



- (51) **International Patent Classification:**
G01R 33/20 (2006.01)
- (21) **International Application Number:**
PCT/US2012/049195
- (22) **International Filing Date:**
1 August 2012 (01.08.2012)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**
61/513,903 1 August 2011 (01.08.2011) US
- (71) **Applicant:** **LOCKHEED MARTIN CORPORATION** [US/US]; 6801 Rockledge Drive, Bethesda, Maryland 20817 (US).
- (72) **Inventors; and**
- (75) **Inventors/Applicants (for US only):** **BALEINE, Clara** [US/US]; c/o Lockheed Martin Corporation, 6801 Rockledge Drive, Bethesda, Maryland 20817 (US). **DRAKE, Christina** [US/US]; c/o Lockheed Martin Corporation, 6801 Rockledge Drive, Bethesda, Maryland 20817 (US). **WRIGHTSON, James A.** [US/US]; c/o Lockheed Martin Corporation, 6801 Rockledge Drive, Bethesda, Maryland 20817 (US). **WERNER, Douglas H.** [US/US]; c/o Lockheed Martin Corporation, 6801 Rockledge Drive, Bethesda, Maryland 20817 (US). **BAL-LON, Douglas J.** [US/US]; c/o Lockheed Martin Corporation, 6801 Rockledge Drive, Bethesda, Maryland 20817 (US). **DYKE, Jonathan P.** [US/US]; c/o Lockheed Martin Corporation, 6801 Rockledge Drive, Bethesda, Maryland 20817 (US). **VOSS, Henning U.** [US/US]; c/o Lockheed Martin Corporation, 6801 Rockledge Drive, Bethesda, Maryland 20817 (US).
- (74) **Agent:** **MUTTER, Michael K.**; c/o Birch, Stewart, Kolasch & Birch, LLP, P.O. Box 747, Falls Church, Virginia 22040-0747 (US).
- (81) **Designated States** (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
- (84) **Designated States** (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).
- Declarations under Rule 4.17:**
- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- Published:**
- without international search report and to be republished upon receipt of that report (Rule 48.2(g))

(54) **Title:** MAGNETIC META-LENSES FOR MAGNETIC IMAGING**Fig 1b**

(57) **Abstract:** Devices and methods for magnetic imaging and / or irradiation are discussed. The magnetic fields produced for imaging and / or irradiating, as well as the associated magnetic field, can be focused using one or more magnetic metalens devices. Variations of magnetic metalens devices may be made of cubic unit cells equipped with capacitor-bearing conductive loops printed on an inside face of a dielectric of the cube(s). Some variations may also include a series capacitor equipped with a matching network that includes at least one series capacitor. Other variations may also include a tapered microstrip.



MAGNETIC META-LENSES FOR MAGNETIC IMAGING

CROSS REFERENCE TO RELATED APPLICATION

[0001] This non-provisional application claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Application No. 61/513,903 filed on August 1, 2011, the entire contents of which are hereby incorporated by reference.

BACKGROUND

[0002] Currently, magnetic imaging techniques, such as MRI (magnetic resonance imaging) are limited in terms of resolution and imaging depth. In part, this is due to limitations of magnetic lenses and magnetic lens designs used in conjunction with MRI coils to produce, focus, and receive magnetic field data for imaging.

SUMMARY

[0003] Variations of techniques, systems, and devices discussed herein pertain to magnetic imaging techniques using magnetic metalenses, magnetic imaging, and magnetic induction

[0004] Some variations of techniques, systems, and devices discussed herein pertain to a magnetic metalens device, the metalens device comprising: an isotropic metalens; a matched resonant coil operating in conjunction with the isotropic metalens; and a matching network that includes at least a series capacitor, where the matched resonant coil is equipped with said matching network.

[0005] In some variations, the isotropic metalens includes a periodic array of subwavelength cubic unit cells, each cubic unit cell including a conducting loop and capacitor on each of six inner faces. In some variations, the capacitors on loops disposed on opposing sides of a cubic unit cell are disposed on alternate sides of their respective loops.

[0006] In some variations, the matching network further includes a tapered microstrip that transforms an impedance of the matched resonant coil. In some variations, the tapered microstrip includes a waveport, a capacitance area, a resistance area, and an inductance area.

[0007] In some variations, the series capacitor reduces or eliminates an inductive reactance portion of a load impedance associated with the resonant coil. In some variations, the waveport transforms an impedance of the series capacitor. In some variations, the magnetic metalens device has a magnetic permeability (μ) of -1.

