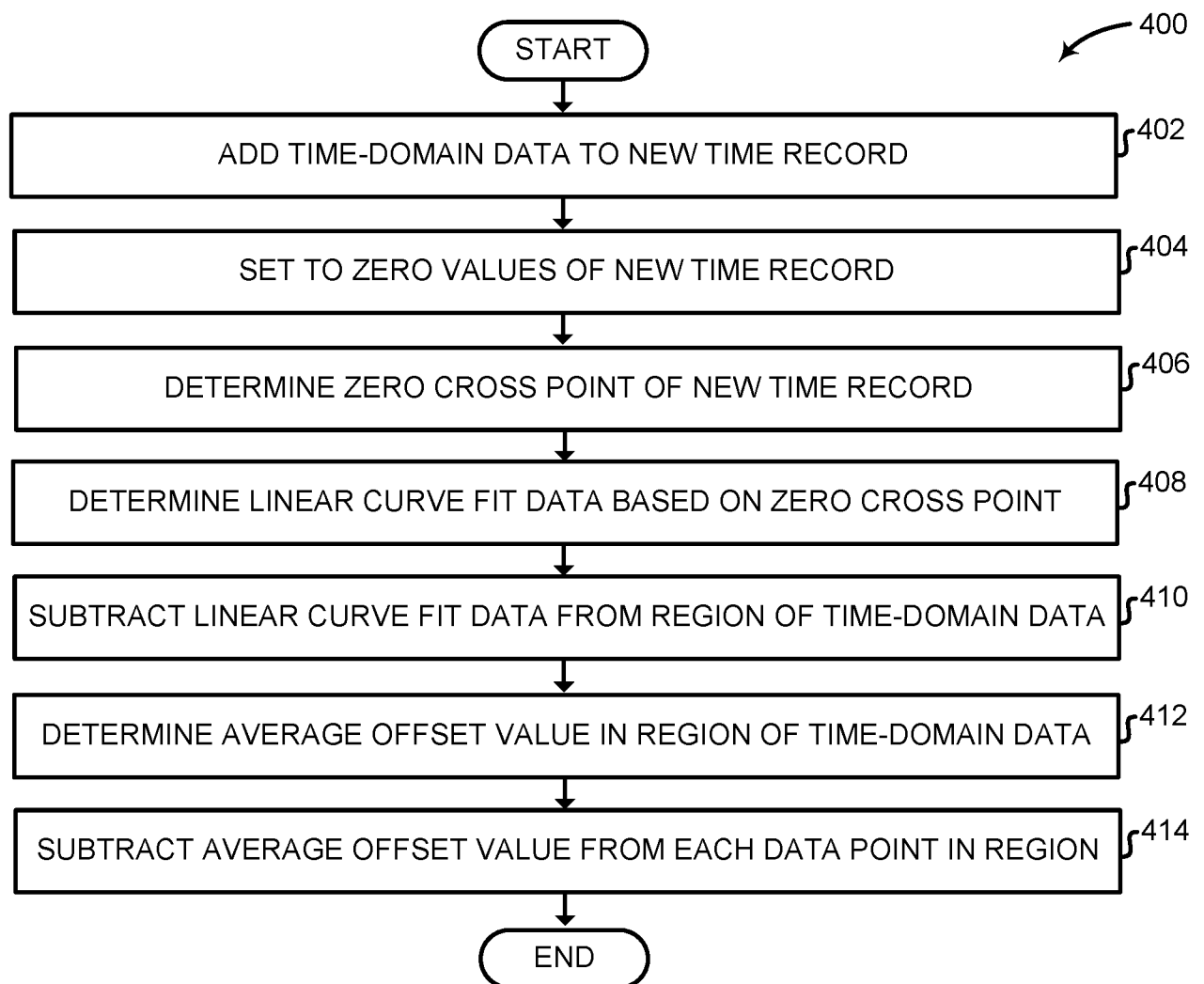
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**FIG. 3**

