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Attorney Docket No. 300167
10 October 2019

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CODE 00T2, BLDG. 102T
NEWPORT, RI 02841

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Filing Date	31 July 2019
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WIDEBAND SLOT ANTENNA WITH INTERDIGITAL BACK PLANE

STATEMENT OF GOVERNMENT INTEREST

[0001] The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

CROSS REFERENCE TO OTHER PATENT APPLICATIONS

[0002] None.

BACKGROUND OF THE INVENTION

(1) Field of the Invention

[0003] The present invention relates to antennas, and more particularly to a slot antenna.

(2) Description of the Prior Art

[0004] An antenna which can operate over wide bandwidths is desirable for many reasons. One reason is that a wide bandwidth antenna can replace narrow bandwidth antennas tuned over the same bandwidth. A second reason is that a wide bandwidth antenna permits simultaneous receive-transmit functions over a prescribed frequency band.

[0005] In the prior art, particularly in the area of slotted antennas, there have been various methods of producing different beam pattern shapes and wide impedance bandwidths. The limitation of these methods has been a requirement that the antenna operate above a cutoff frequency. The cutoff frequency is the frequency where the antenna ceases to operate.

[0006] The cutoff frequency depends on the cross-sectional properties of the antenna. The properties are slot width (w), mean radius (a) and cylinder wall thickness (t). A formula for a cutoff wavelength λ_c of a slotted cylinder antenna has been derived and is expressed in Equation **(1)** as

[0007] $$\lambda_c \approx 2a\left[1 + 3\sqrt{(\pi t/w) + 2\big(1 + ln(a/w)\big)}\right] \quad \textbf{(1)}$$

[0008] The cutoff frequency f_c is then determined with the well-known frequency/wavelength conversion formula of Equation **(2)**

[0009] $$\lambda = \frac{v_o}{f} \quad \textbf{(2)}$$

[0010] where v_o is the speed of light ($\approx 3 \times 10^8$ meters/sec).

[0011] Examining the cutoff wavelength formula indicates a fundamental about the proper operation of the antenna. That is, if the cylinder wall thickness (t) and the slot width (w) are held constant; higher cutoff frequencies would require smaller diameter tubes and lower frequencies would require larger diameter tubes.

[0012] A typical slotted-cylinder antenna has a slot width that is uniform and operates over a frequency bandwidth of at most ±20% from the center design frequency and depends on a length-to-width ratio of the slot for a given cylinder diameter and wall thickness.

[0013] In the typical antenna with uniform slot width, the cylindrical section affects the slot impedance and radiation pattern. The shape of the radiation pattern in the horizontal plane changes with the ratio of the perimeter-to-wavelength (p/λ). For small p/λ (< 0.3), the antenna pattern is omnidirectional; antennas with larger values of p/λ have more directional patterns, the main beam lobe emanating from the slot region.

[0014] As such, there is a continuing need for a smaller diameter slotted antenna that be used at lower frequencies. There is an additional need for a slotted antenna that yields a wide impedance bandwidth.

SUMMARY OF THE INVENTION

[0015] It is therefore a primary object and a general purpose of the present invention to provide a slot antenna that operates over a large bandwidth with an impedance match and radiation beam patterns with a moderately high gain.

[0016] To attain the object of the present invention, a slot antenna is provided to include a metal cavity behind the slot.

The longitudinal slot is configured with aligned rectangular apertures of varying parameters. Each of the rectangular apertures is sized based on an operational frequency.

[0017] The metal cavity comprises a series of spaced-apart interdigital back plates. A feed point is attached to a support stiffener that connects the interdigital back plates with the feed point positioned beneath a central location of the slot.

[0018] The interdigital plates can modify the wave propagation properties of the slot. This is because the shape of the slot controls the impedance at the feed terminal (located at the center of the slot) to a level that is acceptable to load, such as a receiver or transmitter, over a very wide frequency bandwidth (a frequency ratio F_{high}/F_{low} of about 3:1).

[0019] In a typical slotted-cylinder antenna with uniform slot width, the cylindrical section affects the slot impedance and radiation pattern. A plate in the present application affects only the radiation pattern but not the slot impedance in a noticeable way.

[0020] In both cases, the shape of the radiation pattern in the horizontal plane changes with the ratio of the perimeter-to-wavelength (p/λ). For small p/λ (< 0.3), the antenna pattern is omnidirectional; antennas with larger values of p/λ have more directional patterns, the main beam lobe emanating from the slot region.

[0021] The slot antenna can be used for applications requiring wideband performance in a slender silhouette. Wideband performance is determined by the impedance behavior of the slot over a range of frequencies. At low frequencies the perimeter-to-wavelength ratio (p/λ) of the antenna is small, meaning that the antenna is electrically slender, so the pattern in the horizontal plane is omnidirectional.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] Other objects, features and advantages of the present invention will become apparent upon reference to the following description of the preferred embodiments and to the drawings, wherein corresponding reference characters indicate corresponding parts throughout the several views of the drawings and wherein:

[0023] **FIG. 1** depicts an assembled slot antenna of the present invention;

[0024] **FIG. 2** depicts an arrangement of interdigital back plates that form a first section of the slot antenna;

[0025] **FIG. 3** depicts the interdigital back plates with an addition of spacer plates;

[0026] **FIG. 4** depicts the first section with an addition of a support stiffener and a feed port bracket standoff;

[0027] **FIG. 5** depicts the feed port bracket standoff with an addition of a feed port support bracket;

[0028] **FIG. 6** depicts the first section with an addition of a support stanchion for a feed region at a slot center;

[0029] **FIG. 7** depicts the first section with an addition of a slot center feed;

[0030] **FIG. 8** depicts the first section with an addition of a feed cowl;

[0031] **FIG. 9** depicts a configuration of a slotted plate with wideband slot;

[0032] **FIG. 10** depicts an electrical equivalent circuit of a sub-length of the slot configuration;

[0033] **FIG. 11** depicts an electrical equivalent circuit of a slot sub-length with a continuous metal backing;

[0034] **FIG. 12** depicts an electrical equivalent circuit of a slot sub-length with an interdigital metal backing;

[0035] **FIG. 13** depicts the slot antenna of the present invention unfurled to show positioning of the slotted plate in relation to the interdigital plates;

[0036] **FIG. 14** depicts the slot antenna of the present invention unfurled to show surface current distribution at a frequency of 0.63 F0;

[0037] **FIG. 15** depicts the slot antenna of the present invention unfurled to show surface current distribution at a center design frequency; and

[0038] **FIG. 16** depicts the slot antenna of the present invention unfurled to show surface current distribution at a frequency of 1.33 F0.

DETAILED DESCRIPTION OF THE INVENTION

[0039] Referring now to the drawings, **FIG. 1** depicts an assembled slot antenna **10** of the present invention. As shown by an exterior of the slot antenna **10**, the antenna comprises a first section **12** and a slotted plate or a second section **14**. The first section **12** comprises a first interdigital back plate **20**, a second interdigital back plate **22** and a third interdigital back plate **24** with the slotted plate **14** affixed to the back plates. A feed port **52** extends from a first end of the slot antenna **10** and is capable of energizing the whole antenna. Numerous fasteners **60** secure the various components of the slot antenna **10**.

[0040] Although fabricated from aluminum, brass and plastic composites, the slot antenna **10** can be made from other materials to withstand environmental elements or other considerations. The parts to the slot antenna **10** are shown positioned for assembly in **FIGS. 2-8**.

[0041] **FIG. 2** depicts the positioning of the U-shaped first interdigital back plate **20**, the U-shaped second interdigital back plate **22** and the U-shaped third interdigital back plate **24** as part of the first section **12**. Each of the first interdigital back plate **20**, the second interdigital back plate **22** and the third interdigital back plate **24** has a machined flat (with three threaded holes) on one side of the U-shape and a simple edge on the other side of the U-shape. Each machined flat is connected to the slotted plate **14** on alternating sides with fasteners **60**. "Interdigital" refers to the appearance of the mounted U-plates since the attachment points are on opposite sides of the first interdigital back plate **20**, the second interdigital back plate **22** and the third interdigital back plate **24**. The first interdigital back plate **20**, the second interdigital back plate **22** and the third interdigital back plate **24** are spaced apart to create an electrical equivalent circuit.

[0042] At their planar ends, the first interdigital back plate **20**, the second interdigital back plate **22** and the third interdigital back plate **24** are spaced apart from each other. The first interdigital back plate **20**, the second interdigital back plate **22** and the third interdigital back plate **24** include numerous fastener apertures for assembly. The first interdigital back plate **20,** the second interdigital back plate **22** and the third interdigital back plate **24** are made from aluminum.

[0043] **FIG. 3** depicts the positioning of a first insulator spacer **26** and a second insulator spacer **28** affixed to the first interdigital back plate **20.** A third insulator spacer **30** and a fourth insulator spacer **32** are affixed to the second interdigital back plate **22.** A fifth insulator spacer **34** and a sixth insulator spacer **36** are affixed to the third interdigital back plate **24.** The first insulator spacer **26,** the second insulator spacer **28,** the third insulator spacer **30,** the fourth insulator spacer **32,** the fifth insulator spacer **34** and the sixth insulator spacer **36** include numerous fastener apertures for assembly. The insulator spacers are made from fiberglass and are attached to the simple edges of the U-shaped interdigital plates using screws or bolts on the sides of the plates.

