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(54) **PHOTONIC SYSTEM AND METHOD FOR OPTICAL DATA TRANSMISSION IN MEDICAL IMAGING SYSTEMS**

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G06F 19/00	(2011.01)
H04B 10/80	(2013.01)
H04J 14/02	(2006.01)
A61B 6/00	(2006.01)
A61B 8/00	(2006.01)

(52) **U.S. Cl.**

CPC ***H04B 10/801*** (2013.01); ***G06F 19/321*** (2013.01); *H04J 14/0298* (2013.01); *A61B 6/566* (2013.01); *A61B 8/56* (2013.01)

USPC **324/322**; 324/318

(58) **Field of Classification Search**

USPC 324/322, 318, 314, 312

See application file for complete search history.

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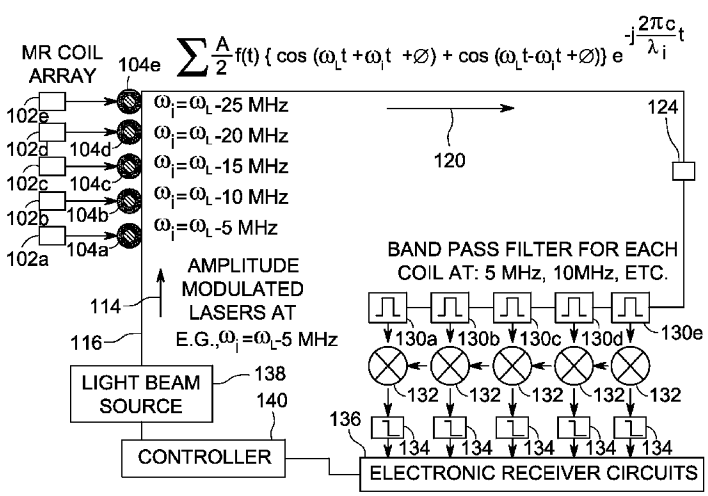
(57) **ABSTRACT**

A photonic system and method for optical data transmission in medical imaging system are provided. One photonic system includes a plurality of optical modulators having different optical resonance wavelengths and configured to receive electrical signals representative of a set of data from a medical imaging device. The photonic system also includes an optical waveguide interfacing with the plurality of optical modulators and configured to transmit an amplitude modulated beam of light at different frequencies to selectively modulate the plurality of optical modulators to transmit an encoded beam of light. The photonic system further includes receiver opto-electronics in communication with the optical waveguide configured to decode the encoded beam of light and convert the decoded beam of light into the electrical signals representative of the set of data.

21 Claims, 7 Drawing Sheets



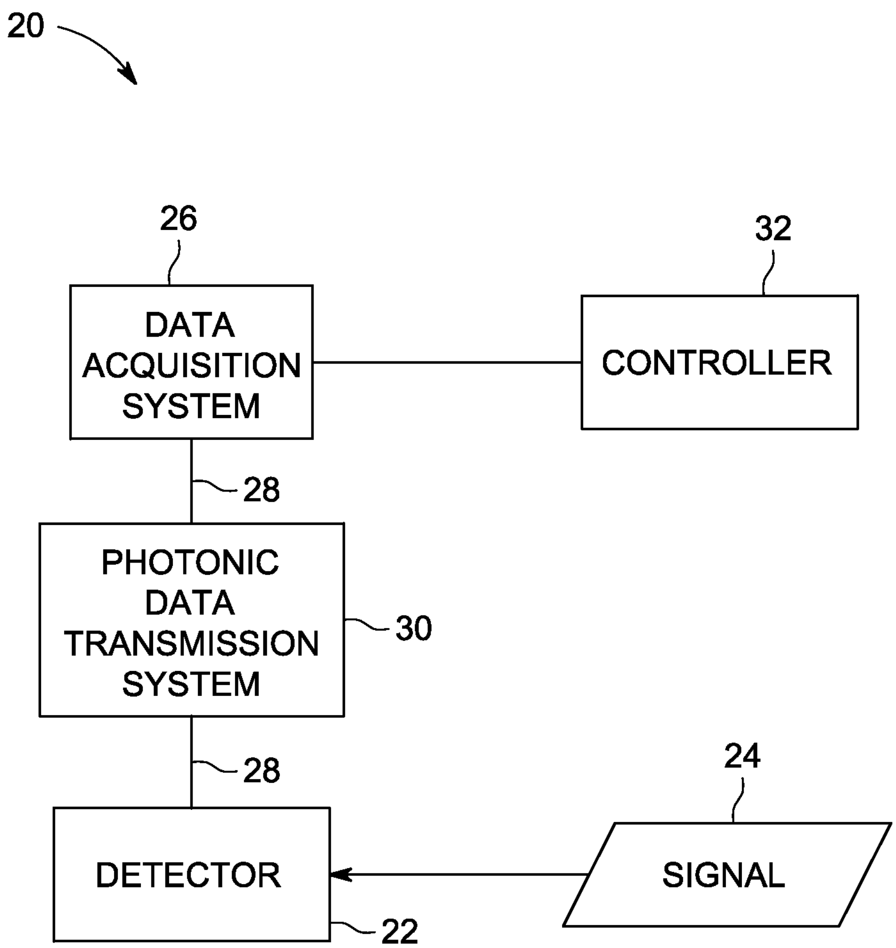

20
26
DATA ACQUISITION SYSTEM
32
CONTROLLER
28
PHOTONIC DATA TRANSMISSION SYSTEM
30
28
24
DETECTOR
SIGNAL
22

FIG. 1

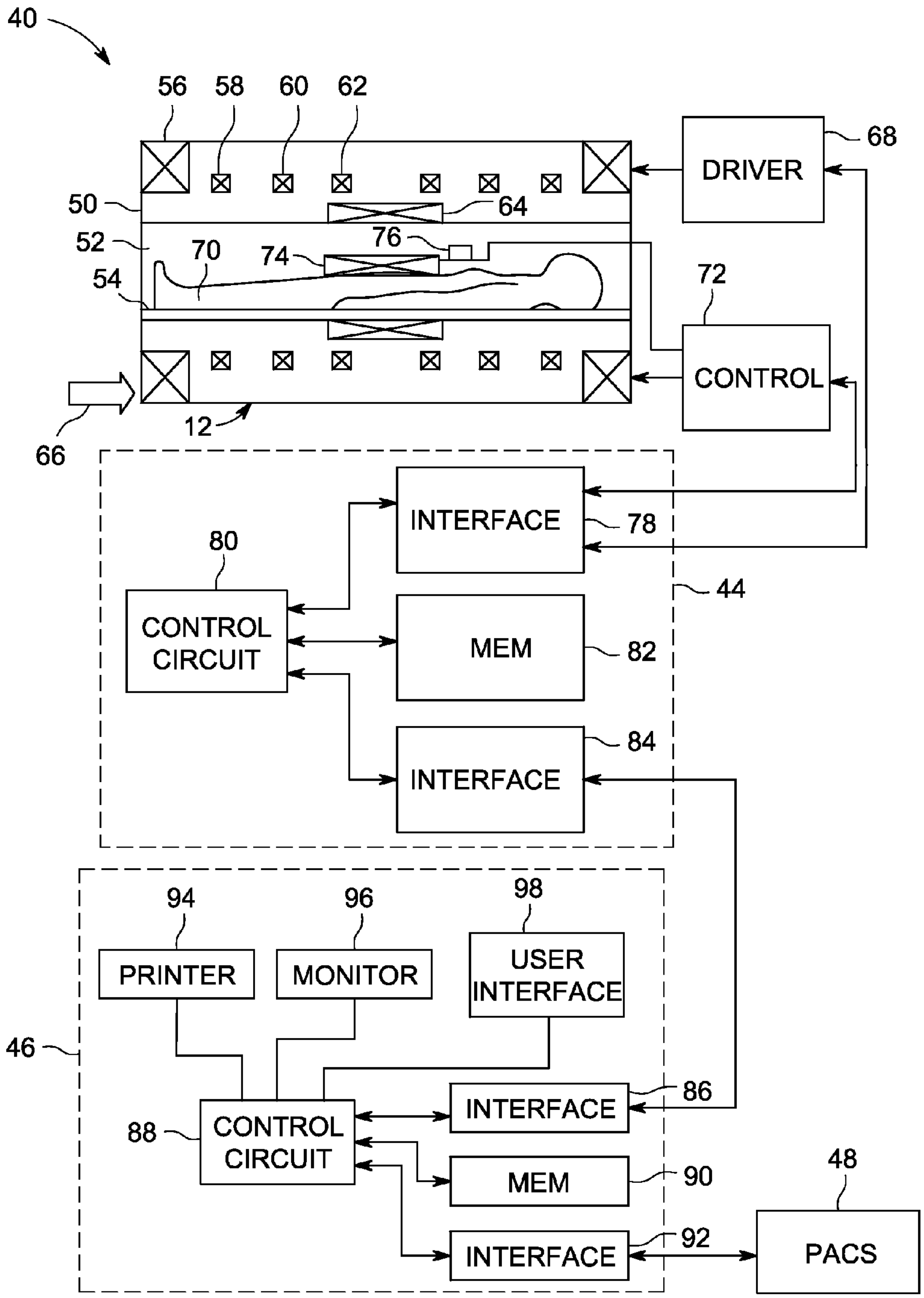

40
56
58
60
62
68
DRIVER
50
64
52
70
74
76
54
72
CONTROL
66
12
INTERFACE
78
80
CONTROL
CIRCUIT
44
MEM
82
84
INTERFACE
94
96
98
PRINTER
MONITOR
USER
INTERFACE
46
86
INTERFACE
88
CONTROL
CIRCUIT
MEM
90
48
92
INTERFACE
PACS