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**FIG. 4**

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**FIG. 5**

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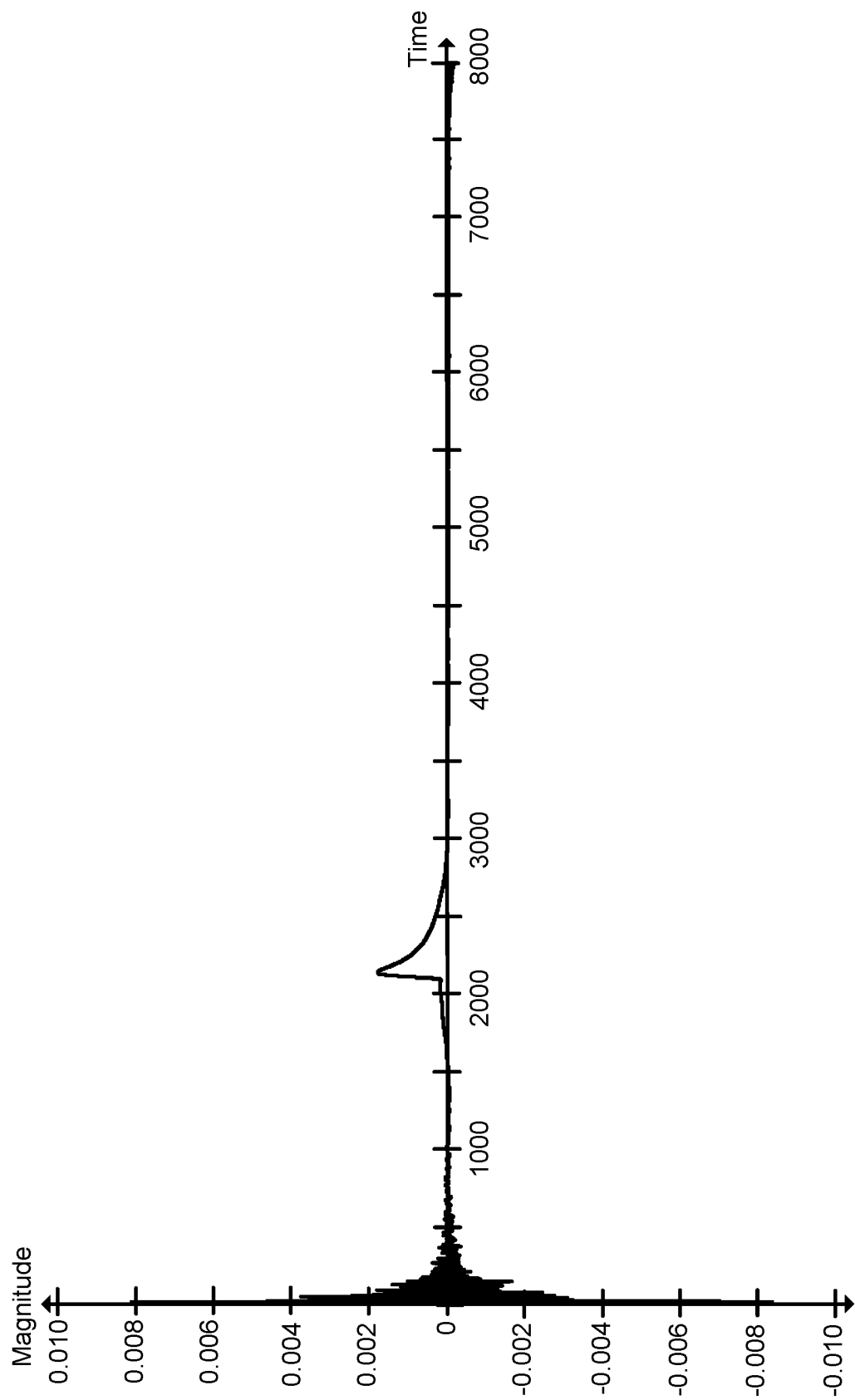


FIG. 6A

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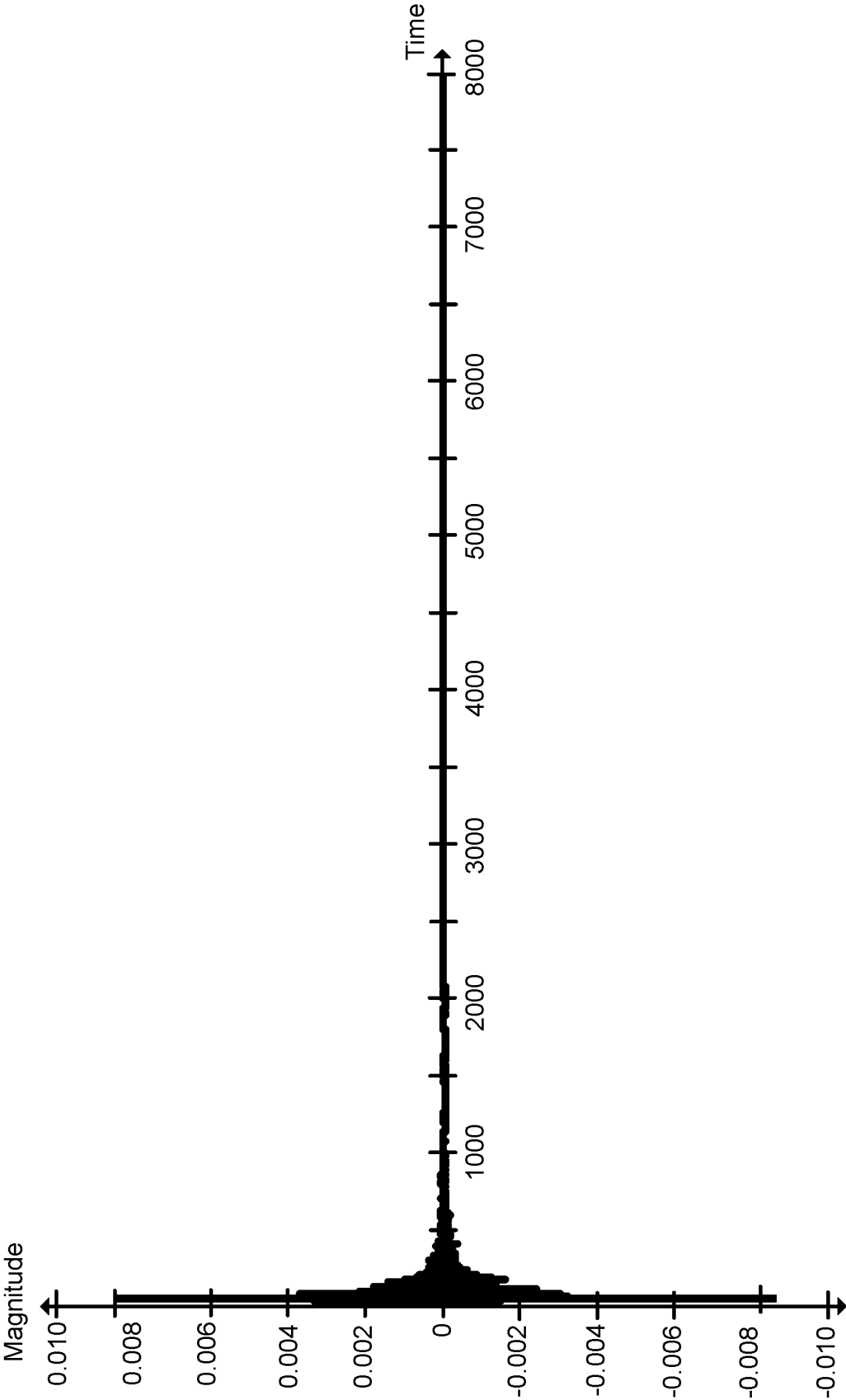


