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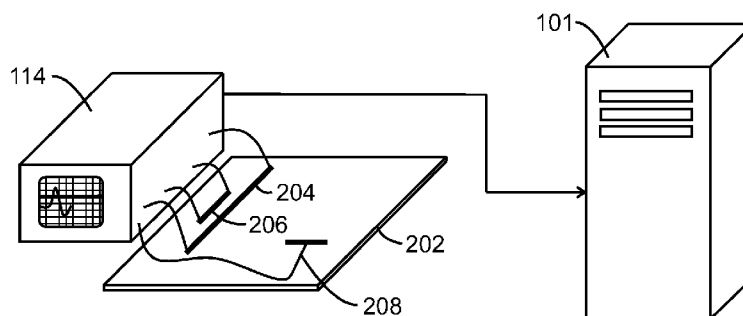
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(54) Title: ESTIMATING CIRCUIT BOARD CHARACTERISTICS



200
FIG. 2

(57) Abstract: Techniques related to circuit board characteristic determination are described herein. Characteristics of a copper trace in a circuit board are received. The characteristics comprise a dielectric constant and a loss tangent. Resonance frequencies of a T-resonator component of the circuit board are received and the characteristics are adjusted based on the measured resonance frequency characteristics.



ESTIMATING CIRCUIT BOARD CHARACTERISTICS

BACKGROUND

[0001] Computing platforms may include components such as circuit boards that function as channels and links for high-speed electric signals. To guarantee signal reception and the operation of the platform, accurate testing of the platform is an important component of product quality. For example, a printed circuit board (PCB) may include copper traces and a substrate dielectric material. However, parameters indicating the characteristics of the PCB may be difficult to determine without destructive techniques, such as cross-sectioning measures of the copper traces and dielectric materials.

BRIEF DESCRIPTION OF THE DRAWINGS

[0002] Certain examples are described in the following detailed description and in reference to the drawings, in which:

[0003] Fig. 1 is a block diagram illustrating a computing system configured to estimate circuit board characteristics;

[0004] Fig. 2 is a diagram illustrating a computing device configured to receive measured characteristics of a circuit board from a measuring device;

[0005] Fig. 3 is a flow diagram illustrating a process of estimating attenuation attributable to surface roughness;

[0006] Fig. 4 is a block diagram illustrating a method of adjusting measured characteristics of a circuit board; and

[0007] Fig. 5 is a block diagram of a computer readable medium that includes modules for adjusting measured characteristics of a circuit board.

DETAILED DESCRIPTION

[0008] Examples described herein provide methods and systems for extracting measured characteristics of a circuit board. As discussed above, accurate testing of circuit boards is an important component of production quality. During production, both a circuit board designer and a circuit board manufacturer may be interested in determining whether manufactured circuit boards meet design specifications. Specifically, both parties may be interested in knowing the dielectric constant, loss

tangent, and surface roughness characteristics of a conductive material used in the circuit board.

[0009] Circuit boards may be measured for step responses on two different lengths of trace and for resonance frequencies at a T-resonator. The T-resonator measurements may be used to adjust values for accuracy in determining further estimates of circuit board characteristics. The techniques described herein also provide analysis of the measured parameters to estimate values useful to evaluate a manufacturing process. For example, measured characteristics may be analyzed to determine values attributable to surface roughness. Other values such as a loss tangent attributable to surface roughness and a dielectric constant may also be determined. In the examples discussed below, either time domain equipment or frequency domain equipment may be used thus providing flexibility in obtaining measurements of a given circuit board.

[0010] Fig. 1 is a block diagram illustrating a computing system configured to estimate circuit board characteristics. The computing system 100 may include a computing device 101 having a processor 102, a storage device 104, a memory device 106, a network interface 108, and a display interface 110. The computing device 101 may communicate, via the network interface 108, with a network 112 to access a testing device 114.

[0011] The storage device 104 may be a non-transitory computer-readable medium having an estimation module 116. The estimation module 116 may be implemented as logic, at least partially comprising hardware logic, as firmware embedded into a larger computing system, or any combination thereof. The estimation module 116 is configured to receive characteristics of a trace in a circuit board. The characteristics of the circuit board may include a dielectric constant. In some embodiments, the estimation module 116 may also receive resonance frequencies measured from a T-resonator component of the circuit board. The estimation module 116 may be configured to adjust the characteristics of the circuit board based on the measured resonance frequency.