[0044] **FIG. 4** depicts the addition of a support stiffener **40** and feed port bracket standoff **42** as part of the first section **12.** The support stiffener **40** and the feed port bracket standoff **42** include fastener apertures for assembly with the support stiffener and the feed port bracket standoff made from fiberglass.

[0045] **FIG. 5** depicts the positioning of a feed port support bracket **44** as part of the first section **12.** The feed port support bracket **44** includes fastener apertures for assembly with the feed port support bracket made from aluminum.

[0046] **FIG. 6** depicts the positioning of a center support **46** on the support stiffener **40.** The center support **46** includes fastener apertures for assembly with the center support made from fiberglass.

[0047] **FIG. 7** depicts the positioning of a feed point **48** on the center support **46.** The feed point **48** is a simple cone. The feed point **48** includes fastener apertures for assembly with the feed point made from brass.

[0048] **FIG. 8** depicts the positioning of a feed cowl **50** as a protective cover for the feed point **48.** The feed cowl **50** can slip on the feed point **48** with the feed cowl preferably made of a Noryl polymer. The feed cowl is a plastic cover that contributes some support and prevents dirt from entering a feed region of the antenna **10.**

[0049] The slotted plate or the second section **14** is shown secured by the fasteners **60** in **FIG. 1.** The sizing of a slot **70** in the slotted plate **14** is shown in **FIG. 9** with the sizing of the slot depending on the operating wavelength λ and calculated by Equation **(3)**

$$\lambda = \frac{v_o}{f} \quad \textbf{(3)}$$

where v_o is the speed of light and f is the operating frequency.

[0050] The feed point **48** of **FIG. 7** spans the width of the slot **70.** One end of the cone of the feed point **48** is grounded to the slotted plate **14** and is attached. The other end of the cone is connected to a center pin of a coaxial connector. An outside metallic shell of the coaxial connector makes contact with the slotted plate **14.** In this way, a source of radio-frequency power can be applied across the connector to energize the slot **70.** The feed point 48 is placed centrally along a length of the slot **70** so that the resulting radiation in the vertical plane is balanced – that is to prevent the beam pattern from tilting to one end of the slot.

[0051] The operating frequency of the slot **70** is actually the center of the operating band (that is, $f = F0$). Dimensions of the slot **70,** as represented in **FIG. 9,** are W1 = λ /33, W2 = λ /17, W3 = λ /5 and L = λ /8. The slot 70 is divided into nine sub-lengths of length “L”. Each sub-length measures λ /8 where λ is the wavelength at the center of the operating band. The total slot length is therefore 9L or 9λ/8 at the band center.

[0052] For understanding the electrical behavior of the slot antenna **10,** a focus should be on the Voltage Standing Wave Ratio. The Voltage Standing Wave Ratio (VSWR) is a measure of how closely matched the slot antenna **10** is to a transmitter or a receiver having a nominal 50-ohm impedance. A VSWR of unity is considered a perfect match but is rarely met in practice.

[0053] For the slot antenna **10**, the VSWR is satisfactory for any application. In practical terms, the VSWR provides information about the loss in power transfer between the slot antenna **10** and the receiver or transmitter due in a mismatch in impedance. The mismatch M (in dB) is given by Equation **(4)**

$$M = 10log\left[\frac{4S}{(S+1)^2}\right] \quad \textbf{(4)}$$

where S is the VSWR of the slot antenna **10**.

[0054] Another focus can be on radiation beam patterns and realized gain. The radiation beam patterns for the slot antenna **10** are generally toroidal in shape and surround the structure of the slot antenna with the beam patterns retaining shape over numerous operational frequency ranges. With extremes in frequency, the shape of the beam patterns change slightly.

[0055] The operation of the slot antenna **10** is explained by simple electrical equivalent circuits which are derived by supposing that the shape of the slot **70** is made of a wire (or band) of infinitesimal diameter and that the slotted plate **14** as well as the first interdigital back plate **20**, the second interdigital back plate **22** and the third interdigital back plate **24** are connected to the thin-wire slot.

[0056] The slotted plate as well as the first interdigital back plate **20**, the second interdigital back plate **22** and the third interdigital back plate **24** are conceptually removed; thereby, leaving behind the thin-wire slot intact and isolated in space. The wire-frame structure left behind is essentially a parallel-wire transmission line with a varying wire separation along a length with short circuits at each end.

[0057] With a sinusoidal voltage source connected across conductors at the midpoint of the slot length, currents will flow along the wires and establish magnetic lines of force around each conductor and electric field lines arcing across the parallel wires of transmission line. Because a cross-section of the transmission line is a fraction of the operating wavelength, the line can be represented as the sum of smaller sub-lengths Δl; each sub-length having an electrical equivalent circuit shown in **FIG. 10**.

[0058] In the figure, R_{se} and L_{se} are the per-unit length series resistance and inductance, respectively, and C_{sh} and G_{sh} are the per-unit length shunt capacitance and conductance, respectively. L_{se} represents the energy storage in the magnetic field of the line with R_{se} being an ohmic dissipation. C_{sh} represents the energy storage in the electric field of the line and G_{sh} represents the energy leakage due to imperfect storage of the electric field.

[0059] The symbols $\hat{z}$ and $\hat{y}$ are the "n" per-unit length impedance (units: Ohms per meter, Ω/m) and admittance (units: Siemens per meter, S/m), respectively, and are functions of the four equivalent circuit elements (R_{se}, L_{se}, C_{sh}, G_{sh}). See Equations **(5)** and **(6)**

$$\hat{z} = R_{se} + j\omega L_{se} \quad \textbf{(5)}$$

$$\hat{y} = G_{sh} + j\omega C_{sh} \quad \textbf{(6)}$$

where ω is the angular frequency ($\omega = 2\pi f$) and $j = \sqrt{-1}$.

[0060] An important quantity derived from the equivalent circuit is the propagation constant γ defined in Equation **(7)** as

$$\gamma = \alpha + j\beta = \sqrt{\hat{z}\hat{y}} \quad \textbf{(7)}$$

where α and β are the per-unit length attenuation and phase constant, respectively. The two quantities describe the amplitude decay, and indirectly, the velocity of the electromagnetic wave as the wave propagates from the voltage source toward the short circuit and back.

[0061] The value of γ for the line above, in terms of the four per-unit length quantities is therefore in Equation **(8)** as

$$\gamma = \sqrt{A + jB} \quad \textbf{(8)}$$

whereas in Equation **(9)** and Equation **(10)**

$$A = R_{se}G_{sh} - \omega^2 L_{se}C_{sh} \quad \textbf{(9)}$$

$$B = \omega(R_{se}C_{sh} + L_{se}G_{sh}) \quad \textbf{(10)}$$

[0062] Quantities A and B are the real and imaginary parts (respectively) of the complex product $\hat{z}\hat{y}$ under the square root which defines the propagation constant γ.

[0063] For an ideal line, $R_{se} = 0$ and $G_{sh} = 0$ and γ attains a value from Equation **(11)** of

$$\gamma = j\omega\sqrt{L_{se}C_{sh}} \quad \textbf{(11)}$$

and in essence that of Equation **(12)** and Equation **(13)**

$$\alpha = 0 \quad \textbf{(12)}$$

$$\beta = \omega\sqrt{L_{se}C_{sh}} \quad \textbf{(13)}$$

[0064] This indicates that wave propagation between the wires of the lossless transmission line travels along the line with no amplitude decay and with a velocity of Equation **(14)**

[0065] $$v = \frac{\omega}{\beta} = \frac{1}{\sqrt{L_{se}C_{sh}}} = v_o \quad \textbf{(14)}$$

where v_o equates to the speed of light.