FIG. 2

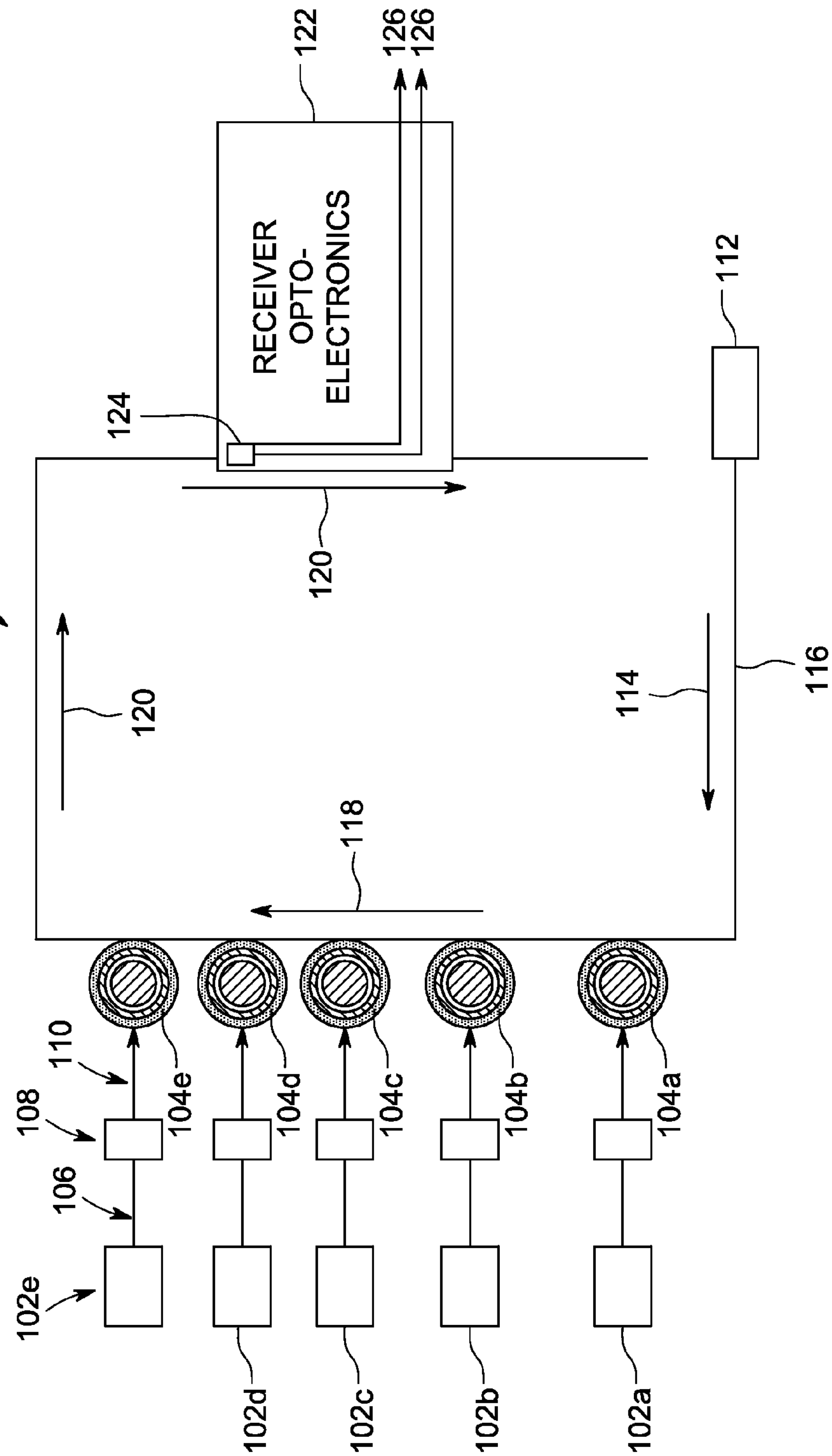

RECEIVER
OPTO-
ELECTRONICS
100
102a
102b
102c
102d
102e
104a
104b
104c
104d
104e
106
108
110
112
114
116
118
120
120
122
124
126
126

FIG. 3

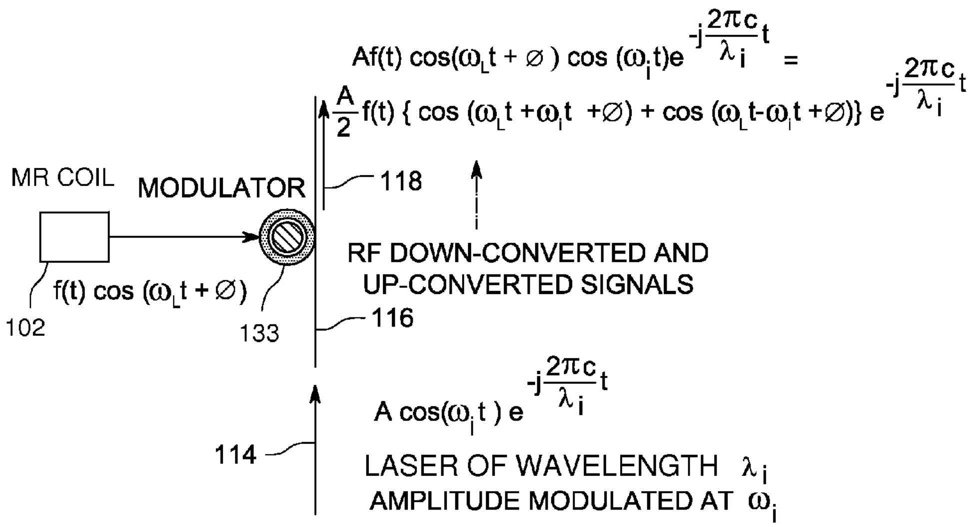

MR COIL
MODULATOR
f(t) cos (ωLt + ∅)
102
133
118
116
114
RF DOWN-CONVERTED AND
UP-CONVERTED SIGNALS
LASER OF WAVELENGTH λi
AMPLITUDE MODULATED AT ωi

FIG. 4

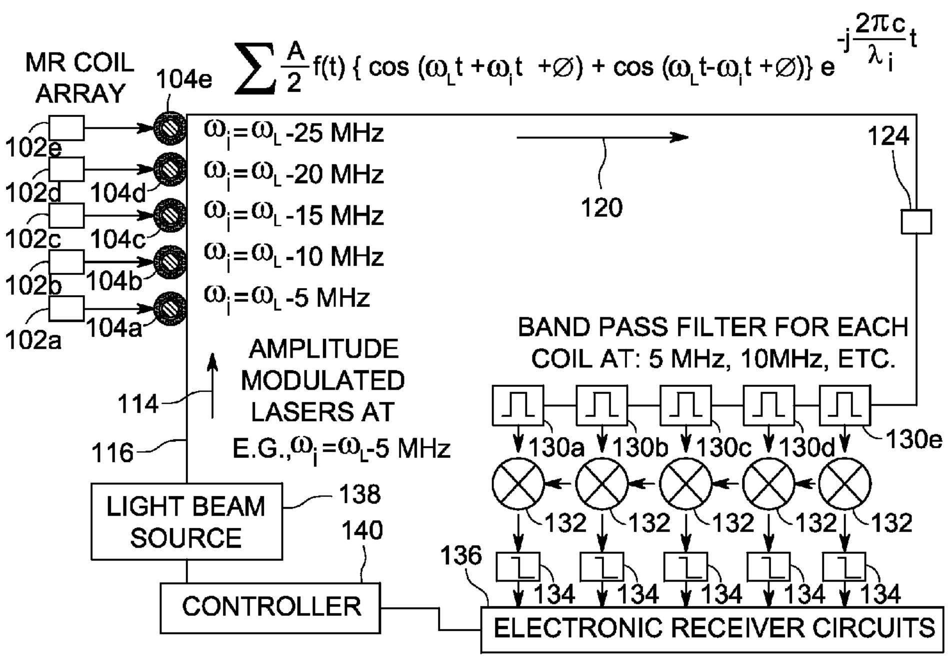
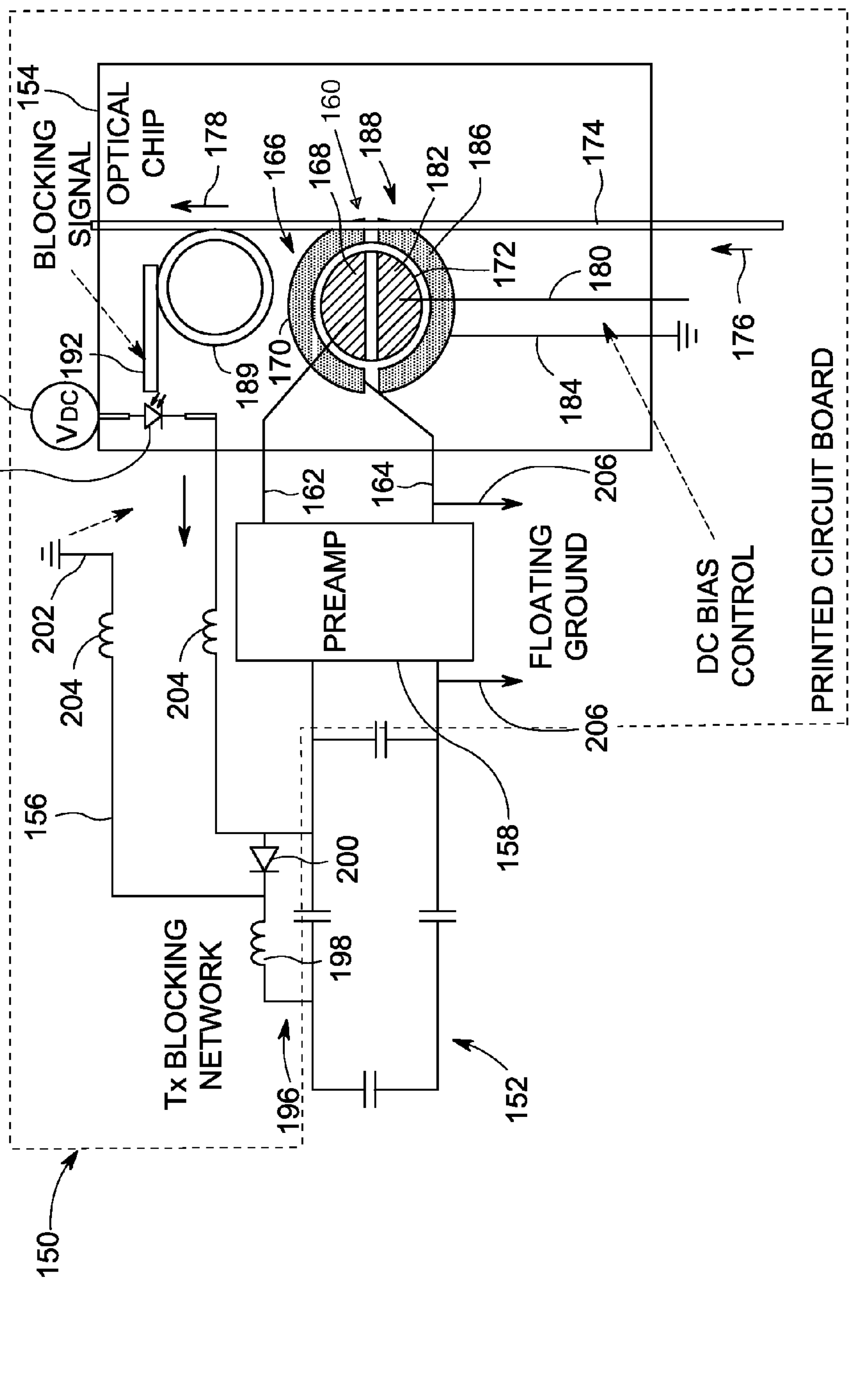

