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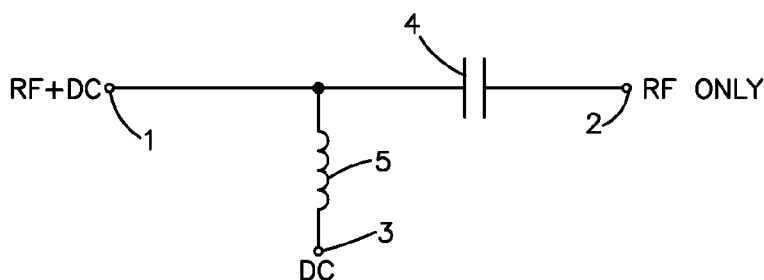


Fig. 1A

(57) Abstract: A coaxial cavity resonator assembly comprising an outer conductor and an inner conductor. The outer conductor including an outer conductor proximal end, an outer conductor distal end, and an outer conductor electrical length that is defined between the outer conductor proximal end and the outer conductor distal end. The center conductor including a center conductor proximal end, a center conductor distal end, and a center conductor electrical length that is defined between the center conductor proximal end and the center conductor distal end. The center conductor proximal end is substantially coplanar with the outer conductor proximal end, the center conductor distal end is substantially coplanar with the outer conductor distal end, and the center conductor electrical length is longer than the outer conductor electrical length by an integer multiple of one-half of one wavelength.



RADIO FREQUENCY DIRECTIONAL COUPLER AND FILTER

RELATED APPLICATIONS

[0001] This application claims priority to and the full benefit of U.S. Provisional Patent application 62/144,019, filed 04/07/2015, which is incorporated by reference.

TECHNICAL FIELD

[0002] This technology relates generally to the field of combining and separating electrical transmissions, and more particularly to applications and methods of combining and separating electrical transmissions having radio frequency components and direct current components.

BACKGROUND

[0003] It is well understood by those of skill in the art that there are two basic categories of electrical signals: (1) radio frequency signals that transmit with a current amplitude that alternates in varying frequencies (“RF”); and (2) signals with a current amplitude that is constant and non-alternating (“DC”). Conventionally the componentry that drives and/or operates within either one of these categories of electrical signals is not suited for use in both RF and DC applications. For example, while transmission lines (e.g., coaxial cables) can carry both RF and DC without disruption, a DC power source must be isolated in some fashion from the RF power in the line, otherwise the DC power source componentry will fail when subjected to the alternating current of the RF. Prior art methods for isolating RF power from reaching a DC power source, have included use of resistive elements, lumped element inductors, and frequency cancellation circuits. However, these methods have several inherent shortcomings and have proliferated in maintenance of antiquated applications for splitting and combining RF and DC.

[0004] Inherent shortcomings in these prior art combination and splitting methods can be represented well by an analysis of the classic bias tee. For most purposes of this analysis, the directionality of whether the RF and DC signals are getting combined or split will get analyzed equally due to the symmetric nature of the operations. But, as will be discussed further below,

that symmetry for analysis purposes breaks down when dealing with multi-frequency RF signals and a DC signal.

[0005] The bias tee has three feed locations and it serves as a frequency cancellation circuit by combining at least a capacitor and an inductor, wherein the values for each will be chosen based on the frequency desired. The three feed locations each have a different characteristic. As seen in FIG. 1, the first feed location 1 will be configured to give or receive a dual signal consisting of both RF and DC components. The second feed location 2 is separated from the first feed location by a capacitor 4 and thus only permits transmits or receives an RF signal. The third feed location 3 is separated from the first feed location by an inductor 5 and only DC signal will pass thereon, i.e., no RF signal.

[0006] The electronic components (i.e., inductors and capacitors) used in the bias tee results in a set of relatively low operating values. The maximum voltage is around 1500 volts. The maximum current is around 4 amperes. The maximum power is around 3 kilowatts at peak pulse and 300 watts continuous. The bias tee should not be operated at temperatures greater than about 70 degrees Celsius otherwise these components may suffer temperature damage while testing the upper limits of their operating values. (Note: these figures are approximates and are found on individual bias tees, no single bias should run at each of the above listed maximums.) In addition, these components will put off their own heat that may lead to early failure. These components have set values once installed and thus are not easy to recalibrate. Replacement of these components can be costly and inopportune based on installation location accessibility. As such, use of these bias tees for combining and/or splitting of dual signals is limited to those high-value applications that are located in easily-accessible controlled-climates and that only demand a relatively low DC voltage (i.e., less than 1500 volts).

[0007] Accordingly, there is a need for a system and method for combining and/or splitting RF and DC signals that has higher operating parameters (i.e., higher voltage, power, and current), is more durable, is lower cost, and is easy to calibrate after installation.

[0008] Advantages over the prior art are herewith provided in the following disclosure.

SUMMARY

[0009] Each of the following summary paragraphs describes a non-limiting example of how the invention may be implemented as a combination of structural or method elements disclosed by the detailed description that follows. Any one or more of the elements of each summary paragraph may be utilized with any one or more of the distinct elements of another.

[0010] A coaxial cavity resonator assembly comprising an outer conductor and an inner conductor. The outer conductor including an outer conductor proximal end, an outer conductor distal end, and an outer conductor electrical length that is defined between the outer conductor proximal end and the outer conductor distal end. The center conductor including a center conductor proximal end, a center conductor distal end, and a center conductor electrical length that is defined between the center conductor proximal end and the center conductor distal end. The center conductor proximal end is substantially coplanar with the outer conductor proximal end, the center conductor distal end is substantially coplanar with the outer conductor distal end, and the center conductor electrical length is longer than the outer conductor electrical length by an integer multiple of one-half of one wavelength.

[0011] A method of splitting a dual signal including a radio frequency signal and a direct current signal. The method comprising connecting the dual signal to a distal end of a center conductor portion of a coaxial cavity resonator assembly, wherein a center conductor electrical length is defined between the center conductor proximal end and a center conductor distal end, and the coaxial cavity resonator assembly also includes an outer conductor having an outer conductor electrical length defined between an outer conductor proximal end and an outer conductor distal end. The method further comprising decoupling the radio frequency signal from the center conductor portion of the coaxial cavity resonator assembly, wherein the center conductor electrical length is longer than the outer conductor electrical length by an integer multiple of one-half of one wavelength. The method completing by transmitting from the center conductor proximal end the direct current signal.

[0012] A method of combining a radio frequency signal and a direct current signal. The method comprising connecting the direct current signal to a proximal end of a center conductor

portion of a coaxial cavity resonator assembly, wherein a center conductor electrical length is defined between the center conductor proximal end and a center conductor distal end, and the coaxial cavity resonator assembly also includes an outer conductor having an outer conductor electrical length defined between an outer conductor proximal end and an outer conductor distal end. The method further comprising coupling the radio frequency signal to the center conductor portion of the coaxial cavity resonator assembly, wherein the center conductor electrical length is longer than the outer conductor electrical length by an integer multiple of one-half of one wavelength. The method completing by transmitting from the center conductor distal end a dual signal including the radio frequency signal and the direct current signal.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] A brief description of each figure is provided below. Elements with the same reference numbers in each figure indicate identical or functionally similar elements. Additionally, as a convenience, the left-most digit(s) of a reference number identifies the drawings in which the reference number first appears.

[0014] Fig. 1A is a schematic diagram of a prior art bias tee.

[0015] Fig. 1B is a cross-sectional view of an example of an exemplary coaxial cavity resonator assembly.

[0016] Fig. 2A is a cross-sectional view of an example of an exemplary coaxial cavity resonator assembly including two assemblies in a series arrangement.

[0017] Fig. 2B is a schematic diagram of an example of an exemplary dual signal combiner and/or splitter.

[0018] Fig. 3 is a cross-sectional view of an example of an exemplary coaxial cavity resonator assembly connected to a direct current power source through an additional resonator assembly acting as an RF attenuator.

[0019] Fig. 4 is a schematic diagram of an example of a coaxial cavity resonator assembly operatively associated with a combustion chamber and wherein a controller directs both an RF power supply and a DC power supply to provide power to the coaxial cavity resonator assembly.

[0020] Fig. 5 is a cross-sectional view of an example of an exemplary coaxial cavity resonator assembly connected to a direct current power source through an additional resonator assembly acting as an RF attenuator.

[0021] Fig. 6 is a cross-sectional view of an example of an exemplary coaxial cavity resonator assembly connected to a direct current power source through an additional resonator assembly acting as an RF attenuator.

[0022] Fig. 7 is a cross-sectional view of an example of an exemplary coaxial cavity resonator assembly connected to a direct current power source through an additional resonator assembly acting as an RF attenuator.

[0023] Fig. 8 is a cross-sectional view of an example of an exemplary coaxial cavity resonator assembly connected to a direct current power source through an additional resonator assembly acting as an RF attenuator.

DETAILED DESCRIPTION

[0024] This written description is provided to meet the enablement requirements of the patent statute without imposing limitations that are not recited in the claims. All or part of each example may be used in combination with all or part of any one or more of the other examples.

[0025] *Single RF Directional Coupler and Filter for use as a Combiner and/or a Splitter*

[0026] In accordance with the present invention, systems and methods are configured to provide an apparatus that is capable of combining and/or splitting RF and DC signals, such an apparatus 100 is shown for example in Fig. 1B. In this particular example, the apparatus 100 is a coaxial cavity resonator assembly arranged along a longitudinal axis 115.