FIG. 6B

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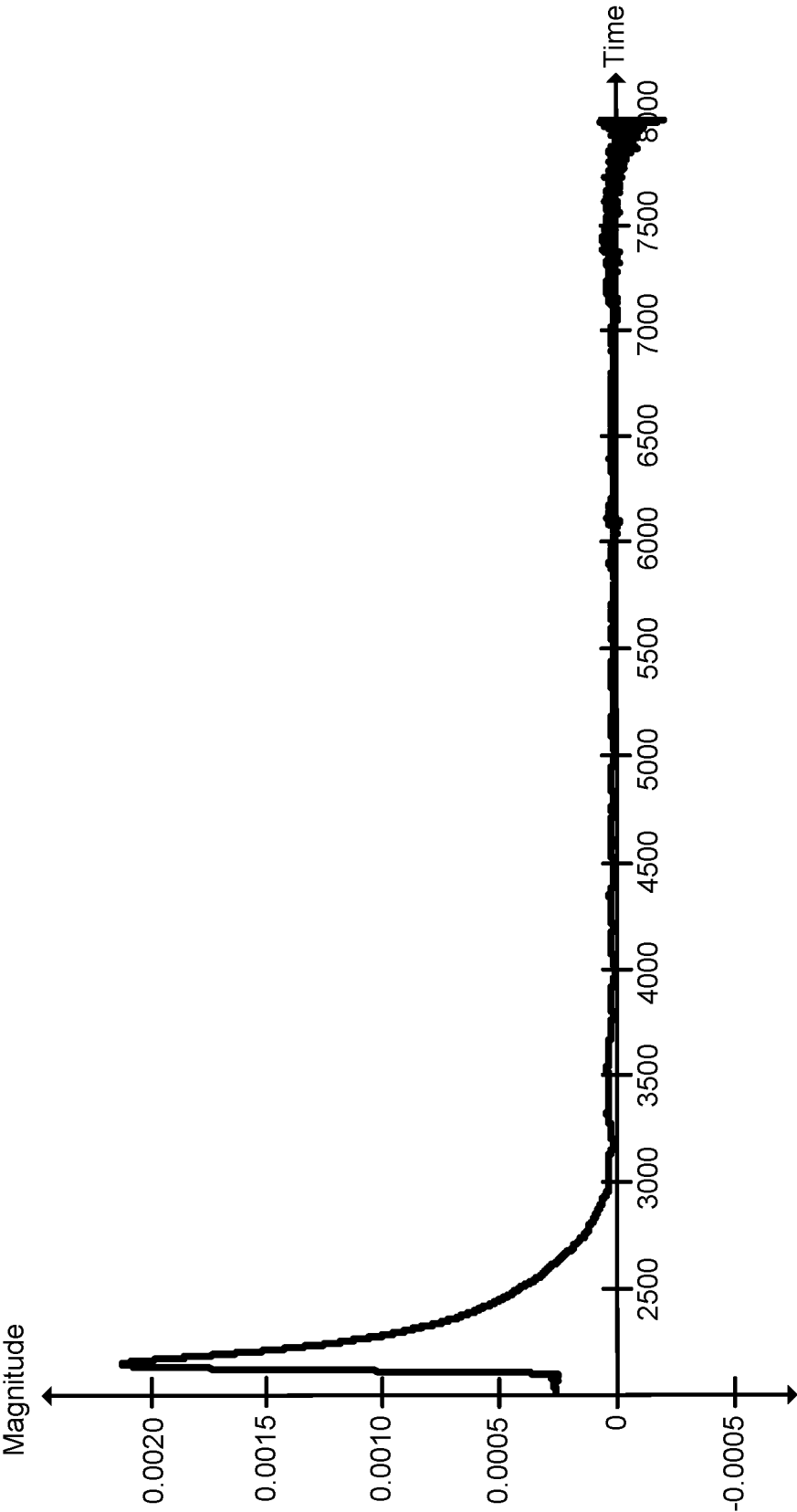