MR COIL
ARRAY
104e
102e
102d
102c
102b
102a
104d
104c
104b
104a
ωi=ωL-25 MHz
ωi=ωL-20 MHz
ωi=ωL-15 MHz
ωi=ωL-10 MHz
ωi=ωL-5 MHz
120
124
BAND PASS FILTER FOR EACH
COIL AT: 5 MHz, 10MHz, ETC.
AMPLITUDE
MODULATED
LASERS AT
E.G.,ωi=ωL-5 MHz
114
116
130a
130b
130c
130d
130e
132
134
136
LIGHT BEAM
SOURCE
138
140
CONTROLLER
ELECTRONIC RECEIVER CIRCUITS

FIG. 5


OPTICAL CHIP
BLOCKING SIGNAL
PREAMP
FLOATING GROUND
DC BIAS CONTROL
PRINTED CIRCUIT BOARD
Tx BLOCKING NETWORK
VDC
150
152
154
156
158
160
162
164
166
168
170
172
174
176
178
180
182
184
186
188
189
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194
196
198
200
202
204
206

FIG. 6

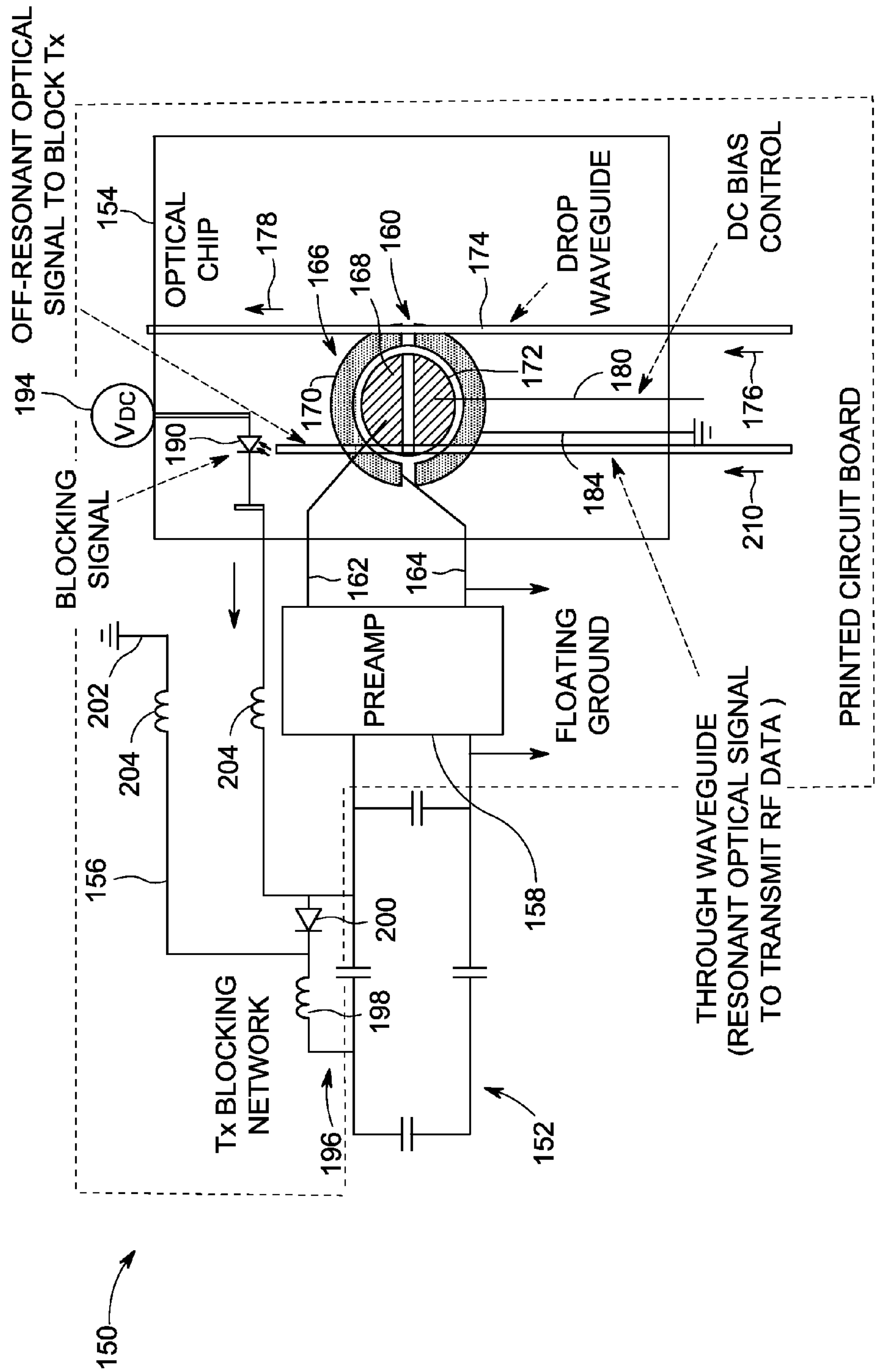
OFF-RESONANT OPTICAL SIGNAL TO BLOCK Tx
OPTICAL CHIP
DROP WAVEGUIDE
DC BIAS CONTROL
BLOCKING SIGNAL
V_{DC}
PREAMP
FLOATING GROUND
THROUGH WAVEGUIDE (RESONANT OPTICAL SIGNAL TO TRANSMIT RF DATA)
PRINTED CIRCUIT BOARD
Tx BLOCKING NETWORK
150
152
154
156
158
160
162
164
166
168
170
172
174
176
178
180
184
190
194
196
198
200
202
204
204
210

FIG. 7

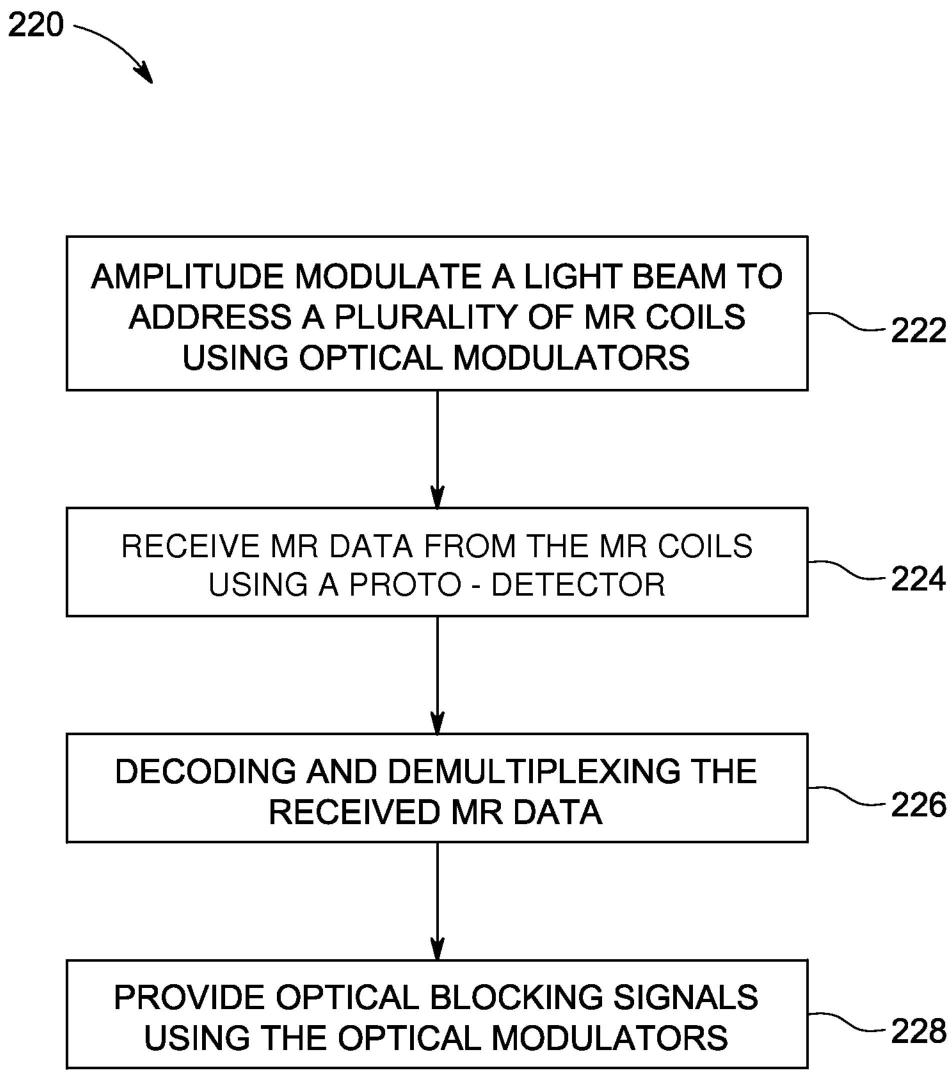
220
AMPLITUDE MODULATE A LIGHT BEAM TO ADDRESS A PLURALITY OF MR COILS USING OPTICAL MODULATORS
222
RECEIVE MR DATA FROM THE MR COILS USING A PROTO - DETECTOR
224
DECODING AND DEMULTIPLEXING THE RECEIVED MR DATA
226
PROVIDE OPTICAL BLOCKING SIGNALS USING THE OPTICAL MODULATORS
228