[0027] In the illustrated example, the coaxial cavity resonator assembly 100 includes a center conductor 191 and an outer conductor wall structure 120. The center conductor 191 includes a folded resonator assembly including a series of center conductor surface portions comprising an interior center conductor portion 192, an exterior center conductor portion 193, and a connecting center conductor portion 194. The connecting center conductor portion 194 connects the interior center conductor portion 192 and the exterior center conductor portion 193, all of which are

surrounded by the outer conductor wall structure 120. A first radial plane is defined by the dotted line labeled A. A second radial plane is defined by the dotted line labeled B.

[0028] The wall structure 120 is constructed of a conducting material 122 and surrounds a first cylindrical cavity 125 centered on the axis 115. The wall structure 120 includes a short outer conducting portion 195 which has a proximal end 156 (situated substantially within the first radial plane A) and a distal end 157 (situated substantially within the second radial plane B). In this example, the first cylindrical cavity 125 is filled with a dielectric material 126.

[0029] The interior center conductor portion 192 has a proximal end 196 (situated substantially within the first radial plane A) and a distal end 197 (situated substantially within the second radial plane B). The exterior center conductor portion 193 has a proximal end 170 (situated substantially within the first radial plane A) and a distal end 172 (situated substantially within the second radial plane B). In this example, the connecting center conductor portion 194 is situated in close proximity to the second radial plane B. The exterior center conductor portion 193 surrounds the interior center conductor portion 192.

[0030] An aperture 179 reaches radially outward through the first wall portion 122 through which a radial conductor 177 extends out from the longitudinal axis 115 for connection to an RF line. The end of the radial conductor 177 that is closer to the longitudinal axis 115 connects to a parallel plate capacitor 175 that is in a coupling arrangement to the center conductor structure 150. The parallel plate capacitor 175 is also in a coupling arrangement to a center conductor 191.

[0031] In the illustrated example, a DC line is connected to the interior center conductor portion 192 at its proximal end 196. In this example, the exterior center conductor portion 193 resembles a cylindrical portion of conducting material surrounding the rest of the interior center conductor portion 192. The longitudinal lengths of the interior center conductor portion 192 and the exterior center conductor portion 193 are approximately equal to the longitudinal length of the parallel plate capacitor 175 that they are in coupling arrangement with.

[0032] In the illustrated example, the electrical length of the outer conductor wall structure 120 is one quarter wavelength between the outer conductor proximal end 156 and the outer conductor

distal end 157. The electrical length of the center conductor 191 is three quarters of a wavelength. The center conductor 191 electrical length may be referred to as an inner conducting path and is further defined as running along the interior center conductor surface 142 from the proximal end 196 to the distal end 197 of the interior center conductor 192 (one quarter wavelength), then along the inward-facing surface of the connecting center conductor portion 194, then along the inward-facing surface 144 of the exterior center conductor portion 193 to its proximal end 170 (one quarter wavelength), then along the outward-facing surface 146 of the exterior center conductor portion 193 between its proximal end 170 to its distal end 172 (one quarter wavelength). Thus, the electrical length of the center conductor 191 is two quarter wavelengths longer than the electrical length of the outer conductor wall structure 120.

[0033] This arrangement provides a filtered region of no RF between the first radial plane A and a DC line that is oriented in a direction pointing from the second radial plane B to the first radial plane A. It also provides a non-filtered region configured to contain both RF and DC between the second radial plane B and outward along the center conductor in a direction pointing from the first radial plane A to the second radial plane B. This arrangement can serve as a splitter or combiner because it is configured to shift RF signals (having frequencies within a specific range) 180 degrees out of phase relative to the ground plane (i.e., the outer conductor) of the coaxial cavity resonator assembly 100. Thus, this arrangement has many advantages in comparison to the prior art bias tee, including, but not limited to higher operating parameters (i.e., voltage ranges greater than 50 kilovolts, current ranges greater than 100 amperes, power ranges greater than 5000 kilowatts, and temperature operating ranges close to 1000 degrees Celsius), is more durable, is lower cost (i.e., doesn't require frequent replacement of electronic components that have failed), and is easy to calibrate after installation (i.e., by adjustment of the electrical length parameters).

[0034] A person of ordinary skill in the art would understand that the particular coaxial cavity resonator assembly arrangement depicted in Fig. 1B is not limiting with regards to the orientation of the center conductor 191. In alternative examples, the entire coaxial cavity resonator assembly arrangement depicted in Fig. 1B may be 'stretched' whereby the center conductor 191 may be disposed further away from the distal end 172 and no longer directly

coupled to the parallel plate capacitor 175, but rather separated by one quarter wavelength from the portion of the center conductor that would remain in direct coupling arrangement with the parallel plate capacitor 175 (as seen in Fig. 6). Alternatively, the entire coaxial cavity resonator assembly arrangement depicted in Fig. 1B could be more compressed whereby the exterior center conductor portions 193 of the center conductor 191 both extend longitudinally as far as the parallel plate capacitor 175 but also surround the portion of center conductor exposed for plasma creation (as seen in Fig. 7). Additional alternative examples to the coaxial cavity resonator assembly arrangement depicted in Fig. 1B may be implemented by arranging the connecting center conductor portion 194 no longer just at the end of the center conductor 191, but in the middle of the center conductor 191 so that the exterior center conductor portions 193 extend in either direction longitudinally about the connecting center conductor portion 194 (as seen in Fig. 8). Any particular geometry of this arrangement would require tweaking to the various parameters of dielectrics to ensure impedance matching and full 180 degree phase cancellation, but these tasks are well understood engineering tasks.

[0035] *Double RF Directional Coupler and Filter for use as a Combiner and/or a Splitter*

[0036] In accordance with the present invention, systems and methods are configured to provide an apparatus that is capable of combining and/or splitting RF and DC signals, such an apparatus 200 is shown for example in Fig. 2A. In this particular example, the apparatus 200 is a coaxial cavity resonator assembly arranged along a longitudinal axis 215.

[0037] In the illustrated example, the coaxial cavity resonator assembly 200 includes a center conductor 291 and an outer conductor wall structure 220. The center conductor 291 includes a folded resonator assembly including a series of center conductor surface portions comprising an interior center conductor portion 292, an exterior center conductor portion 293, and a connecting center conductor portion 294. The connecting center conductor portion 294 connects the interior center conductor portion 292 and the exterior center conductor portion 293, all of which are surrounded by the outer conductor wall structure 220. A third radial plane is defined by the dotted line labeled C. A fourth radial plane is defined by the dotted line labeled D.

[0038] The wall structure 220 is constructed of a conducting material 222 and surrounds a first cylindrical cavity 225 centered on the axis 215. The wall structure 220 includes a short outer conducting portion 295 which has a proximal end 256 (situated substantially within the third radial plane C) and a distal end 257 (situated substantially within the fourth radial plane D). In this example, the first cylindrical cavity 225 is filled with a dielectric material 226.

[0039] The interior center conductor portion 292 has a proximal end 296 (situated substantially within the third radial plane C) and a distal end 297 (situated substantially within the fourth radial plane D). The exterior center conductor portion 293 has a proximal end 270 (situated substantially within the third radial plane C) and a distal end 272 (situated substantially within the fourth radial plane D). In this example, the connecting center conductor portion 294 is situated in close proximity to the fourth radial plane D. The exterior center conductor portion 293 surrounds the interior center conductor portion 292.

[0040] An aperture 279 reaches radially outward through the first wall portion 222 through which a radial conductor 277 extends out from the longitudinal axis 215 for connection to an RF line. The end of the radial conductor 277 that is closer to the longitudinal axis 215 connects to a parallel plate capacitor 275 that is in a coupling arrangement to the center conductor structure 250. The parallel plate capacitor 275 is also in a coupling arrangement to a center conductor 291.

[0041] In this example, the exterior center conductor portion 293 resembles a cylindrical portion of conducting material surrounding the rest of the interior center conductor portion 292. The longitudinal lengths of the interior center conductor portion 292 and the exterior center conductor portion 293 are approximately equal to the longitudinal length of the parallel plate capacitor 275 that they are in coupling arrangement with.

[0042] In the illustrated example, the electrical length of the outer conductor wall structure 220 is one quarter wavelength between the outer conductor proximal end 256 and the outer conductor distal end 257. The electrical length of the center conductor 291 is three quarters of a wavelength. The center conductor 291 electrical length may be referred to as an inner conducting path and is further defined as running along the interior center conductor surface 242

from the proximal end 296 to the distal end 297 of the interior center conductor 292 (one quarter wavelength), then along the inward-facing surface of the connecting center conductor portion 294, then along the inward-facing surface 244 of the exterior center conductor portion 293 to its proximal end 270 (one quarter wavelength), then along the outward-facing surface 246 of the exterior center conductor portion 293 between its proximal end 270 to its distal end 272 (one quarter wavelength). Thus, the electrical length of the center conductor 291 is two quarter wavelengths longer than the electrical length of the outer conductor wall structure 220.

