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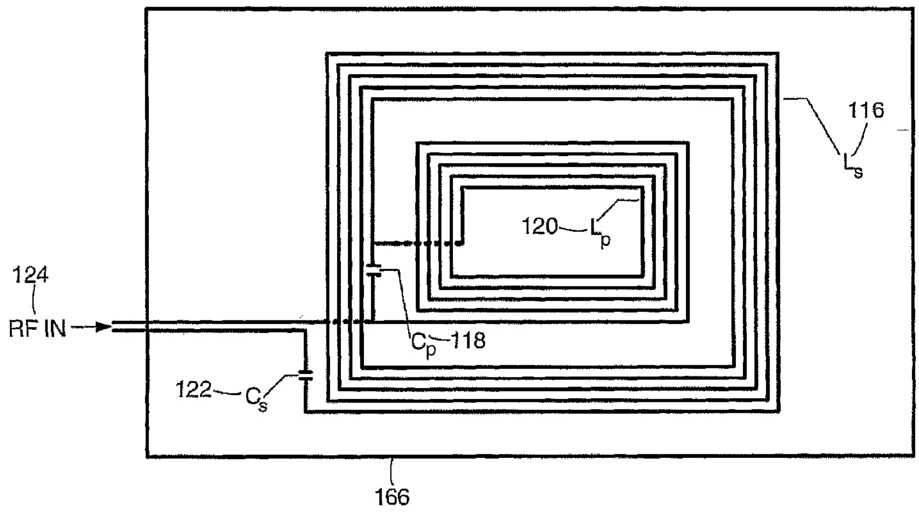
(54) Title: WIRELESS INTERFACE

FIG. 24



(57) Abstract: A wireless interface is provided for supplying all signals and power exclusively wirelessly from a transmitting section (200) to a receiving section (220). The transmitting section (200) comprises a transmitter (210) arranged to modulate a carrier with signals, such as data, control and timing signals. The transmitter (210) is connected to a transmit antenna (166) which comprises a parallel resonant circuit (118, 120) in series with a series resonant circuit (116, 122). The parallel and series resonant circuits include inductors (116, 120) which are inductively coupled to an inductor (111) of a receive antenna (211) in the receiving section (220).

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DESCRIPTION

WIRELESS INTERFACE

TECHNICAL FIELD

The present invention relates to a wireless interface. For example, such an interface may be used for supplying data and power wirelessly within a display system, for example including a flat panel display of liquid crystal or organic light emitting diode type. Another example of an application of such an interface is in a radio frequency identification system. The present invention also relates to a transmitting section and to a receiving section for such an interface.

BACKGROUND ART

Figure 1 of the accompanying drawings shows a generic liquid crystal display system which is an example of a flat panel display. Such a display is made up of an active area including an active matrix 14 which displays the image, a backlight system including a driver 12 to illuminate the display and a number of driver integrated circuits (ICs) 10 to control the addressing of pixels. The system is supplied with the display data 2, a number of control and timing signals 6 and power 4. These signals are typically supplied via a flexible printed cable (FPC). Attaching this cable adds a significant cost in the manufacture of the display. Display systems may also have integrated audio 250 and sensor 270 systems in addition to the active display area as illustrated in Figure 2 of the accompanying drawings. Each one of these systems requires wireline connections to provide the system data (audio data 252, sensor data 266 and display data 2) and the relevant timing and control data (audio timing and control 254, sensor timing and control 268, display timing and control 6). The display system may have a single external power source 256 which may then connect to a series of voltage regulators 271 to meet the different voltage requirements (4, 258, 262, and 277). The increase in the complexity of the display system inevitably leads to a corresponding increase in the number of external connections which results in a bigger FPC connector. However, products incorporating these display systems are becoming physically smaller in size and there is therefore pressure to find alternative methods of transmitting the signals to the display system.

A wireless interface is a very attractive proposition. Figure 3 of the accompanying drawings shows a generic wireless system comprising a data source 20 to generate the data, a transmitter system 22 which carries out the required formatting and signal processing, and a transmit antenna 24.

These items generally form the transmitter side. The transmit antenna launches the signal as an electromagnetic wave or optical signal (depending on the implementation) through the wireless channel 26. On the receiver side, the receive antenna 28 couples the signal to the receiver system 30 which processes the data and passes it on to the data sink 32.