[0012] In embodiments, the estimation module 116 receives the characteristics in terms of raw measurements from the testing device 114. In other embodiments, the estimation module 116 receives processed data from the testing device. In either embodiment, the testing device 114 may be remotely or directly coupled to the computing device 101. The testing device 114 may be a circuit board testing device

configured to run a step response protocol and a T-resonator resonant frequency assessment.

[0013] The processor 102 may be a main processor that is adapted to execute the stored instructions. The processor 102 may be a single core processor, a multi-core processor, a computing cluster, or any number of other configurations. The processor 102 may be implemented as Complex Instruction Set Computer (CISC) or Reduced Instruction Set Computer (RISC) processors, x86 Instruction set compatible processors, multi-core, or any other microprocessor or central processing unit (CPU).

[0014] The memory device 106 can include random access memory (RAM) (e.g., static RAM, dynamic RAM, zero capacitor RAM, Silicon-Oxide-Nitride-Oxide-Silicon, embedded dynamic RAM, extended data out RAM, double data rate RAM, resistive RAM, parameter RAM, etc.), read only memory (ROM) (e.g., Mask ROM, parameter ROM, erasable programmable ROM, electrically erasable programmable ROM, etc.), flash memory, or any other suitable memory systems. The main processor 102 may be connected through a system bus 118 (e.g., PCI, ISA, PCI-Express, etc.) to the network interface 108. The network interface 108 may enable the computing device 101 to communicate, via the network 112, with the testing device 114.

[0015] The block diagram of Fig. 1 is not intended to indicate that the computing device 101 is to include all of the components shown in Fig. 1. Further, the computing device 101 may include any number of additional components not shown in Fig. 1, depending on the details of the specific implementation.

[0016] Fig. 2 is a diagram illustrating a computing device configured to receive measured characteristics of a circuit board from a measuring device. The circuit board 202 may be a printed circuit board (PCB), and may be referred to herein as PCB 202, although other types of circuit boards may be used. The PCB 202 includes two different lengths of trace, including trace 204 and trace 206, to be tested by the testing device 114. The PCB 202 also includes a T-shaped resonator, referred to herein as T-resonator 208.

[0017] The testing device 101 may be a time-domain-transmission (TDT) device. In some embodiments, the testing device 101 may be a frequency domain transmission (FDT) device, such as a vector network analyzer (VNA). In either case, as discussed above in regard to Fig. 1, the testing device 114 may be communicatively coupled to a computing device, such as the computing device 101.

As illustrated in Fig. 2, the testing device 114 is directly communicatively coupled to the computing device 101, rather than via a network, such as the network 112 discussed above in regard to Fig. 1.

[0018] The testing device 114 may be operative to run a step response test on each of the traces 204 and 206, as well as a resonant frequency test on the T-resonator 208. In some scenarios, the testing device 114 may be configured to extract characteristics of the PCB 202, such as total attenuation, a total loss tangent, and resonating frequencies. In other scenarios, the testing device 114 may provide raw step response data and frequency data to the computing device 101, wherein the computing device 101 may be configured to extract the characteristics.

[0019] In an example operation, the testing device 114 may be a TDT device configured to measure a step response at opposite ends of trace 204 and of trace 206. The two different lengths of trace may be used to adjust the step response by cancelling out signal noise associated with connectors of each of the traces 204 and 206. For example, unwanted reflections from measurement probes, any contact pads, vias, cable connectors, and the like, may be filtered based on reflections common to both the traces 204 and 206.

[0020] The step response data may be provided to the computing device 101, wherein a module, such as the estimation module 116 of Fig. 1, converts the responses into frequency response data in a frequency domain. From the frequency responses, a complex propagation constant may be extracted. The complex propagation constant may be based on attenuation and change in phase per meter, as indicated in Equation 1 below:

$$\gamma(f) = \alpha(f) + j * \beta(f)$$

Eq. 1

[0021] In Eq. 1, $\gamma(f)$ is the complex propagation constant, $\alpha(f)$ is the attenuation in a measured trace as a function of frequency (f), and $\beta(f)$ is a change in phase per meter in a measured trace as a function of frequency (f), while j is an imaginary unit wherein $j^2 = -1$. It may be important to note that the total amount of attenuation, $\alpha(f)$, may be decomposed into attenuation attributable to the conductive material ($\alpha_c(f)$) of either trace 204 or trace 206, attenuation attributable to a dielectric material ($\alpha_d(f)$) of the PCB 202, and attenuation attributable to a surface roughness ($\alpha_{SR}(f)$) of the conductive material.