[0043] In the illustrated example, a second coaxial cavity resonator assembly 900 is arranged in series with the coaxial cavity resonator assembly 200. For this example, the coaxial cavity resonator assembly 200 has a resonant frequency of 2.4 Ghz, and the second coaxial cavity resonator assembly 900 has a resonant frequency of 1.6 Ghz. Thus one quarter wavelength of the second coaxial cavity resonator assembly 900 is 50% longer than one quarter wavelength of the coaxial cavity resonator assembly 200, all else being equal.

[0044] The second coaxial cavity resonator assembly 900 includes a center conductor 991 and an outer conductor wall structure 220. The center conductor 991 includes a folded resonator assembly including a series of center conductor surface portions comprising an interior center conductor portion 992, an exterior center conductor portion 993, and a connecting center conductor portion 994. The connecting center conductor portion 994 connects the interior center conductor portion 992 and the exterior center conductor portion 993, all of which are surrounded by the outer conductor wall structure 220. A fifth radial plane is defined by the dotted line labeled E. A sixth radial plane is defined by the dotted line labeled F.

[0045] The wall structure 220 is constructed of a conducting material 222 and surrounds a first cylindrical cavity 225 centered on the axis 215. The wall structure 220 includes a short outer conducting portion 995 which has a proximal end 956 (situated substantially within the fifth radial plane E) and a distal end 957 (situated substantially within the sixth radial plane F). In this example, the first cylindrical cavity 225 is filled with a dielectric material 226.

[0046] The interior center conductor portion 992 has a proximal end 996 (situated substantially within the fifth radial plane E) and a distal end 997 (situated substantially within the sixth radial

plane F). The exterior center conductor portion 993 has a proximal end 970 (situated substantially within the fifth radial plane E) and a distal end 972 (situated substantially within the sixth radial plane F). In this example, the connecting center conductor portion 994 is situated in close proximity to the sixth radial plane F. The exterior center conductor portion 993 surrounds the interior center conductor portion 992.

[0047] An aperture 979 reaches radially outward through the first wall portion 222 through which a radial conductor 977 extends out from the longitudinal axis 215 for connection to an RF line. The end of the radial conductor 977 that is closer to the longitudinal axis 215 connects to a parallel plate capacitor 975 that is in a coupling arrangement to the center conductor structure 950. The parallel plate capacitor 975 is also in a coupling arrangement to a center conductor 991.

[0048] In the illustrated example, the center conductor 991 is connected to the center conductor 291 near its proximal end 296, and a DC line is connected to the interior center conductor portion 992 at its proximal end 996. In this example, the exterior center conductor portion 993 resembles a cylindrical portion of conducting material surrounding the rest of the interior center conductor portion 992. The longitudinal lengths of the interior center conductor portion 992 and the exterior center conductor portion 993 are approximately equal to the longitudinal length of the parallel plate capacitor 975 that they are in coupling arrangement with.

[0049] In the illustrated example, the electrical length of the outer conductor wall structure 220 is one quarter wavelength between the outer conductor proximal end 956 and the outer conductor distal end 957. The electrical length of the center conductor 991 is three quarters of a wavelength. The center conductor 991 electrical length may be referred to as an inner conducting path and is further defined as running along the interior center conductor surface 942 from the proximal end 996 to the distal end 997 of the interior center conductor 992 (one quarter wavelength), then along the inward-facing surface of the connecting center conductor portion 994, then along the inward-facing surface 944 of the exterior center conductor portion 993 to its proximal end 970 (one quarter wavelength), then along the outward-facing surface 946 of the exterior center conductor portion 993 between its proximal end 970 to its distal end 972 (one

quarter wavelength). Thus, the electrical length of the center conductor 991 is two quarter wavelengths longer than the electrical length of the outer conductor wall structure 220.

[0050] This arrangement provides a filtered region of no 2.4 Ghz RF between the third radial plane C and the sixth radial plane F. However, if a 1.6 Ghz RF was introduced near the distal end of the center conductor 291, the region between the third radial plane C and the sixth radial plane F would not be filtered from the 1.6 Ghz RF, and it would only be filtered from the 2.4 Ghz RF. Conversely, if a multi-frequency RF signal containing both 2.4 Ghz RF and 1.6 Ghz RF was introduced near the proximal end of the center conductor 991, the region between the third radial plane C and the sixth radial plane F would be filtered from both the 2.4 Ghz RF and 1.6 Ghz RF. This arrangement can serve as a multi-frequency RF/DC splitter or combiner because it is configured to shift RF signals 180 degrees out of phase relative to the ground plane (i.e., the outer conductor) of the coaxial cavity resonator assembly 900.

[0051] *Multi-Frequency Power Combiner and/or Splitter*

[0052] As shown schematically in Fig. 2B, an exemplary system and method for combining and/or splitting multi-frequency RF/DC signals is presented. The exemplary system 2100 is configured to receive or transmit multi-frequency RF/DC signals on a dual signal transmission line 2200.

[0053] In this embodiment a dual signal having a 20 kilovolt DC signal and both a 2.4 Ghz RF and a 1.6 Ghz RF will be split into its various constituents. A person of ordinary skill in the art would understand that each line may be a feed line or a draw line and the system's operation will only vary in predictable ways. At a RF draw line 2277 a 2.4 Ghz RF signal will be filtered out having been coupled between exterior center conductor 2293 and parallel plate capacitor 2275. At a RF draw line 2977 a 1.6 Ghz RF signal will be filtered out having been coupled between exterior center conductor 2993 and parallel plate capacitor 2975. At DC draw line 2900 all of the RF will have been cancelled and all that will remain is the 20 kilovolt DC signal. At DC draw line 2200 only the 2.4 Ghz RF will have been cancelled, and what remains is a dual signal consisting of the 20 kilovolt DC signal and the 1.6 Ghz RF signal. At a RF draw line 3077 both the 2.4 Ghz RF and the 1.6 Ghz RF signals will be filtered out having been coupled between

exterior center conductor 3093 and parallel plate capacitor 3075. At DC draw line 3000 all of the RF will have been cancelled and all that will remain is the 20 kilovolt DC signal.

[0054] *Ignition System with a Coaxial Cavity Resonator using both Radio Frequency Power and Direct Current Power*

[0055] In accordance with the present invention, an apparatus may further be configured using multiple resonators assembled in a configuration to generate a plasma by applying a combined amount of voltage from radio frequency power and direct current power. Such an apparatus 300 is shown for example in Fig. 3. In this particular example, the apparatus 300 is an assembly of two quarter wave coaxial cavity resonators that are coupled together. More specifically, the resonator assembly 300 shown for example in Fig. 3 includes first and second resonators 310 and 312 coupled in a series arrangement along a longitudinal axis 315.

[0056] In the illustrated example, the first and second resonators 310 and 312 are defined by a common outer conductor wall structure 320. The wall structure 320 includes first and second cylindrical walls 322 and 324 centered on the axis 315. The first wall 322 is constructed of a conducting material and surrounds a first cylindrical cavity 325 centered on the axis 315. The thickness of this material is based on its dielectric breakdown strength. It needs to be strong enough to suppress the current from the outer conductor to the inner conductor. In this example, the first cylindrical cavity 325 is filled with a dielectric material 326 having a relative dielectric constant approximately equal to four ($\epsilon_r = 4$). In this example, the first and second resonators 310 and 312 adjoin one another in a connection plane 332 that is perpendicular to the axis 315. In other examples, the connection plane 332 does not have to be perpendicular, and can change at any rate that maintains a constant impedance between the first and second resonators 310 and 312.

[0057] The second cylindrical wall 312 is constructed of a conducting material and surrounds a second cavity 345 that is also centered on the axis 315. The second cavity 345 is coaxial with the first cavity 325 but has a greater physical length. The second wall 312 provides the second cavity 345 with a distal end 347 spaced along the longitudinal axis 315 from the proximal end 349 of the second cavity 345.

[0058] A center conductor structure 350 is supported within the wall structure 320 of the resonator assembly 300 by the dielectric material 326. The center conductor structure 350 includes first and second center conductors 352 and 354 and a radial conductor 357. The first center conductor 352 reaches within the first cavity 325 along the axis 315. In the illustrated example, the first center conductor 352 has a proximal end 360 adjacent the proximal end 330 of the first cavity 325, and has a distal end 362 adjacent the distal end 349 of the first cavity 325. The radial conductor 357 projects radially from a location adjacent the distal end 362 of the first center conductor 352, across the first cavity 325, and outward through the aperture 339.

[0059] The second center conductor 354 has a proximal end 370 at the distal end 362 of the first center conductor 352, and projects along the axis 315 to a distal end 372 configured as an electrode tip located at or in close proximity to the distal end 347 of the respective cavity 345.

[0060] To minimize any mismatch in impedances between the first and second resonators 310 and 312, the relative radial thicknesses between both the cylindrical walls 322 and 324 and the respective center conductors 352 and 354 are defined in relation to the relative dielectric constant of the dielectric material 326 and the dielectric constant of the air that fills the second cavity 345. In the illustrated example, the physical length along the longitudinal axis 315 of the second center conductor 354 is approximately twice the physical length along the longitudinal axis 315 of the first center conductor 352. However, based at least in part on the dielectric material 326 having a relative dielectric constant approximately equal to four, the electrical lengths of the two center conductors are approximately equal. Note: any gaps between any center conductor and any outer conductor are either filled with a dielectric, or the gap is large enough to minimize arcing. As further shown in Fig. 3, the dielectric material 326 fills the first cavity 325 around the first center conductor 352 and the radial conductor 357.