[0066] The parallel-wire transmission is now attached to a metal box (or cylinder) to form an antenna, but without interdigital (open-short) plates. The equivalent circuit of a small length Δl of slot is represented with the circuit in **FIG. 11.**

[0067] In the figure, L_{sh} is the shunt inductance of the box (or tube) that the parallel-line slot electrically "sees". If it is assumed that $R_{se} = 0$ and $G_{sh} \neq 0$ (because currents are now generated over a surface of the antenna resulting in radiation), the propagation constant γ attains a value (omitting the intermediate steps) by Equation **(15)**:

[0068]
$$\gamma = \sqrt{-\omega^2 L_{se} C_{sh}\left[1 - \frac{1}{(\omega^2 L_{sh} C_{sh})}\right] + j\omega L_{se} G_{sh}} \qquad \textbf{(15)}$$

using Equation **(16)**

$$\hat{z} = j\omega L_{se} \qquad \textbf{(16)}$$

and Equation **(17)**

$$\hat{y} = G_{sh} + j\omega C_{sh} + \frac{1}{j\omega L_{sh}} \qquad \textbf{(17)}$$

Assuming that in Equation **(18)**

$$\omega^2 L_{se} C_{sh}\left[1 - \frac{1}{(\omega^2 L_{sh} C_{sh})}\right] > \omega L_{se} G_{sh} \qquad \textbf{(18)}$$

the propagation constant γ of Equation **(19)** is approximately

$$\gamma \approx \frac{\omega G_{sh}}{2}\sqrt{\frac{L_{se}}{[\omega^2 C_{sh} - (1/L_{sh})]}} + j\omega\sqrt{L_{se} C_{sh}\left[1 - \frac{1}{(\omega^2 L_{sh} C_{sh})}\right]} \qquad \textbf{(19)}$$

and by Equation **(20)**, the phase constant is

$$\beta \approx \omega\sqrt{L_{se} C_{sh}\left[1 - \frac{1}{(\omega^2 L_{sh} C_{sh})}\right]} \qquad \textbf{(20)}$$

[0069] The phase constant indicates that the wave propagation in the slot region depends on the value of L_{sh}. Essentially, L_{sh}

makes the antenna radiate or activate when the term in the square bracket is positive, that is, when by Equation **(21)**

$$\omega^2 L_{sh} C_{sh} > 1 \qquad \textbf{(21)}$$

and is inactivated or non-radiative, when $\omega^2 L_{sh} C_{sh} \leq 1$ because the amplitude of the propagating wave in the slot region decays rapidly as the wave travels away from the source of energy (the feed point **48**).

[0070] The condition of Equation **(22)**

$$\omega^2 L_{sh} C_{sh} = 1 \qquad \textbf{(22)}$$

is identified as the cutoff condition and is well-known in the art.

[0071] In the present invention, the first interdigital back plate **20**, the second interdigital back plate **22** and the third interdigital back plate **24** have alternating gaps along the length of the antenna structure that capacitively couple to the slotted plate **14.** The equivalent circuit of a short length Δl of slot is shown in **FIG. 12.**

[0072] The circuit of the figure illustrates an effect of the slot **70,** which is to maintain wave propagation behavior similar to that found in a simple transmission line, where the phase velocity of the wave in the slot is the same as that of free space. If a solid plate was substituted behind the slotted plate **14**; the phase velocity of the propagating wave in the slot region would differ appreciably from that found in free space as described in **FIG. 11**, such that the physical slot length would need to be longer for the same operating frequency range.

[0073] The interdigital plates modify the wave propagation behavior in the slot region to maintain a slot length comparable to the operating wavelength without affecting the radiation pattern in a significant way.

[0074] In **FIG. 12**, L_p and C_p represent the inductance of the interdigital plate and the capacitance of the gap, respectively. Assuming that $R_{se} = 0$ and $G_{sh} \neq 0$, the propagation constant in the slot region is now (omitting the intermediate steps) detailed in Equation **(23)**

$$\gamma = \sqrt{-\omega^2 L_{se}\left[C_{sh} + \frac{C_p}{1-\omega^2 L_p C_p}\right] + j\omega L_{se} G_{sh}} \quad \textbf{(23)}$$

which is approximately in Equation **(24)** as

$$\gamma \approx \frac{G_{sh}}{2}\sqrt{\frac{L_{se}}{C_{sh}+\left(\frac{C_p}{1-\omega^2 L_p C_p}\right)}} + j\omega\sqrt{L_{se}\left[C_{sh} + \left(\frac{C_p}{1-\omega^2 L_p C_p}\right)\right]} \quad \textbf{(24)}$$

using Equation **(25)**

$$\hat{z} = j\omega L_{se} \quad \textbf{(25)}$$

and by Equation **(26)**

$$\hat{y} = G_{sh} + j\omega C_{sh} + \left(\frac{1}{j\omega L_p + \frac{1}{j\omega C_p}}\right) \quad \textbf{(26)}$$

so that the phase constant now has the form by Equation **(27)**

$$\beta \approx \omega\sqrt{L_{se}\left[C_{sh}+\left(\frac{C_p}{1-\omega^2 L_p C_p}\right)\right]} \qquad \textbf{(27)}$$

[0075] The result above states two important facts in that when $\omega^2 L_p C_p \ll 1$, as would likely be the case when the interdigital plate length is small, the slot antenna **10** does not have a cutoff frequency and that the wave propagation in the slot is independent of L_{sh}.

[0076] The implication is that the use of interdigital plates permits the construction of slotted antennas with very small metal troughs or other back-plane shapes without a concern for cutoff. It also indicates that slot antennas with small metallic backing can be used for low frequency operation if the interdigital technique is employed.

[0077] A traditional slotted tube antenna with a small diameter operates at very high frequencies because the cutoff frequency varies inversely with diameter. By using a small diameter interdigital-plate slotted tube antenna; the frequency of operation can be much lower because the slot length is the only controlling factor. This also means that the slot shape can yield a wideband impedance match over the desired frequency range.

[0078] The radiation beam pattern produced by the antenna at various frequencies is a result of the way in which electric current spreads over its surface, both in magnitude and direction. **FIG. 13** depicts the interdigital arms behind the slot plate unfurled, where the interior lines are locations where there are bends. The current distributions are corresponding to beam patterns referenced earlier are shown in **FIG. 14, FIG. 15** and **FIG. 16.**

[0079] It can be seen in **FIG. 14, FIG. 15** and **FIG. 16** that the currents spread over the antenna surface in interesting ways, as the electrical size of the structure changes from sub-multiples to multiples of the design center frequency F0.

[0080] The advantage of the slot antenna **10** of the present is that the design does not require knowledge of the cutoff frequency to determine operating frequency. Only the slot length determines the operating frequency. This make possible the design of lower-frequency antennas previously thought unfeasible due to the large cylinder sizes required by cutoff considerations. Another advantage is that the radiative beam patterns of the slot antenna **10** are similar to a continuously metal-backed antenna.

[0081] It will be understood that many additional changes in the details, materials, steps and arrangement of parts, which have been herein described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of the expressed in the appended claims.

WIDEBAND SLOT ANTENNA WITH INTERDIGITAL BACK PLANE

ABSTRACT OF THE DISCLOSURE

An antenna is provided with a plurality of spaced-apart interdigital back plates covered by a slotted plate having a longitudinal slot of varying rectangular parameters. A plurality of spacers are positioned between the interdigital back plates and the slotted plate. A support stiffener connects the interdigital back plates at a trough of each back plate with three rectangular stanchions extending perpendicular from the support stiffener to attach to the slotted plate. A feed point is positioned on a central rectangular stanchion and beneath a central slot of the slotted plate. A feed cowl protects the feed point. The sizing of a slot in the slotted plate depends on an operating wavelength.

