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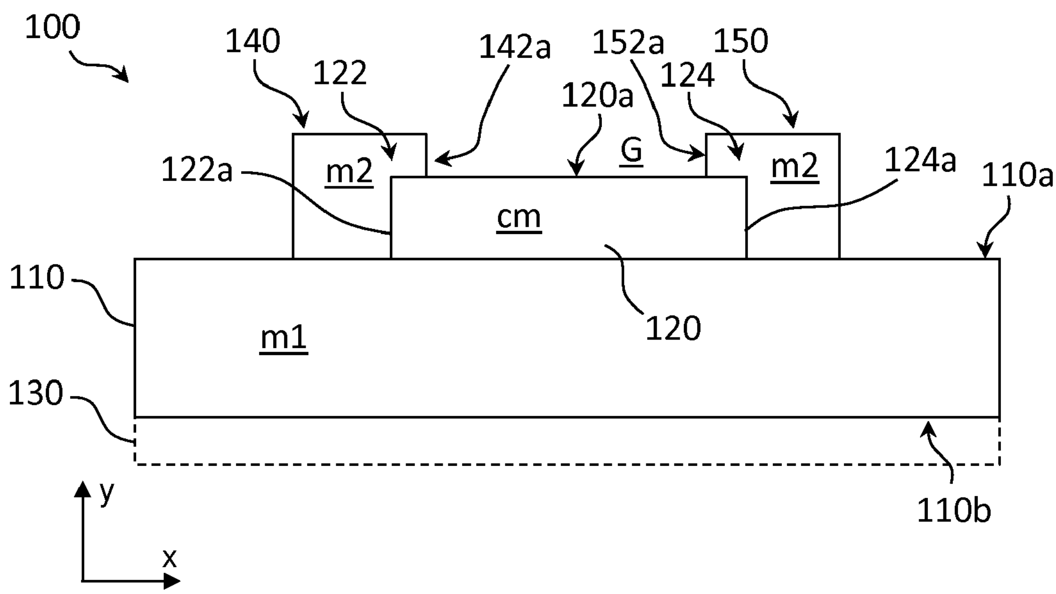
(54) TRANSMISSION LINE FOR RADIO FREQUENCY SIGNALS AND METHOD OF PROVIDING A TRANSMISSION LINE

(57) Transmission line for radio frequency, RF, signals, wherein said transmission line comprises a substrate comprising a first dielectric material having a first relative permittivity, and at least one conductor arranged on a first surface of said substrate, wherein at least one edge of said at least one conductor is covered with a second dielectric material having a second relative permittivity, wherein a thickness of said second dielectric material is smaller than about a thickness of said substrate.

Fig. 2



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Description

Field of the invention

[0001] The disclosure relates to a transmission line for radio frequency, RF, signals. The disclosure further relates to a method of providing such transmission line. This disclosure further relates to a system comprising at least one such transmission line.

Background

[0002] Passive intermodulation (PIM) is a form of intermodulation distortion that occurs in passive RF components such as transmission lines, e.g. of the microstrip line type on printed circuit boards (PCB), carrying two or more high-power input signals. PIM in e.g. a transmission path of a system comprising such transmission line(s) degrades quality/bandwidth of system. To be specific, it causes serious problems in the design of complete RF systems and since it may occur after a final RF filtering, it typically cannot be removed. Because of this, complete conventional RF systems are usually over-engineered, which leads to increased costs. The problem of PIM has recently become a critical parameter, due to spectral over-population of lower GHz (Gigahertz) bands, where spurious signals generated by PIM exceed the signal intensity of received signals and lead to a loss in capacity.

Summary

[0003] In view of this, some embodiments provide an improved transmission line for radio frequency signals, wherein said transmission line comprises a substrate comprising a first dielectric material having a first relative permittivity, and at least one conductor arranged on a first surface of said substrate, wherein at least one edge of said at least one conductor is covered with a second dielectric material having a second relative permittivity, wherein a thickness of said second dielectric material is smaller than about a thickness of said substrate. According to some embodiments, the transmission line may e.g. be of the microstrip-type. The principle of the embodiments, however, is also applicable to other types of transmission lines as well. According to Applicant's analysis, PIM, which may be generated along the edges of a transmission line, e.g. microstrip line, on a substrate such as a PCB makes a major contribution to a total PIM response of the transmission line. The density of an RF current associated with an RF signal transmitted via said transmission line is strongest at the edges and, in general, the narrower the line (i.e., the smaller the conductor, e.g. microstrip conductor), the greater the current density.

[0004] Microstrip lines on PCBs are usually fabricated on double, copper-clad substrates, by removing copper cladding on one of the sides in a pre-determined patterned fashion (e.g., wet/dry etching, laser ablation to name but a couple). The remaining copper pattern on the substrate may form microstrip lines, e.g. of an RF circuit. According to Applicant's analysis, conventional processes of patterning microstrip lines on an RF substrate tend to leave the edges of a microstrip line uneven and at least microscopically rough, which results in increased electric field intensity and, hence, current density in those regions of roughness. The increased electric field along the edges of the microstrip line may become a major contributor to an entire system PIM level due to the creation of the Schottky diode effect. In this respect, PIM arising from non-linearities in a substrate, i.e. the RF substrate of the transmission line, may be termed "voltage-driven" (because nonlinear products can be described as a function of the applied voltage) and "current-driven" when it arises due increased current densities on a conductor of a transmission line such as a microstrip line. The principle according to the embodiments primarily addresses current-driven non-linearities, e.g. the prevention or mitigation of current-driven PIM within a conductor of a transmission line.

[0005] According to Applicant's analysis, covering at least one edge of said at least one conductor of the transmission line greatly reduces at least current-driven PIM in a very cost-effective way. The approach according to the embodiments enables an efficient reduction of the electric field intensity at the (rough) edges of the transmission line, e.g., microstrip line, without a significant impact on its small-signal, linear parameters (characteristic impedance, loss).

[0006] Advantageously, the approach according to the embodiments is far more reliable and cost effective than conventional and more costly PCB fabrication procedures which target at reducing a surface roughness of a conductor of a transmission line (without a firm guarantee, however) or which propose further post-production processes of surface roughness reduction. According to Applicant's analysis, neither of these conventional techniques is likely to result in full elimination of PIM. By contrast, the approach according to the embodiments enables to reliably reduce an electric field intensity at the edges of a conductor of a transmission line and, hence, PIM.

[0007] While it is known to fully cover a top surface of a transmission (i.e., the substrate and its conductor(s) provided on a top surface of said substrate) with another layer of substrate dielectric material thus "sandwiching" the conductor(s) of the transmission line between two dielectric substrate layers (also referred to as "embedded microstrip line"), this does not efficiently address the abovementioned issue of PIM, particularly current-induced PIM. Furthermore, these conventional measures completely alter the small-signal linear parameters of a transmission line such as characteristic impedance and attenuation (loss). Insofar, the approach according to the embodiments is superior as it efficiently addresses the issue of PIM, particularly current-induced PIM, of transmission lines without a significant impact on the small-signal linear parameters of the transmission line.

[0008] According to preferred embodiments, said second relative permittivity, i.e. the relative permittivity of the second dielectric material, which is applied to at least one edge of at least one conductor of the transmission line, is greater than said first relative permittivity, i.e. the relative permittivity of the substrate material of the transmission line. This effects a particularly efficient reduction of electric field peaks in the area of the edges thus efficiently reducing current-induced PIM.

[0009] According to further embodiments, said second relative permittivity of said second dielectric material is equal to or greater than about 8, preferably about 25 (which may e.g. be achieved by using tantalum pentoxide, Ta_2O_5, having a relative permittivity ε_r ranging between about 25 and about 30), preferably equal to or greater than about 81, which may e.g. be achieved by using distilled water as said second dielectric material. According to Applicant's analysis, values of about 8 or greater for said second relative permittivity may effect a significant PIM reduction according to some embodiments.

[0010] According to further embodiments, additionally to or alternatively to using tantalum pentoxide, Ta_2O_5, at least one of the following materials may also be used as said second dielectric material: hafnium oxide (HfO_2), zirconium oxide (ZrO_2), cerium oxide (CeO_2), to name a few. These materials have a similar ε_r and can be produced in a similar manner.

[0011] As such, according to some embodiments, the second dielectric material is not required to be a solid material (at normal temperature), but may rather comprise a fluid (e.g., a liquid, such as distilled water).

[0012] According to further embodiments at least a side surface of said at least one edge is at least partly, preferably substantially fully, covered with said second dielectric material, which further helps to reduce PIM. This way, particularly, a free space between surface features of a "rough" (at least microscopically rough, i.e. having a roughness in the dimension of e.g. some micrometer, μm, to some ten μm or more) side surface of the conductor of the transmission line may at least partly be filled with said second dielectric material reducing the electric field intensity in that area and thus also contributing to PIM reduction.

[0013] According to further embodiments a first element of said second dielectric material is provided at a first edge (preferably around a corresponding side surface) of said transmission line, and/or a second element of said second dielectric material is provided at a second edge (preferably around a corresponding side surface) of said transmission line. Preferably both edges (and/or the respective side surfaces) of the conductor are at least partly, preferably substantially fully, covered with said second dielectric material.

[0014] According to further embodiments, one element covering (only) one of two edges of said conductor may be provided. According to preferred embodiments, however, two elements are provided wherein a first one of said two elements covers a first edge of said conductor, and wherein a second one of said two elements covers a second edge of said conductor.

[0015] According to further embodiments, if the transmission line comprises more than one conductor, said further conductor(s) may also be covered at their edges with said second dielectric material.

[0016] According to further embodiments, said thickness of said second dielectric material is equal to or smaller than about 10 percent of the thickness of said substrate. These embodiments have an even further reduced impact on linear parameters of the transmission line, while still offering superior PIM reduction.

[0017] According to further embodiments, a thickness of said second dielectric material is equal to or smaller than about a thickness of said conductor. These embodiments have an even further reduced impact on linear parameters of the transmission line, while still offering PIM reduction.

[0018] According to further embodiments, a width of said second dielectric material is equal to or smaller than about 150 percent of a width of said conductor, and/or wherein a width of said second dielectric material is equal to or greater than about 100 percent of a width of said conductor, preferably greater than about 102 percent of a width of said conductor. These embodiments are characterized by a particularly small impact on (small-signal) linear parameters (characteristic impedance, loss) of the transmission line as compared to a configuration without any second dielectric material, while offering superior PIM reduction.

[0019] According to further embodiments, a gap, preferably an air gap, is provided between opposing side surfaces of said first element of said second dielectric material and said second element of said second dielectric material. This has the effect of avoiding any unnecessary dielectric loading of said conductor from a PIM mitigation point of view.

[0020] According to further embodiments, a width of said gap ranges between about 90 percent of a width of said conductor and about 100 percent of a width of said conductor, preferably between about 95 percent of a width of said conductor and about 99 percent of a width of said conductor. In other words, the first element of said second dielectric material and said second element of said second dielectric material are provided substantially only in the edge regions of the conductor of the transmission line, where a particularly efficient PIM mitigation is possible, while a central surface region of the conductor remains uncovered by said second dielectric material thus avoiding dielectric losses as known from conventional (embedded) microstrip lines.

[0021] According to further embodiments, said first element and/or said second element comprises a respective housing for receiving a fluid, particularly a liquid. This enables to provide and confine a fluid as said second dielectric material in the region of the edge(s) of the conductor to enable efficient PIM mitigation.

[0022] According to further embodiments, said housing comprises or is made of a material having a third relative permittivity, wherein said third relative permittivity is smaller than said second relative permittivity, thus limiting the dielectric loading of the transmission line while at the same time enabling efficient PIM mitigation.

[0023] According to further embodiments, said housing is made of PDMS (Polydimethylsiloxane, a polymeric organosilicon), which enables a cost-effective production of transmission lines with reduced PIM or even retro-fitting existing transmission lines, e.g. by applying said PDMS housing(s) to the existing transmission lines and optionally by filling the PDMS housing(s) with a dielectric material, particularly a high-dielectric material, such as said second dielectric material, for example distilled water.

[0024] According to further embodiments, said second dielectric material is a fluid, preferably liquid, and said housing comprises one or more channels for receiving said fluid.

[0025] According to further embodiments, the housing(s) comprise(s) micro-channels, which micro-channels comprise said second dielectric material. According to some embodiments, said micro-channels comprise a hydraulic diameter of about 1 millimeter (mm) or smaller, wherein preferably said hydraulic diameter ranges between about 10 μm (or some ten μm, e.g. about 20 μm to about 90 μm) and 100 μm (or some hundred μm, e.g. about 200 μm to about 900 μm) .

[0026] According to further embodiments, at least one pump is provided for driving said fluid through said housing and/or said channel(s), which enables efficient tempering, e.g. cooling, of said transmission line in addition to PIM mitigation.