[0061] In the illustrated example, a DC power source 390 is connected to the center conductor structure 350 through the radial conductor 357 connected adjacent to the virtual short circuit point. An RF control component, specifically, an RF frequency cancellation resonator assembly 391 is disposed between the radial conductor 357 and the DC power source 390 to restrict RF power from reaching the DC power source 390. The RF frequency cancellation resonator assembly is an additional resonator assembly 391 having a center conductor 392 with first and

second portions 393 and 394, each of which has the same electrical length, X , as one another (and the same electrical length as the first and second center conductors 352 and 354). In a preferred example, the electrical length X denoted in figure 3 is equal to one quarter wavelength, or $\lambda/4$, wherein wavelength is inversely related to the frequency of the RF power. The additional resonator assembly 391 also has a short outer conducting wall 395 and a long outer conducting wall 396. The short outer conducting wall 395 has first and second ends on opposite ends of the additional resonator assembly 391. The long outer conducting wall 396 also has first and second ends on opposite ends of the additional resonator assembly 391. The first and second ends of the short outer conducting wall 395 are each on the opposite side from the corresponding first and second ends of the long outer conducting wall 396.

[0062] The difference in electrical length between the short outer conducting wall 395 and the long outer conducting wall 396 is approximately equal to the combined electrical length of the first and second portions 393 and 394, which is also approximately equal to twice the electrical length of the first center conductor 352. The short outer conducting wall 395 and the long outer conducting wall 396 surround a cavity 397 filled with a dielectric material. Under active operation in this example, current running along the outer conductor of the additional resonator assembly 391 will primarily follow the shortest path and run along the short outer conducting wall 395. Accordingly, current on the outer conductor of the additional resonator assembly 391 will travel two fewer quarter wavelengths than current running along the center conductor 392 of the additional resonator assembly 391.

[0063] The additional resonator assembly 391 also has an internal conducting ground plane 398 disposed within the cavity 397 and between the first and second portions 393 and 394 of the center conductor 392. This arrangement provides a frequency cancellation circuit connected between the DC power source 390 and the radial conductor 357. The additional resonator assembly 391 is configured to shift a voltage supply of RF energy 180 degrees out of phase relative to the ground plane of the QWCCR assembly 300 due to the difference in electrical length between the short outer conducting wall 395 and the center conductor 392 of the additional resonator assembly 391.

[0064] As shown schematically in Fig. 4, an RF power source 401 is coupled to the QWCCR assembly 300 across from the first center conductor 352, which is joined to a cylinder 402 in an internal combustion engine, with the electrode tip 372 exposed in a combustion chamber 403 in the cylinder 402. In this preferred example, a controller 404 is coupled to the RF power source 401 and the DC power source 390 for directing the power sources to supply voltages within specific parameters. The controller 404 may comprise any suitable programmable logic controller or other control device, or combination of control devices, that can be programmed or otherwise configured with hardware and/or software to perform as described and claimed.

[0065] When a plasma is to be generated adjacent the electrode tip 372 of the second center conductor 354, the controller 404 directs the RF power source 401 to capacitively couple a voltage supply of RF energy to the first center conductor 352, thereby creating a virtual short adjacent the distal end 362 of the first center conductor 352. This virtual short also couples the voltage supply of RF energy to the second center conductor 354. The voltage supply of RF energy is not sufficient on its own to generate a plasma, and is provided in a first ratio of power over voltage. The controller 404 also directs the DC power source 390 to provide a voltage supply of DC power that is not sufficient on its own to generate a plasma. The voltage supply of DC power is provided in a second ratio of power over voltage that is less than the first ratio of power over voltage associated with the voltage supply of RF energy. The combined voltage from RF energy and DC power is sufficient to generate a plasma. As a result, a plasma is generated adjacent the electrode tip 372 of the second center conductor 354. Determination of the combined voltage sufficient to generate a plasma may be made by the controller 404 in response to conditions measured relative to the combustion chamber 403.

[0066] In alternative examples, the controller 404 is capable of modes of configuration in which more than 51 percent of the voltage sufficient to initiate a plasma at the distal end 372 is provided from the DC power source 390.

[0067] In alternative examples, introduction of the voltage supply of DC power is not limited to the particular virtual short location described above, but rather may be provided near any other virtual short that may be present so as to ensure that the high voltage DC power will have a

minimal effect on the standing electromagnetic wave being formed by the RF power component, and to limit RF power from disturbing the DC power source..

[0068] In alternative examples, either, or both, the DC power source 390 and RF power source 401 may include their own dedicated controllers for directing the provision of a combination of power adequate to generate a plasma at the electrode tip 372; or either, or both, the DC power source 390 and RF power source 401 may be provided within a primary power source. Wherein the primary power source may be configured to control the power output between the DC power source 390 and RF power source 401. In varying examples, the controller 404 may be disposed before or after either or both of the DC power source 390 and the RF power source 401, and the controller 404 may equally be integrated within or without the physical components that house the DC power source 390 and the RF power source 401. The coupling of the RF power source 401 to the center conductors may be enabled by several means: inductive coupling (e.g., an induction feed loop), parallel capacitive coupling (e.g., a parallel plate capacitor), or non-parallel capacitive coupling (e.g., an electric field applied opposite a non-zero voltage conductor end). The particular coupling arrangement employed will depend on the choice of coupling means and the particular structure of the resonator cavities.

[0069] In alternative examples, the RF frequency cancellation resonator assembly 391 may be any component, or series of components, for isolating RF power from reaching the DC power source 390, including, but not limited to: a resistive element, a lumped element inductor, a frequency cancellation circuit. In alternative examples, the RF frequency cancellation resonator assembly 391 may be located in closer proximity to the DC power source 390, the RF frequency cancellation resonator assembly 391 may be located in closer proximity to the QWCCR assembly 300, or the RF frequency cancellation resonator assembly 391 may be located somewhere else between the DC power source 390 and the resonator assembly 300. It is desirable to remove the RF as close to the point of generation as possible to reduce the amount of energy lost to heating, and to keep a high quality factor in the resonator assembly.

[0070] In alternative examples, the teachings of the present disclosure may be applied to a resonator assembly containing as few as one QWCCR, or to assemblies containing multiple QWCCRs arranged in series. Regardless of the number of QWCCRs used, comparatively the

introduction of a (higher voltage, lower power) voltage supply of DC power at a virtual short in combination with a (lower voltage, higher power) voltage supply of RF power will provide a more efficient system for generating a plasma in a greater range of combustion environments while reducing the overall energy requirements for improved combustion and improved overall engine efficiency. By using the voltage supply of DC power as described above, a very large electrical potential is introduced to the system with a negligible use of current or power, in comparison to the RF power used to generate a plasma.

[0071] In accordance with the present invention, an apparatus may further be configured using two resonators assembled in a series configuration to generate a plasma by applying a combined amount of voltage from radio frequency power and direct current power, such an apparatus 500 is shown for example in Fig. 5. In this particular example, the apparatus 500 includes first and second resonator portions 510 and 512 coupled in a series arrangement along a longitudinal axis 515.

[0072] In the illustrated example, the first and second resonator portions 510 and 512 are defined by a common outer conductor wall structure 520. The wall structure 520 includes first and second cylindrical wall portions 522 and 524 centered on the axis 515. The first wall portion 522 is constructed of a conducting material and surrounds a first cylindrical cavity 525 centered on the axis 515. In this example, the first cylindrical cavity 525 is filled with a dielectric material 526. An annular edge 528 of the first wall portion 522 defines a proximal end 530 of the first cavity 525. A proximal end of the second cylindrical wall portion 524 adjoins a distal end 532 of the first cavity 525.

[0073] The second center conductor portion 554 has a proximal end 570 adjoining the distal end 562 of the first center conductor portion 552, and projects along the axis 515 to a distal end 572 configured as an electrode tip located at or in close proximity to the distal end 547 of the second cavity 545.

[0074] An aperture 579 reaches radially outward through the first wall portion 522 through which a radial conductor 577 extends out from the longitudinal axis 515 for connection to the RF power source 401 by an RF power input line. The end of the radial conductor 577 that is closer

to the longitudinal axis 515 connects to a parallel plate capacitor 575 that is in a coupling arrangement to the center conductor structure 550. The parallel plate capacitor 575 is also in a coupling arrangement to an inline folded RF attenuator 591.

[0075] In the illustrated example, a DC power source 390 is connected to the center conductor structure 550 at its proximal end 560 with a DC power input line. The inline folded RF attenuator 591 is disposed between the second resonator portion 512 and the DC power source 390 to restrict RF power from reaching the DC power source 390. The inline folded RF attenuator 591 includes an interior center conductor portion 592 having a first proximal end 596 and a first distal end 597. The inline folded RF attenuator 591 also includes an exterior center conductor portion 593 and a transition center conductor portion 594 that connects interior center conductor portion 592 and the exterior center conductor portion 593. The exterior center conductor portion 593 has a proximal end largely in the same plane as the first proximal end 596, and a distal end largely in the same plane as the first distal end 597. In this example, the transition center conductor portion 594 is located proximal to the first distal end 597. The exterior center conductor portion 593 surrounds the interior center conductor portion 592.