Figure 4 of the accompanying drawings illustrates a generic transmitter system. The first block is a data source 160 to provide the actual content to be transmitted. Assuming the data is digital, it comprises a stream of ones and zeros where a high voltage level represents a one and a low voltage represents a zero. This coding scheme is called non-return to zero (NRZ).

This data may then be further processed and formatted 162 to match it optimally to the wireless channel. There are a number of coding schemes that can be employed at this stage. One of the most popular schemes is Manchester Encoding which is illustrated by the timing waveforms in Figure 5a of the accompanying drawings. Manchester code is a self-clocking code with a minimum of one and a maximum of two level transitions per bit. In the Manchester data 304, a ‘Zero’ is encoded as a High -to- Low transition and a ‘One’ is encoded as a Low -to- High transition. Between two identical bits of data there is an extra level transition. It is normally implemented using the exclusive OR gate (XOR) function 306 between the data clock signal 300 and the NRZ data signal 302 as illustrated in Figure 5b of the accompanying drawings. The XOR function of two variables is 1 if either of them but not both are 1.

After the data has been correctly formatted and encoded (Figure 4), the next stage in the process is called modulation. A modulator 165 uses a data signal 167 to alter one of the properties of the high frequency carrier signal 163 generated by an oscillator 161. Figures 6a to 6e of the accompanying drawings illustrate typical modulation signals. Figure 6a illustrates the high frequency carrier signal 163 and Figure 6b illustrates the data signal 167. The parameters that are normally altered are one of the following: frequency, resulting in frequency shift keying (FSK) 170 (Figure 6c); amplitude, resulting in amplitude shift keying (ASK) 174 (Figure 6e); phase, resulting in phase shift keying (PSK) 172 (Figure 6d). All other modulation schemes are derived from these three basic schemes. There are several methods available to implement these schemes. Figures 7a to 7c of the accompanying drawings summarise possible implementations of simple ASK, PSK and FSK. An amplitude modulated signal 174 is obtained by mixing a carrier signal 163 and a data signal 167 (Figure 7b). A frequency modulated signal is obtained by switching between two carrier signals (f1 163 and f2 171) depending on the data signal 167 (Figure 7a). In phase shift keying 172, the phase of the carrier signal 163 is varied between two values depending on the data signal 167 (Figure 7c).

The modulated signal occupies a certain amount of frequency spectrum. This is a function of the modulation type being employed. The frequency components present in the modulated signal can be identified by computing the Fourier transform of the signal. This plot of the power available in the frequency components is known as the power spectral density (PSD) of the signal. It then leads to the definition of the signal bandwidth (BW). Although there are many acceptable definitions of bandwidth, it is generally referred to as the amount of spectrum occupied by all spectral components which have a power level of at least half the maximum level. The bandwidth of the modulated signal is directly related to the speed of the data signal. A high data rate requires more bandwidth.

The next stage in the transmitter (Figure 4) involves amplifying the modulated signal to make it strong enough to be launched across the wireless channel. This is achieved using a power amplifier 164 which takes the low power modulated signal and produces a high power signal. Several methods for achieving this exist and examples are disclosed in Behzad Razavi, “Design of Analog CMOS Integrated

Circuits", McGraw-Hill 2001.

After the signal has been amplified, it is then launched into the wireless channel using an antenna 166. An antenna transforms the signal from a coupled electromagnetic wave into a radiated one and is designed to optimise power transfer in the frequency range of interest. The radiation will often be required to have a specified directionality i.e. maximise radiation of the signal in a specific direction.

Care must be taken in the design of the power amplifier 164 and the transmit antenna 166 to ensure that they have sufficient bandwidth to handle the modulated signal. If the bandwidth available in these systems is less than the signal bandwidth, then the signal will lose some information and can lead to erroneous decoding of the transmitted data.

The radiated signal travels across the wireless channel 26 (Figure 3) after which it couples to the receive antenna 28. The receive antenna is designed to capture as large a signal as possible from the transmitted signal. Like the transmit antenna, it is designed to be efficient over the specified frequency range and direction.

The signal from the receive antenna then passes to the receiver system 30 whose main function is to extract the original data signal from the received signal. The exact implementation of the receiver system depends on the modulation scheme that was employed at the transmitter.