[0027] Further embodiments feature a system for processing radio frequency, RF, signals, comprising at least one transmission line according to the embodiments.

[0028] According to further embodiments, said system comprises at least one of the following elements: an antenna, a transmitter, a receiver, a diplexer and/or at least one filter for said RF signals.

[0029] As an example, some embodiments may relate to an RF antenna system, e.g. for a base station of a cellular communications network, wherein said RF antenna system comprises at least one transmission line according to the embodiments. Advantageously, said RF antenna system does not substantially suffer from PIM as the transmission line according to the embodiments provides for an efficient PIM mitigation.

[0030] Further embodiments feature a method of providing a transmission line for radio frequency, RF, signals, wherein said method comprises the following steps: providing a substrate comprising a first dielectric material having a first relative permittivity, providing at least one conductor on a first surface of said substrate, covering at least one edge of said at least one conductor with a second dielectric material having a second relative permittivity, wherein a thickness of said second dielectric material is smaller than about a thickness of said substrate.

[0031] According to some embodiments, said step of covering comprises applying a sol-gel process which represents a simple and efficient way to cover said at least one edge of said at least one conductor with a second dielectric material having a second relative permittivity. As an example, the sol-gel process enables to prepare a "high-epsilon" dielectric cover as said second dielectric material in form of one or more thin films and has many advantages such as high purity and homogeneity of the so obtained film, as well as low process temperatures (e.g., via using photo-irradiation) and simple equipment setup. According to further embodiments, many high-epsilon dielectric ceramics can be fabricated in this way and deposition techniques are straightforward such as tape casting, dip-coating, spin coating, spray coating etc. According to further embodiments, these simple techniques allow substrates with a large areas or complex structures to be easily coated applying the principle of the embodiments. According to further embodiments, UV

[0032] (ultraviolet)/ozone curing can be used to produce the ceramic dielectric, allowing the entire process to be performed at room temperature.

[0033] According to further embodiments, one example is the fabrication of tantalum pentoxide (Ta_2O_5) films (permittivity $\varepsilon_r \approx$ 25-30). The sol-gel is e.g. synthesized by photo-irradiating a tantalum ethoxide ($Ta_2(OC_2H_5)$ precursor that has been mixed in solution with H_2O (water), C_2H_6O (ethanol) and HCl (hydrochloric acid). According to further embodiments, application of the prepared sol may comprise using a straightforward doctor blade (tape casting) technique followed by UV/ozone curing to remove residual hydrocarbons and promote further crosslinking of the dielectric ceramic. According to further embodiments, thermal curing may also be used alternatively to or in addition to UV/ozone curing for cross-linking a sol-gel.

[0034] Advantageously, according to some embodiments using a sol-gel process, the second dielectric material is applied in fluid form thus penetrating between rough edges of the conductor, but it becomes a solid dielectric after curing so that e.g. no housing is needed to keep it in place.

[0035] According to further embodiments, said step of covering comprises providing at least one housing for receiving a fluid, e.g. a liquid such as distilled water. According to further embodiments, after providing at least one housing, said fluid, e.g. the liquid, may be filled into the housing, i.e. via one or more channels of the housing, whereby the liquid is brought in place around the at least one edge of the conductor of the transmission line.

[0036] According to further embodiments, the method may also comprise retro-fitting an existing, conventional transmission line, e.g. by providing an existing, conventional transmission line, and by applying a covering step (applying solid second dielectric material and/or liquid second dielectric material) according to at least one of the preceding embodiments.

Brief description of the figures

[0037] Further features, aspects and advantages of the embodiments are given in the following detailed description with reference to the drawings in which:

Figure 1A	schematically depicts a top view of an ideal transmission line,
Figure 1B	schematically depicts a top view of a real transmission line,
Figure 2	schematically depicts a front view of transmission line according to an embodiment,
Figure 3	schematically depicts a front view of transmission line according to a further embodiment,
Figure 4A	schematically depicts a loss and an impedance of a transmission line according to further embodiments,
Figure 4B	schematically depicts a loss and an impedance of a transmission line according to further embodiments,
Figure 4C	schematically depicts a characteristic impedance of a transmission line according to further embodiments,
Figure 5	schematically depicts a front view of a detail of a transmission line according to an embodiment,
Figure 6A, 6B	schematically depict aspects of providing a transmission line according to further embodiments,
Figure 7	schematically depicts a front view in partial cross-section of a transmission line according to a further embodiment,
Figure 8A, 8B	schematically depict scattering parameters of a transmission line according to further embodiments,
Figure 9A, 9B	schematically depict a power level of third order intermodulation products according to further embodiments,
Figure 10	schematically depicts a block diagram of a system according to the embodiments,
Figure 11A	schematically depicts a simplified flowchart of a method according to an embodiment, and
Figure 11B	schematically depicts a simplified flowchart of a method according to a further embodiment.

Description of the embodiments

[0038] Figure 1A schematically depicts a top view of an ideal transmission line 10 for RF signals comprising a dielectric substrate 12 and an ideal conductor 14 arranged on a surface of said substrate. The ideal conductor 14 of the ideal transmission line 10 comprises smooth edges having substantially vanishing roughness so that no passive intermodulation (PIM) as known from conventional transmission lines is expected.

[0039] Figure 1B schematically depicts a top view of a real transmission line 10a comprising a substrate 12 and a real, i.e. non-ideal, conductor 14 which comprises edges 14a' having non-vanishing roughness so that PIM may be encountered.

[0040] Figure 2 schematically depicts a front view of a transmission line 100 according to an embodiment. The transmission line 100 comprises a substrate 110 comprising a first dielectric material m1 having a first relative permittivity. As an example, the substrate 110 may comprise a printed circuit board (PCB), e.g. made from FR4 material. On a first surface 110a of said substrate 110, at least one conductor 120 is arranged. According to further embodiments, the transmission line 100 may also comprise more than one conductor arranged on said first surface 110a (not shown). Optionally, a further conductor 130, e.g. defining a ground plane, may be provided at a second surface 110b of the substrate.

[0041] According to the principle of the embodiments, at least one edge 122, 124 (presently both edges 122, 124) of said at least one conductor 120 is covered with a second dielectric material m2 having a second relative permittivity, wherein preferably said second relative permittivity is greater than said first relative permittivity. As an example, the first relative permittivity of the substrate 110 may e.g. be in the range of about 3.8 to about 4.5 (example for FR4 PCB), while the second relative permittivity may e.g. be in the range of 20 and greater.

[0042] According to some embodiments, tantalum pentoxide, Ta_2O_5, may be used as said second dielectric material m2, having a relative permittivity ε_r ranging between about 25 and about 30. According to further embodiments, distilled water with a relative permittivity of about 81 may be used as said second dielectric material.

[0043] According to further embodiments, the conductor 120 may consist of copper or another material with comparable electric conductivity or better.

[0044] According to further embodiments, at least a side surface 122a, 124a of said at least one edge 122, 124 is at least partly, preferably substantially fully, covered with said second dielectric material m2, which further helps to reduce PIM. This way, particularly, a free space between surface features of a "rough" (at least microscopically rough, i.e. having a roughness in the dimension of e.g. some micrometer, μm, to some ten μm or more) side surface of the conductor 120 of the transmission line 100 may at least partly be filled with said second dielectric material m2 reducing the electric field in that area during operation and thus also contributing to PIM reduction.

[0045] According to further embodiments, a first element 140 of said second dielectric material m2 is provided at a first edge 122 (preferably around a corresponding side surface, as depicted by Fig. 2), and a second element 150 of said second dielectric material m2 is provided at a second edge 124 (again preferably around a corresponding side surface). Preferably, both edges 122, 124 of the conductor 120 (and/or the respective side surfaces 122a, 124a) of the conductor 120 are at least partly, preferably substantially fully, covered with said second dielectric material m2.

[0046] According to further embodiments (not shown), one element covering (only) one of two edges of said conductor may be provided. According to preferred embodiments, however, two elements 140, 150 as depicted by Fig. 2 are provided.

[0047] According to further embodiments, if the transmission line comprises more than one conductor 120 (not shown), said further conductor(s) may also be covered at (one or more of) their edges with said second dielectric material m2. In these cases, too, it may be preferable to "smoothen", i.e. at least partly fill, non-ideal, rough surface portions of the edges of the respective conductor (not shown) thus reducing an electric field and hence PIM. For this purpose, the second dielectric material m2 may be arranged to cover a portion (preferably only a small portion) of the surface 120a (or a comparable surface of the further conductor), as well as at least portions of respective side surfaces of said further conductor. However, a mutual coupling of the several conductors in these cases by means of the second dielectric material m2 is not desired (and not required for attaining PIM mitigation according to some embodiments). For this reason, in embodiments with more than one conductor 120, i.e. on the same substrate surface 110a, the amount of the second dielectric material m2 between adjacent conductors (not shown) may be minimized according to further embodiments, and it would be preferable that adjacent conductors are not (not even "indirectly") connected with each other by means of said second dielectric material m2 proposed to be applied to the conductors' edges for PIM mitigation. Instead, an air gap may be provided between such portions of the second dielectric material m2, similar to the air gap G in the central surface region 120a of the conductor 120 of Fig. 2. The air gap G is created by limiting the overlap of respective opposing side surfaces 142a, 152a of the elements 140, 150.

[0048] Additionally, in Fig. 2 a horizontal axis x and a vertical axis y is indicated. A thickness of the substrate 110 and the conductor 120 may be measured along said vertical axis y, and a width of the substrate 110 and the conductor 120 and the air gap G may be measured along said horizontal axis x.

[0049] Figure 3 schematically depicts a front view of a transmission line 100a according to a further embodiment. A thickness Ts of the substrate 110 may e.g. range between 0.1 mm (millimeter) and 4 mm, presently about 1.52 mm. A thickness Tm of the conductor 120 may e.g. range between about 10 μm (micrometer) and about 70 μm, presently about 35 μm. A width W0 of the conductor 120 may e.g. range between about 100 μm (micrometer) and about 10 mm, presently about 3.4 mm.

[0050] According to preferred embodiments, a width Wc of the air gap G may e.g. range between about 90 percent and about 100 percent of the width W0 of said conductor 120, preferably between about 95 percent and about 99 percent of said width W0. As an example, Wc = 0.95 * W0, where "*" is the multiplication operator. In other words, the first element 140 of said second dielectric material and said second element 150 of said second dielectric material are provided substantially only in the edge regions of the conductor 120 of the transmission line 100a, where a particularly efficient PIM mitigation is possible, while a central surface region of the conductor 120 remains uncovered by said second dielectric material m2 (Fig. 2) thus avoiding dielectric losses as known from conventional (embedded) microstrip lines.

[0051] According to particularly preferred embodiments, a thickness Td of said second dielectric material is smaller than about a thickness Ts of said substrate 110. These embodiments are characterized by a particularly small impact on (small-signal) linear parameters (characteristic impedance, loss) of the transmission line 100a as compared to a configuration without any second dielectric material.

[0052] According to further embodiments, said thickness Td of said second dielectric material m2 (elements 130, 150) is equal to or smaller than about 10 percent of the thickness Ts of said substrate 110. According to further embodiments, the thickness Td of said second dielectric material is equal to or smaller than about a thickness Tm of said conductor 120.

[0053] According to further embodiments, a width Wd of said second dielectric material is equal to or smaller than about 150 percent of the width W0 of said conductor.

[0054] According to further embodiments, the width Wd of said second dielectric material m2 (Fig. 2) is equal to or greater than about 100 percent of a width W0 (Fig. 3) of said conductor 120, preferably greater than about 102 percent of the width W0 of said conductor. These embodiments are characterized by a particularly small impact on (small-signal) linear parameters (characteristic impedance, loss) of the transmission line 100a as compared to a configuration without any second dielectric material, while offering superior PIM reduction.

[0055] In the following, simulation results will be presented with reference to Fig. 4A, 4B, 4C, which have been obtained on the basis of the configuration explained above with reference to Fig. 3 and the following assumptions: Ts = 1.52 mm, Tm = 35 μm, width W0 of the conductor 120 W0 = 3.4 mm, width Wc of the air gap G Wc = 0.95 * W0, and the second relative permittivity of the elements 140, 150 (Fig. 3) is 81 (e.g., assuming distilled water as second dielectric material m2).

[0056] Figure 4A schematically depicts a loss and an impedance of the transmission line 100a (Fig. 3) according to further embodiments over a ratio r1 (Fig. 4A) of a thickness Td of said second dielectric material and the substrate thickness Ts, Td/Ts. The loss is indicated by curve C1 and scaled in decibel (dB) per inch (1 inch = 0.0254 m (meter)) on a vertical axis y1, and the characteristic impedance of the transmission line 100a is indicated by curve C2 and scaled in the unit Ohm on a vertical axis y2. For the depiction of Fig. 4A it is exemplarily assumed that Wd = 4 * W0. It can be seen that for comparatively small ratios r1 in a first range RNG1 between about 0.05 and about 0.075, the loss C1 is not substantially increased and the impedance C2 is not substantially decreased as compared to a configuration without the second dielectric material m2 or a vanishing layer thickness Td thereof, which corresponds with a value of 0.0 for said ratio r1. In other words, if the layer thickness Td is comparatively small with respect to substrate thickness Ts, cf. the first range RNG1, the transmission line parameters loss and impedance are not severely affected, while at the same time this configuration attains efficient PIM mitigation according to Applicant's analysis.