FIG. 7

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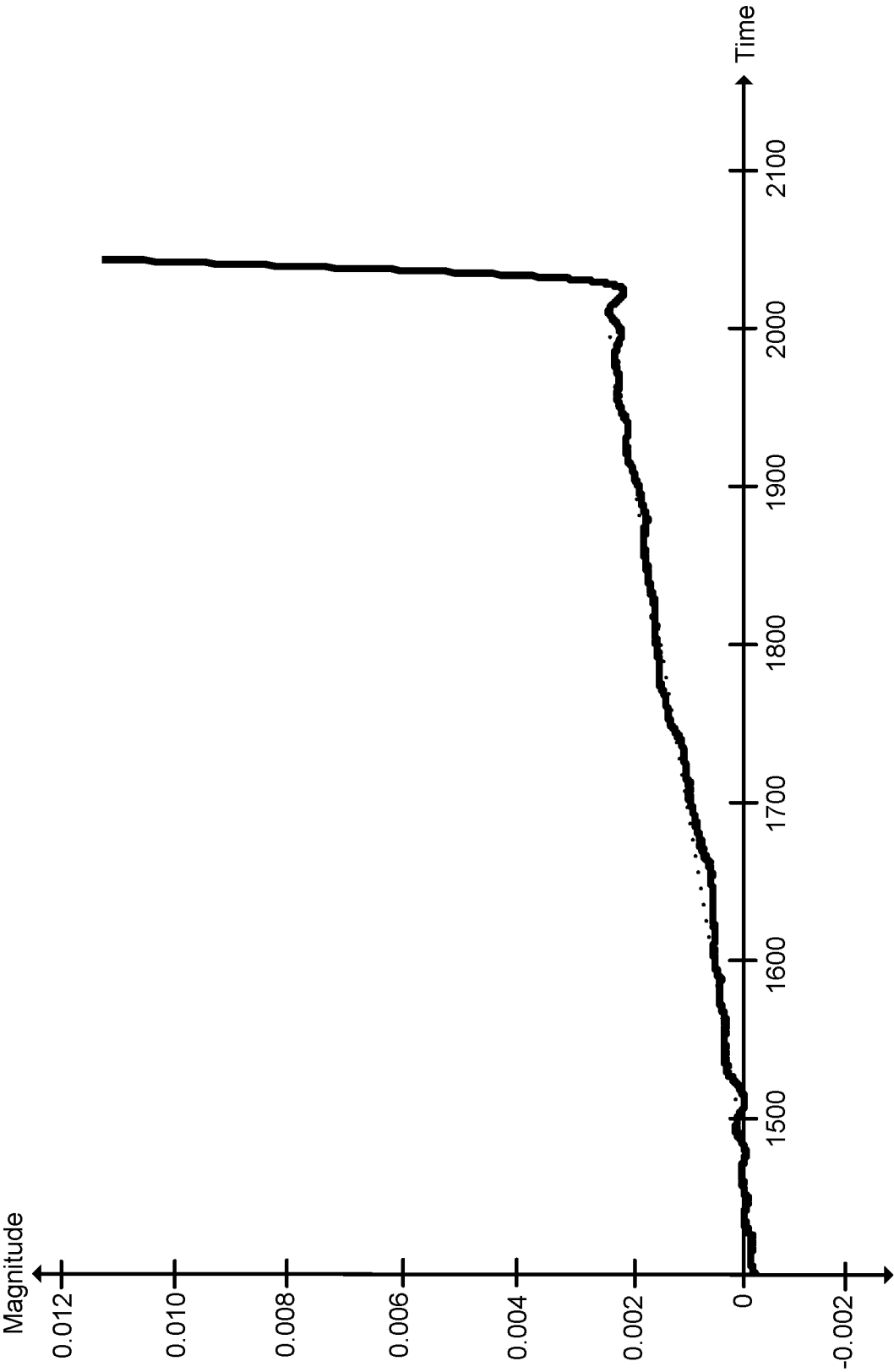