Figure 8d of the accompanying drawings shows a wireless receiver system using an amplitude shift keying modulated signal as an example. A generic wireless receiver system comprises a receive antenna 28, a demodulator 311 which extracts the transmitted data signal and a pulse shaping system 314 to convert the analogue data signal into a digital signal. The output 315 of the receiver system is the same as the data signal 167 that was used to modulate the carrier in the transmitter system (Figure 4). In an amplitude modulated signal 174 (Figure 8a), the data signal is embedded in the envelope (outline) 313 of the modulated carrier. Therefore the main role of the receiver, in this case, is to extract the envelope of the modulated carrier. This is carried out by first of all rectifying the amplitude modulated carrier which results in the output 310 (Figure 8b) only having the positive going part of the original amplitude modulated signal. The rectified signal is then passed through a low pass filter 312 to remove the high frequency carrier signal. The last stage then involves pulse shaping 314 the low pass filtered signal into clean digital signal 315 (Figure 8c) with defined high and low voltage levels.

There are many ways of implementing the pulse shaper. An example is illustrated in Figure 9 of the accompanying drawings. A self-biased comparator circuit may be used to generate a digital output signal 402 from an analogue input signal 400. The high and low output voltage levels 404 and 406 are set during the design of the circuit. An arrangement of this type is disclosed in R. Jacob Baker, Harry W. Li, David E. Boyce, " CMOS, Circuit design, Layout and Simulation" IEEE Press, 1998.

The output signal 315 (Figure 8c) at this point represents the data signal that was used to modulate the carrier at the transmitter side.

All systems employing wireless communication to transfer data are based on the description provided above. The systems will generally differ in the frequency of operation, data rate and modulation schemes employed. Wireless systems also increasingly have extra features such as error correction and perhaps encryption to maintain the integrity of the transmitted signal.

In certain applications, it may be desirable to transmit power wirelessly as this can reduce the number of wireline connections required by a system. This is normally achieved by transmitting power in the magnetic field of one coil and coupling it into a second coil. A generic scheme for transmitting power is illustrated in Figure 10 of the accompanying drawings. Power transmission is achieved by coupling the magnetic field 34 of coil A 36 to that of coil B 38. Coil A is supplied with a power signal 35 in the form of an alternating current. The output signal 37 in coil B will also have an alternating current. The next step is to rectify this signal as illustrated in Figure 11 of the accompanying drawings. A full wave rectifier 354 can be used to obtain an output signal 352 of single polarity (0 to $+V_P$) from a dual polarity ($-V_P$ to $+V_P$) input power signal 350. At this point the signal is not a proper direct current power signal as it contains ripples. These can be removed by using some form of smoothing circuitry. This could be a large capacitor connected across the output signal. Once the relatively ripple free power signal has been obtained, it can then be regulated and stepped down to the required voltage levels.

To improve the efficiency of the power transfer using magnetic coupling, resonance circuits can used. The efficient transfer of power wirelessly can be achieved using series resonance at the transmitter and parallel resonance at the receiver. The series resonance at the transmitter maximises the current in the circuit, which in turn maximises the coupling magnetic field. The parallel resonance at the receiver maximises the voltage. Two types of such circuits are shown in Figures 12a and 12b of the accompanying drawings. The resonance of a series circuit (Figure 12a) with resistor 40 of resistance R, inductor 42 of inductance L, and capacitor 44 of capacitance C, occurs when the inductive and capacitive reactances are equal in magnitude but cancel each other because they are 180 degrees apart in phase. Series resonance results in maximum current flowing through the circuit whose value depends on the resistance R. The sharpness of the resonance depends on the value of R and characterizes the "Q" of the circuit. The quality factor, "Q", is a property of the inductor and is given by:

$$Q = \frac{\omega L}{r_s}$$

where ω is the angular frequency ($2\pi f$) and r_s is the equivalent series resistance of the metal windings of the inductor. The quality factor is a measure of the inductor's ability to store energy in its magnetic field such that a high Q results in a large current or voltage at resonance and efficient power transfer. Figure 13 of the accompanying drawings shows examples of a response with high Q 390 and low Q 392.

Parallel resonance in a circuit with capacitor 46 of capacitance C, inductor 48 of inductance L, and resistor 50 of resistance R occurs at the frequency when the reactance due to the inductor is equal and opposite to the reactance due to the capacitor. Parallel resonance results in a maximum voltage across the resistor. The value R of the resistor 50 dictates the value of this voltage. Power transfer at resonance is more efficient as the voltages or currents at resonance are maximized as illustrated in Figure 14 of the accompanying drawings, which plots the variation of the coupling magnetic field 65 with frequency 64. At the resonance frequency 60, the coupling magnetic field 65 is maximum and therefore the power transfer will be maximum at this frequency.