[0057] Figure 4B schematically depicts a loss and an impedance of a transmission line 100a (Fig. 3) according to further embodiments over a ratio r2 (Fig. 4A) of a width Wd of said second dielectric material and the width W0 of said conductor 120, Wd/W0. The loss is indicated by curve C3 and scaled in decibel (dB) per inch on a vertical axis y3, and the characteristic impedance of the transmission line 100a is indicated by curve C4 and scaled in Ohms on the vertical axis y4. For the depiction of Fig. 4B it is exemplarily assumed that Td = Ts. It can be seen that for comparatively small ratios r2 in a second range RNG2 between about 1.0 and about 1.5, the loss C3 is not substantially increased and the impedance C4 is not substantially decreased as compared to a configuration without the second dielectric material m2 or a vanishing width Wd thereof, which corresponds with a value of 0.0 for said ratio r2. In other words, if the width Wd is not much larger than the width W0 of the conductor 120, cf. the second range RNG2, the transmission line parameters loss and impedance are not severely affected, while at the same time this configuration attains efficient PIM mitigation according to Applicant's analysis.

[0058] Figure 4C schematically depicts a characteristic impedance of a transmission line 100a (Fig. 3) according to further embodiments, over a ratio r3 of a thickness Td of said second dielectric material and the substrate thickness Ts, Td/Ts, similar to ratio r1 of Fig. 4A.

[0059] The characteristic impedance of the transmission line 100a is indicated by curves C5, C6, C7, C8 and scaled in Ohms on the vertical axis y5. For the depiction of Fig. 4C, the width Wd (Fig. 3) of the second dielectric material is used as a parameter, wherein curve C5 corresponds with a width Wd = 4 * W0, curve C6 corresponds with a width Wd = 3 * W0, curve C7 corresponds with a width Wd = 2 * W0, and curve C8 corresponds with a width Wd = 1.5 * W0.

[0060] It can be seen that for curve C8, i.e. Wd = 1.5 * W0, the impedance C8 is not substantially decreased over a wide range of values for said ratio r3 from about 0.0 to about 1.0. This is indicated by the third range RNG3 indication impedance values between about 40 Ohm and about 50 Ohm. In other words, for a wide range of thickness ratios Td/Ts, in the case of Wd = 1.5 * W0, i.e. curve C8, the impedance of the transmission line 100a (Fig. 3) does not substantially change, i.e. does not leave the third range RNG3, while at the same time this configuration, too, attains efficient PIM mitigation according to Applicant's analysis.

[0061] According to further embodiments, in the light of the simulation results discussed above with reference to Fig. 3, 4A, 4B, 4C, for PIM mitigation applications, a very thin dielectric layer of said second dielectric material m2 may be deposited as this results in very little dielectric loading of the transmission line 100a and hence very minor changes of its linear parameters, such as characteristic impedance and phase velocity.

[0062] According to further embodiments, it may be beneficial to deposit said second dielectric material m2 (i.e., schematically represented by the elements 140, 150 of Fig. 3) between the rough edges of the transmission line 100a or its conductor 120, for example via liquid or vapor phase deposition, optionally followed by curing.

[0063] According to further embodiments, the second dielectric material m2 may only cover immediate rough edges of the microstrip line or its conductor 120, respectively. Since according to some embodiments, the rough edges may have a length dimension of e.g. tens of microns (pm), this indicates that according to further embodiments a minimum portion of the microstrip line or its conductor 120 that may be covered in/with said second dielectric 22 is also in a range of tens of microns.

[0064] However, according to some embodiments, this range of tens of microns may be considered as a smallest dimension (i.e., lower limit) and, according to further embodiments, in practical applications, a greater area may be covered, but this may be dependent on the width W0 of the particular microstrip line conductor 120.

[0065] According to further embodiments, exact dimensions for a geometry (width Wd, thickness Td) of the second dielectric material m2 (Fig. 3) based on a desired tolerable loss and impedance can be found by constructing a plot, which shows a dependence of linear parameters on both dielectric thickness Td and width Wd simultaneously, similar to Fig. 4C.

[0066] According to further embodiments, nevertheless, the upper bound of the thickness Td of the deposited second dielectric material m2 may be substantially commensurate with the thickness Tm of the conductor 120.

[0067] According to further embodiments, a similar reasoning as in the preceding passages can be applied for the width, Wd, as also evidenced by Fig. 3, 4A, 4B, 4C. As an example, according to preferred embodiments, the width Wd may not be greater than 1.5 W0, but it can be lower than that, cf. the range RNG3 of Fig. 4C.

[0068] According to further embodiments, by bearing in mind the above considerations based on Fig. 3, 4A, 4B, 4C, the linear parameters of the transmission line, such as insertion and return losses, characteristic impedance, phase velocity and propagation constant are minimally affected, in many embodiments well below 20 % (percent) of their nominal value (i.e., as compared to conventional transmission lines without the PIM mitigation approach according to some embodiments, or conventional embedded transmission lines, which are purposefully loaded with a dielectric in order to affect the linear parameters, such as insertion and return losses, characteristic impedance, phase velocity and propagation constant).

[0069] Figure 5 schematically depicts a front view of a detail of a transmission line 100b according to a further embodiment. According to some embodiments, the second dielectric material m2, cf. the element 140, is provided such to the edge 122 of the conductor 120 that a horizontal overlap o1 ranges between about 0 μm and about 200 μm, preferably between about 0 μm and about 50 μm.

[0070] According to further embodiments, the second dielectric material m2, cf. the element 140, is provided such to the edge 122 of the conductor 120 that a vertical overlap o2 ranges between about 0 μm and about 120 μm, preferably between about 0 μm and about 25 μm.

[0071] According to further embodiments, the second dielectric material m2, cf. the element 140, is provided such to the edge 122 of the conductor 120 that a width w1 ranges between about 50 μm and about 220 μm, preferably between about 50 μm and about 110 μm.

[0072] Further embodiments feature a method of providing a transmission line for radio frequency, RF, signals, wherein said method comprises the following steps, cf. the flow-chart of Fig. 11A: providing 200 a substrate 110 (Fig. 2) comprising a first dielectric material m1 having a first relative permittivity, providing 210 (Fig. 11A) at least one conductor 120 (Fig. 2) on a first surface 110a of said substrate 110, covering 220 (Fig. 11A) at least one edge 122, 124 (Fig. 2) of said at least one conductor 120 with a second dielectric material m2 having a second relative permittivity.

[0073] According to some embodiments, said step 220 of covering comprises applying a sol-gel process which represents a simple and efficient way to cover said at least one edge 122, 124 of said at least one conductor 120 with a second dielectric material m2 having a second relative permittivity. As an example, the sol-gel process enables to prepare a "high-epsilon" dielectric cover as said second dielectric material m2 in form of one or more thin films and has many advantages such as high purity and homogeneity of the so obtained film, as well as low process temperatures (e.g., via using photo-irradiation) and simple equipment setup. According to further embodiments, many high-epsilon dielectric ceramics can be fabricated in this way and deposition techniques are straightforward such as tape casting, dip-coating, spin coating, spray coating etc.

[0074] According to further embodiments, these simple techniques allow substrates with a large areas or complex structures to be easily coated applying the principle of the embodiments. According to further embodiments, UV (ultraviolet)/ozone curing can be used to produce the ceramic dielectric, allowing the entire process to be performed at room temperature.

[0075] According to further embodiments, one example is the fabrication of tantalum pentoxide (Ta_2O_5) films (permittivity $\varepsilon_r \approx 25\text{-}30$) as said second dielectric material m2. The sol-gel is e.g. synthesized by photo-irradiating a tantalum ethoxide ($Ta_2(OC_2H_5)$) precursor that has been mixed in solution with H_2O (water), C_2H_6O (ethanol) and HCl (hydrochloric acid). According to further embodiments, application, cf. step 222 of Fig. 11B, of the prepared sol may comprise using a straightforward doctor blade (tape casting) technique followed by UV/ozone curing, cf. step 224 of Fig. 11B, to remove residual hydrocarbons and promote further crosslinking of the dielectric ceramic.

[0076] This is schematically exemplarily depicted by Figures 6A, 6B which depict aspects of providing a transmission line 100c according to further embodiments. Fig. 6A shows a substrate 110 of a first dielectric material m1 (also cf. Fig. 2), and a real conductor 120 formed thereon, e.g. by using conventional processes. The real conductor 120 has rough edges 122, 124 which may cause unwanted PIM. Hence, a sol-gel process is applied as explained above with reference to Fig. 11A, 11B, cf. the prepared sol symbolically depicted by element 200 of Fig. 6A, which is applied to the surface of the substrate 110 and the conductor 120, particularly around at least one of said rough edges 122, 124 using a doctor blade (Fig. 6B). After that, radiation, e.g. UV radiation, is applied to the so prepared setting to effect curing, as mentioned above, cf. the block arrows denoted with reference sign hv.

[0077] According to further embodiments, said step 220 (Fig. 11A) of covering comprises providing at least one housing for receiving a fluid, e.g. a liquid such as distilled water, on the surface 110a (Fig. 2) of the substrate 110.

[0078] According to further embodiments, after providing said at least one housing, said fluid, e.g. the liquid, may be filled into the housing, i.e. via one or more channels of the housing, whereby the liquid is brought in place around the at least one edge of the conductor of the transmission line.

[0079] According to further embodiments, the method may also comprise retro-fitting an existing, conventional transmission line, e.g. by providing said existing, conventional transmission line, and by applying step 220 in any of the aforementioned variants thereto.

[0080] Figure 7 schematically depicts a front view in partial cross-section of a transmission line 100d according to a further embodiment. Presently, said first element and/or said second element comprises a respective housing 143, 153 for receiving a fluid 146, 156, particularly a liquid such as distilled water. This enables to provide and confine the fluid as said second dielectric material in the region of the edge(s) 122, 124 of the conductor 120 of the transmission line 100d to enable efficient PIM mitigation.

[0081] According to further embodiments, said housing 143, 153 comprises or is made of a material having a third relative permittivity, wherein said third relative permittivity is smaller than said second relative permittivity, thus limiting the dielectric loading of the transmission line 100d while at the same time enabling efficient PIM mitigation.

[0082] According to further embodiments, said housing 143, 153 is made of PDMS (Polydimethylsiloxane, a polymeric organosilicon), which enables a cost-effective production of transmission lines 100d with reduced PIM or even retro-fitting existing transmission lines, e.g. by applying said PDMS housing(s) to the existing transmission lines (cf. reference sign 10a of Fig. 1B), and optionally by filling the PDMS housing(s) with a dielectric material, particularly a high-dielectric material, such as said second dielectric material, for example distilled water.

[0083] In other words, according to further embodiments, existing conventional transmission lines with rough edges suffering from PIM may be retro-fitted or "upgraded" by applying the second dielectric material m2 as explained above. Said step of applying for retro-fitting may e.g. comprise embodiments using sol-gel processes (Fig. 6A, 6B) and/or providing fluid housings as mentioned above.

[0084] According to further embodiments, said second dielectric material m2 is a fluid, preferably liquid, and said housing 143, 153 comprises one or more channels 144, 154 for receiving said fluid. According to further embodiments, the housing(s) 143, 153 comprise(s) micro-channels, which micro-channels comprise said second dielectric material.

[0085] According to some embodiments, said micro-channels comprise a hydraulic diameter of about 1 millimeter (mm) or smaller, wherein preferably said hydraulic diameter ranges between about 10 μm (or some ten μm, e.g. about 20 μm to about 90 μm) and 100 μm (or some hundred μm, e.g. about 200 μm to about 900 μm).

[0086] According to further embodiments, at least one pump 160 (Fig. 7) is provided for driving said fluid 146, 156 through said housing 143, 153 and/or said channel(s) 144, 154 (and/or micro-channels), which enables efficient tempering, e.g. cooling, of said transmission line 100d in addition to PIM mitigation.

[0087] According to further embodiments, to experimentally demonstrate the usability and effectiveness of the approach according to the embodiments, the effect of applying a second dielectric material m2 (Fig. 2), e.g. in the form of a dielectric coating, on small- and large-signal characteristics of transmission lines 100, e.g. microstrip lines, was further investigated. It was decided to use uniform microstrip lines of length L=275 mm printed on RF-35 and TLF-35 substrates (organic-ceramic laminates with woven glass reinforcement) as the test cells, which represents a configuration similar to that of Fig. 1B.