[0022] The techniques described herein include estimating $\alpha_{SR}(f)$ for any given PCB 202 that is tested. As described in more detail below, estimating $\alpha_{SR}(f)$ may be performed by extracting additional processes discussed in reference to Fig. 3.

[0023] Fig. 3 is a flow diagram illustrating a process of estimating attenuation attributable to surface roughness. The process begins at 302, and at block 304 step responses are measured for two different lengths of traces, such as the traces 204 and 206 discussed above in reference to Fig. 2. Block 304 may also include measuring resonance frequencies at a T-resonator, such as the T-resonator 208 of Fig. 2.

[0024] As discussed above in reference to Fig. 2, the step responses from two different lengths of trace are compared to filter out data attributable to components, such as connectors, that are external to the traces 204, 206 themselves. If the step responses were measured using TDT equipment, the responses are converted into frequency responses in a frequency domain.

[0025] From the step response data, the total attenuation is extracted from the complex propagation constant (γ) at block 306 based on the measured step response 304. The complex propagation constant is composed of determinable elements including the attenuation $\alpha(f)$ and the change in phase per meter $\beta(f)$, extracted at block 306, as discussed above in regard to Eq. 1. The dielectric constant ϵ_r may be described by a closed-form model that requires $\alpha(f)$ and $\beta(f)$ as inputs, as shown in Equation 2:

$$\epsilon_r = f(\alpha, \beta) \quad \text{Eq. 2}$$

At 308, α and β are used as inputs to Eq. 2. At block 310, a total loss tangent, $\tan \delta$ associated with the measured traces is determined. Similar to the model above, the total loss tangent is a function of α and β , as indicated by Eq. 3:

$$\tan \delta = f(\alpha, \beta) \quad \text{Eq. 3}$$

[0026] It is important to note that the total loss tangent is composed of loss tangents attributable to different factors. Specifically, the total loss tangent may be composed of loss tangents attributable to surface roughness, dielectric material, and the conductive material of the trace, as indicated in Equation 4:

$$\tan \delta = \tan \delta_c + \tan \delta_d + \tan \delta_{SR}$$

Eq. 4

In Eq. 4, $\tan \delta_c$ is the loss tangent attributable to the conductive material of the traces 204 and 206, $\tan \delta_d$ is the loss tangent attributable to the dielectric material of the PCB 202, and $\tan \delta_{SR}$ is the loss tangent attributable to the surface roughness of the conductive material of the traces 204 and 206.

[0027] At block 312, the dielectric constant and the total loss tangent that were determined in blocks 308 and 310, respectively, are adjusted. The adjustment at 312 may be performed based on the measurements from the T-resonator 208 performed at block 314. For dielectric constant and loss tangent values, values obtained from less than 1 Gigahertz (Ghz) resonant frequencies are most likely caused by the dielectric material only. Therefore, the T-resonator measurements performed at 314 may be less than 1 Ghz in order to adjust the dielectric constant and the total loss tangent at 312. The values of the dielectric constant and the total loss tangent are adjusted across wide-band frequencies until the extracted dielectric constant and total loss tangent values are within a range of allowable deviation from the dielectric constant and loss tangent values obtained from the T-resonator 208, at block 314. In embodiments, the range may be set by a user, an operator, and the like, based on desired testing accuracy.

[0028] A per-unit-length modeling of traces on the PCB may be performed at block 316. The per-unit-length modeling may include a $R(f)$, $L(f)$, $C(f)$, $G(f)$ model based on dimensions of a given trace, wherein R is resistance, L is inductance, C is capacitance, and G is conductance. For example, the per-unit-length model may be based on a width, length, and thickness of a given trace, such as one of the traces 204 or 206. In embodiments, the dimensions may be an average of both the traces 204 and 206. In either case, the per-unit-length model may then be used to derive a dimension-based attenuation (α'), at block 318. At block 320, the dimension-based attenuation is compared to the attenuation (α) extracted at block 306. The dimension-based attenuation should be the same as the attenuation extracted at block 306. However, if it is not, one or more surface roughness elements in the per-unit-length model are adjusted at block 322. For example, surface roughness of a conductor may be adjusted in the $R(f)$ component of the per-unit-length model. In embodiments, the adjustment 322 may be iterated until the dimension based

attenuation is within a predetermined allowable deviation of the attenuation extracted at block 306.