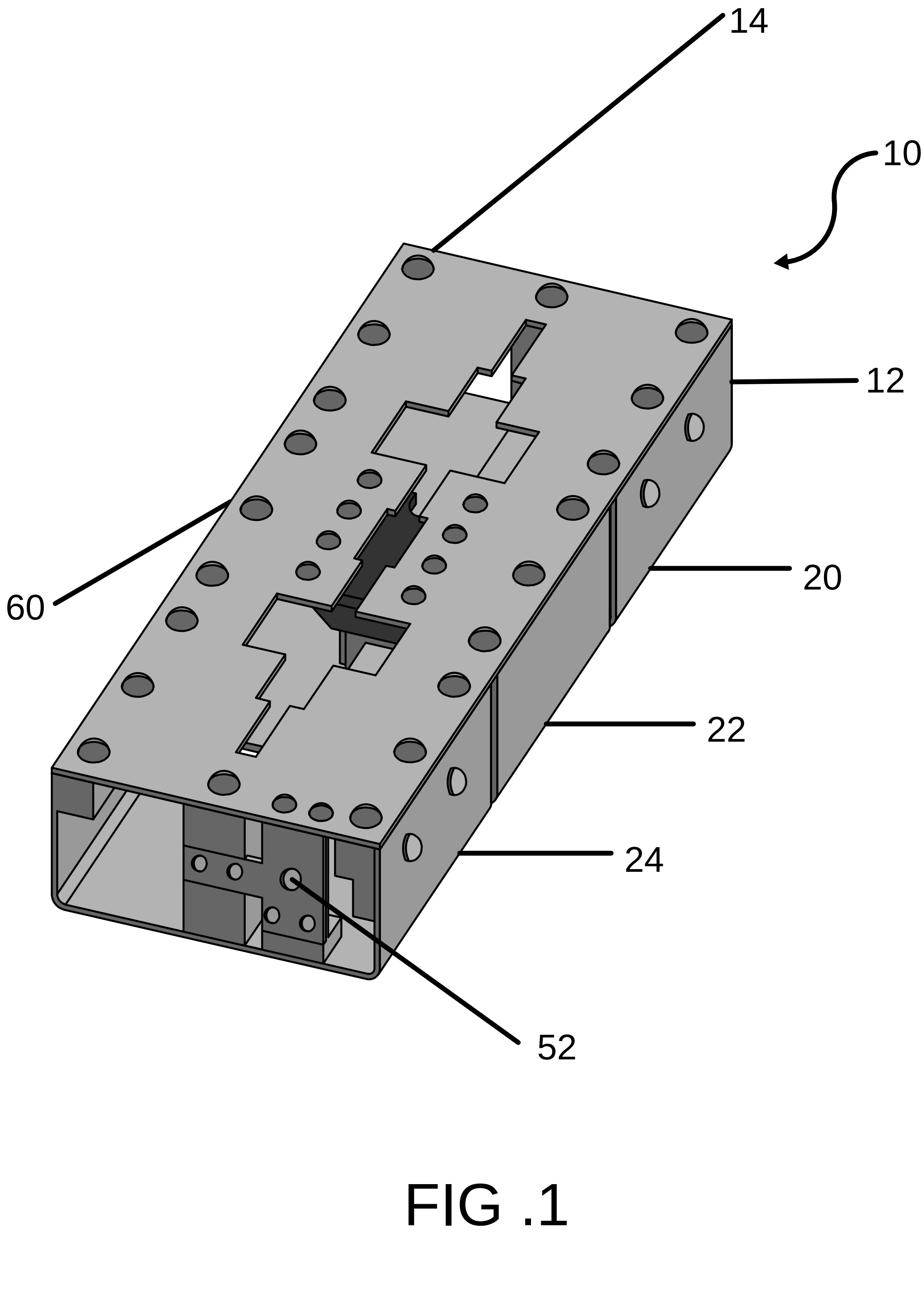

FIG .1

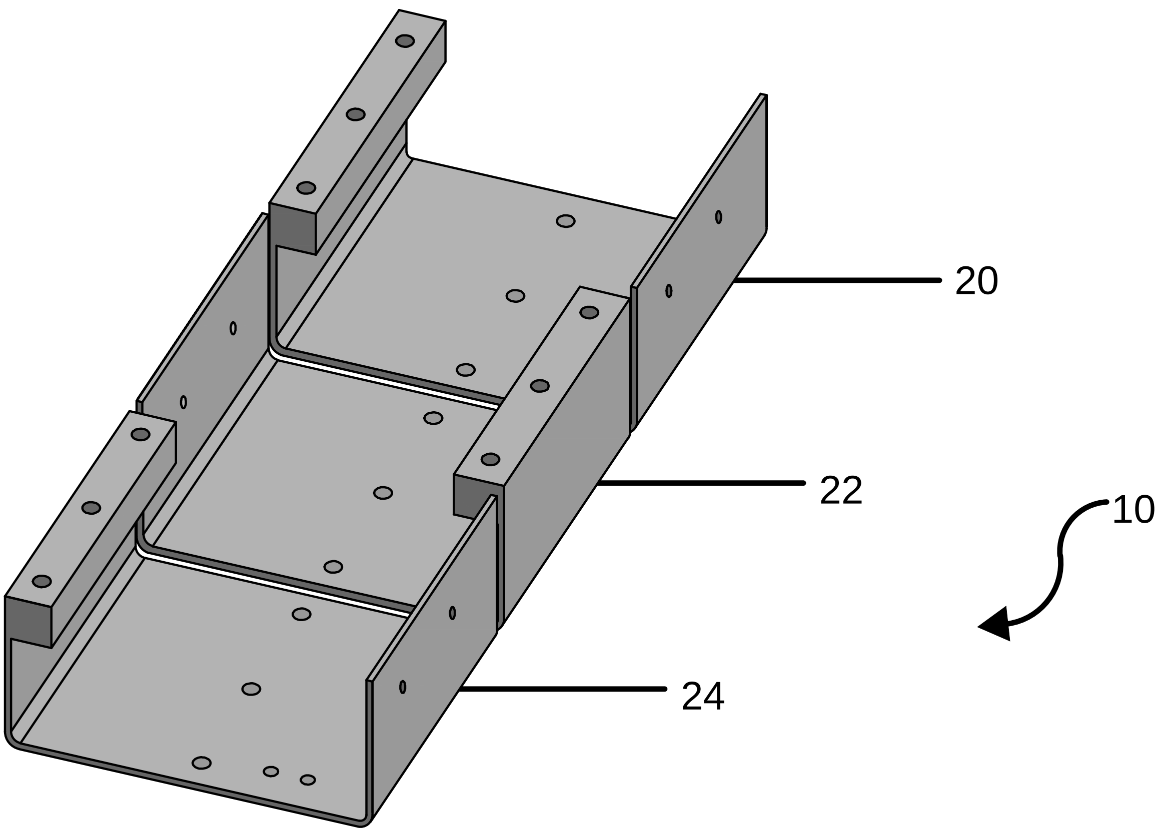

FIG .2

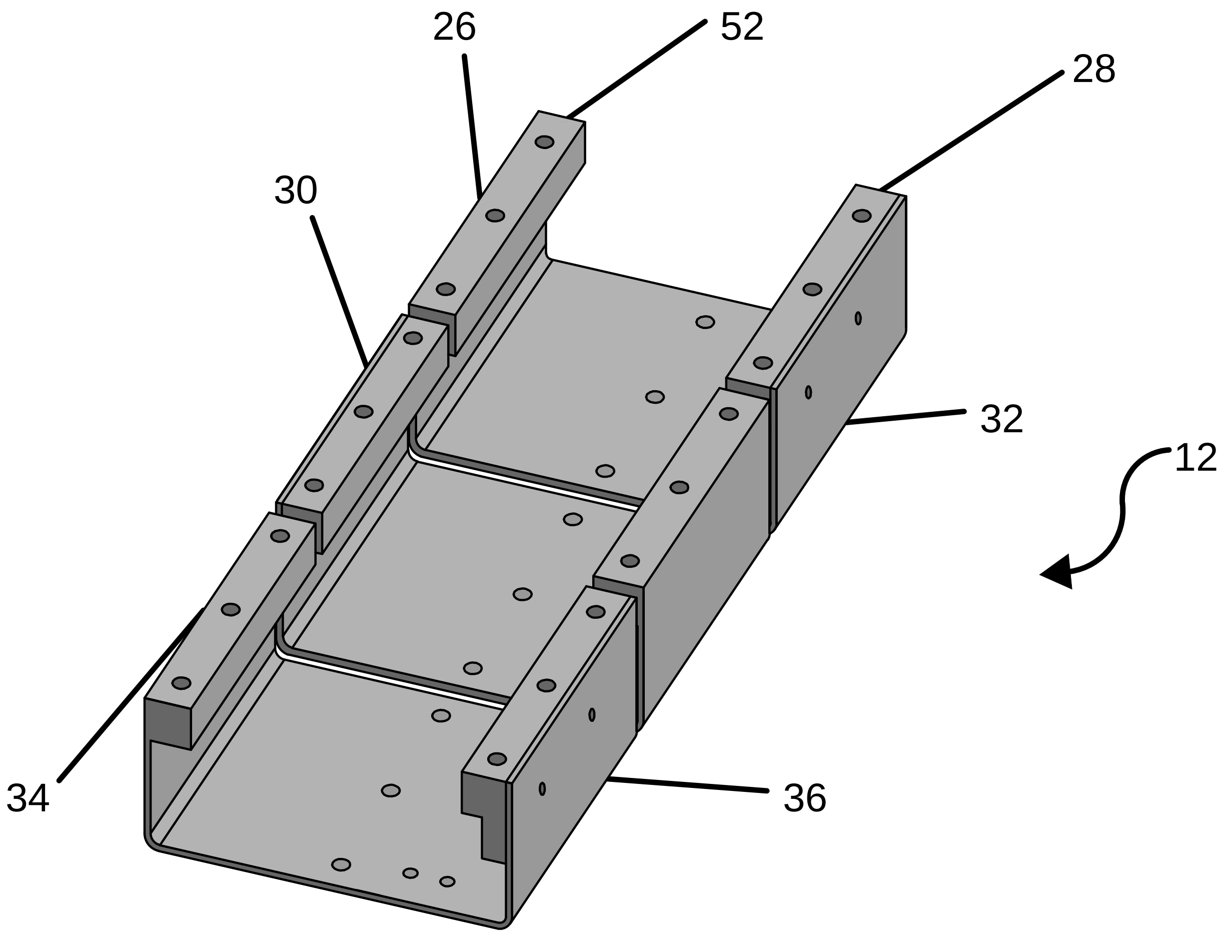

FIG .3