[0088] According to a first comparative example ("example 1"), microstrip lines or their conductor 14a (Fig. 1B) were covered by a specially made housing or cover from PDMS material. Liquid dielectric (e.g., distilled water) was injected into an air gap between the microstrip line and top surface of the PDMS housing, which is substantially comparable to a scenario as depicted by Fig. 4A. The dimensions of this gap are equal to about 250x20x0.8 mm^3. The PDMS housing was used to prevent a leakage and evaporation of water.

[0089] According to a second comparative example ("example 2"), to demonstrate the advantages of the second dielectric material m2 penetrating the regions of rough edges, the same transmission lines were covered by solid ceramic dielectric bodies (not shown) with a permittivity of $\varepsilon r = 30$, which - in contrast to a dielectric fluid, cannot enter the rough surface regions of the conductor 14a. In other words, these solid ceramic dielectric bodies substantially only covered a top surface of the conductor 14a, but not rough portions of the edges 14a' or side surfaces of said conductor 14a.

[0090] After that, the scattering parameters were measured in the frequency range from about 0.6 GHz to about 2 GHz, cf. Fig. 8A, 8B, wherein Fig. 8A depicts along a vertical axis y6 the scattering parameter S11 (characterizing an input reflection coefficient) over frequency f1 in the abovementioned range, and wherein Fig. 8B depicts along a vertical axis y7 the scattering parameter S21 (characterizing a forward transmission coefficient) over frequency f2 in the same abovementioned range.

[0091] In Fig. 8A, the curve C9 represents the scattering parameter S11 for a reference transmission line (i.e., conventional construction with rough edges and no dielectric cover, i.e. especially without water and ceramic dielectrics), the curve C10 represents the scattering parameter S11 for a transmission line with distilled water as said second dielectric material m2 according to the embodiments provided at both edges 122, 124 of the conductor 120, similar to the embodiment of Fig. 7 explained above, the curve C11 represents the scattering parameter S11 for a transmission line entirely immersed in distilled water (cf. "example 1" defined above, i.e. the distilled water not only covering the edges but also a top surface 120a of the conductor), and the curve C12 represents the scattering parameter S11 for a transmission line a conductor's surface 120a of which is covered with solid dielectric bodies, cf. "example 2" defined above.

[0092] In Fig. 8B, depicting the scattering parameter S21, curve C13 is associated with said reference transmission line, curve C14 is associated with said transmission line with distilled water as said second dielectric material m2 according to the embodiments provided at both edges 122, 124 of the conductor 120, similar to the embodiment of Fig. 7 explained above, curve C15 is associated with the "example 1" transmission line defined above, and curve C16 is associated with the "example 2" transmission line defined above.

[0093] Since the small-signal parameters of microstrip lines printed on RF-35 and TLG-35 substrates are almost identical, only the S parameters S11, S21 relating to RF-35 substrate are exemplarily presented in these figures 8A, 8B. As mentioned, the measured scattering parameters of a reference microstrip line (without water and ceramic dielectrics), cf. curves C9/C13, and a microstrip line entirely immersed in water, cf. curves C11/C15, are plotted on the same graph for comparison.

[0094] As can be seen, in the case when the entire microstrip line is immersed in water (curve C11), the transmission coefficient S21 (Fig. 8B) drops quite significantly, especially at higher frequencies. This situation can be significantly improved according to the embodiments, where e.g. only small areas around the microstrip line edges 122, 124 are covered in water as said second dielectric medium m2 (see Fig. 7).

[0095] According to Applicant's analysis, the embodiment depicted in Fig. 7 represents a particularly efficient physically realizable and usable solution for the reduction of PIM, when the dielectric is in a liquid form. In this case, the dielectric liquid 146, 156 is contained along the rough edges of a microstrip line (or, more precisely, along the rough edges of its conductor 120) in a low dielectric constant container (e.g. the PDMS housing 143, 153).

[0096] Similar advantages may also be obtained with further embodiments, wherein a second dielectric material is applied in a sol-gel process as already mentioned above, as the sol-gel liquid will also penetrate between the rough edges and will remain in place by forming into a solid dielectric following UV/ozone (and/or thermal) curing - without the need for housing, that may be required for second dielectric material according to some embodiments that is permanently in the liquid phase.

[0097] As can also be seen from Fig. 8A, 8B, the placing of solid ceramic dielectrics on top of the microstrip line (curve C12) increases insertion losses compared to the case of the reference microstrip line (curve C9).

[0098] After that the forward PIM products generated on microstrip lines covered by water (both partially and entirely) and a ceramic dielectric at a frequency of 1870 MHz (carrier frequencies f1 = 1930 MHz and f2 = 1990 MHz) were measured in a range of carrier powers from 36 dBm to 46 dBm, see Fig. 9A, 9B. Exemplarily, the PCS 1900 band has been chosen for further analysis because the variation of the transmission coefficient for all considered scenarios is large as compared to variations within the E-GSM 900 frequency band.

[0099] Figure 9A, 9B schematically depict a power level of measured third order intermodulation products ("PIM3 products") according to further embodiments, generated on RF-35 (Fig. 9A, vertical axis y7) and TLF-35 (Fig. 9B, vertical axis y8) type PCBs as substrate covered by water and ceramic dielectric as a function of carrier sweep power P0, cf. the axes p1, p2.

[0100] In the Figures 9A, 9B, curves C17, C21 are associated with said reference transmission line, curves C20, C24 are associated with said transmission line with distilled water as said second dielectric material m2 according to the embodiments provided at both edges 122, 124 of the conductor 120, similar to the embodiment of Fig. 7 explained above, curves C19, C23 are associated with the "example 1" transmission line defined above, and curves C18, C22 are associated with the "example 2" transmission line defined above.

[0101] Several aspects may be taken into consideration. First, ceramic coating with solid bodies (curves C18, C22) cannot mitigate PIM generated on microstrip lines, small reduction (around 2.5 dB) that we can observe in Fig. 9A can be explained by the degradation of transmission coefficient (around 1 dB). In this case, the amplitude of the current density is decreased due to additional losses and the change of the propagation environment.

[0102] On the other hand, according to further embodiments, using liquid dielectric materials allows a decrease in the nonlinear response of the tested microstrip lines. It may be mentioned that the measured PIM response of both microstrip lines becomes almost equal after water coating in spite of the fact that their initial PIM responses were quite different. This infers that this approach allows the mitigation of nonlinear products generated by a specific nonlinear source, in this case the current driven nonlinearity. In the considered cases, according to further embodiments, the sources of PIM were located along the line edges 122, 124, and they were much stronger in the case of RF-35 PCB. Moreover, according to further embodiments, we find a very good overall transmission behaviour when only the edges of the microstrip are covered by the liquid dielectric layer (water), similar to the embodiment of Fig. 7. In this case, small-signal characteristics of microstrip lines do not degrade significantly as compared to the nonlinear products. For example, PIM level was decreased by 28 dB for the microstrip line printed on the RF-35 substrate and by 4.5 dB for TLF-35 PCB, while the transmission coefficient was decreased by less than 0.7 dB.

[0103] On the other hand, according to further embodiments, using liquid dielectric materials allows a decrease in the nonlinear response of the tested microstrip lines. It may be mentioned that the measured PIM response of both microstrip lines becomes almost equal after water coating in spite of the fact that their initial PIM responses were quite different. This infers that this approach allows the mitigation of nonlinear products generated by a specific nonlinear source, in this case the current driven nonlinearity. In the considered cases, according to further embodiments, the sources of PIM were located along the line edges, and they were much stronger in the case of RF-35 PCB. Moreover, as it was demonstrated, according to further embodiments, only the edges may be covered by this liquid dielectric layer to attain a desired effect. In this case, small-signal characteristics of microstrip lines do not degrade significantly as compared to the nonlinear products. For example, PIM level was decreased by 28 dB for the microstrip line printed on the RF-35 substrate and by 4.5 dB for TLF-35 PCB, while the transmission coefficient was decreased by less than 0.7 dB.

[0104] These insights prove that the approach according to the embodiments is both cost effective and useful in combating PIM.

[0105] A particular strength of the approach according to the embodiments lies in its simplicity. According to preferred embodiments, the edges 122, 124 of microstrip lines or their conductor(s) 120, respectively, which may form part of a complete RF system 1000, cf. below, and which are exhibiting PIM can e.g. be covered with liquid-filled micro-channels in PMDS (cf. Fig. 7) or by applying a sol-gel technique in order to reduce PIM.

[0106] In this way, even existing systems, which are deemed to exhibit PIM, may efficiently be retro-fitted with a simple, yet, very effective solution. It is believed that this will not only result in cost savings on new systems which will implement this solution, but it will also allow older, PIM exhibiting systems to be retro-fitted with this simple solution. According to further embodiments, since the liquid in the micro-channels does not need to be stationary according to Applicant's analysis, one can have a liquid running through the micro-channels for combined substrate cooling and PIM control. In this way, effectively two big problems inherent to complete RF systems can be solved using the approach of the embodiments.

[0107] Further embodiments feature a system 1000 for processing radio frequency, RF, signals, comprising at least one transmission line according to the embodiments. An exemplary system 1000, which may be a simplified complete Frequency Division Duplex (FDD) system, is shown by Fig. 10. Both a transmitter 1004 and a receiver 1006 are connected to a Diplexer 1008, which feeds a common antenna 1002. Evidently, there is a huge disparity between the amount of RF signal powers present at the transmitter 1004 and the receiver 1006. According to some embodiments, the transmitter 1004 may need to generate 10s or even 100s of watts, whereas the receiver 1006 handles very low powers, all the way down to microwatts (pW). As such, the connection 100e between the transmitter 1004 and the diplexer 1008 is the main source of PIM signals, which may enter the receiver 1006. In that case, the receiver 1006 becomes non-functional and the whole system 1000 needs to be replaced. By using transmission lines according to the embodiments, especially for the transmission line(s) 100e connecting the transmitter 1004 and the diplexer 1008, the amount of PIM is significantly reduced. This results in substantially PIM free operation.

[0108] Further, in order to provide a further PIM barrier, according to further embodiments, the transmission line(s) 100f connecting the receiver 1006 and the diplexer 1008 and the transmission line(s) 100g connecting the output of the diplexer 1008 and the antenna 1002 can also be provided according to the embodiments, e.g. covered in a proposed liquid solution, cf. Fig. 7.

[0109] According to some embodiments, new RF systems such as the system 1000 depicted above or generally any RF system processing RF signals may be provided with at least one transmission line according to the embodiments to provide efficient PIM mitigation and/or cooling.

[0110] According to further embodiments, even existing, conventional RF systems, particularly such RF systems suffering from PIM, may be retrofitted by covering the edge(s) 122, 124 of at least one conductor 120 (Fig. 2) of a transmission line of said existing, conventional RF systems with a second dielectric material m2 according to the embodiments. Also, according to further embodiments, fluid housing(s), cf. Fig. 7, may be applied to existing RF systems to upgrade them in the sense of the embodiments, cf. e.g. Fig. 7, so that even fluid-dielectric-based PIM mitigation and/or cooling is enabled.

[0111] As an example, further embodiments may relate to an RF antenna system, e.g. for a base station of a cellular communications network, wherein said RF antenna system comprises at least one transmission line 100, 100a, 100b, 100c, 100d according to the embodiments. Advantageously, said RF antenna system does not substantially suffer from PIM as the transmission line according to the embodiments provides for an efficient PIM mitigation.

[0112] By applying the principle according to the embodiments, using more expensive fabrication techniques to reduce roughness may be avoided, which yields substantial cost savings. As an example, laser resist ablation is one of the more expensive techniques used in the fabrication of PCBs, however, even in this case, small surface roughness irregularities still persist, so that the approach of the embodiments is superior both regarding manufacturing costs and the degree of PIM mitigation obtained thereby.

[0113] Applying the principle according to the embodiments also enables to avoid employing conventional roughness reduction techniques at a post-production stage. Traditional methods used in the production of PCB tracks include photoengraving and PCB milling and recently, laser resist ablation. Photoengraving is the most common way of patterning PCB, which usually involves wet etching using either ferric chloride or ammonium persulfate. The problem associated with photoengraving lies with overetching/underetching and uneven surface roughness. PCB manufacturers adopt various techniques to address these issues, however, most of them are considered to be house secrets and at the same time, they do not fully result is the complete removal of surface roughness. PCB milling involves copper removal by means of a CNC router. The most common issue with PCB milling lies with the removal of not only the desired copper track, but small parts of the RF substrate too. The surface roughness of the copper track is seriously affected by the size and speed of the milling drill.

[0114] As can be seen, based on the above discussed conventional approaches, there still exists a genuine need for the reduction of the effects of surface roughness in a not only a cost-effective way, but also in the that enables implementation in both new deployments and also retrofitting older deployments to improve transmission characteristic. This can be attained by applying the principle according to the embodiments.