[0029] Since the surface roughness of the R(f) component is known from the adjustment block 324, an attenuation (α'') with a surface roughness of 0 may be calculated. At block 325, the attenuation having a surface roughness of 0 may be subtracted from the dimension based attenuation at block 318, to determine an attenuation attributable to surface roughness (α_{SR}). The determination of attenuation attributable to surface roughness at block 324, is illustrated in Equations 5-7 below:

$$\alpha' = \alpha'_c + \alpha'_d + \alpha'_{SR} \quad \text{Eq. 5}$$

$$\alpha'' = \alpha'_c + \alpha'_d \quad \text{Eq. 6}$$

$$\alpha' - \alpha'' = \alpha'_{SR} \quad \text{Eq. 7}$$

[0030] In embodiments, the determination of attenuation attributable to surface roughness in block 324 is performed without destruction of the PCB 202 by destructive methods such as cross-sectioning the PCB 202. Once the attenuation attributable to surface roughness is known, a loss tangent attributable to surface roughness ($\tan \delta_{SR}$) may be determined at block 326, based on the relationship between the attenuation and the loss tangent. For example, the relationship between the loss tangent and the attenuation may be expressed by Eq. 8:

$$\tan d = \frac{\alpha * 2}{\beta} \quad \text{Eq. 8}$$

[0031] At block 328, attenuation (α_c) and the loss tangent ($\tan \delta_c$) attributable to the conductive material of the trace are determined. The attenuation and loss tangent attributable to the conductive material may be modeled by a skin-depth effect. The skin-depth effect is based on the tendency of a current to become distributed within a conductor such that the current density is largest near a surface of the conductor. The determination at block 328 may be based on the step response measurement performed at 304. At block 330, a loss tangent $\tan \delta_d$ attributable to a dielectric material of the PCB 202 is determined by subtracting $\tan \delta_c$ and $\tan \delta_{SR}$ from the total loss tangent $\tan \delta$ determined at block 310.

[0032] Fig. 4 is a block diagram illustrating a method of adjusting measured characteristics of a circuit board. The method 400 may include receiving characteristics of a trace in a circuit board at block 402. At block 404, resonance frequencies of a T-resonator component of the PCB are received. The resonance frequency may be limited to frequencies below a predefined threshold. For example, the resonance frequencies may be less than 1 GHz to eliminate attribution of surface roughness to the measurement, as discussed above in regard to Fig. 3. The characteristics of the trace are adjusted based on the measured resonance frequency at block 406.

[0033] The method 400 is not limited to the blocks shown in Fig. 4, but may include any number of other blocks or actions. For example, the method 400 may include estimating attenuation and loss attributable to a surface roughness of a conductive material of the trace. The attenuation and loss attributable to the surface roughness may be obtained without destructive PCB analysis methods such as cross-sectioning of the PCB.

[0034] Estimating attenuation attributable to surface roughness may include identifying a first total attenuation estimation (α) based on the measured characteristics. A second total attenuation estimation (α') may be determined by a per-unit-length model, such as the per-unit-length model discussed above in reference to Fig. 3. A third total attenuation estimation (α'') based on the per-unit-length model is determined with the assumption that the contribution of attenuation attributable to surface roughness is zero. The difference between the third and second attenuation estimations may provide the attenuation attributable to surface roughness.

[0035] Determining the second total attenuation estimation includes adjusting the surface roughness in the per-unit-length model. For example, elements in a resistance calculation of the per-unit-length model may include a surface roughness element. This element may be adjusted up or down in order to bring the second total attenuation estimation closer to the first total attenuation estimation.

[0036] Fig. 5 is a block diagram of a computer readable medium that includes modules for adjusting measured characteristics of a circuit board. The computer readable medium 500 may be a non-transitory computer readable medium, a storage device configured to store executable instructions, or any combination

thereof. In any case, the computer-readable medium is not configured as a carry wave or a signal.

[0037] Each module of the computer-readable medium 500 includes code adapted to direct a processor 502 to perform actions for estimating circuit board characteristics. The processor 502 accesses the modules over a system bus 504.

[0038] The modules can include a receiving module 506 and an adjustment module 508. The receiving module 506 receives characteristics of a trace in a circuit board. The characteristics include a dielectric constant and a loss tangent. The receiving module 506 may also receive the dielectric constant and the loss tangent at resonance frequencies of a T-resonator component of the circuit board. The adjustment module 508 may be configured to adjust the characteristics based on the values at the measured resonance frequency.

[0039] While the present techniques may be susceptible to various modifications and alternative forms, the examples discussed above have been shown only by way of example. It is to be understood that the technique is not intended to be limited to the particular examples disclosed herein. Indeed, the present techniques include all alternatives, modifications, and equivalents falling within the true spirit and scope of the appended claims.