[0008] In some variations, the matched resonant coil is a receiving coil. In some variations, the matched resonant coil is a transmitting coil. In some variations, the matched resonant coil is used for transmitting and receiving. In some variations, the magnetic metalens device further includes a second matched resonant coil, where the matched resonant coil is a transmitting coil and the second matched resonant coil is a receiving coil.

[0009] Some variations of techniques, systems, and devices discussed herein pertain to an imaging device, said imaging device comprising; a magnetic field generating device that generates a magnetic field for imaging; a magnetic field detector that detects a magnetic field associated with an imaging target, said associated magnetic field being caused by an interaction of the generated magnetic field and the imaging target; and a first magnetic metalens device that focuses the magnetic field before it is detected by the magnetic field detector.

[0010] In some variations, the first magnetic metalens device is disposed between said detector and said imaging target and where the first magnetic metalens device focuses said associated magnetic field for detection. In some variations, the first magnetic metalens device is disposed between the magnetic field generating device and the imaging target, and where the magnetic metalens device focuses said generated magnetic field for imaging.

[0011] In some variations, the imaging device further includes a second magnetic metalens device disposed between said detector and said imaging target and where the second magnetic metalens device focuses said associated magnetic field for detection. In some variations, the first magnetic metalens device focuses said generated magnetic field for imaging and also focuses said associated magnetic field for detection.

[0012] In some variations, either or both of the magnetic metalens devices may be a magnetic metalens device as discussed in one or more of the variations listed above and described further herein.

[0013] Further scope of applicability of the present invention will become apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

BRIEF DESCRIPTION OF DRAWINGS

[0014] The present invention will become more fully understood from the detailed description given herein below and the accompanying drawings which are given by way of illustration only, and thus are not limitative of the present invention, and wherein

[0015] FIG. 1a is a block diagram of an embodiment of an apparatus as described herein;

[0016] FIG. 1b is a block diagram of an embodiment of an apparatus as described herein;

[0017] FIG. 1c is a block diagram of an embodiment of an apparatus as described herein;

[0018] FIG. 1d is a block diagram of an embodiment of an apparatus as described herein;

[0019] FIG. 2a is a block diagram of an embodiment of an apparatus as described herein;

[0020] FIG. 2b is a block diagram of an embodiment of an apparatus as described herein; and

[0021] FIG. 3 is a block diagram of an embodiment of an apparatus as described herein.

[0022] The drawings will be described further in the course of the detailed description.

DETAILED DESCRIPTION

[0023] The following detailed description of the techniques and solutions discussed herein refers to the accompanying drawings. The same reference numbers in different drawings identify the same or similar elements. Also, the following detailed description does not limit the techniques and solutions discussed herein. Instead, the scope of the techniques and solutions discussed herein is defined by the appended claims and equivalents thereof.

[0024] In magnetic imaging applications, a magnetic field used for imaging can be detected through the detection of the magnetic resonance image in variations that employ an MRI, or by direct detection only of changes in magnetic field intensities, detected in a similar way to diffusion tensor measurements in motion resonance, in variations that employ direct magnetic imaging devices or techniques.

[0025] One variation of an imaging and detection arrangement is shown in Fig. 1a. In the arrangement shown, a magnetic imaging device 2010 may concentrate or otherwise generate magnetic field directed at an imaging target 2020. The magnetic imaging device 2010 may include an MRI, direct magnetic imaging device, or other device configured to perform magnetic imaging. The target 2020 may include a living organism, such as a hospital patient, or may include machines, devices, structures, archeological findings, rocks, and / or other types or combinations of organic, inorganic, animate, and / or in-animate objects. A detection result of the imaging is then detected by a detector 2030 which may be part of the magnetic imaging device 2010 or, in some cases, a separate device.

[0026] In some variations, when imaging, a magnetic RF pulse generated by the imaging device 2010 is preferably at 90 degrees perpendicular to the polarizing main field of the imaging device 2010. In some variation, the magnetic field detector 2030 may be arranged downstream from the magnetic imaging device 2010. Variations of such a detector 2030 may include a solenoid, a superconducting quantum interference device (SQUID), or a solid state magnetometer.

[0027] In some variations, after generating a magnetic field with imaging intensity, a focusing step may be performed that focuses the magnetic field generated by the magnetic imaging device via a magnetic metalens device. In some variations, the magnetic field may

also be concentrated and focused with a magnetic metalens device as part of an irradiating process or other magnetic radiation exposure process.

[0028] In some variations, the magnetic field may be focused by the magnetic metalens device as part of an imaging process meant to enable and improve detection of an irradiation target area to improve the effectiveness of the irradiation. The focused magnetic field may also be generated by the magnetic imaging device as part of a process of irradiating.