[0115] The description and drawings merely illustrate the principles of the invention. It will thus be appreciated that those skilled in the art will be able to devise various arrangements that, although not explicitly described or shown herein, embody the principles of the invention and are included within its spirit and scope.

[0116] Furthermore, all examples recited herein are principally intended expressly to be only for pedagogical purposes to aid the reader in understanding the principles of the invention and the concepts contributed by the inventor(s) to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions. Moreover, all statements herein reciting principles, aspects, and embodiments of the invention, as well as specific examples thereof, are intended to encompass equivalents thereof.

[0117] It should be appreciated by those skilled in the art that any block diagrams herein represent conceptual views of illustrative circuitry embodying the principles of the invention. Similarly, it will be appreciated that any flow charts, flow diagrams, state transition diagrams, pseudo code, and the like represent various processes which may be substantially represented in computer readable medium and so executed by a computer or processor, whether or not such computer or processor is explicitly shown.

[0118] A person of skill in the art would readily recognize that steps of various above-described methods can be performed and/or controlled by programmed computers. Herein, some embodiments are also intended to cover program storage devices, e.g., digital data storage media, which are machine or computer readable and encode machine-executable or computer-executable programs of instructions, wherein said instructions perform some or all of the steps of said above-described methods. The program storage devices may be, e.g., digital memories, magnetic storage media such as a magnetic disks and magnetic tapes, hard drives, or optically readable digital data storage media. The embodiments are also intended to cover computers programmed to perform said steps of the above-described methods.

[0119] It should be appreciated by those skilled in the art that any block diagrams herein represent conceptual views of illustrative circuitry embodying the principles of the invention. Similarly, it will be appreciated that any flow charts, flow diagrams, state transition diagrams, pseudo code, and the like represent various processes which may be substantially represented in computer readable medium and so executed by a computer or processor, whether or not such computer or processor is explicitly shown.

Claims

1. A transmission line (100; 100a; 100b; 100c; 100d; 100e; 100f; 100g) for radio frequency, RF, signals, wherein said transmission line (100; 100a; 100b; 100c; 100d; 100e; 100f; 100g) comprises a substrate (110) comprising a first dielectric material (m1) having a first relative permittivity, and at least one conductor (120) arranged on a first surface (110a) of said substrate (110), wherein at least one edge (122, 124) of said at least one conductor (120) is covered with a second dielectric material (m2) having a second relative permittivity, wherein a thickness (Td) of said second dielectric material (m2) is smaller than about a thickness (Ts) of said substrate (110).

2. The transmission line (100; 100a; 100b; 100c; 100d; 100e; 100f; 100g) according to claim 1, wherein said second relative permittivity is greater than said first relative permittivity.

3. The transmission line (100; 100a; 100b; 100c; 100d; 100e; 100f; 100g) according to at least one of the preceding claims, wherein said second dielectric material (m2) is a fluid.

4. The transmission line (100; 100a; 100b; 100c; 100d; 100e; 100f; 100g) according to at least one of the preceding claims, wherein at least a side surface (122a, 124a) of said at least one edge (122, 124) is covered with said second dielectric material (m2).

5. The transmission line (100; 100a; 100b; 100c; 100d; 100e; 100f; 100g) according to at least one of the preceding claims, wherein said thickness (Td) of said second dielectric material is equal to or smaller than about 10 percent of the thickness (Ts) of said substrate (110).

6. The transmission line (100; 100a; 100b; 100c; 100d; 100e; 100f; 100g) according to at least one of the preceding claims, wherein a thickness (Td) of said second dielectric material is equal to or smaller than about a thickness (Tm) of said conductor (120).

7. The transmission line (100; 100a; 100b; 100c; 100d; 100e; 100f; 100g) according to at least one of the

preceding claims, wherein a width (Wd) of said second dielectric material is equal to or smaller than about 150 percent of a width (W0) of said conductor (120), and/or wherein a width (Wd) of said second dielectric material is equal to or greater than about 100 percent of a width (W0) of said conductor (120).

8. The transmission line (100; 100a; 100b; 100c; 100d; 100e; 100f; 100g) according to at least one of the preceding claims, wherein a width (Wd) of said second dielectric material is equal to or smaller than about 150 percent of a width (W0) of said conductor (120).

9. The transmission line (100; 100a; 100b; 100c; 100d; 100e; 100f; 100g) according to at least one of the preceding claims, wherein a first element (140) of said second dielectric material (m2) is provided at a first edge (122) of said transmission line (100), and wherein a second element (150) of said second dielectric material (m2) is provided at a second edge (124) of said transmission line (100).

10. The transmission line (100; 100a; 100b; 100c; 100d; 100e; 100f; 100g) according to claim 9, wherein a gap, preferably an air gap, is provided between opposing side surfaces (142a, 152a) of said first element (140) and said second element (150).

11. The transmission line (100; 100a; 100b; 100c; 100d; 100e; 100f; 100g) according to at least one of the claims 9 to 10, wherein said first element (140) and/or said second element (150) comprises a respective housing (143, 153) for receiving a fluid (146, 156).

12. The transmission line (100; 100a; 100b; 100c; 100d; 100e; 100f; 100g) according to claim 11, wherein said housing (143, 153) comprises or is made of a material having a third relative permittivity, wherein said third relative permittivity is smaller than said second relative permittivity.

13. The transmission line (100; 100a; 100b; 100c; 100d; 100e; 100f; 100g) according to at least one of the claims 9 to 10, wherein said second dielectric material (m2) is a fluid, and wherein said housing (143, 153) comprises one or more channels (144, 154), which comprise said second dielectric material (m2).

14. The transmission line (100; 100a; 100b; 100c; 100d; 100e; 100f; 100g) according to at least one the claims 11 to 13, wherein at least one pump (160) is provided for driving said fluid through said housing (143, 153) and/or said channel(s) (144, 154).

15. A system (1000) for processing radio frequency, RF, signals, comprising at least one transmission line (100; 100a; 100b; 100c; 100d; 100e; 100f; 100g) according to at least one of the preceding claims.

16. The system (1000) according to claim 15 wherein said system (1000) comprises at least one of the following elements: an antenna (1002), a transmitter (1004), a receiver (1006), a diplexer (1008) and/or at least one filter for said RF signals.

17. A method of providing a transmission line (100; 100a; 100b; 100c; 100d; 100e; 100f; 100g) for radio frequency, RF, signals, wherein said method comprises the following steps: providing (200) a substrate (110) comprising a first dielectric material (m1) having a first relative permittivity, providing (210) at least one conductor (120) on a first surface (110a) of said substrate (110), covering (220) at least one edge (122, 124) of said at least one conductor (120) with a second dielectric material (m2) having a second relative permittivity, wherein a thickness (Td) of said second dielectric material (m2) is smaller than about a thickness (Ts) of said substrate (110).

18. The method according to claim 17, wherein said step of covering (220) comprises applying a sol-gel process.

19. The method according to at least one of the claims 17 to 18, wherein said step of covering comprises providing at least one housing (143, 153) for receiving a fluid (146, 156).

Fig. 1A

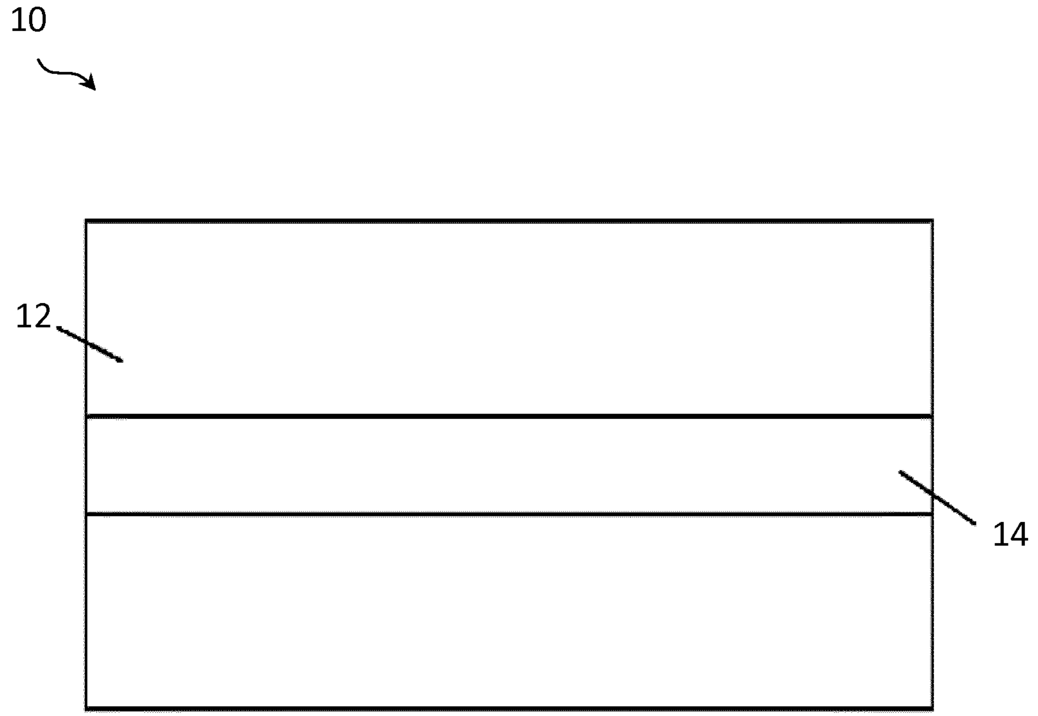


Fig. 1B

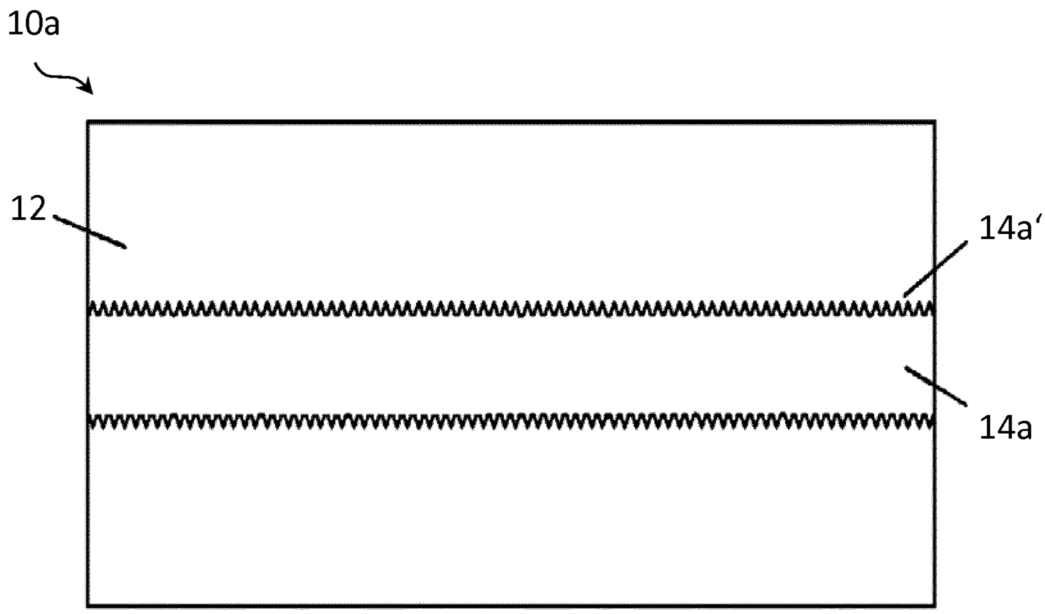


Fig. 2

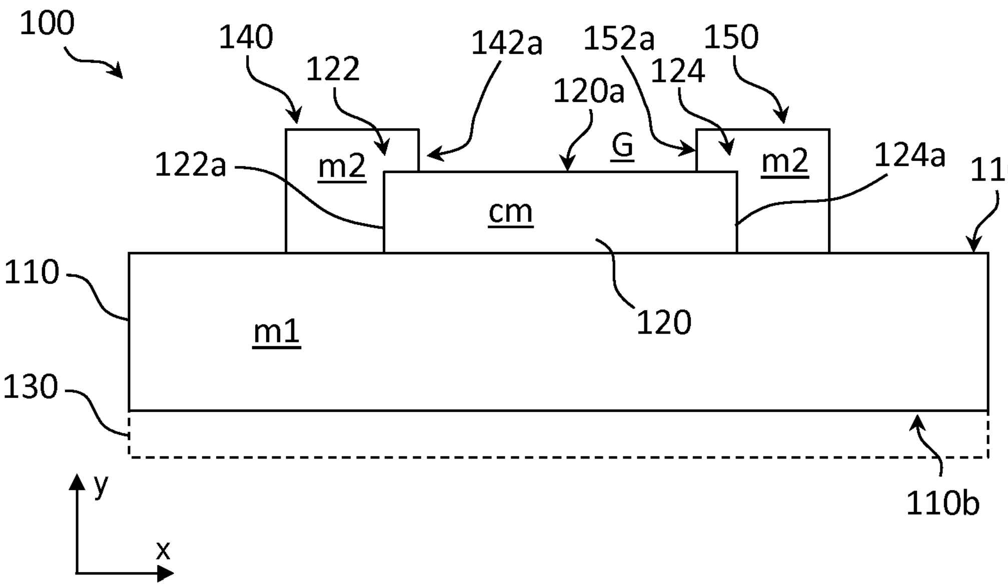

100
140
122
142a
152a
150
124
120a
G
m2
m2
122a
124a
110a
cm
110
120
m1
130
110b
y
x