CLAIMS

What is claimed is:

1. A method for estimating circuit board characteristics, comprising:
receiving characteristics of a trace in a circuit board, the characteristics comprising:
a dielectric constant; and
a loss tangent;
receiving resonance frequencies of a T-resonator component of the circuit board; and
adjusting the characteristics based on the measured characteristics of the T-resonator component at the resonance frequencies.
2. The method of claim 1, further comprising:
estimating attenuation attributable to a surface roughness of a conductive material of the trace; and
estimating a loss tangent attributable to the surface roughness of the conductive material based on the estimated attenuation attributable to the surface roughness.
3. The method of claim 2, wherein the dielectric constant, the loss tangent, and attenuation and loss tangent attributable to surface roughness of the conductive material are determined without cross-sectioning of the circuit board.
4. The method of claim 2, wherein estimating attenuation attributable to surface roughness comprises:
identifying a first total attenuation estimation based on the adjusted characteristics;
determining a second total attenuation estimation based on a per-unit-length model of the trace;
determining a third total attenuation estimation based on the per-unit-length model with the assumption that the contribution of attenuation attributable to surface roughness is zero; and

determining a difference between the third total attenuation estimation and the second total attenuation to estimate attenuation attributable to surface roughness.

5. The method of claim 4, wherein determining the second total attenuation estimation comprises adjusting surface roughness in the second attenuation estimation based on a difference between the first and second attenuation estimation.

6. The method of claim 1, wherein the resonance frequencies are limited to frequencies below a predetermined frequency.

7. The method of claim 7, wherein the predetermined frequency is set to a frequency wherein characteristics of the circuit board attributed to surface roughness of a conductor of the circuit board are assumed to be approximately zero.

8. The method of claim 1, wherein the dielectric constant is extracted from a measured step response of the trace based on a closed form model having attenuation and a change in phase per unit length as inputs.

9. The method of claim 8, wherein the measured step response is measured in a time domain by time domain transmission equipment.

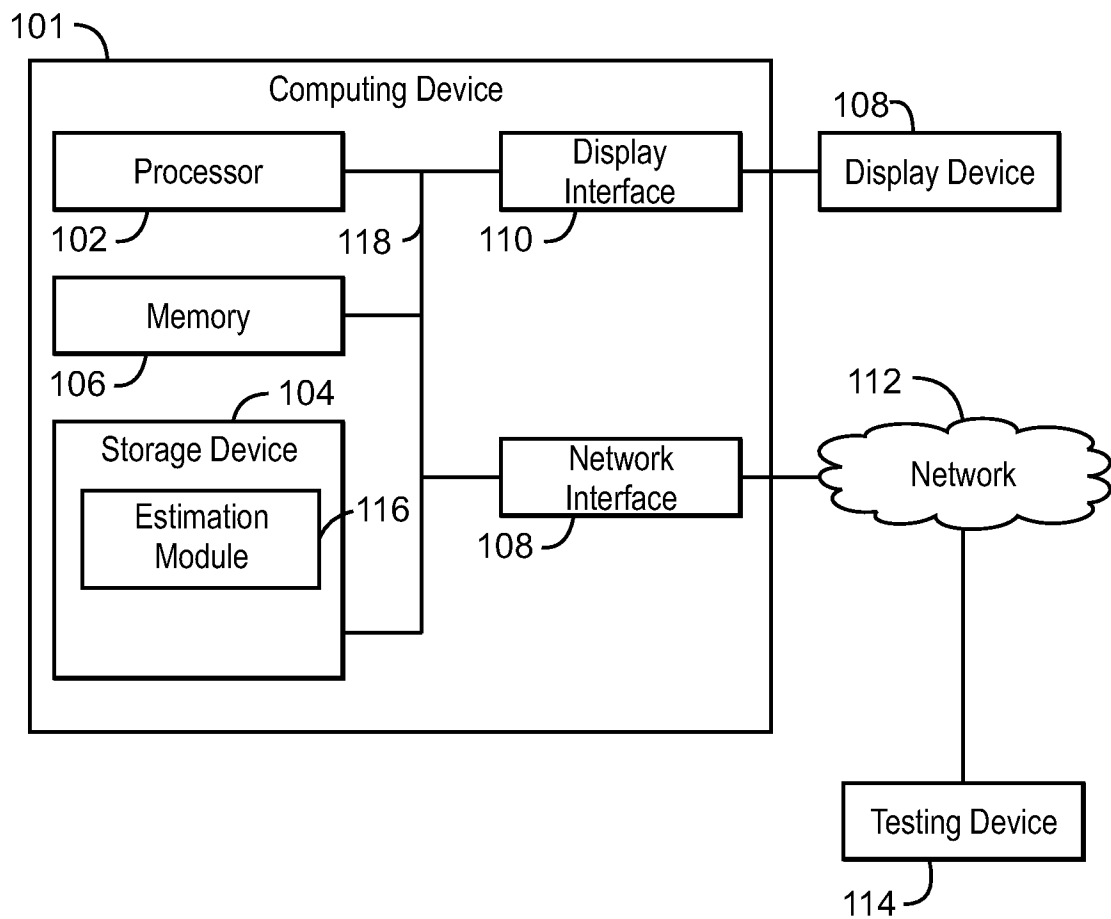
10. A system for estimating circuit board characteristics, comprising:
a processing unit;
a storage device to store instructions that when executed by the processing unit, cause the processing unit to:
receive characteristics of a trace in a circuit board, the characteristics comprising:
a dielectric constant; and
a loss tangent;
receive resonance frequencies of a T-resonator component of the circuit board; and