FIG. 8

PHOTONIC SYSTEM AND METHOD FOR OPTICAL DATA TRANSMISSION IN MEDICAL IMAGING SYSTEMS

BACKGROUND

The subject matter disclosed herein relates generally to data transmission in imaging and communication systems, and more specifically, to the communication of control signals and data via photonics within medical imaging systems, such as in Magnetic Resonance Imaging (MRI) systems.

In different imaging modalities, the quality, resolution, and/or speed of a resulting image is dependent on the number of detection elements (e.g., photodiodes, transducers, or coils) in respective detector arrays. As these imaging modalities add detection features, a system channel that electrically couples each detection feature to transmit and/or receive circuitry is needed. Because the number of system channels available may be limited, the number of detection features in a given detector array is often limited. As a result of the limited number of detection features, the scanning speed and the resolution of these modalities with a given type of detection array may be limited. As an alternative, additional channels must be added to the system.

Additionally, each of the channels not only require extra electrical materials and power to amplify the signals produced by the detectors, but also increase the weight and complexity of a given array. For example, MRI systems can include high-density multiple-coil MRI receiver arrays having increased cabling density, power consumption and protective device overhead. In particular, the complexity of the receiver-array cabling and protective elements has increased significantly with the use of 64 and 128 channel systems, resulting in a higher likelihood of signal-to-noise (SNR) degradation, preamp instability, and cable/balun heating from the RF transmit field.

BRIEF DESCRIPTION

In accordance with various embodiments, a photonic data transmission system for medical imaging is provided. The photonic data transmission system includes a plurality of optical modulators having different optical resonance wavelengths and configured to receive electrical signals representative of a set of data from a medical imaging device. The photonic data transmission system also includes an optical waveguide interfacing with the plurality of optical modulators and configured to transmit an amplitude modulated beam of light at different frequencies to selectively modulate the plurality of optical modulators to transmit an encoded beam of light. The photonic data transmission system further includes receiver opto-electronics in communication with the optical waveguide configured to decode the encoded beam of light and convert the decoded beam of light into the electrical signals representative of the set of data.

In accordance with other various embodiments, a photonic data transmission system for a Magnetic Resonance Imaging (MRI) system is provided. The photonic data transmission system includes a light source operable to produce a beam of light comprising one or more discrete optical wavelengths and one or more modulation frequencies, wherein the discrete optical wavelengths are amplitude modulated at different Radio-Frequency (RF) frequencies. The photonic data transmission system further includes a plurality of optical modulators configured to receive electrical signals representative of a set of medical data from a plurality of receive coils of the MRI system. Each optical modulator is operable to modulate a subset of photons corresponding to an optical wavelength within an encoded beam of light to encode the photons with the set of medical data from a corresponding receiver coil to produce encoded photons, wherein each modulator is selectable using a different optical wavelength and RF mixing frequency for the amplitude modulated beam of light. The photonic data transmission system also includes an optical waveguide interfacing the light source and the plurality of optical modulators with an opto-receiver configured to remove the encoded photons from the encoded beam of light. The photonic data transmission system further includes receiver opto-electronics configured to decode the encoded beam of light received by the opto-receiver and convert the decoded beam of light into the electrical signals representative of the set of medical data.

In accordance with yet other various embodiments, an upgrade kit for a Magnetic Resonance Imaging (MRI) system is provided. The upgrade kit includes an optical chip having a photonic data transmission system. The photonic data transmission system is configured to interface with a plurality of Radio-Frequency (RF) coils of the MRI system and is operable to convert electrical data signals representative of Magnetic Resonance (MR) data generated at the RF coils into a multiplexed optical data signal representative of the MR data with a plurality of optical modulators selectably activated by an amplitude modulated beam of light using different RF mixing frequencies and optical wavelengths.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a simplified block diagram illustrating generally an imaging system that may incorporate a photonic data transmission system in accordance with various embodiments.

FIG. **2** is a block diagram illustrating a Magnetic Resonance Imaging (MRI) system that may incorporate data transmission using photonics in accordance with various embodiments.

FIG. **3** is a diagrammatic illustration of image data transmission from a Radio-Frequency (RF) coil array of the MRI system of FIG. **2** using photonics in accordance with various embodiments.

FIG. **4** is a simplified diagrammatic illustration of photonic RF multiplexing in accordance with various embodiments.

FIG. **5** is a diagrammatic illustration of photonic RF multiplexing illustrating receiver opto-electronics in accordance with various embodiments.

FIG. **6** is a diagrammatic illustration of an optical readout system in accordance with various embodiments.

FIG. **7** is a diagrammatic illustration of an optical readout system in accordance with other various embodiments.

FIG. **8** is a flowchart of a method for controlling photonic systems in accordance with various embodiments.

DETAILED DESCRIPTION

The foregoing summary, as well as the following detailed description of certain embodiments, will be better understood when read in conjunction with the appended drawings. To the extent that the figures illustrate diagrams of the functional blocks of various embodiments, the functional blocks are not necessarily indicative of the division between hardware. Thus, for example, one or more of the functional blocks may be implemented in a single piece of hardware or multiple pieces of hardware. It should be understood that the various embodiments are not limited to the arrangements and instrumentality shown in the drawings. Additionally, the system blocks in the various figures or the steps of the methods may be rearranged or reconfigured.

As used herein, an element or step recited in the singular and proceeded with the word "a" or "an" should be understood as not excluding plural of said elements or steps, unless such exclusion is explicitly stated. Furthermore, references to "one embodiment" are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features. Moreover, unless explicitly stated to the contrary, embodiments "comprising" or "having" an element or a plurality of elements having a particular property may include additional such elements not having that property.

Various embodiments provide photonic multiplexing, such as nanophotonic optical RF multiplexing of Magnetic Resonance (MR) signals from receive coil arrays of a Magnetic Resonance Imaging (MRI) system. By practicing various embodiments, cable bulk and system interactions may be reduced. Additionally, a simpler and lighter means for frequency division multiplexing using MR optical readout systems may be provided. In accordance with other embodiments, photonic circuits for medical imaging systems are provided, such as for MR RF coils in an MRI system, having balunless optical readout and an integrated optical blocking system. By practicing other various embodiments, the use of RF baluns, cable traps and DC signal lines are reduced or eliminated.

Moreover, the various embodiments may enable a reduction in system cost and detector array weight, which can improve patient comfort, reduce overhead costs, increase patient safety, and result in better image quality. Technical effects of various embodiments include improved image quality, increased channel capability, reduced electromagnetic interference, immunity of optical signals and improved bandwidth capacity of the optical cables.

The various embodiments may be used to provide data transmission using photonic devices, such as nanophotonics devices. For example, micron-sized devices with low energy and drive voltage requirements may be used, such as in an imaging system employing nanophotonic transmitters, receivers and wavelength division multiplexing (WDM). In one embodiment, a full optical interface with an imaging system detector array using nanophotonic interconnects and nanophotonic control signal communication methods is provided. The photonic elements may include, for example, silicon-based devices, which provide compatibility with Complimentary Metal Oxide Semiconductor (CMOS) fabrication techniques.

It should be noted that the various embodiments may be utilized in a variety of imaging applications, such as in medical imaging, product inspection for quality control, and for security inspection (e.g., baggage inspection), among others. Thus, although examples discussed herein relate generally to medical imaging, particularly MRI, the various embodiments are not limited to such examples. In particular, FIG. **1** illustrates generally a medical imaging system **20** that may incorporate nanophotonic optical RF multiplexing for optical data transmission or nanophotonic circuits for RF readout of signals. For example, the medical imaging system **20** may be an X-ray imaging system such as a Computed Tomography (CT)/C-arm imaging system, a Positron Emission Tomography/Single Photon Emission Computed Tomography (PET/SPECT) imaging system, an ultrasound imaging system, or an MRI system, among others.