[0076] In this example, the exterior center conductor portion 593 resembles a cylindrical portion of conducting material surrounding the rest of the interior center conductor portion 592. The longitudinal lengths of the interior center conductor portion 592 and the exterior center conductor portion 593 are approximately equal to the longitudinal length of the parallel plate capacitor 575 that they are in coupling arrangement with. The electrical length between the first proximal end 596 to the first distal end 597, for both the interior center conductor portion 592 and the exterior center conductor portion 593, is approximately equal to one quarter wavelength. The second center conductor 554 and the second cylindrical wall portion 524 are both configured to have an electrical length of one quarter wavelength.

[0077] The wall structure 520 includes a short outer conducting portion 595 which has a proximal end largely in the same plane as the first proximal end 596, and a distal end largely in the same plane as the first distal end 597. An outer conducting path runs from the distal end of the wall structure 520 (that is substantially coplanar with the distal end 547 of the second cavity 545), along the short outer conducting portion 595, and stops at the proximal end 530 of the first

wall portion 522. In this example, the outer conducting path has an electrical length of two quarter wavelengths.

[0078] An inner conducting path runs from the distal end electrode tip 572 to the proximal end 570 of the second center conductor portion 554, along the outside of the transition center conductor portion 594, then along the outside from the distal end to the proximal end of the exterior center conductor portion 593, then along the interior wall 599 of the exterior center conductor portion 593 from its proximal end to its distal end, then along the interior center conductor portion 592 from its distal end to its proximal end. In this example, the electrical length of this inner conducting path is four quarter wavelengths, or two half wavelengths. The difference in electrical lengths between the inner conducting path and the outer conducting path is one half wavelength.

[0079] This arrangement provides a radio frequency control component connected between the DC power source 390 and the voltage supply of RF energy. This particular example of a radio frequency control component is an inline folded RF attenuator 591 and is configured to shift a voltage supply of RF energy 180 degrees out of phase relative to the ground plane of the QWCCR assembly 500.

[0080] A person of ordinary skill in the art would understand that the particular QWCCR arrangement depicted in Fig. 5 is not limiting with regards to the orientation of the inline folded RF attenuator 591. In alternative examples, the entire QWCCR arrangement depicted in Fig. 5 may be 'stretched' whereby the inline folded RF attenuator 591 may be disposed further away from the distal end 572 and no longer directly coupled to the parallel plate capacitor 575, but rather separated by one quarter wavelength from the portion of the center conductor that would remain in direct coupling arrangement with the parallel plate capacitor 575 (as seen in Fig. 6). Alternatively, the entire QWCCR arrangement depicted in Fig. 5 could be more compressed whereby the exterior center conductor portions 593 of the inline folded RF attenuator 591 both extend longitudinally as far as the parallel plate capacitor 575 but also surround the portion of center conductor exposed for plasma creation (as seen in Fig. 7). Additional alternative examples to the QWCCR arrangement depicted in Fig. 5 may be implemented by arranging the transition center conductor portion 594 no longer just at the end of the inline folded RF

attenuator 591, but in the middle of the inline folded RF attenuator 591 so that the exterior center conductor portions 593 extend in either direction longitudinally about the transition center conductor portion 594 (as seen in Fig. 8). Any particular geometry of this arrangement would require tweaking to the various parameters of dielectrics to ensure impedance matching and full 180 degree phase cancellation, but these tasks are well understood engineering tasks.

[0081] In one example, the QWCCRs of the present invention and the particular combination of components that provide the RF signal to the QWCCR are contained in a body dimensioned approximately the size of the prior art spark plug 106 and adapted to mate with the combustion chamber of a combustion engine. More specifically, this example uses a microwave amplifier at the resonator and uses the resonator as the frequency determining element in an oscillator amplifier arrangement. The amplifier/oscillator would be attached at the top of the plug, and would have the high voltage supply also integrated in the module with diagnostics. This example permits the use of a single low voltage DC supply for feeding the module along with a timing signal.

[0082] In the context of this description various terms may refer to locations where as a result of a particular configuration, and under certain conditions of operation, a voltage component may be measured as close to non-existent. For example, “voltage short” may refer to any location where a voltage component may be close to non-existent under certain conditions. Similar terms may equally refer to this location of close-to-zero voltage, *e.g.*, “virtual short circuit,” “virtual short location,” or “voltage null.” Often times a person of ordinary skill in the art might limit the use of “virtual short” to only those locations where the close-to-zero voltage is a result of a standing wave crossing zero. “Voltage null” may at times more often be used to refer to locations of close-to-zero voltage for a reason other than as result of a standing wave crossing zero, *e.g.*, voltage attenuation or cancellation. Moreover, in the context of this disclosure, each of these terms that can refer to locations of close-to-zero voltage are meant to be non-limiting, and instead only limited by their surrounding context including the particular dimensions and specifications of the application within which they are described.

[0083] The examples of the invention shown in the drawings and described above are exemplary of numerous examples that may be made within the scope of the appended claims.

Additional examples of the invention may further include elements selected from any one or more of the prior art examples described above as needed to accomplish any desired implementation of the structure and function made available by the invention. It is the applicant's intention that the scope of the patent will be limited only by the scope of the appended claims.

What is claimed is:**1. A coaxial cavity resonator assembly comprising:**

an outer conductor including an outer conductor proximal end, an outer conductor distal end, and an outer conductor electrical length that is defined between the outer conductor proximal end and the outer conductor distal end;

a center conductor including a center conductor proximal end, a center conductor distal end, and a center conductor electrical length that is defined between the center conductor proximal end and the center conductor distal end; and

wherein the center conductor proximal end is substantially coplanar with the outer conductor proximal end, the center conductor distal end is substantially coplanar with the outer conductor distal end, and the center conductor electrical length is longer than the outer conductor electrical length by an integer multiple of one-half of one wavelength.

2. The coaxial cavity resonator assembly of claim 1, wherein the center conductor includes a first folded resonator assembly including a series of center conductor surface portions comprising:

an interior center conductor portion having an interior center conductor proximal end and an interior center conductor distal end;

an exterior center conductor portion having an exterior center conductor proximal end and an exterior center conductor distal end between which an inward-facing exterior center conductor portion surrounds the interior center conductor portion and an outward-facing exterior center conductor portion is surrounded by the outer conductor;

a connecting center conductor portion connected to the interior center conductor distal end and the exterior center conductor distal end;

wherein the interior center conductor proximal end and the exterior center conductor proximal end are substantially coplanar to the outer conductor proximal end, the interior center conductor distal end and the exterior center conductor distal end are substantially coplanar to the outer conductor distal end, and the center conductor electrical length is further defined as running

along the interior center conductor portion between the interior center conductor proximal end to the connecting center conductor portion,

along the inward-facing exterior center conductor portion between the exterior center conductor distal end to the exterior center conductor proximal end, and

along the outward-facing exterior center conductor portion between the exterior center conductor proximal end to the exterior center conductor distal end.

3. The coaxial cavity resonator assembly of claim 1, wherein the outer conductor is configured to permit a coupling arrangement between the center conductor and a radio frequency coupler.
4. The coaxial cavity resonator assembly of claim 1, wherein the center conductor is configured to connect to a direct current power source.
5. The coaxial cavity resonator assembly of claim 2, wherein the center conductor includes a second folded resonator assembly and is configured to provide a filtered region along the center conductor between the first folded resonator assembly and the second folded resonator assembly.
6. The coaxial cavity resonator assembly of claim 5, wherein the outer conductor is configured to permit a first coupling arrangement between the center conductor and a first radio frequency coupler and a second coupling arrangement between the center conductor and a second radio frequency coupler.
7. The coaxial cavity resonator assembly of claim 1, further comprising at least one rigid dielectric disposed between the center conductor and the outer conductor.

8. A method of combining a radio frequency signal and a direct current signal, comprising:
- connecting the direct current signal to a proximal end of a center conductor portion of a coaxial cavity resonator assembly, wherein a center conductor electrical length is defined between the center conductor proximal end and a center conductor distal end, wherein the coaxial cavity resonator assembly also includes an outer conductor having an outer conductor electrical length defined between an outer conductor proximal end and an outer conductor distal end;
- coupling the radio frequency signal to the center conductor portion of the coaxial cavity resonator assembly, wherein the center conductor electrical length is longer than the outer conductor electrical length by an integer multiple of one-half of one wavelength; and
- transmitting from the center conductor distal end a dual signal including the radio frequency signal and the direct current signal.

9. The method of claim 8, wherein the center conductor portion includes a first folded resonator assembly including a series of center conductor surface portions comprising:

an interior center conductor portion having an interior center conductor proximal end and an interior center conductor distal end;

an exterior center conductor portion having an exterior center conductor proximal end and an exterior center conductor distal end between which an inward-facing exterior center conductor portion surrounds the interior center conductor portion and an outward-facing exterior center conductor portion is surrounded by the outer conductor;

a connecting center conductor portion connected to the interior center conductor distal end and the exterior center conductor distal end;

wherein the interior center conductor proximal end and the exterior center conductor proximal end are substantially coplanar to the outer conductor proximal end, the interior center conductor distal end and the exterior center conductor distal end are substantially coplanar to the outer conductor distal end, and the center conductor electrical length is further defined as running

along the interior center conductor portion between the interior center conductor proximal end to the connecting center conductor portion,

along the inward-facing exterior center conductor portion between the exterior center conductor distal end to the exterior center conductor proximal end, and

along the outward-facing exterior center conductor portion between the exterior center conductor proximal end to the exterior center conductor distal end.