adjust the characteristics based on the received resonance frequency characteristics.

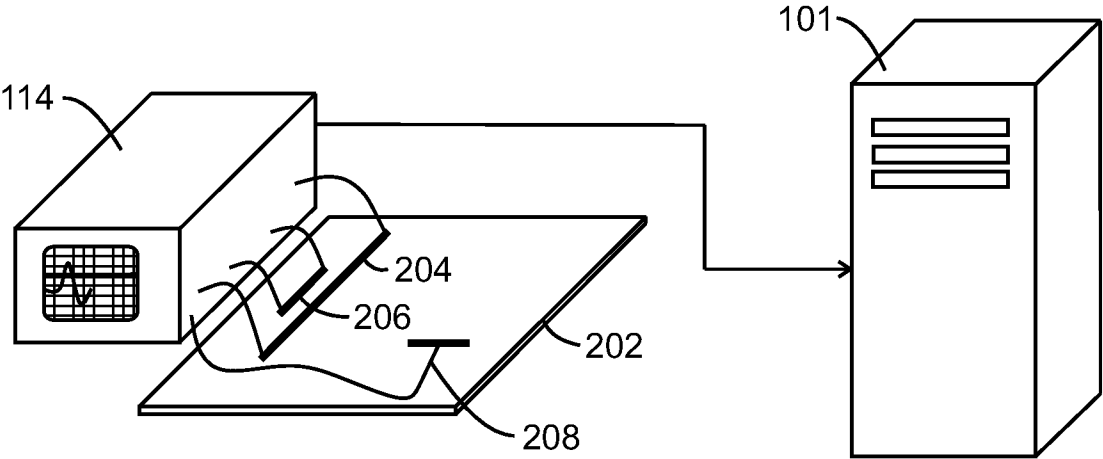
11. The system of claim 11, further comprising instructions that when executed by the processing unit, cause the processing unit to:
 - estimate attenuation attributable to a surface roughness of a conductive material of the trace; and
 - estimate a loss tangent attributable to the surface roughness of the conductive material based on the estimated attenuation attributable to the surface roughness.
12. The system of claim 11, wherein the dielectric constant, the loss tangent, and attenuation and loss tangent attributable to surface roughness of the conductive material are determined without cross-sectioning of the circuit board.
13. The system of claim 11, wherein to estimate attenuation attributable to surface roughness comprises to:
 - identify a first total attenuation estimation based on the adjusted characteristics;
 - determine a second total attenuation estimation based on a per-unit-length model of the trace;
 - determine a third total attenuation estimation based on the per-unit-length model with the assumption that the contribution of attenuation attributable to surface roughness is zero; and
 - determine a difference between the third total attenuation estimation and the second total attenuation to estimate attenuation attributable to surface roughness.
14. The system of claim 13, wherein determining the second total attenuation estimation comprises adjusting attenuation attributable to the surface roughness in the second attenuation estimation based on a difference between the first and second attenuation estimation.

15. The system of claim 10, wherein the resonance frequency is limited to frequencies below a predetermined frequency comprising a frequency wherein characteristics of the circuit board attributed to surface roughness of a conductive material of the circuit board are assumed to be approximately zero.