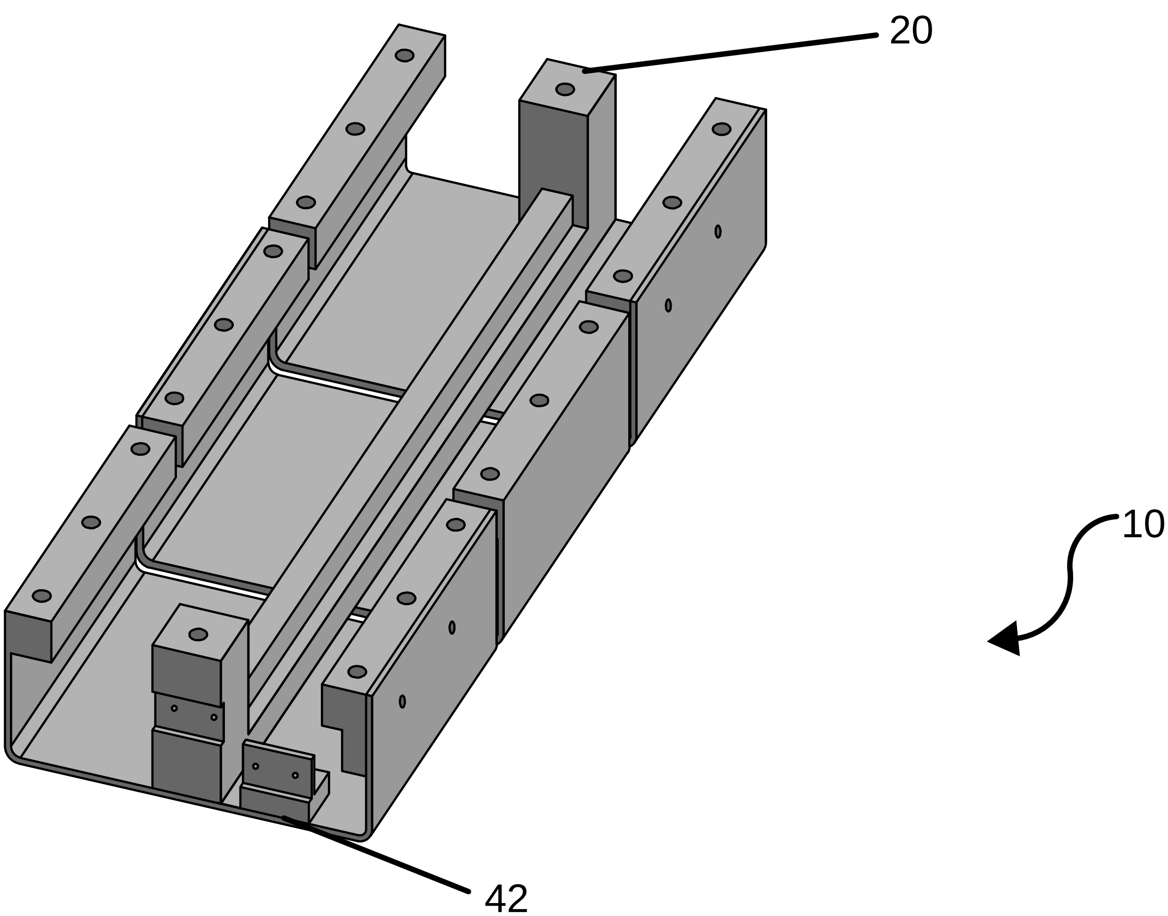

FIG .4

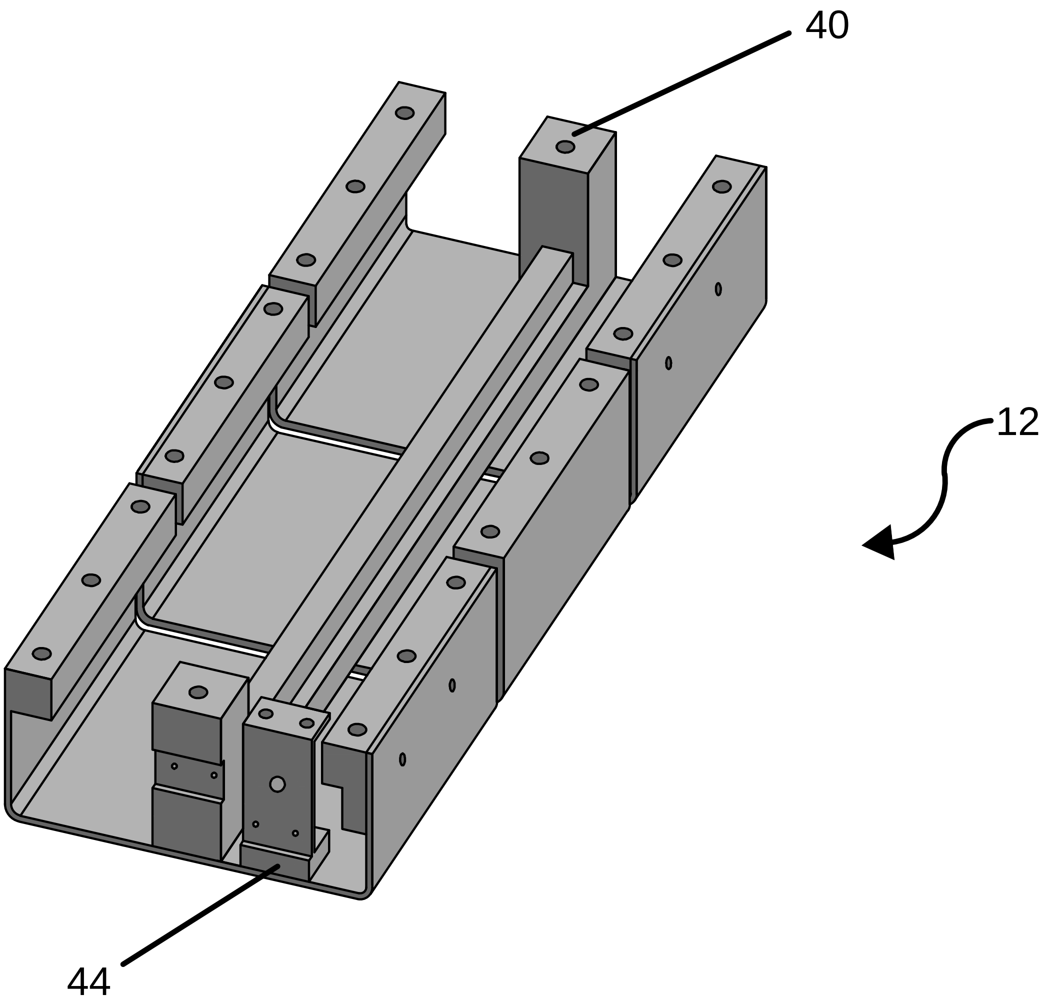

FIG .5

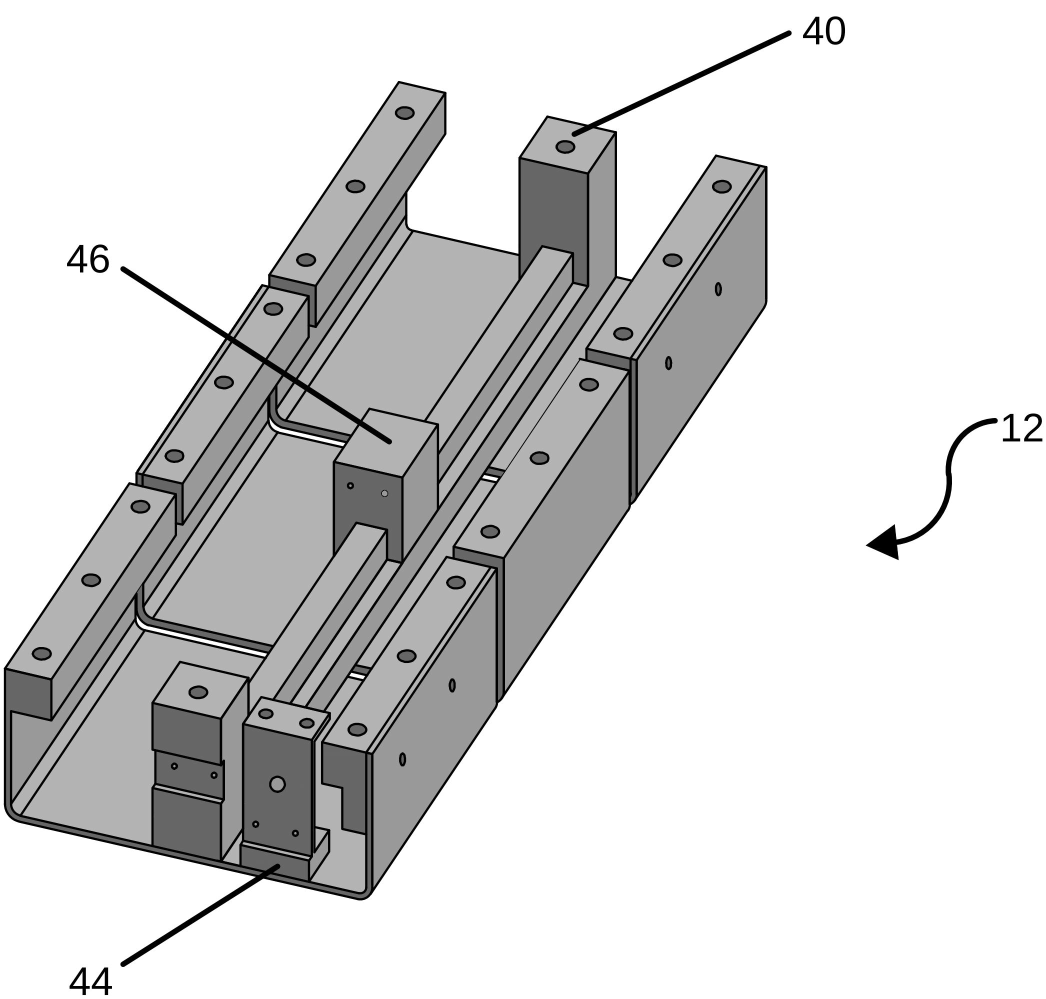

FIG .6

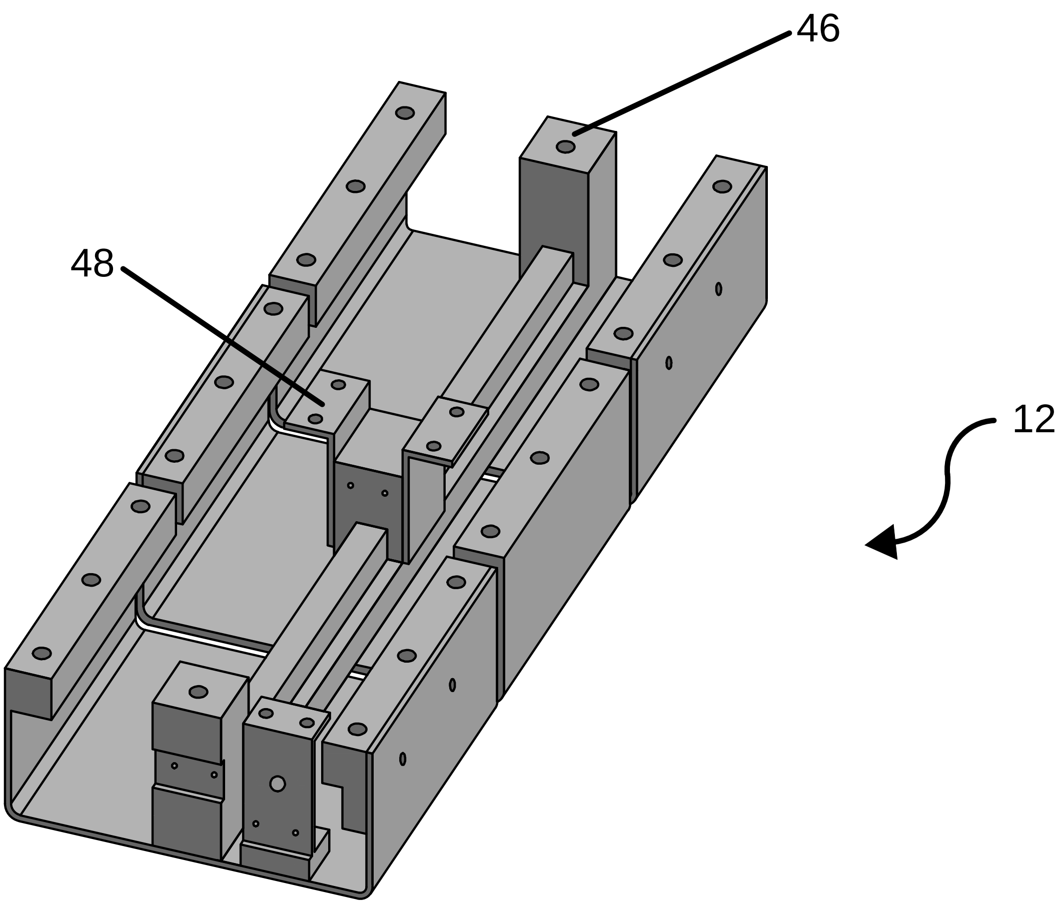