FIG. 8A

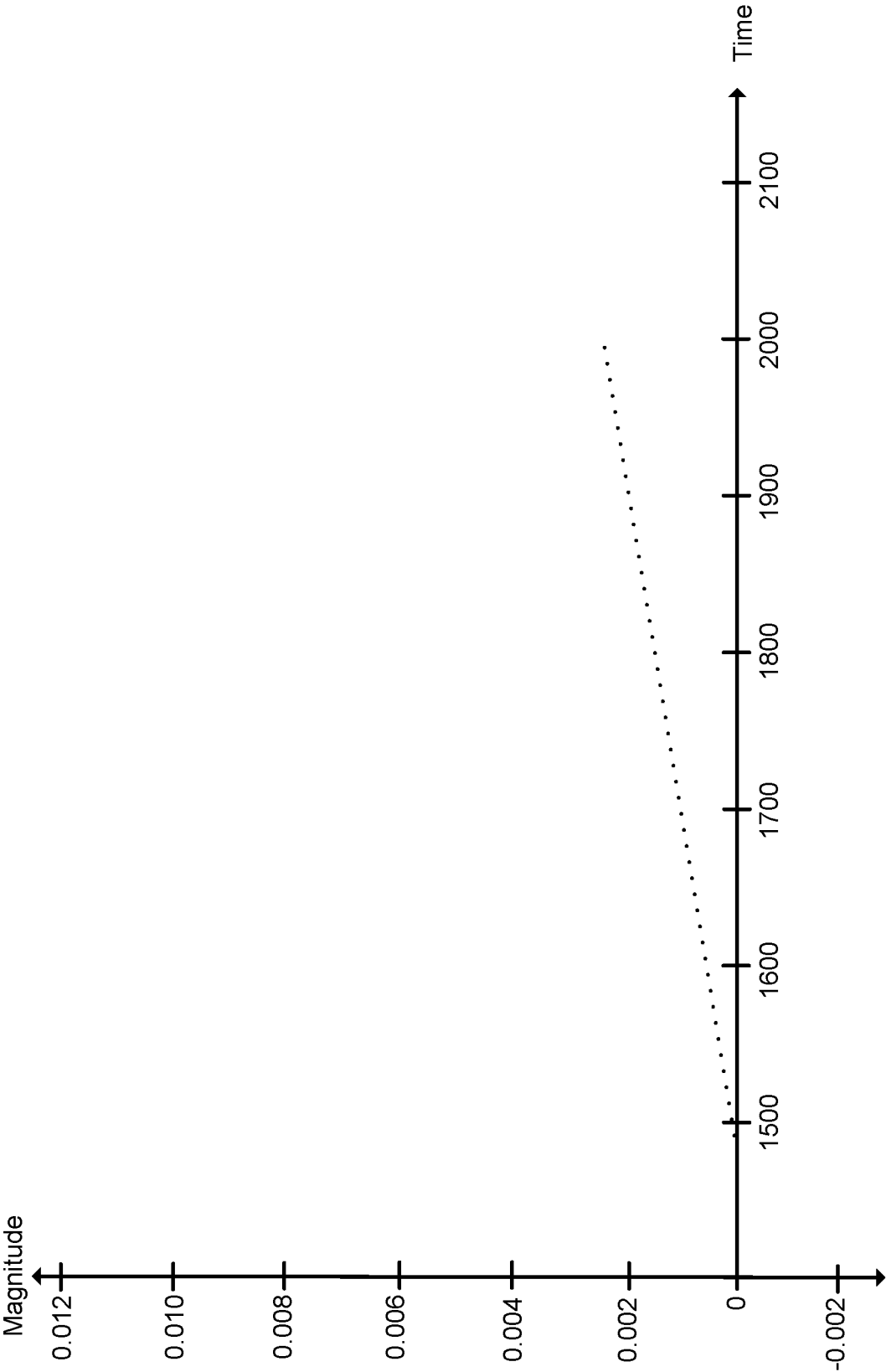


FIG. 8B

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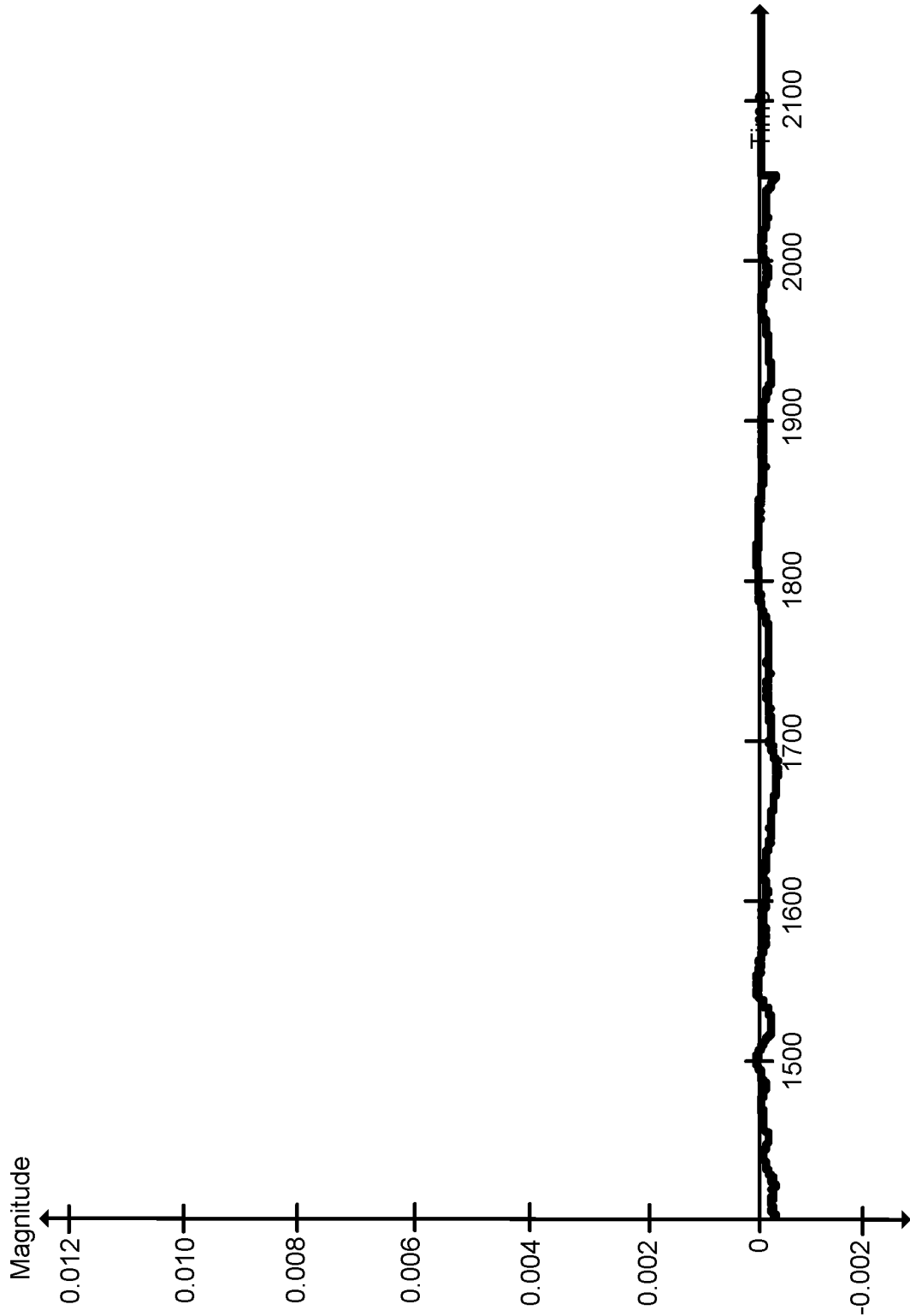