Wireless transmission of data alone is well known. The same can be said of wireless power transfer alone. However, the difficulty arises when an application requires both power and data to be transmitted wirelessly across the same wireless channel. Transferring data requires the data signal to somehow “piggyback” or be carried on the power signal. An example of such a technique is using the carrier signal to transfer the power and then using Amplitude Shift Keying modulation to couple the data to this carrier as illustrated in Figure 15 of the accompanying drawings. The amplitude of the power carrying signal 74 is modified by the data carrying signal 76. This results in a composite transmitted signal 78 which carries both the power and data. The receiver for this scenario is different from the generic receiver illustrated in Figure 8 as it now has to extract both the power and data from the transmitted signal. Figure 16 of the accompanying drawings shows an example of such a receiver system. The transmitted signal is coupled to the receiver system 222 via a receive antenna 130. This is then followed by two rectifiers (power rectifier 134 and data rectifier 140) to extract the power and data signals. The output of the power rectifier is an unregulated voltage which is regulated by voltage regulators 136 to provide the required voltage level, V_R 138. In the data signal extraction path, the output 141 of the data rectifier 140 is connected to a demodulator 144 which produces an analogue version of the data signal. This is then passed through a pulse shaping stage 145 to produce a digital signal 146 which is the same as the transmitted data signal.

Mathematically, ASK is a multiplication process of the carrier signal with the data signal in the time domain. Sometimes it may be necessary for the depth of the envelope (also called modulation depth) to be variable. In this case, a dc component is added to the data signal before the multiplication process is carried out. If the power carrying signal 74 is represented by equation,

$$x_c = \cos(2\pi f_c t),$$

the data carrying signal 76 by equation

$$x_{data} = \cos(2\pi f_{data} t),$$

then the resulting transmitted signal 78 is represented, mathematically, by

$$x_{trans} = (A + x_{data})x_c = A\cos(2\pi f_c t) \quad + \cos[2\pi t(f_c - f_{data})]$$

$$+ \cos[2\pi t(f_c + f_{data})]$$

where the depth of modulation is represented by a dc component A, f_c is the frequency of the power carrying signal and f_{data} is the frequency of the data carrying signal.

This implies that, in addition to the carrier (power carrying) signal component f_c, the transmitted signal will have frequency components at $(f_c - f_{data})$ and $(f_c + f_{data})$. Figure 17 of the accompanying drawings shows the components of the transmitted signal in the frequency domain. The frequency components (fc - fdata 68) and (fc + fdata 62) are termed the sidebands of the transmitted signal. If the data carrying signal 76 has bandwidth, BW, the total bandwidth required to transmit both the sidebands is 2×BW 72.

For successful recovery of the power and data at the receiver side, the carrier and the two sidebands should be linearly transmitted across the wireless channel. In other words, the received signal should be directly proportional to the transmitted signal. The system transfer function (shape of the transmitter resonance curve) should, therefore, be such that it passes the signal without any distortion. Figure 18 of the accompanying drawings shows the power carrying signal 60, the two sidebands 68, 62 and the system transfer function curve 67. For successful recovery at the receiver, the two sidebands should lie within the envelope of the transfer function curve 67. If the sidebands lie outside the resonance curve 67, such as at 61 and 63, data recovery will be impossible. The implication is that it is more difficult to recover both power and data if the data signal has high bandwidth. The equation relating this bandwidth limitation to the quality factor (Q) of the resonance curve is given by:

$$Q = fc/(2 \times BW)$$

Increasing Q improves the power transferring capability of the system but reduces the overall bandwidth of the data that can be transmitted. This makes the transmission of both power and high bandwidth data a very challenging problem.