[0029] In some variations, the imaging process and irradiation process may be performed using separate or otherwise distinct pieces of equipment. In some variations, even if the same magnetic source is used for imaging and irradiating, a metalens used or configured for imaging may be different from a metalens used or configured for irradiating. In other variations, the same metalens may be used for both applications.

[0030] A variation of a magnetic imaging arrangement using a magnetic metalens is shown in Fig. 1b. In the variation shown, a magnetic metalens device 2120 is disposed between a magnetic imaging device 2110 and an imaging target 2130. The magnetic field concentrated or otherwise generated by the magnetic imaging device 2110 may be focused by the magnetic metalens device 2120 to improve the imaging and / or irradiation characteristics of the field with respect to the target 2130. In an imaging embodiment, the focused magnetic field may then be detected by a magnetic field detector 2140 to produce an image of the target 2120.

[0031] Variations of a metalens device having transmitting and receiving coils may be configured to not only focus the magnetic radiation from the magnetic imaging device 2210, but to also focus a magnetic field signature back to the magnetic field detector. In one such variation, shown in Fig. 1d, the positioning of the metalens device for receiving 2340

may be different than that of the metalens device for transmitting 2120. Such a positioning change may help in focusing a magnetic field signature by optimizing the signal to noise ratio of the detector 2250. In such a variation, the magnetic imaging device 2310 may concentrate a magnetic field onto the target 2330. The field is then focused 2340 by the magnetic metalens device 2340 after it has been used to image the target but before the imaging result is detected at the detector 2350.

[0032] In yet further variations, a magnetic metalens device may be used in either or both of pre-imaging focusing and post-imaging, pre-detection focusing. Such a variation is depicted in Fig. 1c. In the variation shown, a first magnetic metalens device 2220 is disposed between the imaging device 2210 and the target 2230 to focus the magnetic field from the imaging device onto the target 2230. A second magnetic metalens device 2240 may then be disposed between the target 2230 and the detector 2250 to focus the magnetic field after it has imaged the target 2230 to improve the detection result(s). In some variations, the same magnetic metalens may be used to focus the magnetic field onto the target 2230 and onto the detector 2250.

[0033] Variations of such magnetic metalens device(s) may be disposed at varying distances from a patient or imaging subject / target depending on the lens characteristics and the properties and intensity of the imaging radiation source(s).

[0034] Some variations of such a magnetic metalens device may include an isotropic metalens, and a matched resonant coil operating in conjunction with the metalens, where the coil is equipped with a matching network that includes at least a series capacitor. In such a variation, a metalens may include a periodic array of subwavelength cubic unit cells, with a conducting loop and capacitor on each of the six inner faces. In some variations, a matching network may further include a tapered microstrip that transforms an impedance of the coil. In

one variation, the matched resonant coil is a receiving coil. In another variation, the resonant coil is a transmitting coil. In yet another variation, the magnetic metalens device may include a second matched coil, where one of the coils is a transmitting coil, and one of the coils is a receiving coil.

[0035] In a further variation, a tunable metalens device may be used. A tunable metalens device may include a metalens having adjustable or otherwise configurable properties, such as variable impedance. In a still further variations, two different metalens devices may be used – one for focusing during imaging and one for focusing during irradiating. In one variation, a magnetic metalens device where $\mu = -1$ (used for enhancing a magnetic field) may be used for imaging, while a second metalens device where $n = -1$ (for focusing a magnetic field) may be used for irradiating.

[0036] A matched resonant coil in conjunction with an isotropic metamaterial lens (metalens) may increase the detection depth of a magnetic resonance imaging (MRI) system inside the body and / or imaging subject or target. In some variations, a metamaterial lens may include a periodic array of subwavelength cubic unit cells, with a conducting loop and capacitor on each of the six inner faces. Such a structure can provide an isotropic effective magnetic permeability of -1 with low loss at operating frequency for an approximately 3 Tesla (T) MRI system. Such a configuration can enhance the magnetic field strength at the receiving coil, and thus increase the received signal power, improving the signal-to-noise ratio (SNR). Since MRI scan time is inversely proportional to the square of the SNR, even modest improvements in SNR can reduce the scan time dramatically or allow for significantly more scanning passes in a given time period.