FIG. 8C

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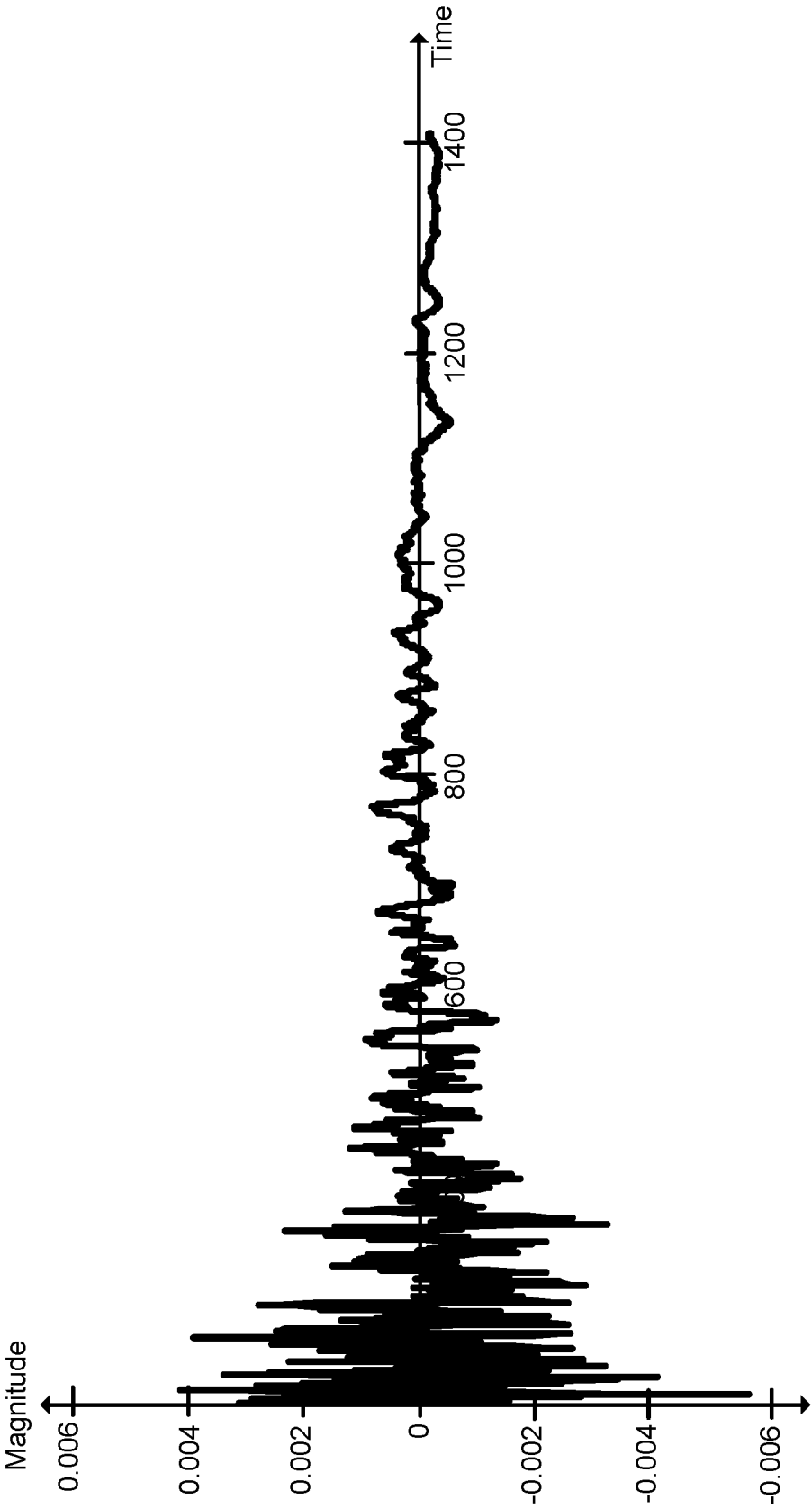