In particular, a block diagram of the imaging system **20** is shown in FIG. **1**. The imaging system **20** includes a detector **22** for detecting a signal **24**. The detector **22** may include one or more arrays of detection elements such as photodiodes, coils, sonic transducers, scintillators, photomultiplier tubes, among others, to detect the signal **24**. The signal **24** may generally include some form of electromagnetic or other radiation, such as gamma rays, X-rays, sonic echoes, RF, sound waves, among others. The signal **24** may be generated by a source external to an object being imaged (e.g., an X-ray tube) or internal to the object (e.g., an injected radiopharmaceutical).

The detector **22** generates electrical signals in response to the detected radiation and the electrical signals are communicated by respective channels to a data acquisition system (DAS) **26** via a data link and using a photonic data transmission system **30** as described in more detail herein. In various embodiments, the data link **28** includes a plurality of electrical wires that may be bundled, insulated, thermally maintained, and otherwise protected. In accordance with various, the data link **28** has a reduced number of lines, for example a single waveguide line, or a few optical lines, connecting the detector **22** with the DAS **26** through the photonic data transmission system **30**. Further, such an optical interface may transmit all data from all of the channels received from the detector **22**. The data link **28** in accordance with some embodiments may include, for example, as part of the photonic data transmission system **30**, one or more modulators having optical resonators (e.g., micro-ring resonators) that encode each electrical signal (such as for each channel) received from the detector with specific wavelengths and frequencies of light. The wavelengths and frequencies of light may be multiplexed and transmitted to the DAS **26**, for example via one or more waveguide lines, using amplitude modulation as described herein.

Downstream along the data link **28** (i.e., towards the DAS **26**), the waveguide line may include receiver optoelectronics, which may include one or more demultiplexers and band pass filters that are tuned to specific wavelengths at which each channel is optically encoded, as described in more detail herein. Each channel is converted back into an electrical signal, such as using a transducer, for example, a photodetector, and provided to the DAS **26**. Various methods for multiplexing and demultiplexing are described in detail below.

When the DAS **26** receives the electrical signals, which may be analog signals, the DAS **26** may digitize or otherwise condition the data for subsequent processing (e.g., image reconstruction). For example, the DAS **26** may filter the image data based on time (e.g., in a time series imaging routine) or may filter the image data for noise or other image aberrations. The DAS **26** then provides the data to a controller **32** operatively connected thereto. The controller **32** may be, for example, an application-specific or general purpose computer with appropriately configured software. The controller **32** may include computer circuitry configured to execute programs and algorithms such as imaging protocols, data processing, diagnostic evaluation, as well as other processes. As an example, the controller **32** may direct the DAS **26** to perform image acquisition at certain times or to filter certain types of data. Additionally, the controller **32** may include components for interfacing with an operator, such as an Ethernet connection, an Internet connection, a wireless transceiver, a keyboard, a mouse, a trackball, a display, etc.

In one embodiment, the imaging system **20** may be provided as an MRI system, such as illustrated in FIG. **2**, which depicts an MRI system **40** including a scanner **42**, a scanner control circuit **44**, and a system control circuit **46**. The MRI system **40** additionally includes remote access and storage systems or devices, such as a picture archiving and communication system (PACS) **48**, or other devices such as teleradiology equipment such that data acquired by the MRI system **40** may be accessed on- or off-site. While the MRI system **40** may include any suitable scanner or detector, in the illustrated embodiment, the system **40** includes the full body scanner **42** having a housing **50** through which a bore **52** is formed. A table **54** is moveable into the bore **52** to allow a patient **70** to be positioned therein for imaging selected anatomy.

The scanner **42** includes a plurality of associated coils for producing one or more controlled magnetic fields and for detecting emissions from gyromagnetic material within the anatomy of the patient **70** being imaged. A primary magnet coil **56** is provided for generating a primary magnetic field that is generally aligned with the bore **52**. A series of gradient coils **58**, **60**, and **62** permit controlled magnetic gradient fields to be generated during examination sequences. An RF coil **64** is provided for generating RF pulses for exciting the gyromagnetic material, such as for spin preparation, relaxation weighting, spin perturbation or slice selection. A separate receive coil (e.g., a receive coil array **74**) or the RF coil **64** may receive magnetic resonance signals from the gyromagnetic material during examination sequences.

The various coils of the scanner **42** are controlled by external circuitry to generate the desired field and pulses, and to receive emissions from the gyromagnetic material in a controlled manner. In one embodiment, a main power supply **66** is provided for powering the primary magnet coil **56**. A driver circuit **68** is also provided for pulsing the gradient coils **58**, **60**, and **62**. The driver circuit **68** in various embodiments includes amplification and control circuitry for supplying current to the gradient coils **58**, **60**, and **62** as defined by digitized pulse sequences output by the scanner control circuit **44**.

Another control circuit **72** is provided for regulating operation of the RF coil **64**. The control circuit **72**, in some embodiments, may include a switching device for alternating between active and passive modes of operation, wherein the RF coil **64** transmits and receives signals, respectively. However, in the illustrated embodiment, the control circuit **72** is in communication with the receive coil array **74**, such as an array that may be placed on the patient **70**. In various embodiments, the receive coil array **74** includes an optical interface **76**, for example for the communication of data, providing control signals, and providing other control and communication operations. The control circuit **72** also includes amplification circuitry for generating the RF pulses and receiving circuitry for processing magnetic resonance signals received by the receive coil array **74**. The manner in which the communication of data between the coils, amplifiers, and control circuit **72** (which may include control signals) is described in further detail with respect to FIGS. **3** through **7**.

The scanner control circuit **44** includes an interface circuit **78** which outputs signals for driving the gradient coils **58**, **60** and **62** and the RF coil **64** and for receiving the data representative of the magnetic resonance signals produced in examination sequences. The interface circuit **78** is also coupled to a control circuit **80**. The control circuit **80** executes the commands for driving the control circuit **72** and the driver circuit **68** based on defined protocols selected via the system control circuit **46**. The control circuit **80** also operates to receive the magnetic resonance signals and performs subsequent processing before transmitting the data to the system control circuit **46**. The scanner control circuit **44** also includes one or more memory circuits **82** that store, for example, configuration parameters, pulse sequence descriptions, examination results, among other data. Another interface circuit **84** is coupled to the control circuit **80** for communicating data between the scanner control circuit **44** and the system control circuit **46**. Such data may include the selection of specific examination sequences to be performed, configuration parameters of these sequences, and acquired data, which may be transmitted in raw or processed form from the scanner control circuit **44** for subsequent processing, storage, transmission and/or display.

The system control circuit **46** includes an interface circuit **86** that receives data from the scanner control circuit **44** and transmits data and commands back to the scanner control circuit **44**. The interface circuit **86** is coupled to a control circuit **88** that may include a CPU in a multi-purpose or application specific computer or workstation. The control circuit **88** is coupled to a memory circuit **90** to store, for example, programming code for operation of the MRI system **40** and to store the processed image data for later reconstruction, display and transmission. An additional interface circuit **92** may be provided for communicating image data, configuration parameters, and other information with external system components such as the PACS **48**. Finally, the system control circuit **88** may include various peripheral devices for facilitating operator interface and for generating outputs, such as producing hard copies of the reconstructed images. In the illustrated embodiment, these peripheral devices include a printer **94**, a monitor **96**, and a user interface **98**, which may include user input devices such as a keyboard or a mouse.

Various embodiments of a photonic data transmission system that includes nanophotonic optical RF multiplexing and RF optical readout with optical blocking will be described in the context of MR data transferred, for example, from the RF receive coil array **74** to image processing circuitry, such as the scanner control circuit **44** and/or the system control circuit **46**. However, it should be noted that the various embodiments may be implemented in different systems and are not limited to an MRI system, such as the MRI system **40** shown in FIG. **2**.

Specifically, as shown in FIG. **3**, a photonic system **100**, illustrated as a nanophotonic data transmission system (which may be embodied as the photonic data transmission system **30** of FIG. **1**) may be provided for the optical transmission of data from one or more array RF receive coils **102**, which may be similar to receive coil array **74** of FIG. **2**, to image processing circuitry. It should be noted that all or a part of the photonic system **100** may be integrated on a single chip or a plurality of chips.

In the illustrated embodiment, the photonic system **100** includes an array of optical modulators **104** that are configured to convert electrical signals representative of, for example, medical image data, into optical signals. In general, each of the optical modulators **104***a-e* may include one or more optical resonators configured to operate at a distinct wavelength from each of the other optical modulators **104***a-e*. Specifically, each of the modulators **104** modulate a distinct subset of photons contained within a beam of light so as to encode the subset of photons with respective sets of data to produce encoded subsets of photons. Each subset of photons may be so categorized in that the subset may have a plurality of photons having similar wavelengths (e.g., within a few nm of each other), the same wavelengths, the same polarizations, or in that the plurality of photons arrive at the modulator at substantially the same time. As used herein, the subsets Of photons may include a plurality of photons such that the photons may exhibit a collective behavior or characteristic, as opposed to behavior of single quanta. The wavelength control exhibited by the resonators may be provided, for example, via lithography or via thermal tuning. In various embodiments, the photonic system **100** may employ any or a combination of micro-ring resonators, arrayed waveguide gratings, and/or Mach-Zender interferometers for the purpose of performing optical multiplexing and/or demultiplexing on the subsets of photons contained within a beam of light as described herein. Again, each resonator/photonic element is designed to operate at a unique optical wavelength and the signals therefrom modulated at a mixing frequency as described herein.