FIG .7

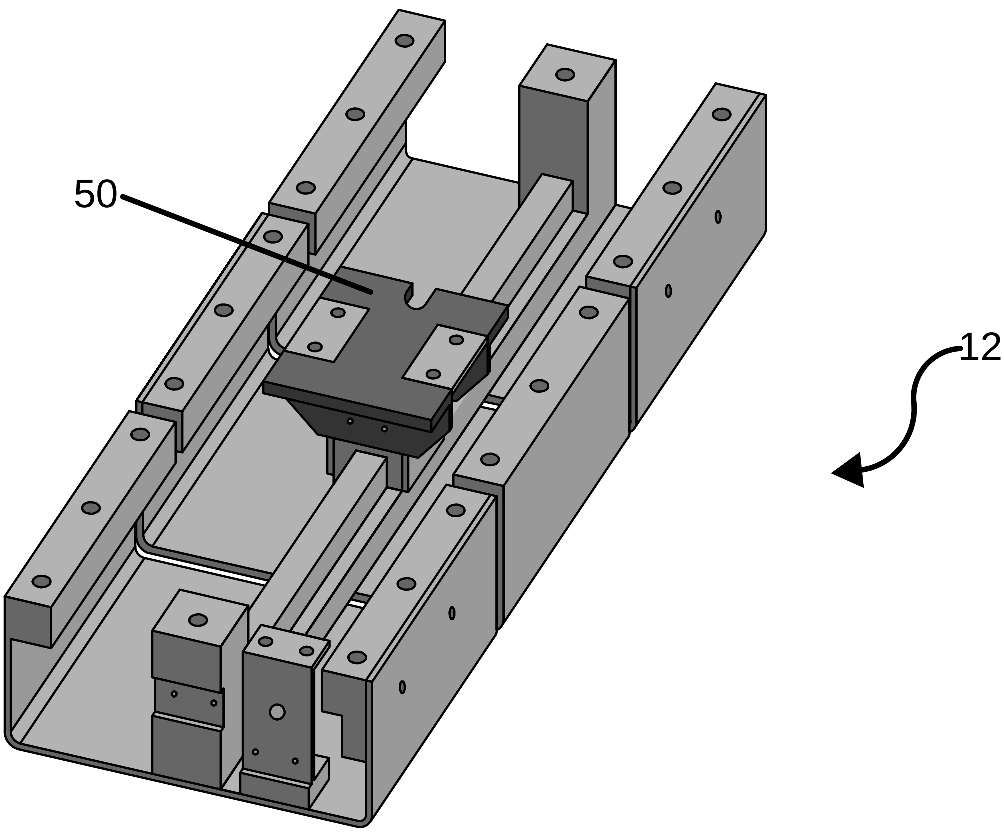

FIG .8

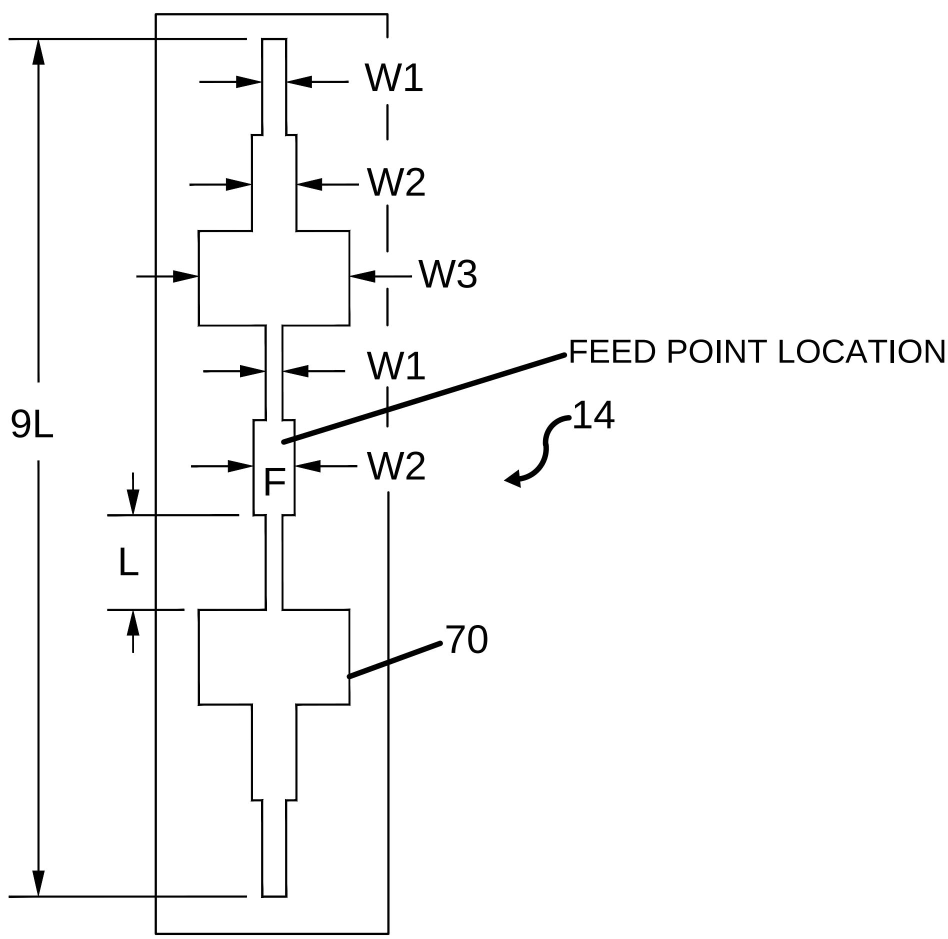

FIG .9

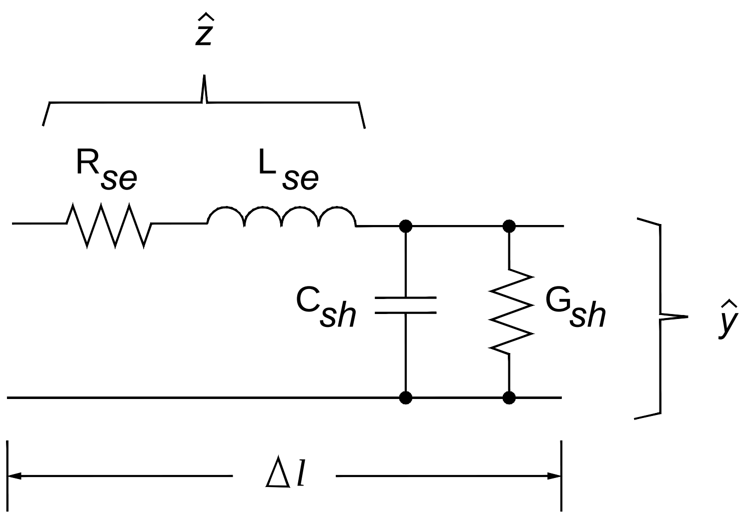