Fig. 3

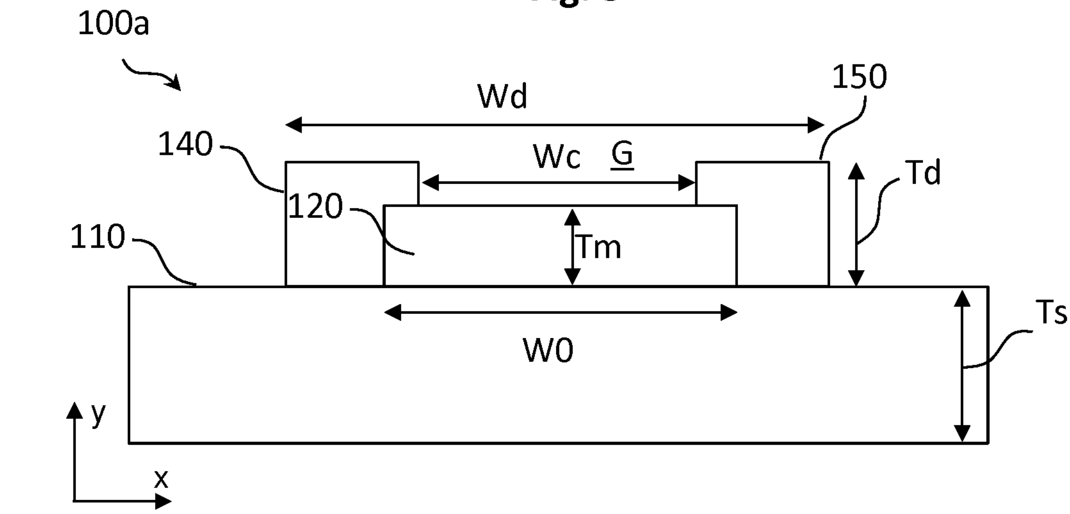

100a
150
Wd
140
Wc
G
Td
120
110
Tm
Ts
W0
y
x

Fig. 4A

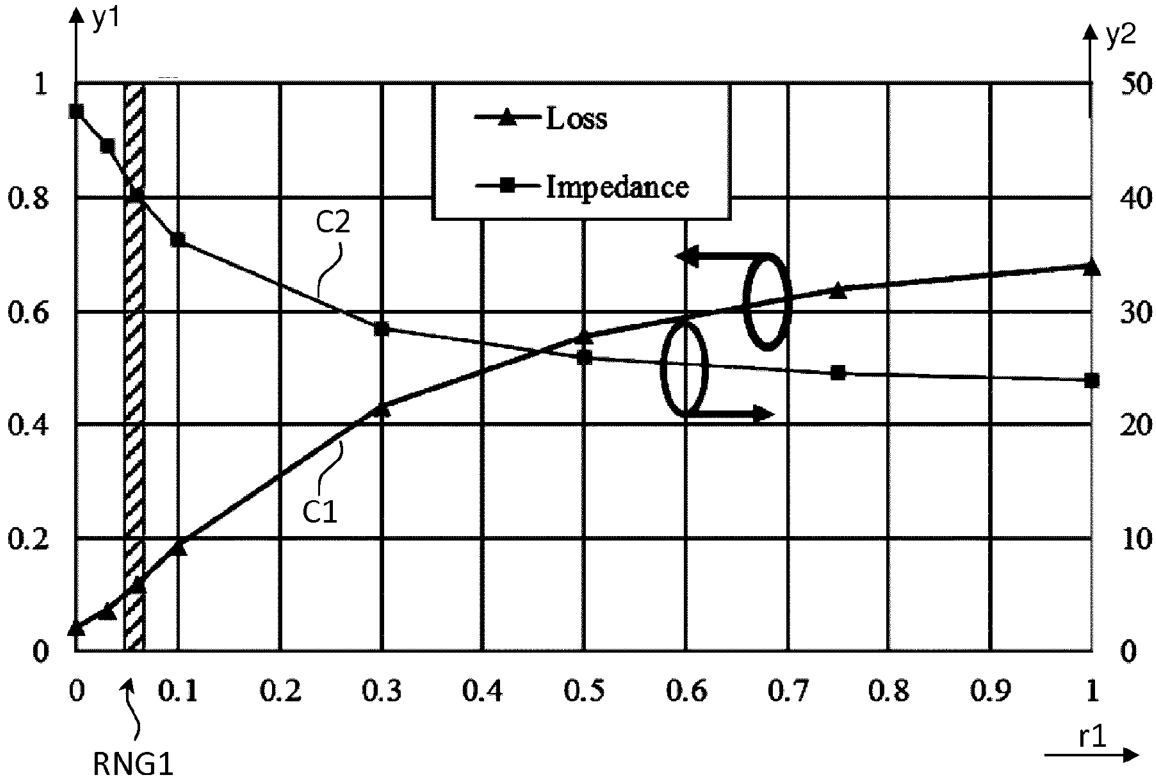

y1
y2
Loss
Impedance
C2
C1
RNG1
r1
0
0.2
0.4
0.6
0.8
1
10
20
30
40
50
0.1
0.3
0.5
0.7
0.9

Fig. 4B

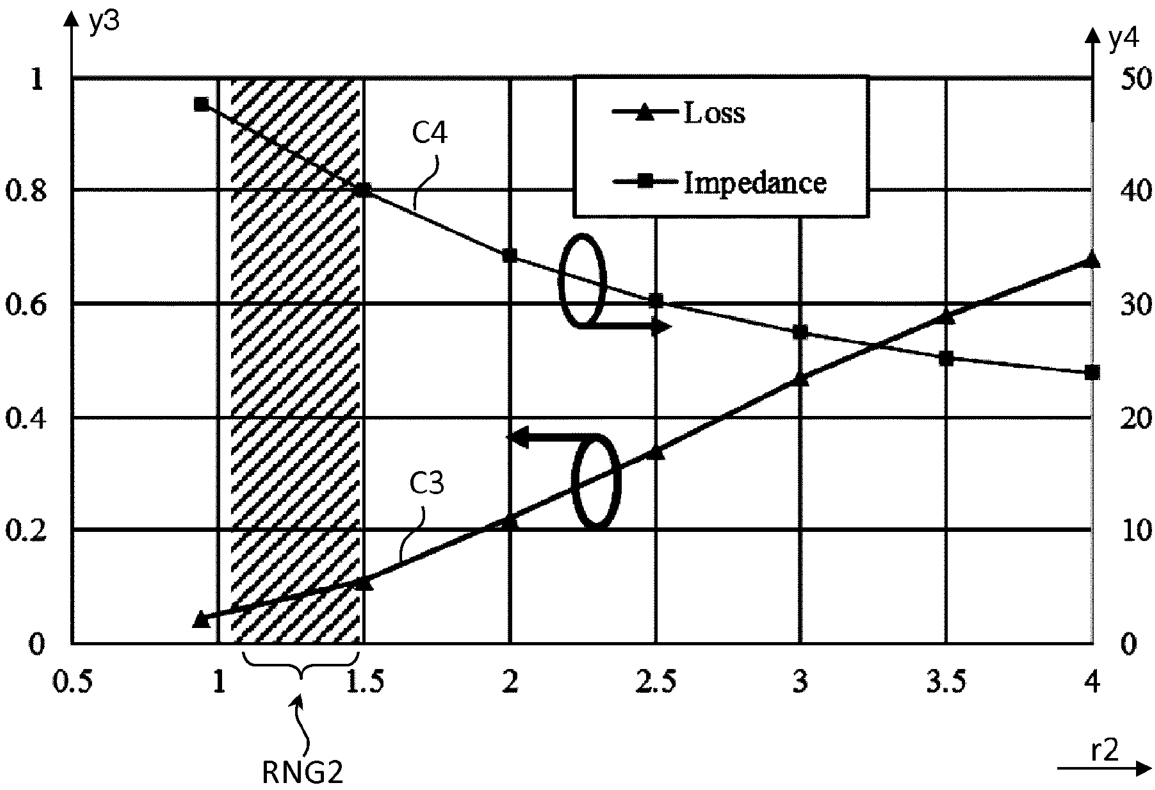

y3
y4
Loss
Impedance
C4
C3
RNG2
r2
0.5
1
1.5
2
2.5
3
3.5
4
0
0.2
0.4
0.6
0.8
10
20
30
40
50

Fig. 4C

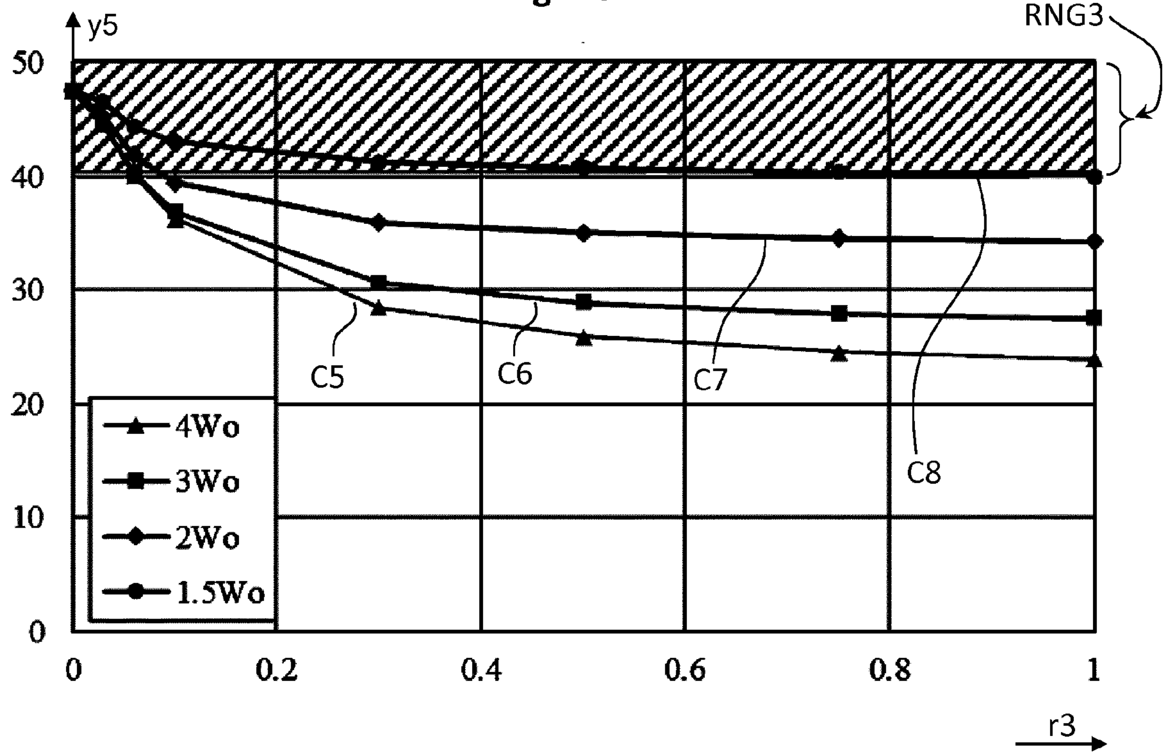
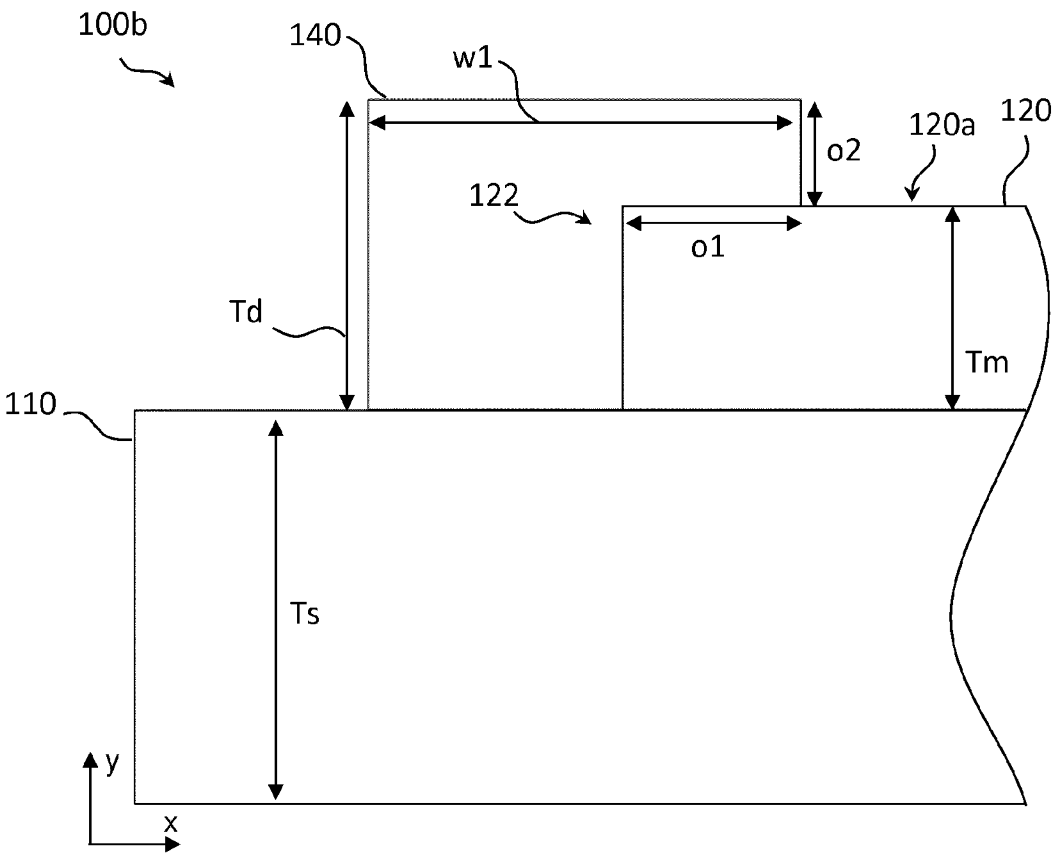