[0037] A variation of a subwavelength cubic unit cell is shown in Fig. 2a. In the variation shown, each cubic unit cell 2620 may be equipped with a conducting loop 2600 and

capacitor 2610 on each of the six inner faces. In some variations, the capacitors may be lumped capacitors. In some variations, as shown in Fig. 2b, the capacitors 2900, 2910 on opposing rings 2920, 2930 may alternate sides to eliminate or reduce bi-anisotropy. In some variations, such a capacitor-loaded conducting loop 2930 may be printed on the inner wall of the dielectric of each side of the cube. A 3D periodic structure composed of such unit cells has nearly identical responses to plane waves coming from three orthogonal directions.

[0038] A receiving coil in such a metalens-equipped system may be tuned for a match in free space at the operating frequency of an MRI or other magnetic imaging system. In some variations, a matching network of at least a series capacitor can be added to maintain the match when the coil is adjacent to the metalens, thereby improving received signal power. In some variations, the matching network may include additional components, such as more than one series capacitor and / or capacitance array(s) (which may be a series or parallel array, or a mix thereof).

[0039] A block diagram illustrating operation of such a capacitor-equipped variation is shown in Fig. 3. In the variation shown, a series capacitor 2710 is connected to cancel the inductive reactance of a load impedance 2720. A tapered microstrip 2700 may then transform the impedance to a better match level. For instance, using the exemplary numbers shown in the figure, a load impedance 2720 may have an impedance of 26.5Ω and an inductive reactance of $122.86nH$. An 11.8 pF capacitor 2710 can cancel out the inductive reactance, leaving only an impedance of 26.5Ω . This impedance may then be transformed by a tapered microstrip 2700.

[0040] In a further variation, the matching network may include a tapered microstrip as shown in Fig. 2c. The microstrip variation shown in Fig. 2c may be equipped with a wave port 2800, capacitance region 2810, resistance region 2830, and inductance region 2820.

Such a microstrip may be represented in some cases by an equivalent RLC (resistance, inductance, and capacitance) circuit (not shown). In one variation, the wave port 2800 may be a 50Ω wave port, the inductance may be 122.86nh , the resistance may be 26.5Ω , and the capacitance may be 11.8pF . In such a variation, operating at 132MHz , a variation of the microstrip shown in Fig. 2c may act as an impedance transformer, transforming the impedance from 26.5Ω to 50Ω .

[0041] In one variation of a microstrip as depicted in Fig. 2c, the microstrip width may be 4.745mm (which may provide an impedance of 50Ω). The length of such a microstrip variation may be 10mm . In some variations, the substrate material of such a microstrip may be Rogers RT5880. The substrate may be 1.575mm thick and 60mm wide.

[0042] Microstrip variations, such as the type shown in Fig. 2c, may be configured to transform an impedance of the coil. In one variation, the matched resonant coil is a receiving coil. In another variation, the resonant coil is a transmitting coil. In yet another variation, the first magnetic metalens device includes a second matched coil, where one of the coils is a transmitting coil, and one of the coils is a receiving coil.

[0043] In some variations, such a metalens and receiving coil variation may be used in traditional MRI systems as an external component that can simply be plugged in to the machine like any other optional receiving coil. Such variations of MRI systems with metalens and receiving coil arrangements as discussed herein may provide improved operating characteristics in terms of loss, isotropy, homogeneity, resolution, and detection depth.

[0044] Variations of a matched resonant coil design as discussed herein have much lower loss, a critical aspect that affects both the imaging property and the detection depth, compared with the current state-of-the-art. On tests with metalens prototypes, an imaginary

part of permeability as small as 0.05, was achieved. Compared to an imaginary part around 0.25 in current state-of-the-art devices, variations of metalenses as described herein suffer from much lower loss as an electromagnetic wave propagates through. Reduced loss characteristics of this type are useful in many aspects. In one particular variation, low-loss characteristics may be advantageous for thick lenses, which are generally used to increase MRI detection depth

[0045] Variations of metalens designs described herein are more isotropic than existing lenses. As discussed above, variations of the metalens unit cell may be equipped with a capacitor loaded square ring printed on the inner walls of the dielectric on each of the six sides. The capacitors on opposing rings may alternate sides to eliminate bi-anisotropy. A 3D periodic structure composed of such a unit cell may have nearly identical responses to plane waves coming from three orthogonal directions, verifying its isotropy. In some variations, the transmission between two small loop antennas is invariant to tilting the lens.

[0046] Variations of metalens designs as discussed herein have more homogeneous properties than existing lenses, partially arising from the ability to have a small unit cell size and partially because of the above-mentioned lens isotropy. In some variations, both the imaging properties and the transmission between two loop antennas are well maintained despite changes in the position of the source and receiver relative to the lens (in the middle, or near the edge of the lens).