FIG .10

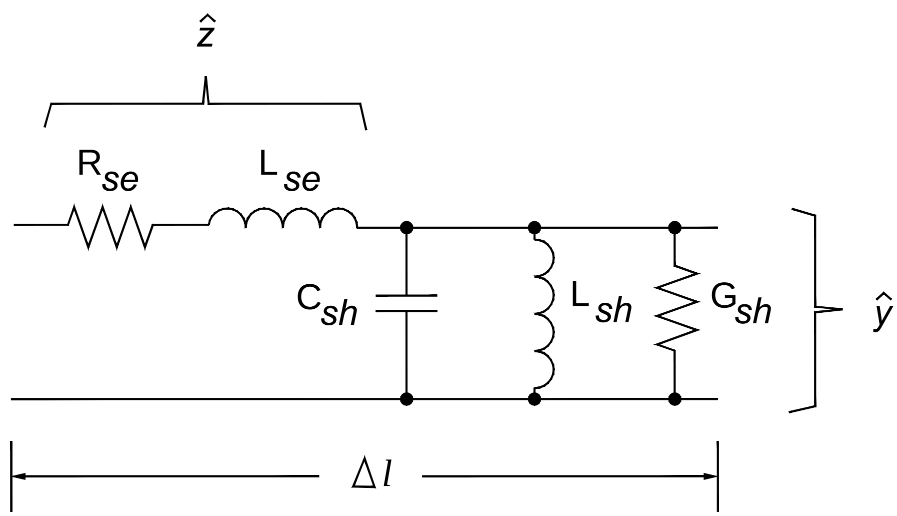

FIG .11

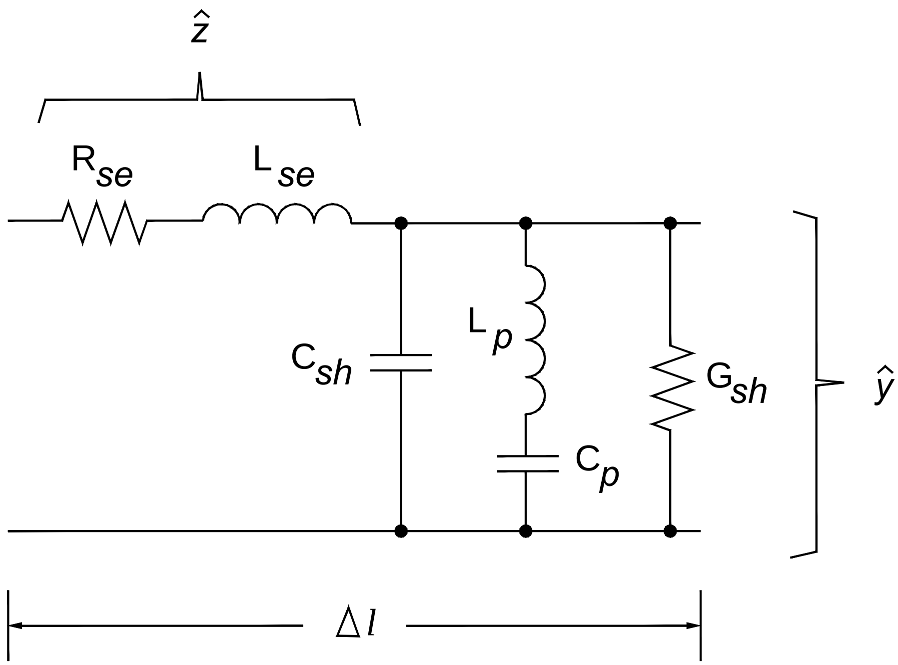

FIG .12

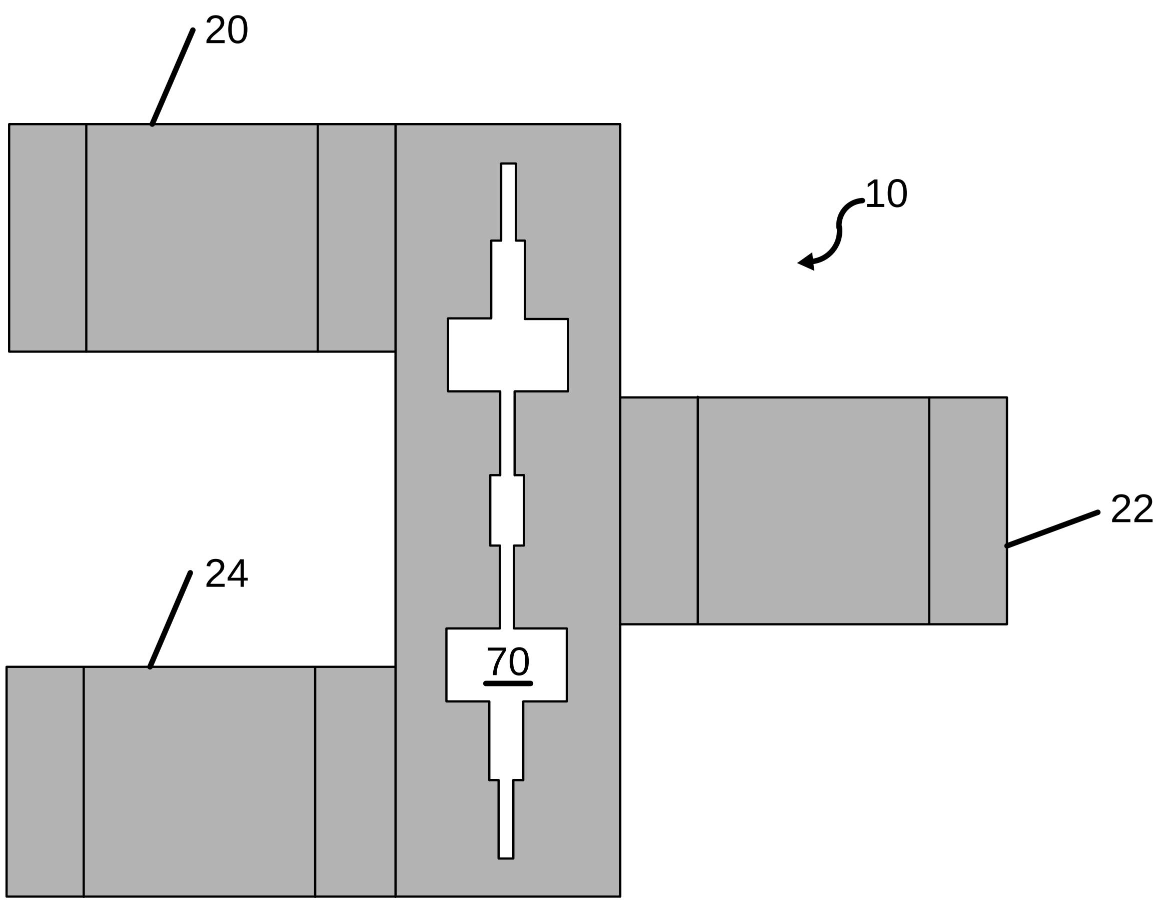