10. A method of splitting a dual signal including a radio frequency signal and a direct current signal, comprising:

connecting the dual signal to a distal end of a center conductor portion of a coaxial cavity resonator assembly, wherein a center conductor electrical length is defined between the center conductor proximal end and a center conductor distal end, wherein the coaxial cavity resonator assembly also includes an outer conductor having an outer conductor electrical length defined between an outer conductor proximal end and an outer conductor distal end;

decoupling the radio frequency signal from the center conductor portion of the coaxial cavity resonator assembly, wherein the center conductor electrical length is longer than the outer conductor electrical length by an integer multiple of one-half of one wavelength; and

transmitting from the center conductor proximal end the direct current signal.

11. The method of claim 10, wherein the center conductor portion includes a first folded resonator assembly including a series of center conductor surface portions comprising:

an interior center conductor portion having an interior center conductor proximal end and an interior center conductor distal end;

an exterior center conductor portion having an exterior center conductor proximal end and an exterior center conductor distal end between which an inward-facing exterior center conductor portion surrounds the interior center conductor portion and an outward-facing exterior center conductor portion is surrounded by the outer conductor;

a connecting center conductor portion connected to the interior center conductor distal end and the exterior center conductor distal end;

wherein the interior center conductor proximal end and the exterior center conductor proximal end are substantially coplanar to the outer conductor proximal end, the interior center conductor distal end and the exterior center conductor distal end are substantially coplanar to the outer conductor distal end, and the center conductor electrical length is further defined as running

along the interior center conductor portion between the interior center conductor proximal end to the connecting center conductor portion,

along the inward-facing exterior center conductor portion between the exterior center conductor distal end to the exterior center conductor proximal end, and

along the outward-facing exterior center conductor portion between the exterior center conductor proximal end to the exterior center conductor distal end.

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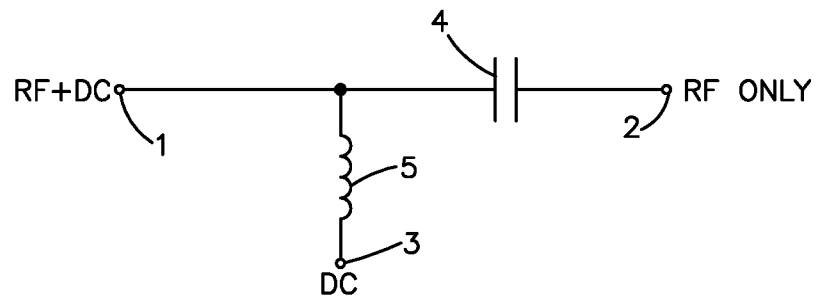