y5
RNG3
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1
r3
C5
C6
C7
C8
4Wo
3Wo
2Wo
1.5Wo

Fig. 5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140
w1
o2
120a
120
122
o1
Td
Tm
110
Ts
y
x

Fig. 6A

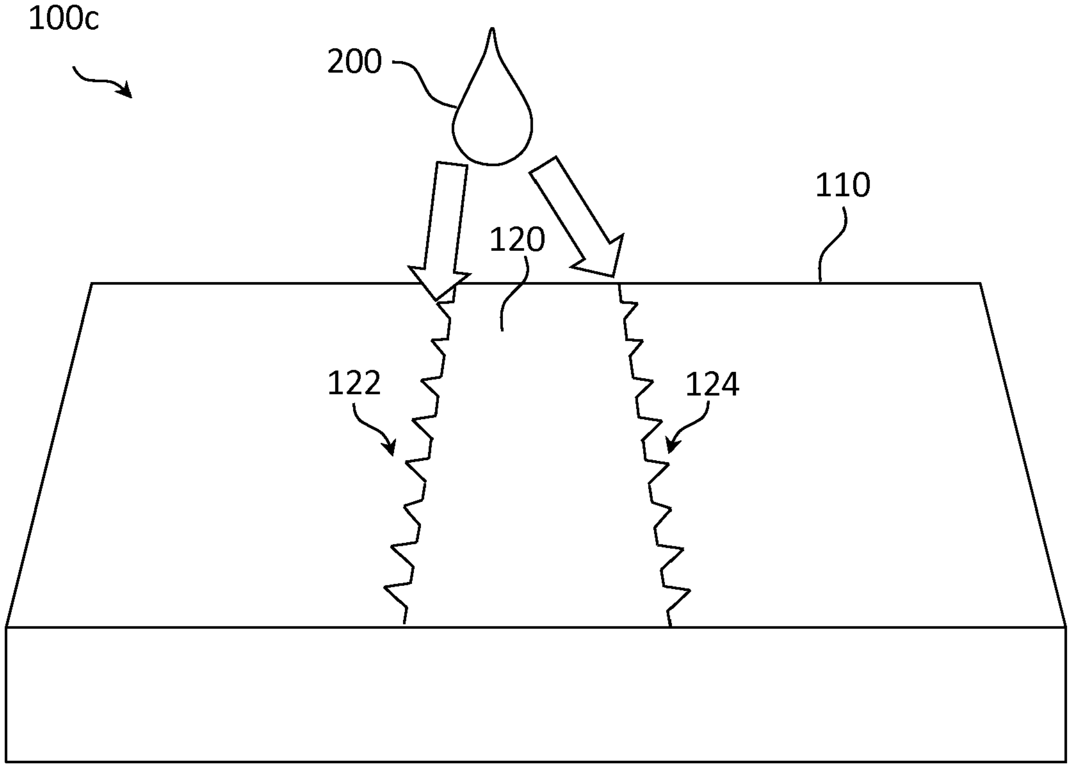


Fig. 6B

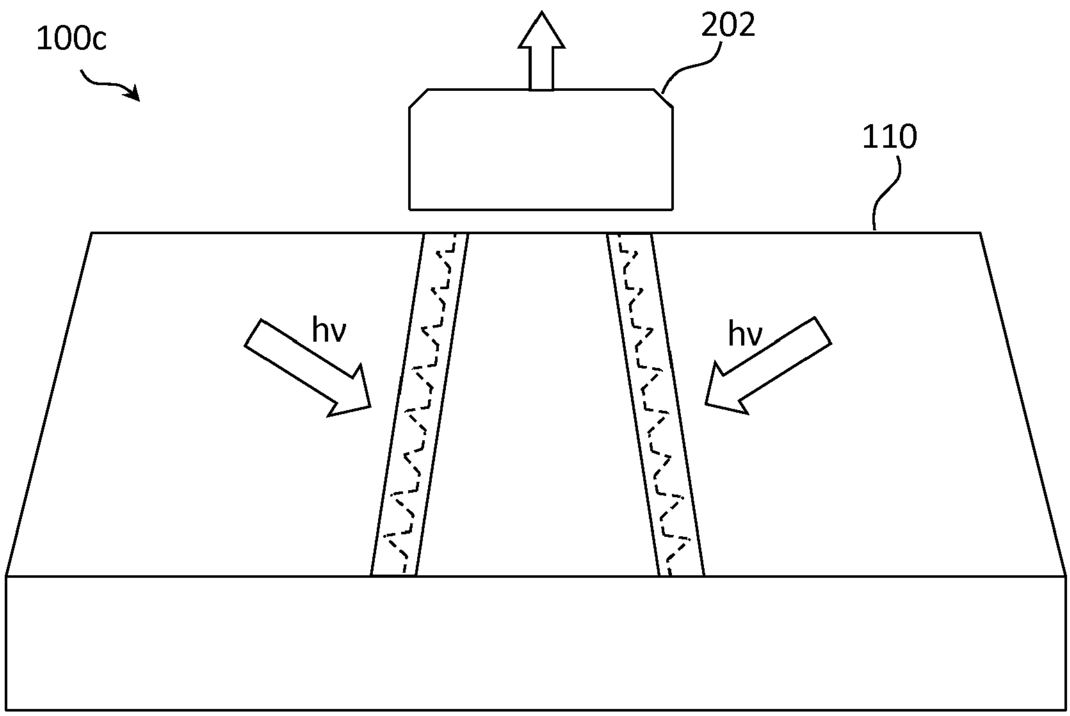


Fig. 7

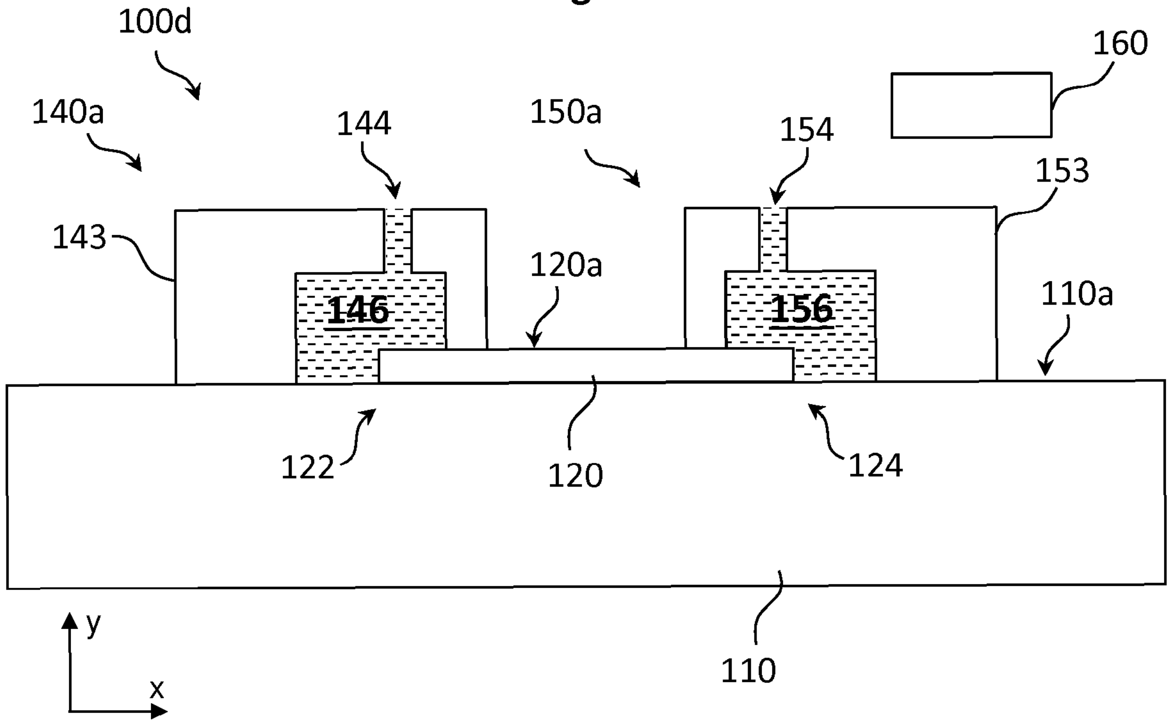

100d
140a
144
150a
154
160
153
143
146
156
120a
110a
122
120
124
110
y
x

Fig. 8A

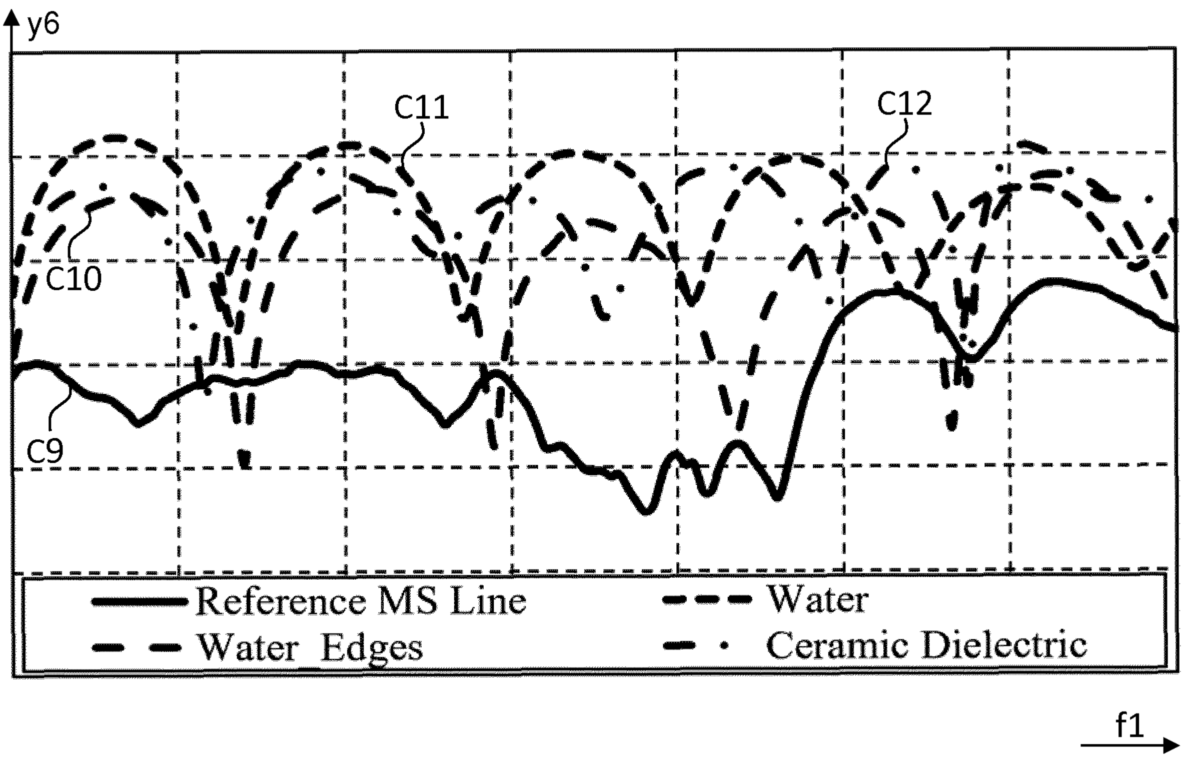

y6
C11
C12
C10
C9
Reference MS Line
Water
Water_Edges
Ceramic Dielectric
f1

Fig. 8B

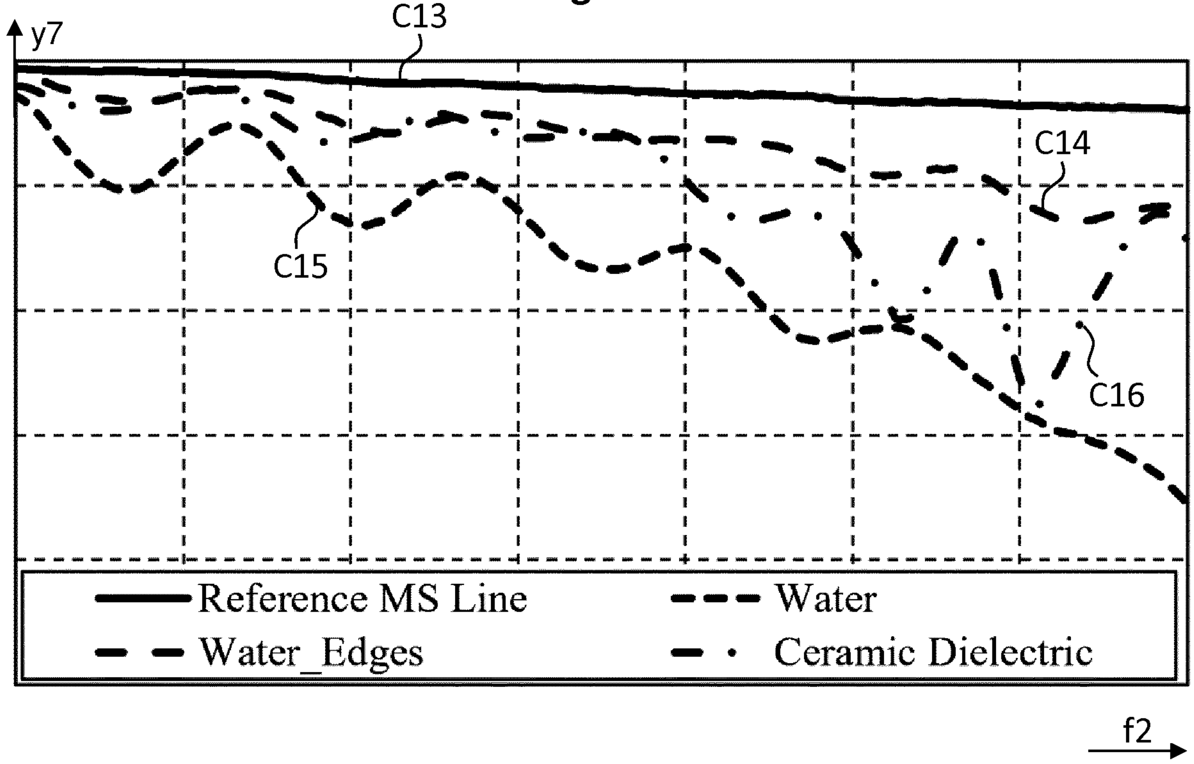

y7
C13
C14
C15
C16
Reference MS Line
Water
Water_Edges
Ceramic Dielectric
f2

Fig. 9A

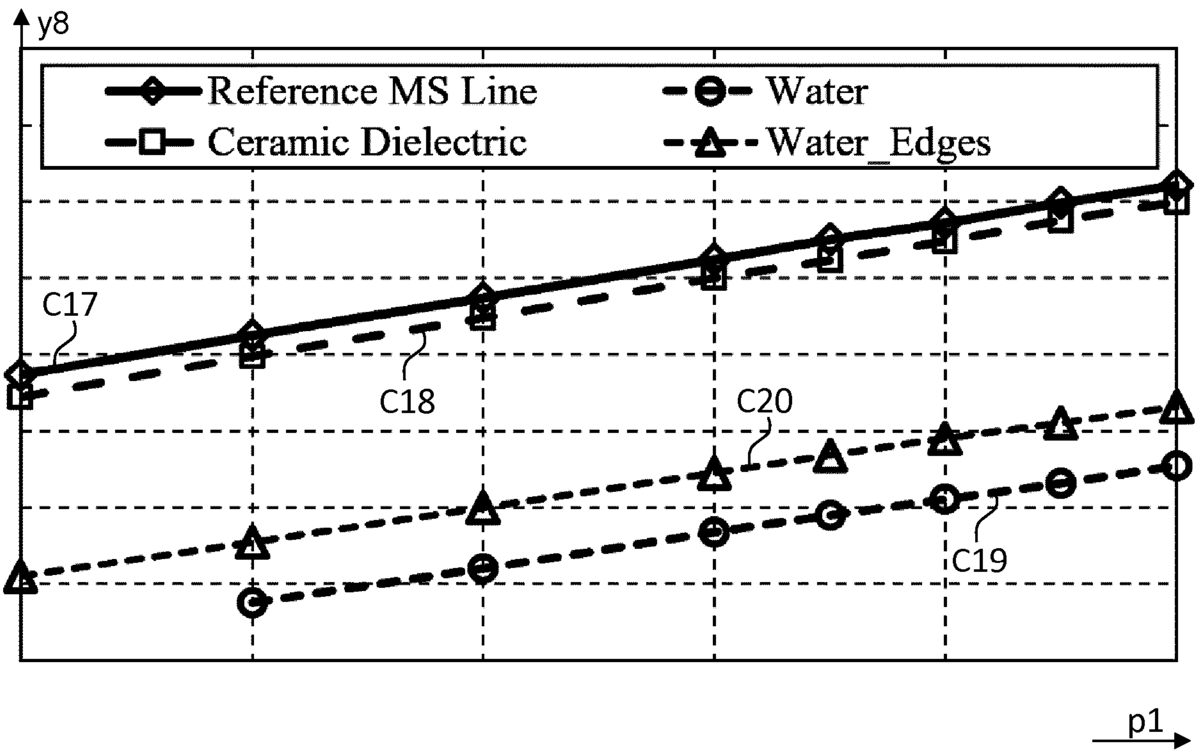

y8
Reference MS Line
Water
Ceramic Dielectric
Water_Edges
C17
C18
C20
C19
p1

Fig. 9B