FIG .13

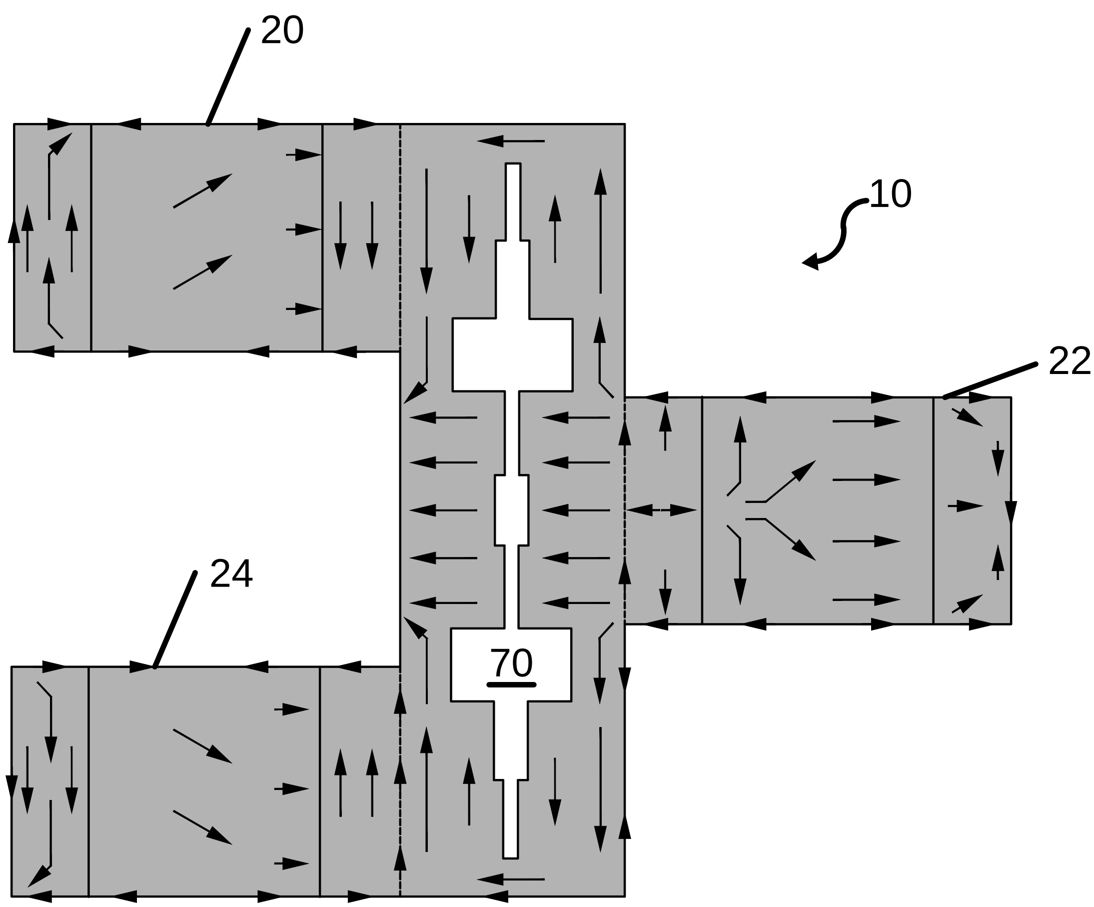

FIG .14

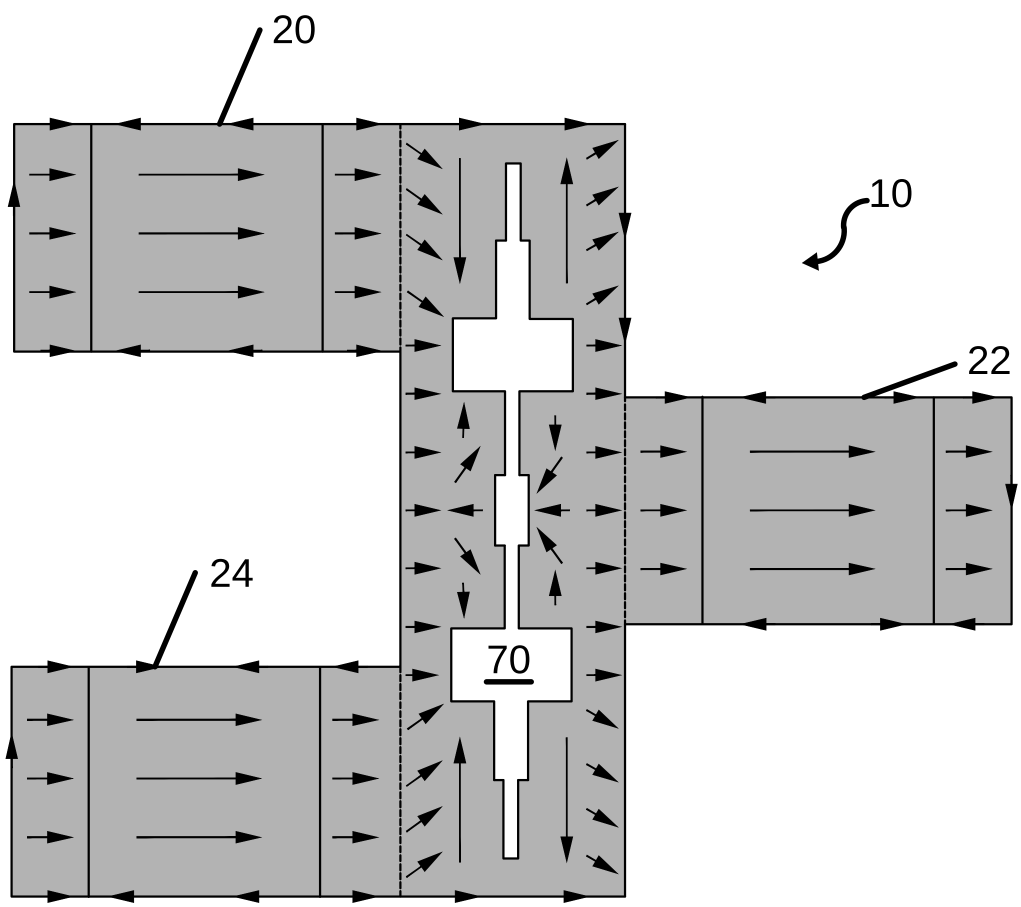

FIG .15

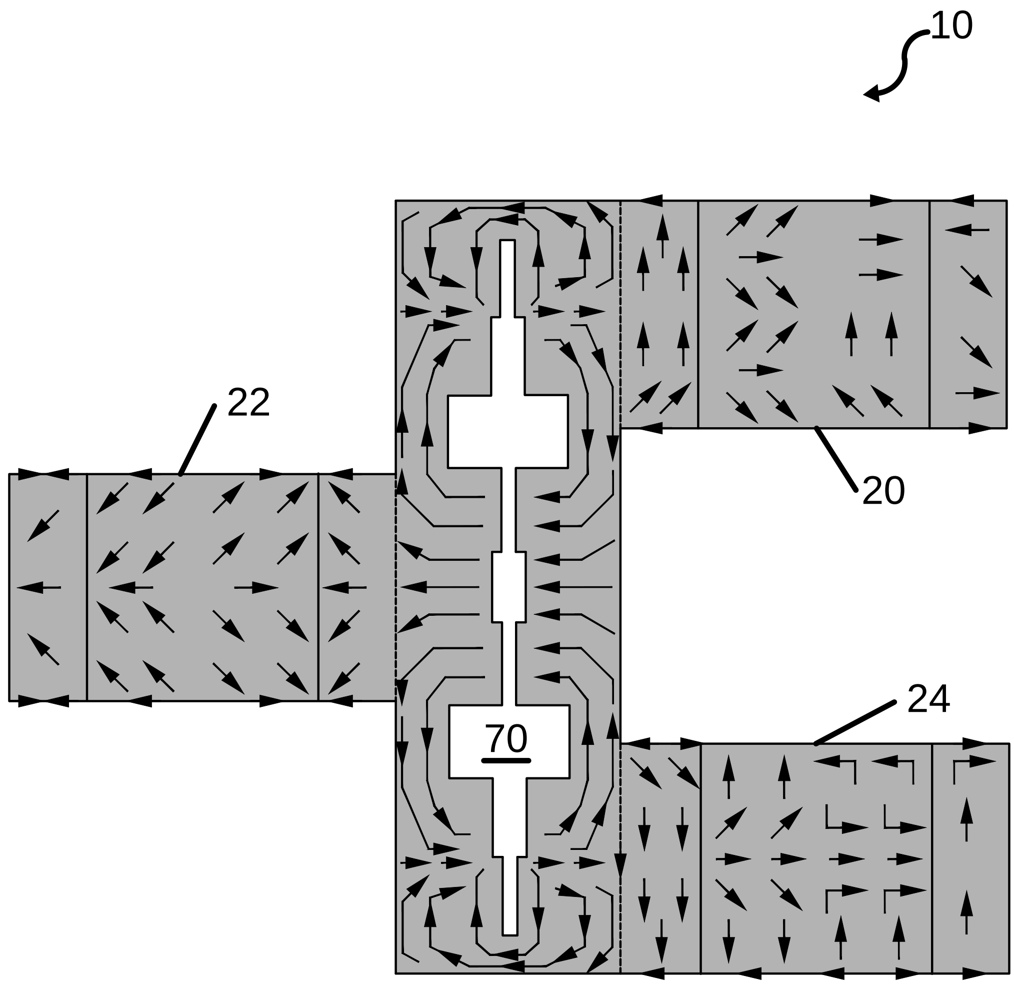

FIG .16