During operation of the photonic system **100**, the RF receive coils **102** (also referred to as a coil set **102**) each receive respective MR signals. The MR signals are then converted into electrical signals **106**, which are directed to respective amplifiers **108** (e.g., pre-amplifiers). As an example, the amplifiers may be low noise amplifiers (LNAs) that are powered using between about 0.005 Watts (W) and 1 W of power (e.g., between about 5 mW and about 500 mW, or about ⅓ W). In some embodiments, the LNAs may generate MR-compatible low noise within a narrow bandwidth around the Larmor frequency (typically at approximately either 64 MHz or 128 MHz for hydrogen nuclei at 1.5 T and 3 T respectively, but at other frequencies corresponding to 31 P, 13 C, or other nuclei) so as to avoid the introduction of noise into MR signals received at the RF receive coils **102**. The amplifiers amplify the electrical signals **106**, which are then sent as amplified electrical signals **110** to the array of optical modulators **104**.

In a process occurring substantially simultaneously to the transmission of data to the array of optical modulators **104**, a source of light **112**, such as generated by one or more LEDs, diode lasers, micro ring lasers, or the like, sends an optical beam **114** through an optical waveguide **116**, for example a fiber optic conduit. The optical beam **114** may include a plurality of optical wavelengths each at a different modulated frequency. That is, the optical beam may include subsets of photons, with each subset having respective polarizations, wavelengths and/or modulation frequencies. While the illustrated embodiment depicts the photonic system **100** as including a single waveguide, it should be noted that the use of more than one waveguide is contemplated herein, such as a series of waveguides interfacing with a plurality of optical modulators, or a waveguide used for transmission to the optical modulators and a separate waveguide used as a drop line to carry modulated optical signals from the modulators.

As illustrated in FIG. **3**, the optical beam **114** is transmitted along the waveguide **116** and encounters the array of optical modulators **104**. The waveguide **116** may be a single or multimodal optical fiber, and may include only one or multiple optical fibers, or may be a channel etched into a silicon chip. Additionally, the waveguide line **116** may be formed from a silicon-based waveguide material, or may include any one or a combination of waveguide materials known in the art, such as silicon, fluorozirconate, fluoroaluminate, chalcogenide, sapphire, and/or plastic materials. As the optical beam **114** encounters the array of optical modulators **104**, each modulator encodes a portion of the optical beam **114** with MR data received at the respective coil in the coil set **102**, resulting in an optical beam **118** that becomes increasingly modulated (e.g., as the optical beam **118** encounters more optical modulators **104**). For example, the optical beam **114** may include a plurality of wavelengths (of polarizations or frequencies) to which one of the plurality of optical modulators **104** may be tuned. In accordance with various embodiments, the wavelengths that are able to be differentially encoded by the modulators **104** may be separated, for example, by as little as a few nanometers (nm), or as much as a micron. In some embodiments, the wavelengths to which the optical modulators **104** are tuned may be in the range of about 1520 nm to about 1570 nm (i.e., about 1.57 μm).

In one embodiment, the photonic system **100** includes a plurality of different optical modulators, illustrated as five modulators **104***a*, **104***b*, **104***c*, **104***d*, and **104***e*, which may be tuned to respective wavelengths contained in the optical beam **118** (e.g., λa, λb, λc, λd, and λe, respectively). Accordingly, the optical modulator **104***a* may encode a wavelength λa with magnetic resonance data received from the respective RF coil **102***a*, modulator **104***b* may encode a wavelength λb with magnetic resonance data received from the respective RF coil **102***b*, and so on. Additionally, amplitude modulation at different frequencies is also provided described herein. In the illustrated embodiment, after the optical beam **118** has encountered the optical modulator **104***e*, an optical beam **120** that has been fully encoded with MR data from the RE receiving coils **102** may be transmitted through the waveguide **116**. That is, the optical beam **120** is multiplexed with the data captured by the RF receive coils **102**. Accordingly, it should be noted that the process described above may be performed substantially continuously as MR data is collected at the RF receive coils **102**.

In various embodiments, as described in more detail herein in connection with FIGS. **4** and **5**, amplitude modulated light is used as the input to the optical modulators **104**, namely, the optical beam **114** is an amplitude modulated light source that can provide on-coil RF frequency division multiplexing (FDM). Accordingly, multiple light wavelengths for multicoil MR optical readout may be provided using a single receiver in some embodiments. It should be noted that in various embodiments silicon photonic elements form the nanophotonic devices. The nanophotonic elements enabling the MRI receiver system may be, for example, nanophotonic modulators, nanophotonic detectors and nanophotonic wavelength division multiplexed (WDM) devices. The nanophotonic elements may be sized, for example, between 1 micron and 1 mm.

Returning again to the operation of the photonic system **100** of FIG. **3**, once the fully encoded optical beam **120** has been produced, the waveguide **116** (e.g., optical fiber) transmits the beam **120** along a path to receiver opto-electronics **122**, which in this embodiment includes a single photo-detector **124**. The encoded optical beam **120** is then decoded and demultiplexed by the receiver opto-electronics **122** as described below, for example, using filters and isolators to recover the original signal frequency using any suitable RF FDM method. It should be noted that any order of demultiplexing, allowing the system to be tuned to any desired wavelength and any desired multiplexing/demultiplexing order may be provided.

Thus, the photo-detector **124** may produce electrical signals **126** that are then filtered and demultiplexed. The photo-detector **124** may be a photodiode array, a Germanium waveguide integrated detector, or any photo-detector that is capable of acting as a transducer to generate the electrical signals **126** from the optical beams **120**. The electrical signals **126** are representative of the MR data that is detected at the RF receive coils **102**. Accordingly, the electrical signals **126** are sent to processing circuitry, such as the scanner control circuit **44** and/or the system control circuit **46** (both shown in FIG. **2**) to allow the MR data to be processed, stored, and/or interpreted.

It should be noted that various embodiments may also optionally or alternatively provide for the transmission of power to the amplifiers **108** (shown in FIG. **3**) to drive the modulators **104** or transmit control signals as described in more detail herein.

Thus, as shown in FIG. **4**, wherein the RF receive coils **102***a-e* are represented for simplicity by the single MR coil

102 and the optical modulators **104***a-e* are represented for simplicity by the nanophotonic modulator **133**, optical readout from each MR receive coil, namely the MR coil **102** is provided using the nanophotonic modulator **133**, which also includes RF mixing. In particular, the optical beam **114** in various embodiments is an amplitude modulated laser signal used as the input to the nanophotonic modulator **133** at a desired RF mixing frequency (ω_i), also referred to as an intermediate frequency. In one embodiment, a laser of wavelength λ_i is amplitude modulated at an RF mixing frequency ω_i, which is used as the input to the nanophotonic modulator **133**, resulting in an MR RF signal that is converted to an optical signal at the desired RF center frequency. For example, as illustrated in FIG. **4**, the optical beam **114** may be defined as follows:

$$A\cos(\omega_i t)e^{-j\frac{2\pi c}{\lambda_i}},$$

where c is the speed of light.

After the light passes through modulator **133**, RF down-converted and up-converted signals result as follows:

$$Af(t)\cos(\omega_L t+\phi)\cos(\omega_i t)e^{-j\frac{2\pi c}{\lambda_i}t} = \frac{A}{2}f(t)\{\cos(\omega_L t+\omega_i t+\phi)+\cos(\omega_L t-\omega_i t+\phi)\}e^{-j\frac{2\pi c}{\lambda_i}t}$$

Thus, using the nanophotonic modulator **133**, a modulated laser input of the optical beam **114** produces an optical output encoded with the MR signal at the desired RF center frequency, where ω_L is the Larmor frequency and ω_i is the amplitude modulation mixing frequency. In operation, MR optical readout and RF frequency conversion is thereby provided. For example, a 5 MHz modulated laser input as the optical beam **114** produces an optical signal with RF content offset from the Larmor frequency by +/−5 MHz.

Using the amplitude modulation scheme of the various embodiments, for example, as described above in connection with FIG. **4**, multichannel signal transmission on a single line may be provided by combining FDM and WDM, such as on a single optical fiber. It should be noted that the various embodiments are not limited to a particular frequency division method, and any suitable method may be used.

In one embodiment, for example as shown in FIG. **5**, nanophotonic optical RF multiplexing is provided by assigning each coil element, for example, each RF receive coil **102** a unique optical wavelength λ_i and RF modulation frequency ω_i. In order to physically address the i^{th} coil element, the incoming light, namely the optical beam **114**, at wavelength λ_i is amplitude modulated at RF frequency ω_i. Thus, the RF receive coils **102** are optically addressed with the unique frequency used to distinguish the MR signal from a corresponding RF receive coil **102** at the receive end. It should be noted that the amplitude modulation may be performed using any suitable modulation scheme. Thus, the incoming laser light comprises multiple wavelength λ_i, each of which is modulated by a corresponding unique RF frequency ω_i. As the light, illustrated as the optical beam **114**, interacts with each coil element i, only the wavelength component λ_i interacts with the corresponding i^{th} modulator **104**, and the RF frequency ω_i is modulated by the MR receive signal (centered at ω_i) to produce a low frequency signal centered at $\omega_L-\omega_i$. The light on the fiber, illustrated as the optical beam **118** (e.g., light beam) on the waveguide **116** that exits the coil elements, illustrated as the RF receive coils **102**, comprises multiple wavelengths λ_i, each of which carries a different low-frequency signal centered at $\omega_L-\omega_i$. For example, as illustrated in FIG. **5**, each modulator **104** mixes the MR receive signal from the RF receive coils **102** with a mixing frequency, shown as decrementing by 5 MHz for each of the RF receive coils **102**. However, it should be noted that different intervals of mixing frequencies may be used, which may be varied differently, randomly selected, etc.