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100
FIG. 1



200
FIG. 2

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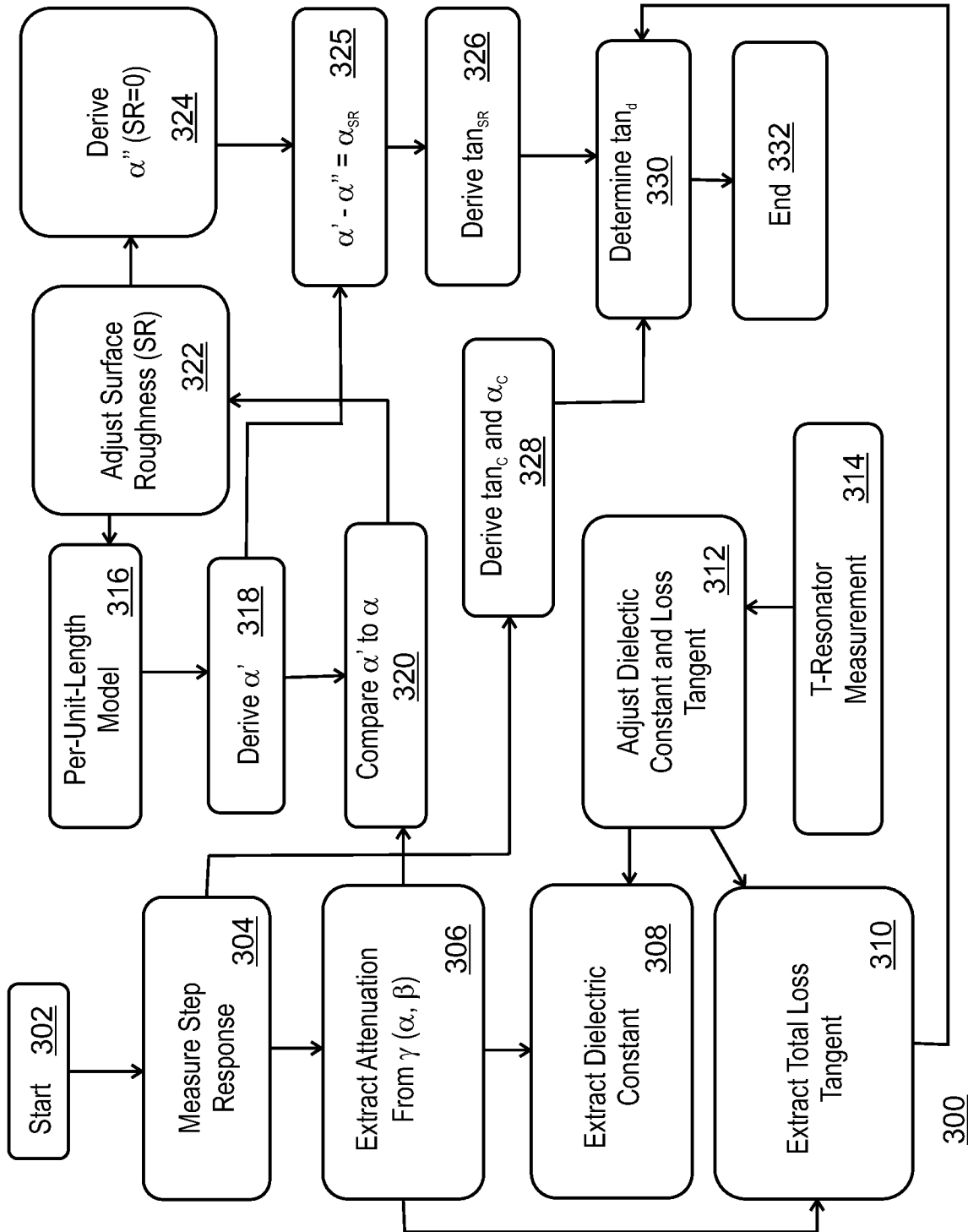
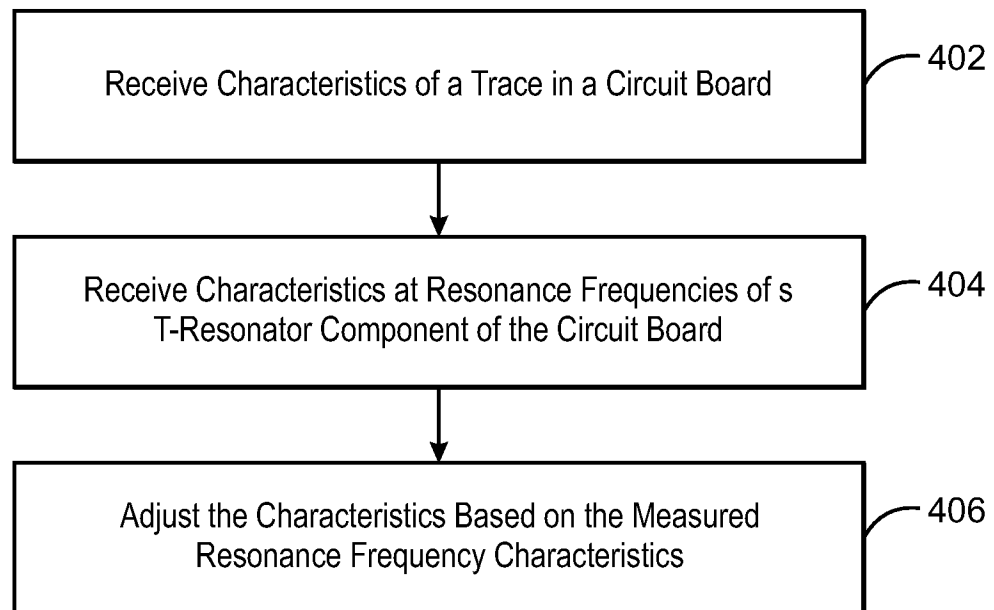