[0047] Variations of metalens designs as described herein can resolve two small sources with a separation distance smaller than 3.5 times the unit cell size (approximately 0.011λ). Furthermore, by including a matching network, the input impedance of the loop is well matched when it is in close proximity of the lens. Doing so allows the detection depth of an MRI device equipped with such a metalens to reach the thickness of the lens.

[0048] In one variation, the matched resonant coil is a receiving coil. In another variation, the resonant coil is a transmitting coil. In yet another variation, the imaging magnetic metalens device may include two matched coils, where one of the coils is a transmitting coil, and one of the coils is a receiving coil.

[0049] Some embodiments of a magnetic metalens device as depicted above may be configured for magnetic imaging and irradiating. For focusing different frequencies, the design and composition of the metalens device may be variable. Variations may occur in unit cell size, capacitors, inductors, and copper rings versus crosses. In some variations, the different components may be individually or jointly tuned to achieve a proper resonance. Also, variations in the spacing of the unit cells may affect the resonance at which the desired μ or n is achieved. In one variation, the magnetic metalens device may be configured where $\mu = -1$. In a different variation, the magnetic metalens device may be configured so that $n = -1$. In yet another variation, the metalens device may include an isotropic metalens and a matched resonant coil operating in conjunction with the metalens, where the coil is equipped with a matching network that includes at least a series capacitor. The composition of such a metalens device is variable based upon the frequency to be focused; therefore, the composition or configuration of the metalens device (and any associated resonant coil(s)) may be different during imaging or irradiating operations. Furthermore, a metalens device used or configured for focusing during a transmission portion of an imaging process may be different from a metalens device used or configured for focusing during a reception portion of an imaging process.

[0050] In further variations, the coil equipped with a matching network (connected to the transmitting antenna), and the series capacitor may also be variable to facilitate the power

required for the strength of the input field. The matching network may be disposed behind the metalens (in close proximity), and may be connected to the transmitting antenna.

[0051] The invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims

We Claim:

1. A magnetic metalens device, the metalens device comprising:
an isotropic metalens;
a matched resonant coil operating in conjunction with the isotropic metalens; and
a matching network that includes at least a series capacitor, where the matched resonant coil is equipped with said matching network.
2. The magnetic metalens device of claim 1, where the isotropic metalens includes a periodic array of subwavelength cubic unit cells, each cubic unit cell including a conducting loop and capacitor on each of six inner faces.
3. The magnetic metalens device of claim 2, where the capacitors on loops disposed on opposing sides of a cubic unit cell are disposed on alternate sides of their respective loops.
4. The magnetic metalens device of claims 1, 2, or 3 where the matching network further includes a tapered microstrip that transforms an impedance of the matched resonant coil.
5. The magnetic metalens device of claim 4, where the tapered microstrip includes a waveport, a capacitance area, a resistance area, and an inductance area.
6. The magnetic metalens device of any preceding claim, where the series capacitor reduces or eliminates an inductive reactance portion of a load impedance associated with the resonant coil.

7. The magnetic metalens device of claim 5 or 6, where the waveport transforms an impedance of the series capacitor.
8. The magnetic metalens device of any preceding claim, where the matched resonant coil is a receiving coil.
9. The magnetic metalens device of any preceding claim, where the matched resonant coil is a transmitting coil.
10. The magnetic metalens device of any preceding claim, the magnetic metalens device further comprising a second matched resonant coil, where the matched resonant coil is a transmitting coil and the second matched resonant coil is a receiving coil.
11. The magnetic metalens device of any preceding claim, where the magnetic metalens device has a magnetic permeability (μ) of -1.
12. An imaging device, said imaging device comprising;
 - a magnetic field generating device that generates a magnetic field for imaging;
 - a magnetic field detector that detects a magnetic field associated with an imaging target, said associated magnetic field being caused by an interaction of the generated magnetic field and the imaging target; and
 - a first magnetic metalens device that focuses the magnetic field before it is detected by the magnetic field detector.

13. The imaging device of claim 12, where the first magnetic metalens device is disposed between said detector and said imaging target and where the first magnetic metalens device focuses said associated magnetic field for detection.

14. The imaging device of claim 12, where the first magnetic metalens device is disposed between the magnetic field generating device and the imaging target, and where the magnetic metalens device focuses said generated magnetic field for imaging.

15. The imaging device according to claims 12 or 14, further comprising:
a second magnetic metalens device disposed between said detector and said imaging target and where the second magnetic metalens device focuses said associated magnetic field for detection.

16. The imaging device according to claims 13 or 14, where the first magnetic metalens device focuses said generated magnetic field for imaging and also focuses said associated magnetic field for detection.