Thus, the optical beam **120** may be defined as follows:

$$\sum\frac{A}{2}f(t)\{\cos(\omega_L t+\omega_i t+\phi)+\cos(\omega_L t-\omega_i t+\phi)\}e^{-j\frac{2\pi c}{\lambda_i}t}$$

Accordingly, an optically multiplexed signal is provided wherein the input laser for each optical channel is modulated to a desired RF mixing frequency, which is then received or collected by the receiver opto-electronics **122** (shown in FIG. **3**), which in this embodiment includes the single photo-detector **124**. The receiver opto-electronics **122** also includes various components to allow for the separation and demultiplexing of the data encoded with the light beam **120**.

In particular, the electrical signals received from the photo-detector **124** comprise the RF signals from a plurality of the RF receive coils **102**, which may be all or a subset of the RF receive coils **102**. The received signals are encoded at RF multiplexing frequencies selected for each of the plurality of channels corresponding to the RF receive coils **102**. In one embodiment, a plurality of band pass filters **130** are connected to the photo-detector **124**, with each of the band pass filters **130** having a filter frequency to allow MR data from a corresponding one of the RF receive coils **102** to pass. For example, the band pass filters **130***a-e* may filter the signal to allow the MR data from the RF receive coils **102***a-e*, respectively, to pass, thereby demultiplexing the signals. The band pass filters **130** are connected to mixers **132**, which may be modulated by a single local oscillator source for all of the band pass filters **130** or separate oscillator sources. The local oscillator modulating mixer **132** may be tuned to a desired or required frequency, such as based on the mixing frequency, the MR signal frequency, or system requirements, among others. In some embodiments, the local oscillator modulating mixer **132** is a low frequency oscillator having a low frequency, for example, 16 MHz.

In operation, using the band pass filters **130** and the local oscillator modulating mixer **132**, the frequencies for each of the channels corresponding to the RF receive coils **102** is down-converted to the base band. These signals may then further be filtered using low pass filters **134**. It should be noted that high frequency components at $\omega_L+\omega_i$ in the signal from the photo-detector **124** are filtered out and discarded by the band pass filters **130**.

Thereafter, the down-converted signals are received by electronic receiver circuits **136** that provide analog-to-digital conversion of the signal. In another embodiment, the filters and mixers downstream from the photo-detector **124** may be removed and direct A/D sampling performed on the combined signals after the photo-detector **124**. Then the different frequency components may be sorted out and filtered in the digital domain. Thus, nanophotonic optical FDM (performed in various embodiments by the band pass filters **130**, the oscillator modulating mixer **132**, and the low pass filters **134**) is provided in various embodiments, using a light beam, such as a laser beam, that is amplitude modulated at a mixing frequency for each of a plurality of optical channels. The light beam may be generated, for example, by a light beam source **138**, which in one embodiment is a modulated laser, which can generate the laser beam at any desired or required frequency.

In the various embodiments, a controller **140** is connected to at least one of the light beam source **138** or the electronic receiver circuits **136**. The controller **140** may be embodied in hardware, software or a combination thereof. The controller **140** is configured to control the light beam source **138** or the electronic receiver circuits **136** as described in more detail herein.

Additionally, different configurations of RF optical readout of the MR signals may be provided, for example, as illustrated in FIGS. **6** and **7**. Specifically, the arrangements of FIGS. **6** and **7** provide optical readout having active optical blocking. Accordingly, in these embodiments, routing of DC blocking signals using, for example, twisted pairs are not used. In these embodiments, a split-ring optical modulator arrangement is used. However, other types and arrangements of optical modulators may be provided.

In particular, the optical readout system **150** of FIG. **6** provides for modulating MR data received from one or more resonant coils **152**, which may be embodied as the RF receive coils **102** (shown in FIGS. **3** and **5**). An optical chip **154** is provided that forms part of a printed circuit board **156** in this embodiment. The optical chip **154** includes a low-noise amplifier **158** (illustrated as a preamplifier) and an integrated on-chip photo-detector, illustrated as a split-ring modulator **160** for producing an optical signal encoded with MR data. It should be noted that the optical chip **154** or the printed circuit board **156** may be provided as an upgrade kit including, for example, the connection wires, brackets, etc. for connection to an MRI system, such as the MRI system **40** (shown in FIG. **2**).

The low-noise amplifier **158** includes at least two connections with the split-ring modulator **160**. Specifically, the low-noise amplifier **158** interfaces with the split-ring modulator **160** via first connection **162** and a second connection **164**, with both connections being on a first side **166** of the split-ring modulator **160**. The first connection **162** interfaces with a first inner n-region **168** and the second connection **164** interfaces with a first outer p-region **170**, which are separated by a micro ring resonator **172**.

Thus, the optical modulator **160** may be, for example, a PN-type diode, a PIN-type diode, or a multilayered structure such as PINIP device or a Metal Oxide Semiconductor (MOS) capacitor. The micro ring resonator **172** is the area in which photons having specific wavelengths and frequencies are modulated by the bias created between the p-region **170** and the n-region **168**. In this embodiment, an optical waveguide **174** (e.g., a waveguide etched into the silicon of the optical chip **154**) transmitting an optical beam **176** interfaces with the optical modulator **160**, and a subset of optical wavelengths and frequencies within the optical beam **176** having wavelengths to which the optical modulator **160** is tuned are modulated or encoded with the MR data to produce a modulated or encoded optical beam **178**.

In operation, the discontinuity between the portions of the split-ring modulator **160** allows an electrical bias to be placed across the split-ring modulator **160** to allow tuning to one or more specific wavelengths for modulation. Thus, a DC bias control **180** is connected to a second inner n-region **182**, with a ground **184** being connected to a second outer p-region **186**. Accordingly, a voltage is placed on a second side **188** to create a bias across the split-ring modulator **160** to allow wavelength tuning.

It should be noted that the one or more resonant coils **152** are generally configured to receive low level or "faint" RF signals from nuclear spins within the patient **70** after the spins have been excited by the transmitting RF coil **64** of the MRI system **40** (all shown in FIG. **2**), and the one or more resonant coils **152** receive the signals as the gyromagnetic nuclei return to an equilibrium magnetization. Accordingly, the one or more resonant coils **152** may also have additional components in addition to those in the illustrated embodiment, such as to deactivate the one or more resonant coils **152** during RF transmission, to avoid damaging electrical components when the MRI system **40** is transmitting a large amount of RF energy, which in some embodiments is provided using signal blocking with active optical blocking signals. For example, in the embodiment illustrated in FIG. **6**, another optical modulator **189** (which in this embodiment is not a split-ring modulator) is also provided along and interfaces with the optical waveguide **174**. The optical modulator **189** (which may be referred to as a blocking signal optical modulator) is also optically connected to a photo-diode **190** via ah optical waveguide **192** to allow the communication of an optical blocking signal from the optical modulator **189** to the photo-diode **190**. The photo-diode **190** connects a voltage source **194**, for example, a DC source, that provides a blocking DC signal to a transmit blocking network **196**. The transmit blocking network **196** may be any suitable blocking network providing electrical blocking signals, which includes in the illustrated embodiment an inductor **198** in series with a diode **200** (blocking diode). The transmit blocking network **196** is connected to ground **202**. It should be noted that the paths from the transmit blocking network **196** to the photo-diode **190** and to the ground **202** optionally include chokes **204**, which minimize or prevent the DC lines from picking up RF.

Thus, in operation the photo-diode **190** receives an optical switching signal to turn on and off the transmit blocking network **196** providing an optical readout having optical active blocking. The optical signals provided along the optical waveguide **174** in various embodiment include two wavelengths, one to modulate the optical modulator **160** to read MR signals from the one or more resonant coils **152** and another to resonate with the secondary, namely the optical modulator **189** to activate the transmit blocking network **196** by sending a blocking signal from the voltage source **194**. Accordingly, an integrated optical filter with a photo-detector receives optical signals encoded with a determined wavelength and also provides active blocking signals when receiving blocking pulses (different wavelengths of light), which are directed to the photo-diode **190**. Once the photo-diode **190** is activated or turned on, electrical blocking signals may be applied to the transmit blocking network **196**. It should be noted that the photo-diode **190** may be replaced with any type of photo-detector and also may be positioned in the RF coil electronics. Thus, in various embodiments the optical signals are used to minimize the likelihood or block the one or more resonant coils **152** from resonating with the RF energy generated by the MRI system **40** during the RF transmit pulse.

Accordingly, during operation, the one or more resonant coils **152** receive an RF signal, which is representative of MR data of the patient **70**. The one or more resonant coils **152** then produce an electrical data signal representative of the MR data, which is provided to the optical modulator **160** in the form of a balanced electrical signal. In the illustrated embodiment, the electrical signal is balanced due to a floating reference ground **206** that is separate from a universal ground of the MR system **40** (shown in FIG. **2**).

Variations and modifications are contemplated. For example, as shown in FIG. **7**, the splitting modulator **160** may be used as the optical filter to route active blocking signals received along an optical waveguide **208** that interfaces with both the split-ring modulator **160** and the photo-diode **190**. It should be noted that like numerals represent like parts in the Figures. Thus, in this embodiment, the optical modulator **189** and optical waveguide **192** are removed. In particular, in the illustrated embodiment, the light wavelength tuned to the optical resonance wavelength of the split-ring modulator **160** is filtered by the split-ring modulator **160**, encoded with the electrical signal and routed to the optical waveguide **174**. The light wavelength not tuned to the optical resonance wavelength of the split-ring modulator **160** (namely an off-resonant optical signal), illustrated as the optical beam **210** (carrying the active blocking signals) is routed through the optical waveguide **208**, passes the split-ring modulator **160** (because the wavelength is different than the resonant wavelength of the split-ring modulator **160**) to the photo-diode **190**. The photocurrent from the photo-diode **190** is again used to control the transmit blocking network **196**.