FIG. 9A

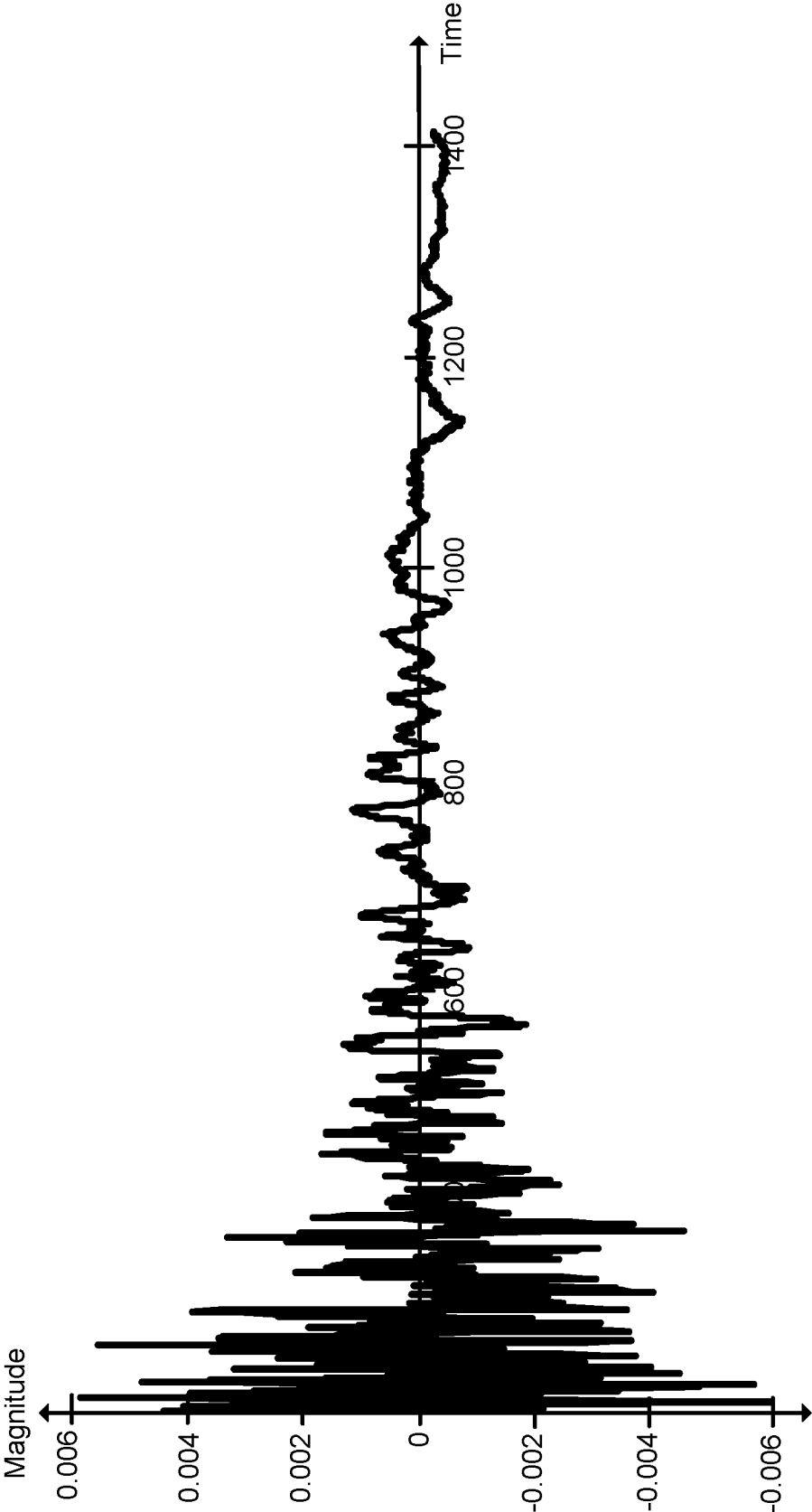


FIG. 9B

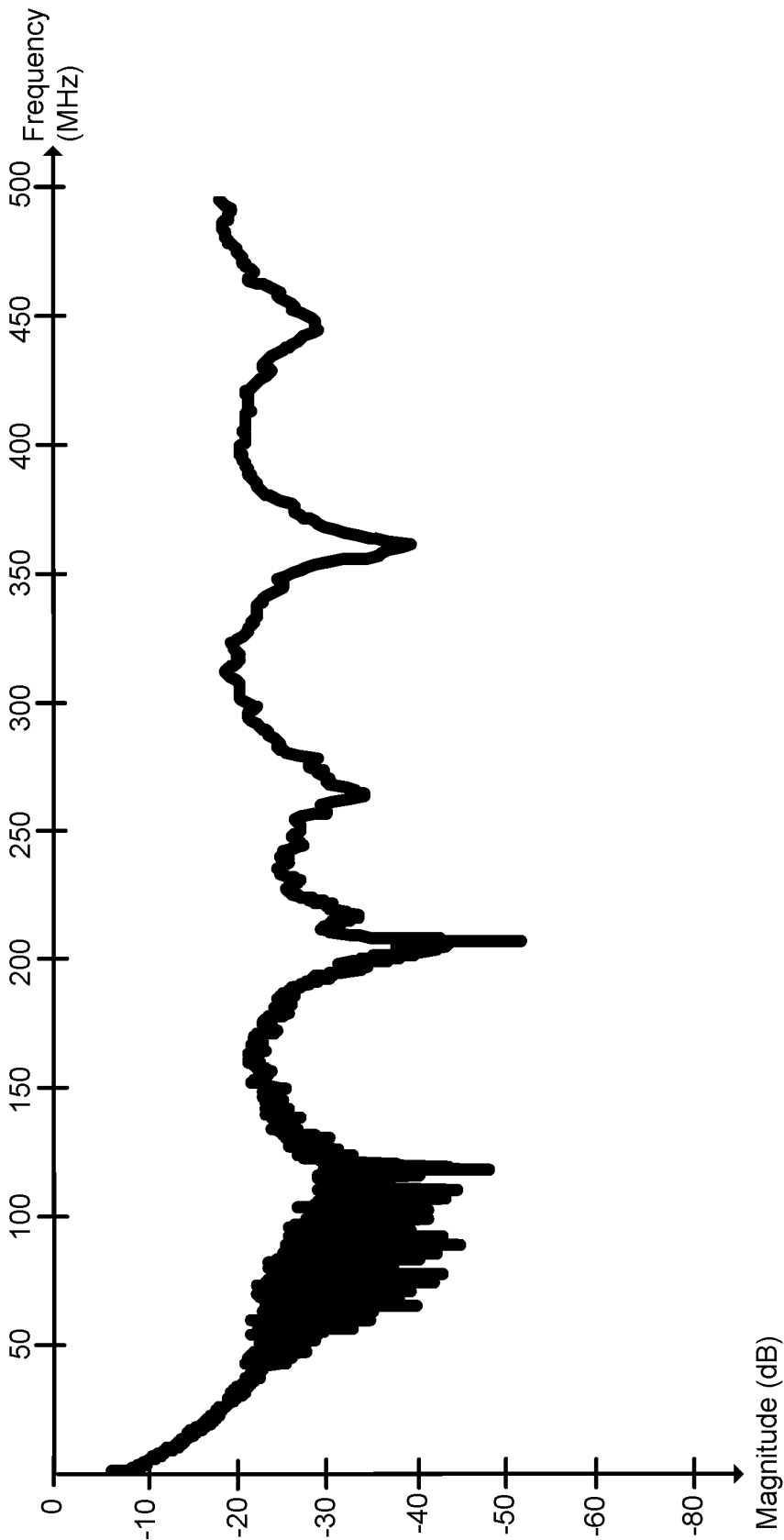


FIG. 10A

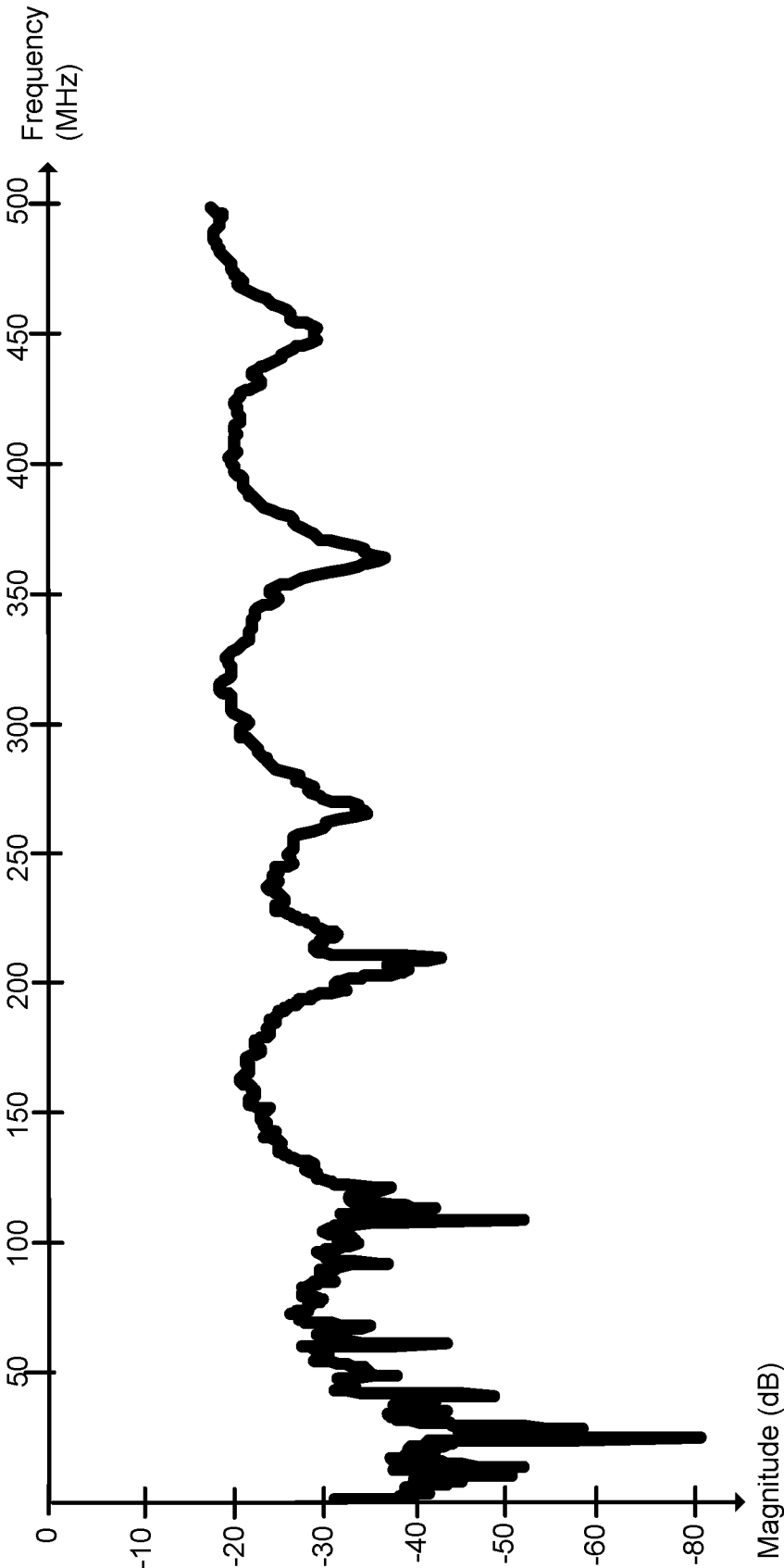


FIG. 10B

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2020/032963

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01R31/08 G01R31/11
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 106 771 849 A (41ST INST CHINA ELECTRONICS TECHNOLOGY GROUP CORP) 31 May 2017 (2017-05-31) the whole document	1-20
A	----- US 2016/084895 A1 (IMHOF MICHAEL [US]) 24 March 2016 (2016-03-24) abstract; claims 1-20; figures 1-12B paragraph [0004] - paragraph [0005] paragraph [0024] - paragraph [0078]	1-20
A	----- US 2006/164066 A1 (SHIOIRI SATOMI [JP] ET AL) 27 July 2006 (2006-07-27) abstract; claims 1-36; figures 1-11 paragraph [0011] - paragraph [0016] paragraph [0029] - paragraph [0073] ----- -/-	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

20 August 2020

Date of mailing of the international search report

28/08/2020

Name and mailing address of the ISA/

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Authorized officer

Nadal, Rafael

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2020/032963

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2017/155541 A1 (ZHANG XIAOLONG [CN] ET AL) 1 June 2017 (2017-06-01) abstract; claims 1-16; figures 1-15 paragraph [0010] - paragraph [0025] paragraph [0044] - paragraph [0256] -----	1-20

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2020/032963

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US 2006164066	A1	27-07-2006	JP 2006208060 A 10-08-2006 US 2006164066 A1 27-07-2006
US 2017155541	A1	01-06-2017	CN 105829901 A 03-08-2016 EP 3163313 A1 03-05-2017 US 2017155541 A1 01-06-2017 WO 2016023185 A1 18-02-2016