17. The imaging device according to any one of claims 12 - 16, said first magnetic metalens device comprising:

an isotropic metalens;

a matched resonant coil operating in conjunction with the isotropic metalens; and

a matching network that includes at least a series capacitor, where the matched resonant coil is equipped with said matching network.

18. The imaging device according to any one of claims 12 - 17, where the isotropic metalens includes a periodic array of subwavelength cubic unit cells, each cubic unit cell including a conducting loop and capacitor on each of six inner faces.
19. The imaging device according to any one of claims 12 - 18, where the capacitors on loops disposed on opposing sides of a cubic unit cell are disposed on alternate sides of their respective loops.
20. The imaging device according to any one of claims 12 - 19, where the matching network further includes a tapered microstrip that transforms an impedance of the matched resonant coil.
21. The imaging device according to any one of claims 12 - 20, where the tapered microstrip includes a waveport, a capacitance area, a resistance area, and an inductance area.
22. The imaging device of according to any one of claims 12 - 21, where the series capacitor reduces or eliminates an inductive reactance portion of a load impedance associated with the resonant coil.
23. The imaging device according to any one of claims 12 - 22, where the waveport transforms an impedance of the series capacitor.
24. The imaging device according to any one of claims 12 - 23, where the matched resonant coil is a receiving coil.

25. The imaging device according to any one of claims 12 - 24, where the matched resonant coil is a transmitting coil.

26. The imaging device according to any one of claims 12 - 25, the magnetic metalens device further comprising a second matched resonant coil, where the matched resonant coil is a transmitting coil and the second matched resonant coil is a receiving coil.

27. The imaging device according to any one of claims 12 - 26, where the magnetic metalens device has a magnetic permeability (μ) of ~ 1 .