A method of meeting this challenge was suggested in “A wideband Frequency-Shift Keying Wireless Link for Inductively Powered Biomedical Implants”, M. Ghovanloo and K. Najafi, IEEE Trans. On Circuits and Systems, vol.51, No. 12, Dec. 2004. The approach taken by these authors is to shape the transfer function curve so that it passes the required frequency components in the transmitted signal without reducing the Q of the system. The authors use both series and parallel resonance circuits (Figure 19 of the accompanying drawings) to produce two peaks in the transfer function to allow the power and the data carrying signal to be transmitted (Figure 20 of the accompanying drawings). The system uses a form of Frequency Shift Keying (FSK) by transmitting data bit ‘0’ at one frequency and data bit ‘1’ at another frequency. A major drawback of this method is that the frequency at which the data bits ‘1’ and ‘0’ are transmitted should be highly stable. This is because the high Q of each peak in the transfer function of Figure 20 results in a locally narrow band system and any deviation of the signal components from these frequencies will completely corrupt the transmitted signal. In Figure 20, fdata 69 and fc 60 should therefore lie exactly at the centre of the respective peaks of the transfer function. This is very difficult if the Q is made very high to allow sufficient power transfer.

Another drawback of the system is that only one element of the antenna transmits the signal. In Figure 19, this corresponds to Lp 120. The other inductor Ls, 116 does not transmit at all and just functions as a transfer function shaper. As the amount of power transfer the system can handle is related to the total inductance of the system, this will mean that the amount of power is limited to the amount that the single inductor Lp 120 can transmit. The actual implementation of this system is shown in Figure 21 of the accompanying drawings where Ls 116 only has the function of shaping the signal and Lp 120 is the only transmitting element. This arrangement would suffice for low power systems. However, for high power system requirements such as powering the backlight of an LC display, a single transmitting element would not supply sufficient power.

Another known arrangement is disclosed in US 7,071,629 B2 (Figure 22 of the accompanying drawings). This system claims to be able to transmit both data 85 and power 84 wirelessly to a display system 81. This is implemented using a wireless transmitter element 90 and a receiver element 83 which incorporates a data and power extractor. However, the system is only able to transmit sufficient power to supply the driver ICs 87 and 89. The system still requires power to be supplied externally for the high voltage requirements of the display system in the form of HV 82 and GND 80 and cannot therefore be described as being totally wireless.

DISCLOSURE OF INVENTION

According to a first aspect of the invention, there is provided a wireless interface comprising a receiving section and a transmitting section arranged to supply signals and power exclusively wirelessly to the receiving section, the transmitting section comprising a transmitter arranged to modulate a carrier with the signals and connected to a transmit antenna comprising a parallel resonant circuit including a first inductor and a series resonant circuit including a second inductor, the receiving section comprising a receive antenna comprising at least one third inductor arranged to be inductively coupled to the first and second inductors.

It is thus possible to provide an arrangement which permits completely wireless interfacing of all signals and power between transmitting and receiving sections. For example, in the case of a display, it is possible to supply sufficient power for all power requirements of a display together with all signaling, such as data, timing and control signals. It is possible to supply sufficient power with sufficient bandwidth to accommodate high speed data transfer without requiring any wireline connection. All of the signal and power transmission can be supplied across a single wireless interface so that the receiving section, for example, including a display device, backlight and the like, may be self-contained and independent.

The interface may comprise a display. The receiving section may include an image display device. The device may be a liquid crystal device. The receiving section may include a display backlight.

The interface may comprise a radio frequency identification system.

The first and second inductors may be arranged to be substantially permanently inductively coupled to the at least one third inductor.

The first and second inductors may be arranged to be temporarily inductively coupled to the at least one third inductor.

The carrier may be a radio frequency carrier.

The parallel resonant circuit and the series resonant circuit may be connected in series.

The first and second inductors may be planar inductors. The first and second inductors may be coplanar. One of the first and second inductors may be disposed inside the other of the first and second inductors and coaxial therewith. The at least one third inductor may be arranged to be coaxial with the first and second inductors.

The at least one third inductor may be a planar inductor.

The parallel and series resonant circuits may be tuned to different frequencies. The parallel and series resonant circuits may be tuned substantially to respective sideband frequencies of the modulated carrier.

The parallel and series resonant circuits may have resonant frequencies and Q's such that the carrier and the sidebands of the modulated carrier are within the half power bandwidth of the transmit antenna.

The receive antenna may comprise a further resonant circuit including the at least one third inductor. The further resonant circuit may be a parallel resonant circuit. The further resonant circuit may be tuned to a frequency between the sidebands of the modulated carrier. The further resonant circuit may be tuned to the geometric mean of the sideband frequencies. The further resonant circuit may have a resonant frequency and a Q such that the carrier and the sidebands of the modulated carrier are within the half power bandwidth of the receive antenna.

The transmit and receive antennae may be arranged such that the carrier and sidebands of the modulated carrier are within the half power bandwidth of the inductive coupling.