Fig. 1A

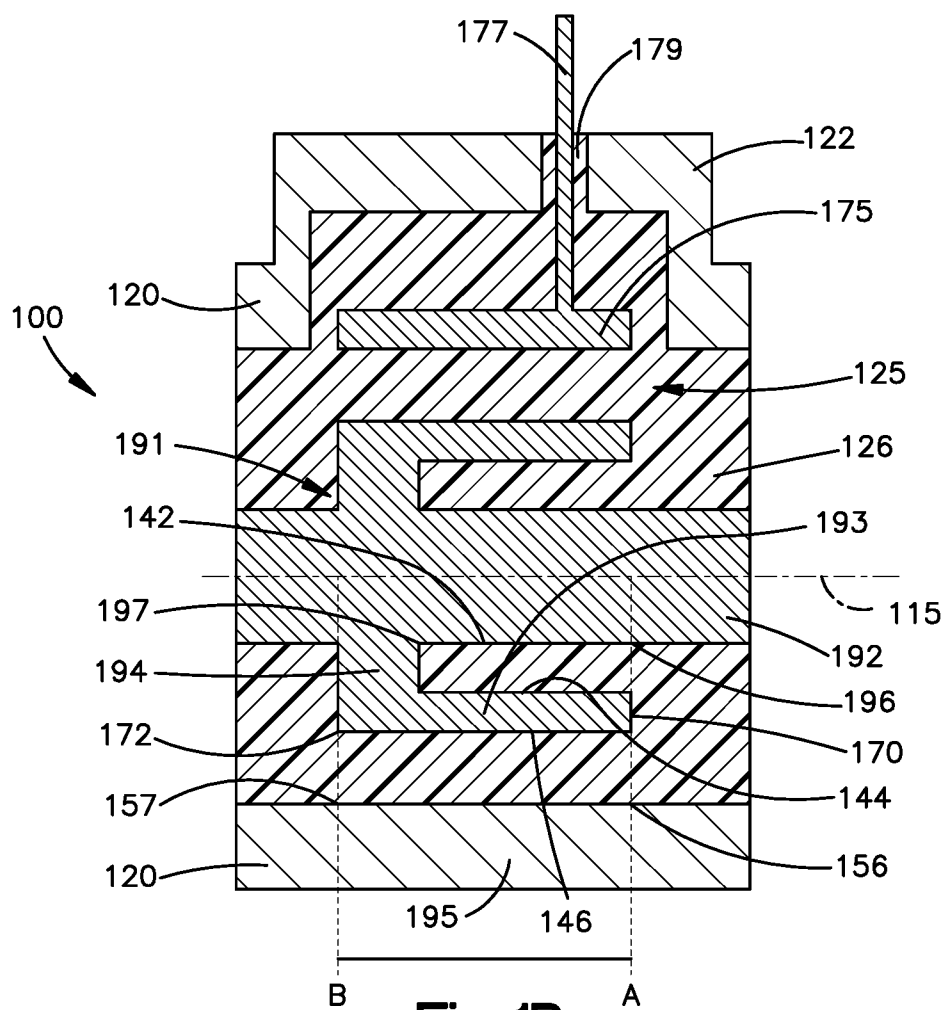


Fig. 1B

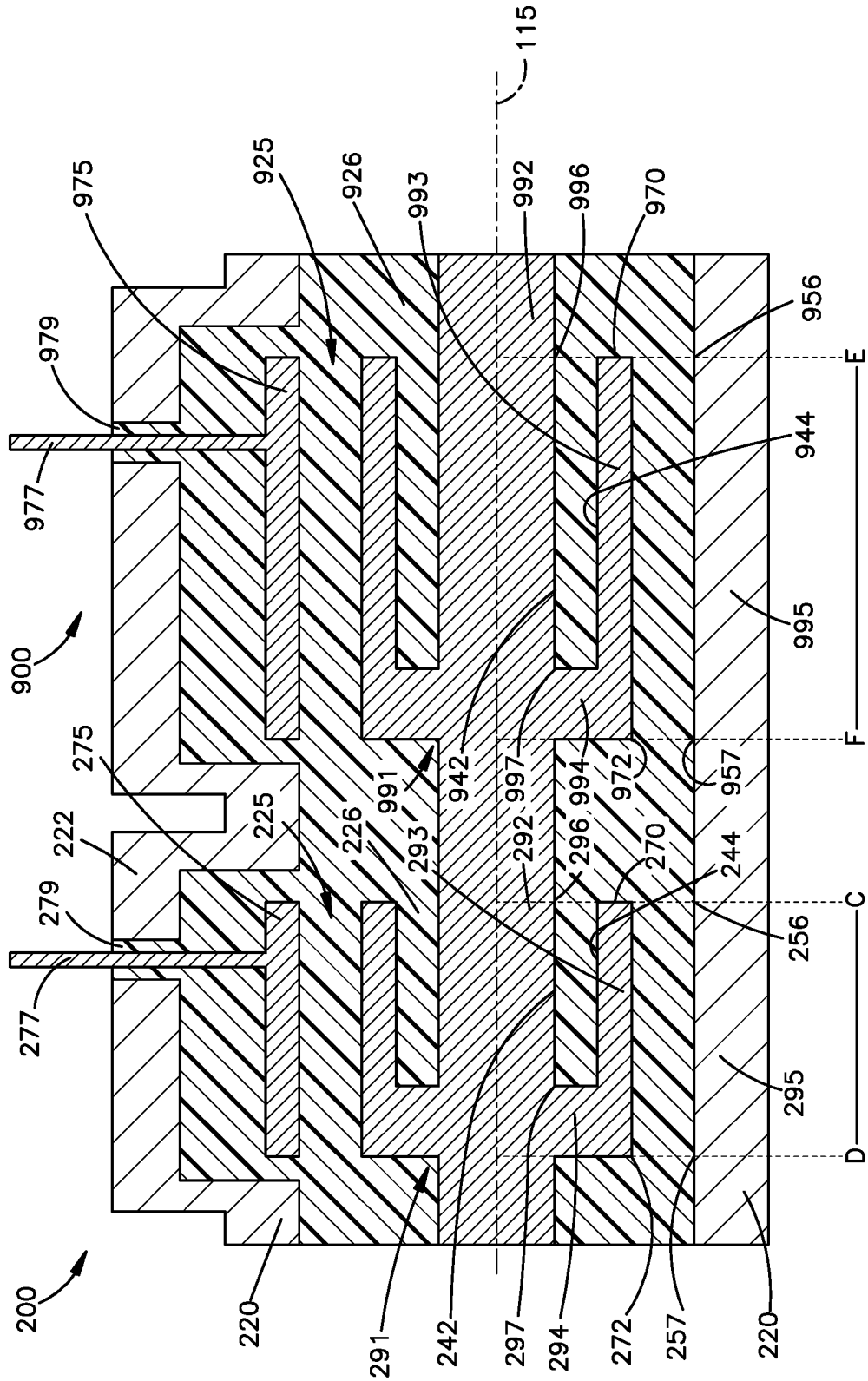
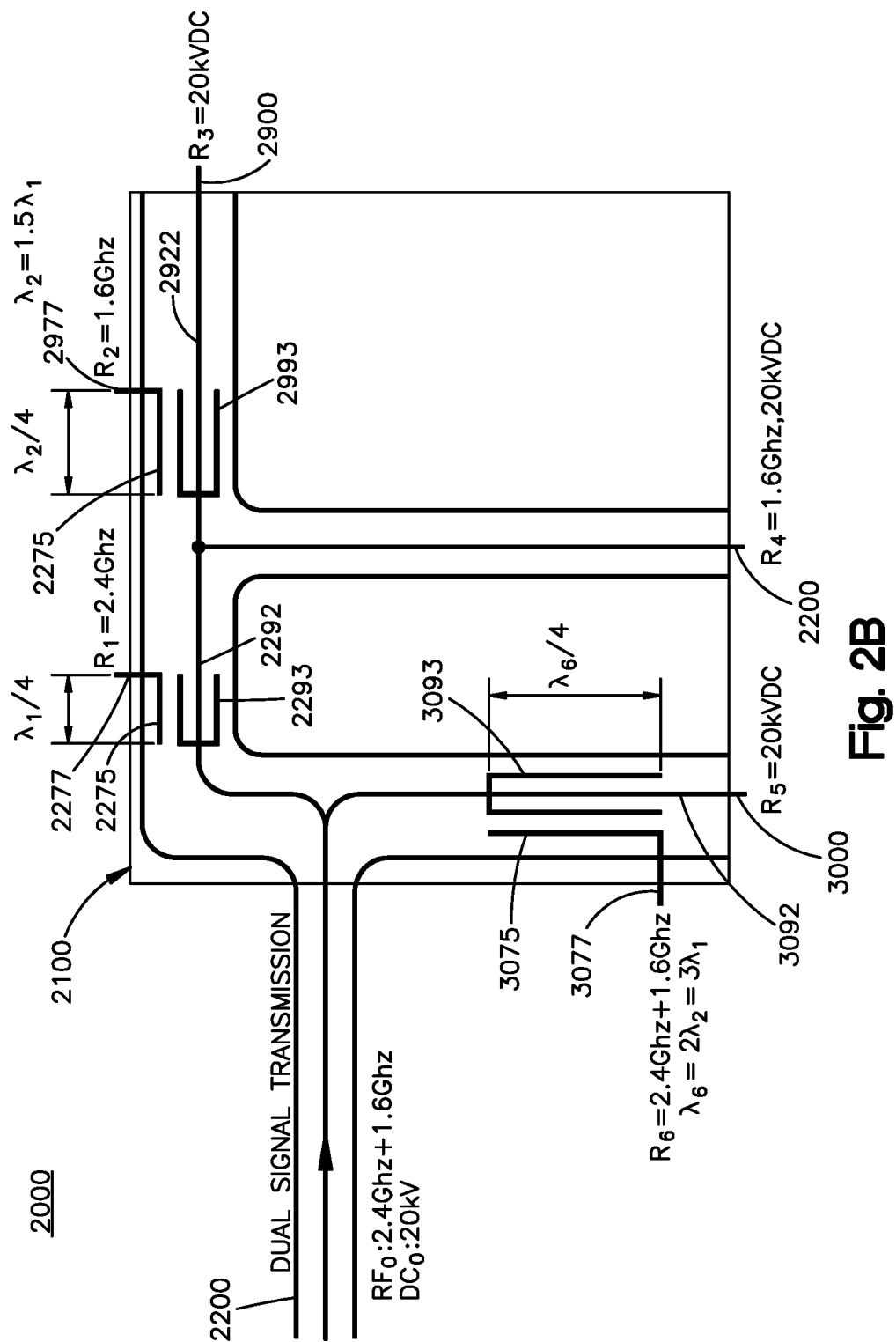
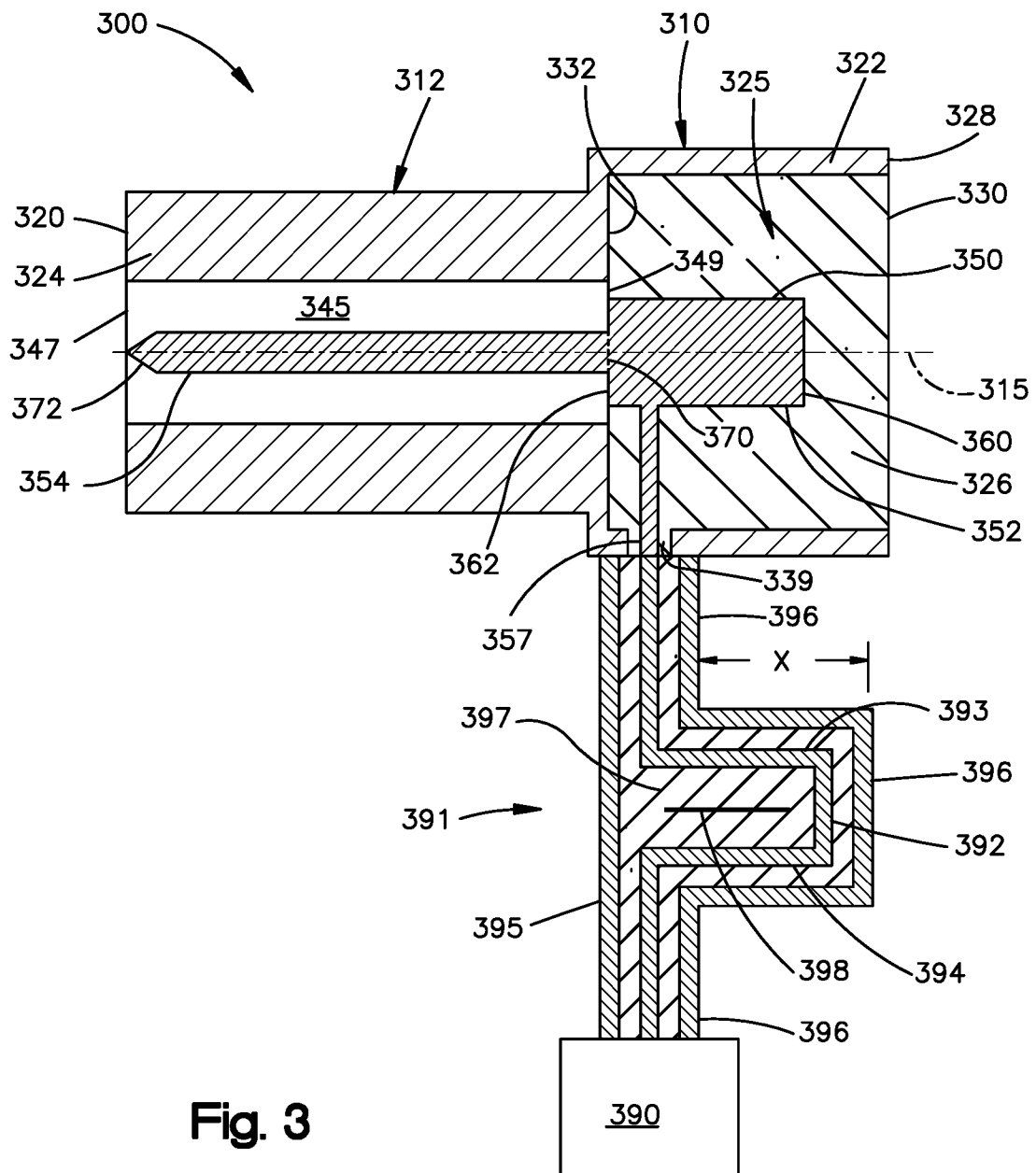


Fig. 2A



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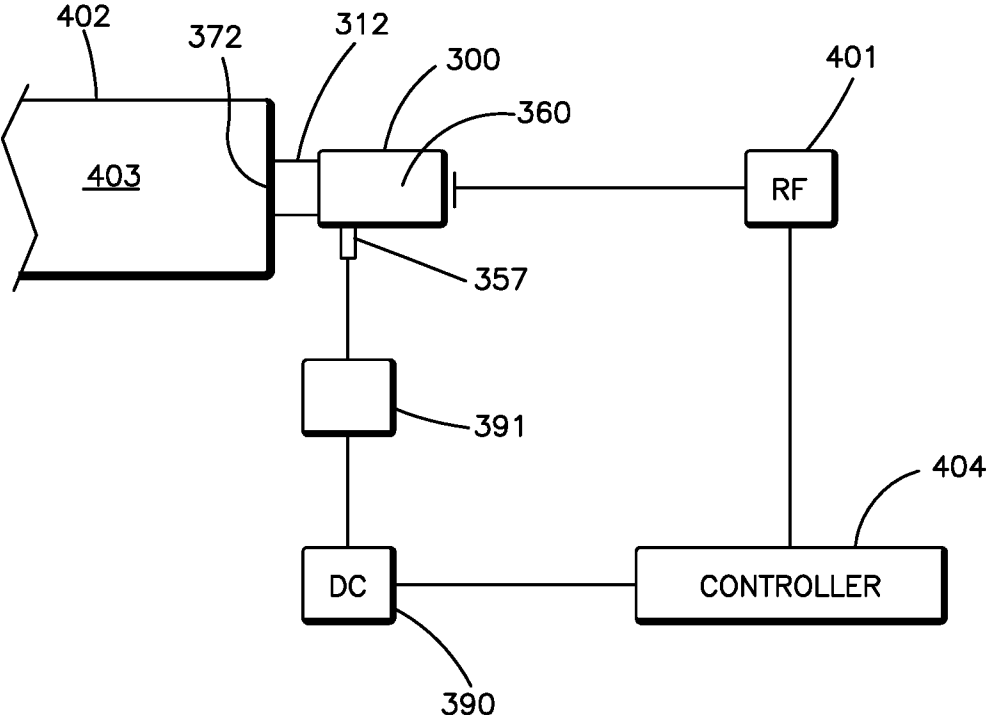