Fig 1a

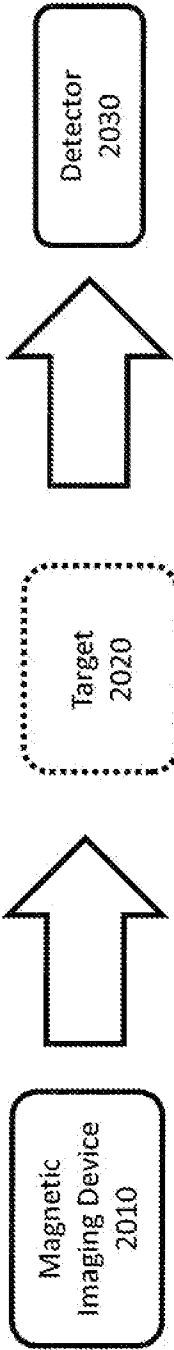


Fig 1b

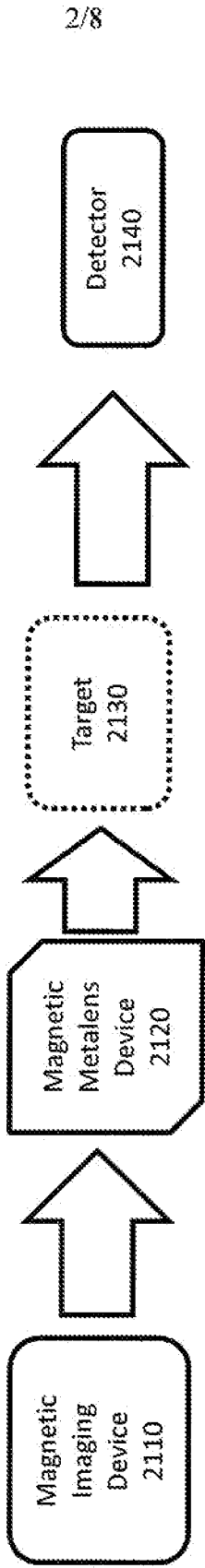


Fig 1d

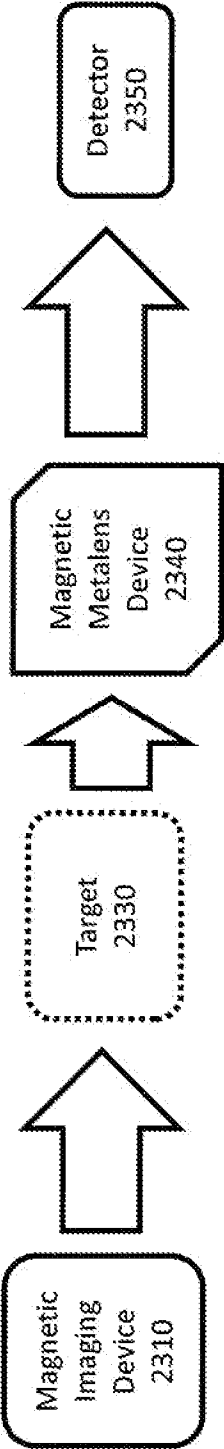


Fig 1c

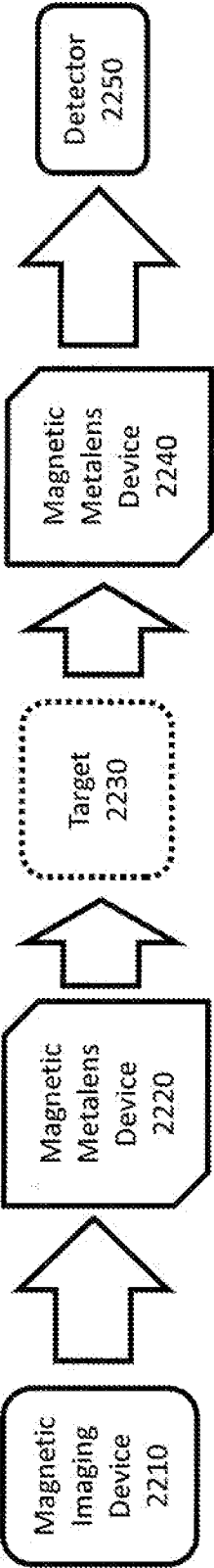