FIG. 3

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400
FIG. 4

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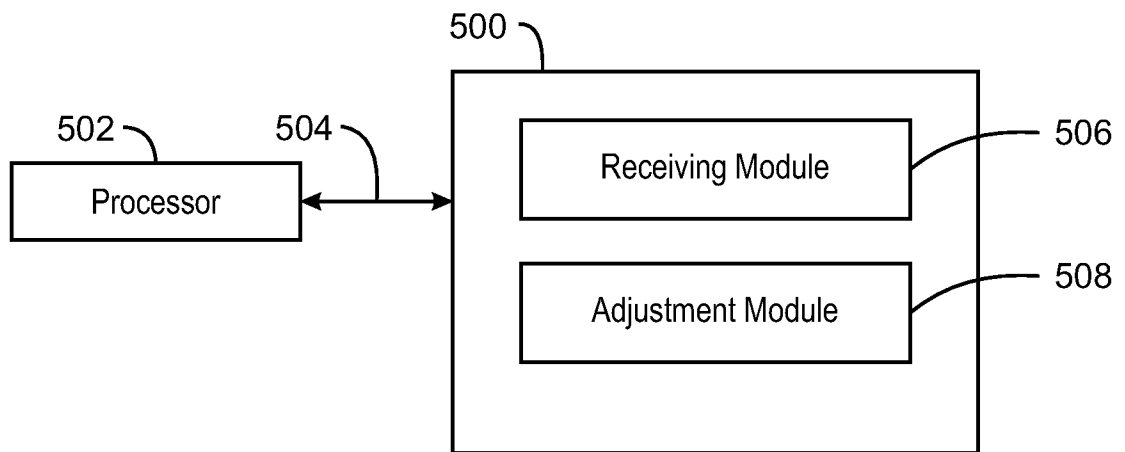


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/045098**A. CLASSIFICATION OF SUBJECT MATTER****G01R 31/28(2006.01)i**

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 31/28; G01N 27/00; G01R 31/20; G01N 27/26; G01R 27/26; G01R 27/04; G01B 7/34; H01P 7/00

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & keywords: circuit, trace, resonator, test, attenuation, roughness, characteristic

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6173604 B1 (XIANG et al.) 16 January 2001 See column 11, line 1 - column 12, line 34, claims 1-4 and figures 1-3.	1-15
Y	US 6873162 B1 (BOIS et al.) 29 March 2005 See column 3, line 4 - column 5, line 54, claims 1, 7 and figures 1-3.	1-15
A	US 2004-0246079 A1 (EHATA) 09 December 2004 See abstract, paragraphs [0113]-[0254] and figures 1-7.	1-15
A	US 2013-0021050 A1 (CHUI et al.) 24 January 2013 See abstract, claims 1-9 and figures 1A-8.	1-15
A	US 2005-0093555 A1 (EHATA) 05 May 2005 See abstract, claims 1-8 and figures 1-9.	1-15



Further documents are listed in the continuation of Box C.



See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search

25 March 2015 (25.03.2015)

Date of mailing of the international search report

26 March 2015 (26.03.2015)

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2014/045098

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