Fig. 4

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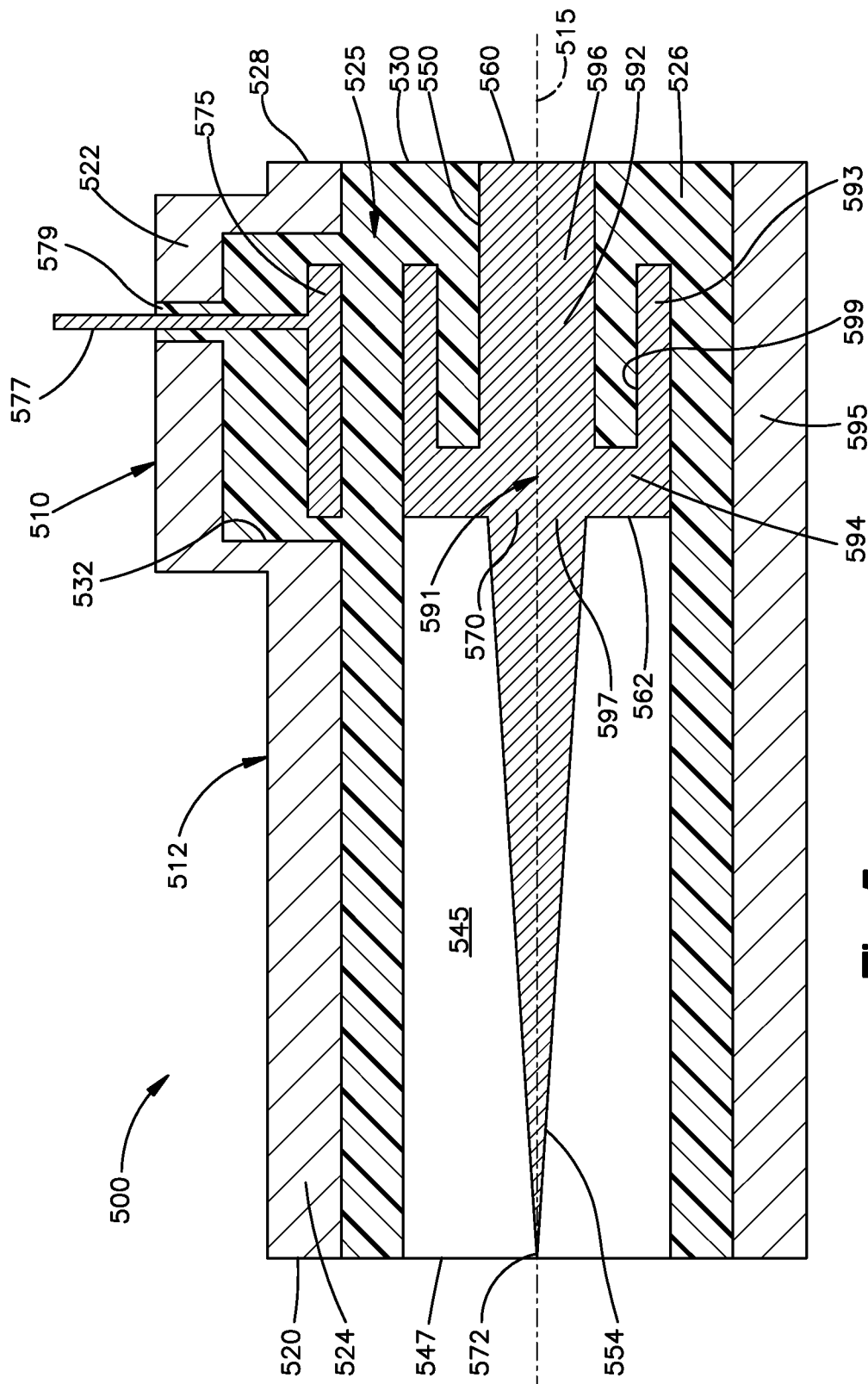


Fig. 5

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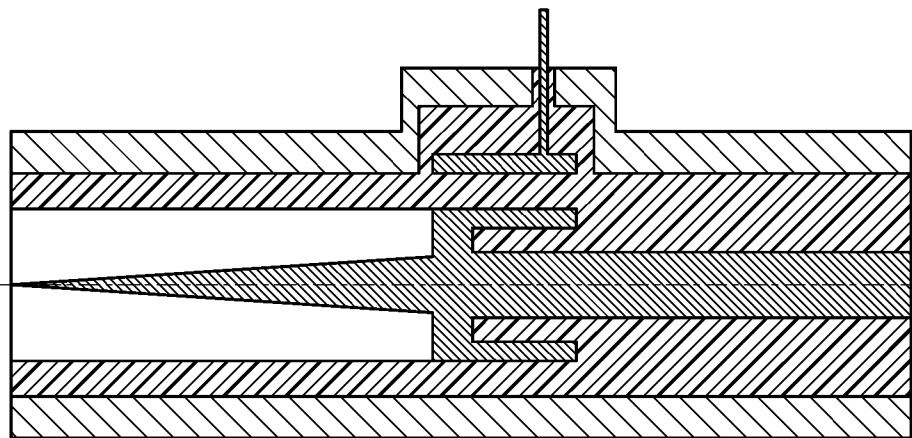


Fig.6

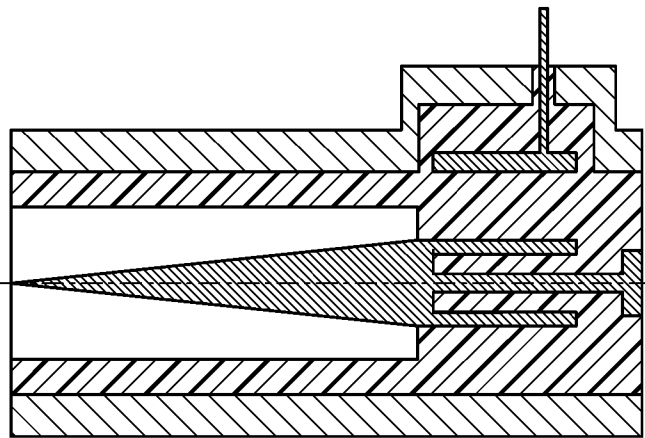


Fig.7

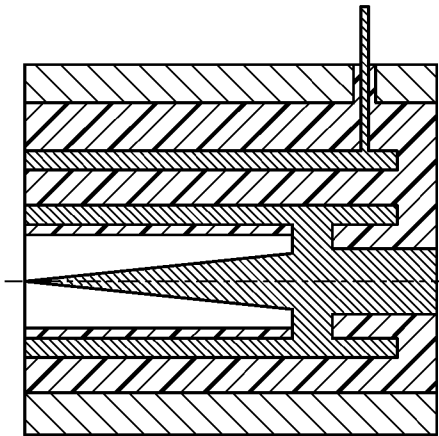


Fig.8

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2016/026478

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - H01P 7/06; H01P 1/16; H01P 3/06 (2016.01)

CPC - H01P 1/202; H01P 7/06; H01P 1/16; H01P 1/2056 (2016.02)

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)

IPC(8) - H01P 7/06; H01P 1/16; H01P 3/06 (2016.01)

CPC - H01P 7/06; H01P 1/16; H01P 1/202; H01P 1/2056 (2016.02)

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

USPC - 333/206, 222, 227, 228, 230 (keyword delimited)

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

Orbit, Google Patents, ProQuest

Search terms used: radio frequency, directional coupler, filter, coaxial cavity resonator, distal, proximal, wavelength, ac, rf, electrical length, folded, outer conductor, center conductor, exterior, interior, connecting

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2011/0175691 A1 (SMITH et al) 21 July 2011 (21.07.2011) entire document	1-11
Y	US 2,630,490 A (RICHARDS PAUL I) 03 March 1953 (03.03.1953) entire document	1-11
A	US 5,517,163 A (SAGAWA et al) 14 May 1996 (14.05.1996) entire document	1-11
A	US 5,668,564 A (SEWARD et al) 16 September 1997 (16.09.1997) entire document	1-11

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

01 June 2016

Date of mailing of the international search report

24 JUN 2016

Name and mailing address of the ISA/

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