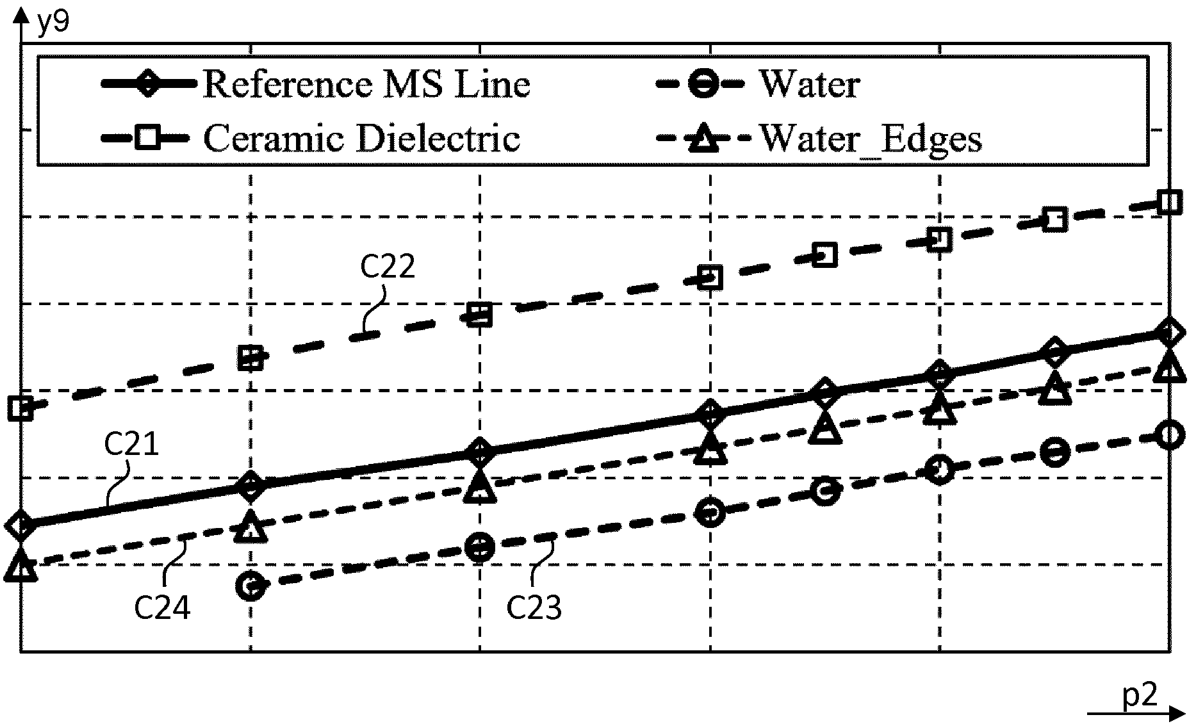

y9
Reference MS Line
Water
Ceramic Dielectric
Water_Edges
C22
C21
C24
C23
p2

Fig. 10

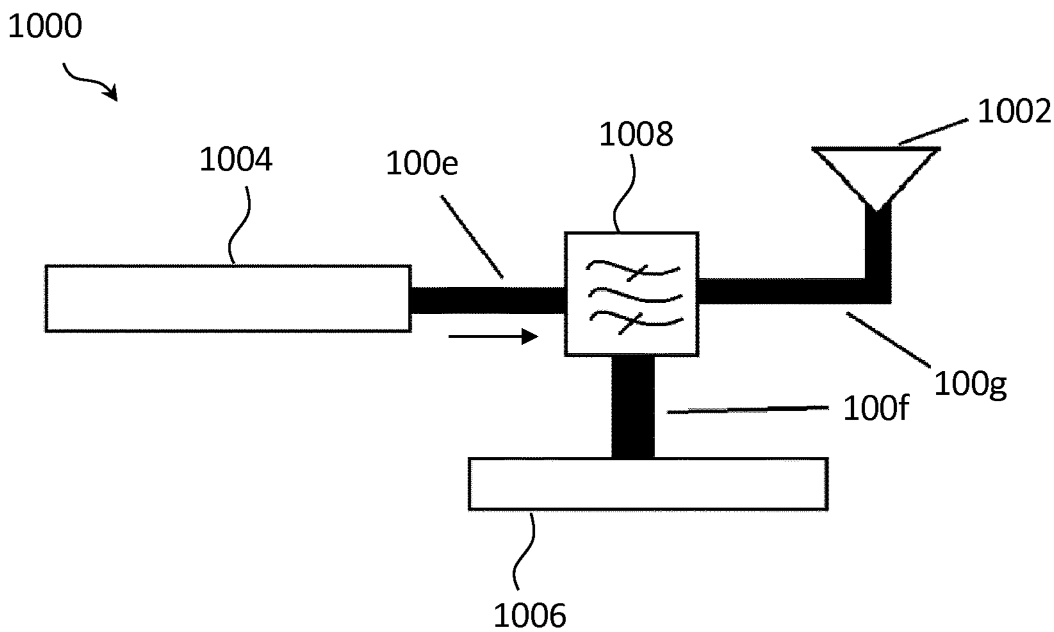

1000
1004
100e
1008
1002
100g
100f
1006

Fig. 11A

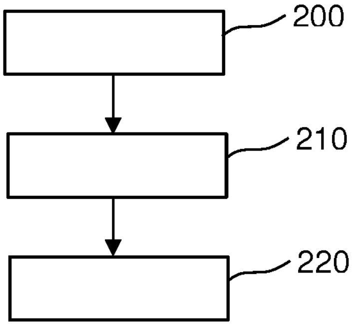
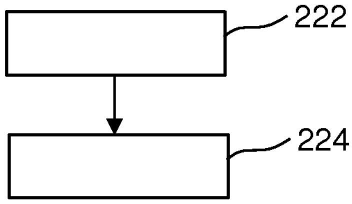


Fig. 11B



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EUROPEAN SEARCH REPORT

Application Number
EP 17 20 7818

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Y	JP H06 291519 A (NIPPON CHEMICON) 18 October 1994 (1994-10-18) * abstract; figures 1(a)-1(b) * -----	1,2, 4-10, 15-17	INV. H01P3/08
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The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
The Hague	13 June 2018	Pastor Jiménez, J

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