Various embodiments also may provide a method **220** for controlling the various embodiments of a photonic system as described herein. For example, the method includes at **222**, amplitude modulating a light beam, such as from a laser, to optically address a plurality of MR coils using optical modulators. For example, different mixing frequencies may be used to address the different MR coils, in combination with different wavelengths of light (optical resonance) as described herein. Thereafter, MR data within an optical beam are received using a photo-detector at **224**, which in one embodiment is a single photo-diode. Thereafter, the received MR data are decoded and demultiplexed at **226** as described herein. Optical blocking signals also may be provided at **228** to a transmit blocking network using the optical modulators as described herein.

Thus, various embodiments provide photonic optical RF multiplexing and RF readout of MR signals (with optical routing of active blocking signals).

The various embodiments and/or components, for example, the modules, or components and controllers therein, also may be implemented as part of one or more computers or processors. The computer or processor may include a computing device, an input device, a display unit and an interface, for example, for accessing the Internet. The computer or processor may include a microprocessor. The microprocessor may be connected to a communication bus. The computer or processor may also include a memory. The memory may include Random Access Memory (RAM) and Read Only Memory (ROM). The computer or processor further may include a storage device, which may be a hard disk drive or a removable storage drive such as an optical disk drive, solid state disk drive (e.g., flash RAM), and the like. The storage device may also be other similar means for loading computer programs or other instructions into the computer or processor.

As used herein, the term "computer" or "module" may include any processor-based or microprocessor-based system including systems using microcontrollers, reduced instruction set computers (RISC), application specific integrated circuits (ASICs), field-programmable gate arrays (FPGAs), graphical processing units (GPUs), logic circuits, and any other circuit or processor capable of executing the functions described herein. The above examples are exemplary only, and are thus not intended to limit in any way the definition and/or meaning of the term "computer".

The computer of processor executes a set of instructions that are stored in one or more storage elements, in order to process input data. The storage elements may also store data or other information as desired or needed. The storage element may be in the form of an information source or a physical memory element within a processing machine.

The set of instructions may include various commands that instruct the computer or processor as a processing machine to perform specific operations such as the methods and processes of the various embodiments of the invention. The set of instructions may be in the form of a software program, which may form part of a tangible non-transitory computer readable medium or media. The software may be in various forms such as system software or application software. Further, the software may be in the form of a collection of separate programs or modules, a program module within a larger program or a portion of a program module. The software also may include modular programming in the form of object-oriented programming. The processing of input data by the processing machine may be in response to operator commands, or in response to results of previous processing, or in response to a request made by another processing machine.

As used herein, the terms "software" and "firmware" are interchangeable, and include any computer program stored in memory for execution by a computer, including RAM memory, ROM memory, EPROM memory, EEPROM memory, and non-volatile RAM (NVRAM) memory. The above memory types are exemplary only, and are thus not limiting as to the types of memory usable for storage of a computer program.

It is to be understood that the above description is intended to be illustrative, and not restrictive. For example, the above-described embodiments (and/or aspects thereof) may be used in combination with each other. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the various embodiments of the invention without departing from their scope. While the dimensions and types of materials described herein are intended to define the parameters of the various embodiments of the invention, the embodiments are by no means limiting and are exemplary embodiments. Many other embodiments will be apparent to those of skill in the art upon reviewing the above description. The scope of the various embodiments of the invention should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled. In the appended claims, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein." Moreover, in the following claims, the terms "first," "second," and "third," etc. are used merely as labels, and are not intended to impose numerical requirements on their objects. Further, the limitations of the following claims are not written in means-plus-function format and are not intended to be interpreted based on 35 U.S.C. §112, sixth paragraph, unless and until such claim limitations expressly use the phrase "means for" followed by a statement of function void of further structure.

This written description uses examples to disclose the various embodiments of the invention, including the best mode, and also to enable any person skilled in the art to practice the various embodiments of the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the various embodiments of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if the examples have structural elements that do not differ from the literal language of the claims, or if the examples include equivalent structural elements with insubstantial differences from the literal languages of the claims.

What is claimed is:

1. A photonic data transmission system for medical imaging, comprising:

a plurality of optical modulators having different optical resonance wavelengths and configured to receive electrical signals representative of a set of data from a medical imaging device;

an optical waveguide interfacing with the plurality of optical modulators and configured to transmit an amplitude modulated beam of light at different frequencies to selectively modulate the plurality of optical modulators to transmit an encoded beam of light; and

receiver opto-electronics in communication with the optical waveguide configured to decode the encoded beam of light and convert the decoded beam of light into the electrical signals representative of the set of data.

2. The photonic data transmission system of claim **1**, further comprising a light beam source configured to amplitude modulate the beam of light to selectively modulate the plurality of optical modulators using predetermined mixing frequencies and wavelengths of light.

3. The photonic data transmission system of claim **1**, wherein the receiver opto-electronics comprises a single photo-detector interfacing with the optical waveguide.

4. The photonic data transmission system of claim **1**, wherein the medical imaging device is a Magnetic Resonance Imaging (MRI) scanner, and wherein the plurality of optical modulators are connected to a plurality of Radio-Frequency (RF) coils of the MRI scanner.

5. The photonic data transmission system of claim **4**, wherein each of the plurality of RF coils is assigned a unique optical wavelength and RF modulation frequency to address the coil element using the amplitude modulated beam of light.

6. The photonic data transmission system of claim **5**, wherein the plurality of optical modulators are configured to modulate the RF frequency with Magnetic Resonance (MR) signals to produce an optical signal at an intermediate frequency.

7. The photonic data transmission system of claim **1**, wherein the plurality of optical modulators comprise splitring modulators or Mach-Zehnder modulators.

8. The photonic data transmission system of claim **1**, further comprising a blocking signal optical modulator, the optical waveguide and another optical waveguide interfacing with the blocking signal optical modulator, wherein the other optical waveguide interfaces the blocking signal optical modulator with a transmit blocking network via a photodiode configured to selectively activate the transmit blocking network.

9. The photonic data transmission system of claim **8**, further comprising a light beam source configured to amplitude modulate a beam of light to selectively modulate the plurality of optical modulators using a predetermined mixing frequency and to generate a blocking signal light beam to modulate the blocking signal optical modulator, the blocking signal light beam modulated at a different frequency than the beam of light selectively modulating the plurality of optical modulators.

10. The photonic data transmission system of claim **9**, wherein the medical imaging device is a Magnetic Resonance Imaging (MRI) scanner, and the transmit blocking network is connected to a plurality of Radio-Frequency (RF) coils of the MRI scanner, and further comprising a bias source to generate an electrical bias signal to activate the transmit blocking network.

11. The photonic data transmission system of claim **1**, further comprising another optical waveguide interfacing with the plurality of optical modulators and a photo-diode configured to selectively activate a transmit blocking network based on a blocking signal light beam transmitted along the other optical waveguide.

12. The photonic data transmission system of claim **1**, further comprising an optical chip having the plurality of optical modulators thereon and the optical waveguide etched thereto.

13. A photonic data transmission system for a Magnetic Resonance Imaging (MRI) system, the photonic data transmission system comprising:

a light source operable to produce an amplitude modulated beam of light comprising one or more discrete optical wavelengths and one or more modulation frequencies, wherein the discrete optical wavelengths are amplitude modulated at different Radio-Frequency (RF) frequencies;

a plurality of optical modulators configured to receive electrical signals representative of a set of medical data from a plurality of receive coils of the MRI system, each optical modulator operable to modulate a subset of photons corresponding to an optical wavelength within an encoded beam of light to encode the photons with the set of medical data from a corresponding receiver coil to produce encoded photons, wherein each modulator is selectable using a different optical wavelength and RF mixing frequency for the amplitude modulated beam of light;

an optical waveguide interfacing the light source and the plurality of optical modulators with an opto-receiver configured to remove the encoded photons from the encoded beam of light; and

receiver opto-electronics configured to decode the encoded beam of light received by the opto-receiver and convert the decoded beam of light into the electrical signals representative of the set of medical data.

14. The photonic data transmission system of claim **13**, wherein the opto-receiver comprises a single photo-detector.

15. The photonic data transmission system of claim **13**, wherein the light source is operable to produce an off-resonance blocking signal beam of light having a resonance frequency different than the plurality of optical modulators, and further comprising a photo-diode, the optical waveguide interfacing with the photo-diode.

16. The photonic data transmission system of claim **15**, further comprising a transmit blocking network connected to the plurality of receive coils and receiving a blocking signal when the photo-diode is switched on by the blocking signal beam of light.

17. The photonic data transmission system of claim **13**, further comprising a blocking signal optical modulator, the optical waveguide and another optical waveguide interfacing with the blocking signal optical modulator, wherein the other optical waveguide interfaces the blocking signal optical modulator with a transmit blocking network via a photodiode configured to selectively activate the transmit blocking network.

18. An upgrade kit for a Magnetic Resonance Imaging (MRI) system, comprising:

an optical chip having a photonic data transmission system configured to interface with a plurality of Radio-Frequency (RF) coils of the MRI system and being operable to convert electrical data signals representative of Magnetic Resonance (MR) data generated at the RF coils into a multiplexed optical data signal representative of the MR data with a plurality of optical modulators selectably activated by an amplitude modulated beam of light using different RF mixing frequencies and optical wavelengths.

19. The upgrade kit of claim **18**, wherein the photonic data transmission system comprises a transmit blocking system for transmitting a blocking signal to the RF coils, the transmit blocking system optically activated with a photo-diode.

20. The upgrade kit of claim **18**, wherein the plurality of optical modulators comprise split-ring modulators.

21. The photonic data transmission system of claim **1**, wherein the optical waveguide is configured to transmit an amplitude modulated beam of light at different frequencies by combining frequency division multiplexing (FDM) and wavelength division multiplexing (WDM).

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