Fig. 2a

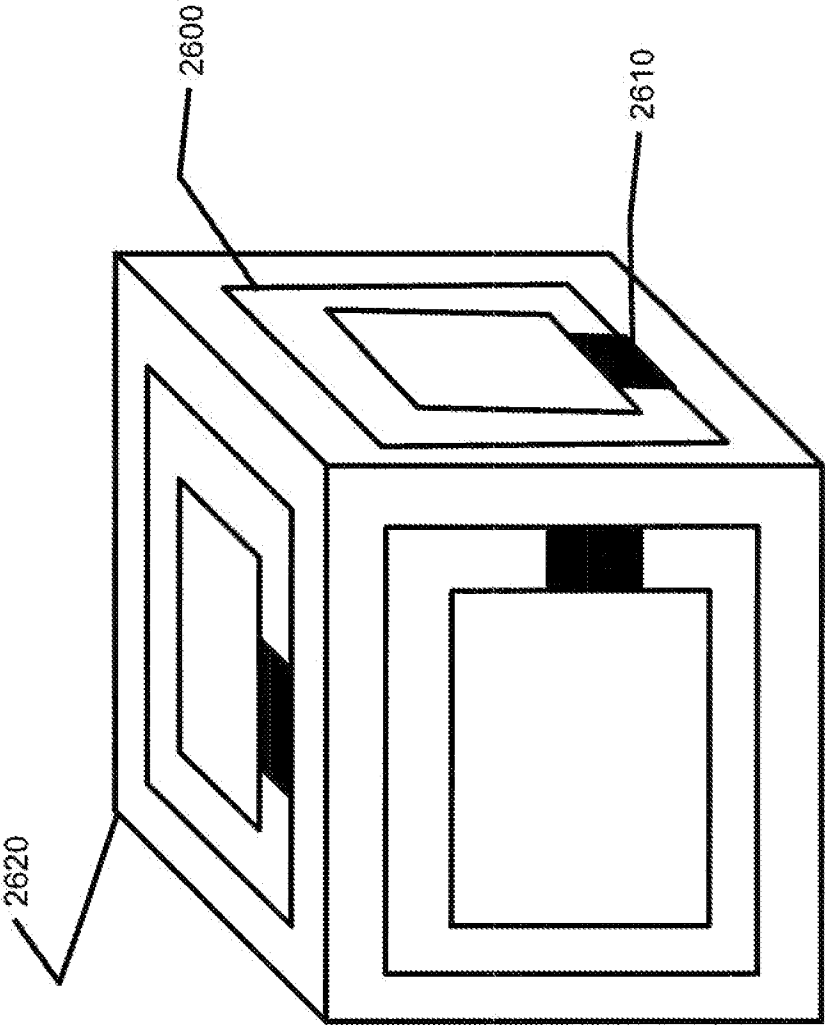


Fig. 2b

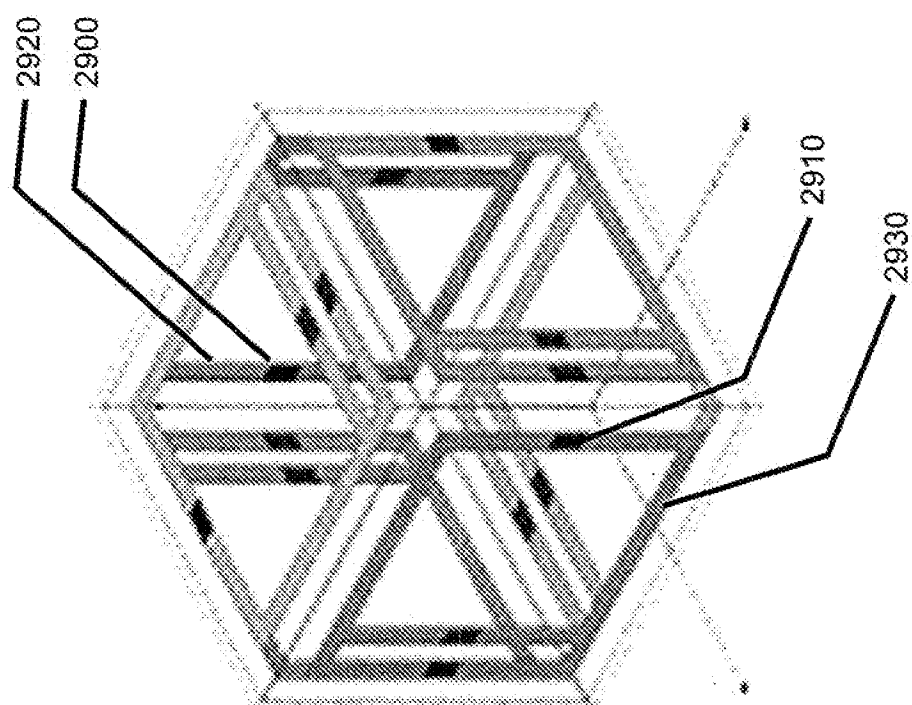
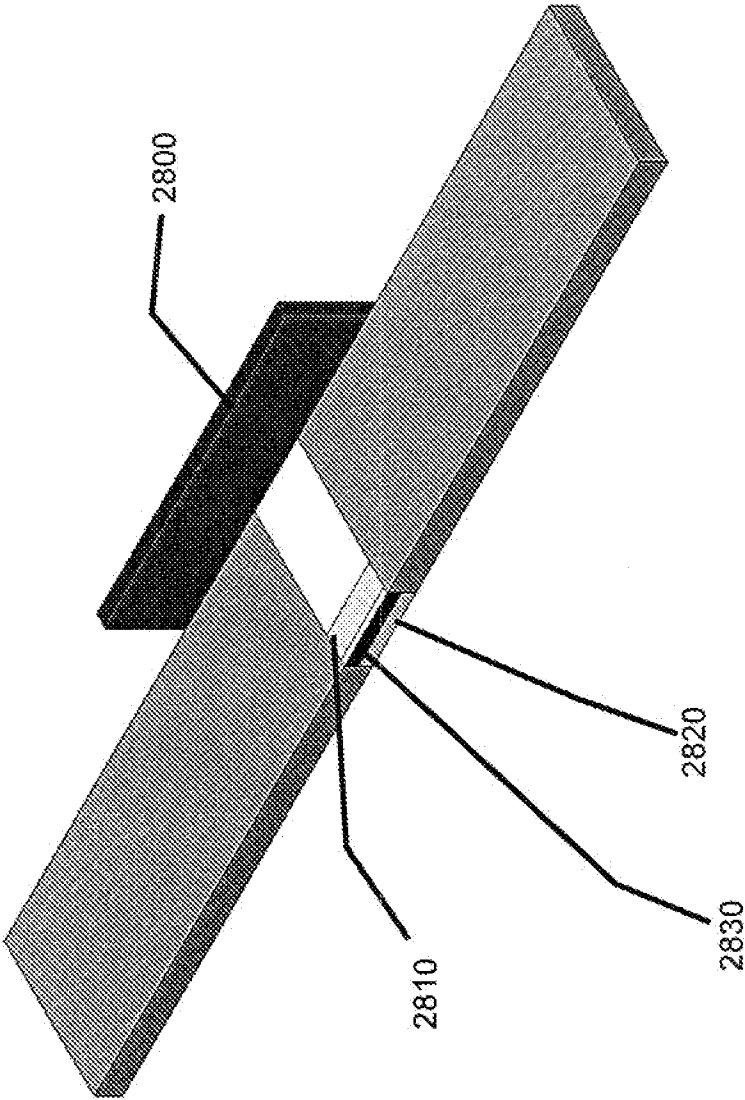


Fig. 2c



8/8

Fig. 3