The transmitter may be arranged to perform one of amplitude modulation, frequency modulation and phase modulation.

The receiving section may comprise a demodulator for demodulating signals received by the receive antenna.

The receiving section may comprise a power supply arrangement arranged to power the whole of the receiving section exclusively from power received by the receive antenna.

According to a second aspect of the invention, there is provided a transmitting section for a wireless interface for supplying signals and power exclusively wirelessly to a receiving section of the interface, comprising a transmitter arranged to modulate a carrier with the signals and connected to a transmit antenna comprising a parallel resonant circuit including a first inductor and a series resonant circuit including a second inductor.

According to a third aspect of the invention, there is provided a receiving section for a wireless interface for receiving signals and power exclusively wirelessly from a transmitting section of the interface, comprising a receive antenna comprising at least one third inductor arranged to be inductively coupled to first and second inductors of a transmit antenna of the transmitting section.

BRIEF DESCRIPTION OF DRAWINGS

Preferred embodiments of the present invention will now be described by way of illustrative examples with reference to the accompanying figures, in which:

Figure 1 is a block schematic diagram of a generic known type of liquid crystal display;

Figure 2 is a block schematic diagram of a known type of integrated display system;

Figure 3 is a block schematic diagram of a generic known type of wireless system;

Figure 4 is a block schematic diagram of a known type of wireless transmitter of a system of the type shown in Figure 3;

Figure 5a is a timing diagram illustrating Manchester encoding and Figure 5b is a diagram illustrating the use of an XOR gate to provide such encoding;

Figures 6a to 6e comprise waveform diagrams illustrating examples of modulation schemes for use in wireless systems;

Figures 7a to 7c are block schematic diagrams illustrating modulators for implementing the modulation schemes illustrated in Figures 6c to 6e;

Figure 8d is a block schematic diagram of a known type of receiver system and Figures 8a to 8c are diagrams illustrating waveforms occurring in the receiver system;

Figure 9 is a circuit diagram illustrating a known type of pulse shaping circuit;

Figure 10 illustrates a known type of power transfer arrangement using magnetic coupling;

Figure 11 is a circuit diagram illustrating a power rectifier for use with the arrangement shown in Figure 10;

Figures 12a and 12b illustrate examples of known series and parallel resonant circuits;

Figure 13 is a graph of magnetic coupling field against frequency for parallel resonant circuits having different Q’s;

Figure 14 is a graph of coupling magnetic field against frequency for a parallel resonant circuit of typical Q;

Figure 15 comprise waveform diagrams illustrating data and power transfer using amplitude shift keying modulation;

Figure 16 illustrates a known type of receiver for extracting power and data;

Figure 17 is a graph illustrating the frequency spectrum of a typical amplitude modulated signal;

Figure 18 is a graph of coupling magnetic field against frequency illustrating bandwidth requirements for transmitting both power and data;

Figure 19 is a circuit diagram illustrating a known type of circuit combining parallel and series resonant circuits;

Figure 20 is a graph of coupling magnetic field against frequency illustrating a transmitter resonant curve;

Figure 21 illustrates diagrammatically a known type of transmit antenna using the circuit of Figure 19;

Figure 22 is a block schematic diagram of a known type of partially wireless display system;

Figure 23 is a block schematic diagram illustrating a wireless interface for a display constituting an embodiment of the invention;

Figure 24 is a diagram illustrating a transmit antenna of the interface of Figure 23;

Figure 25 is a graph of coupling magnetic field against frequency illustrating the performance of the antenna of Figure 24;

Figure 26 is a diagram illustrating a receive antenna of the interface of Figure 23; and

Figure 27 is a graph of coupling magnetic field against frequency illustrating the coupling performance of the interface of Figure 23.

BEST MODE FOR CARRYING OUT THE INVENTION

Figure 23 shows a complete wireless system comprising a driver system 200 constituting a transmitting section and a wireless display system 220 constituting a receiving section. The driver system 200 comprises a data source 202 to supply the display system data 212 and the control and timing signals 208. These signals are then connected to the transmitter system 210 which is then connected to a transmit antenna 166. The driver system 200 is supplied with power 204 externally to power all the circuitry. After the signal is launched from the transmit antenna 210, it traverses the wireless channel 26 to couple to the wireless display system 220. The wireless display system comprises the receive system 224 which is connected to the display system 257. A receive antenna 211 which captures the transmitted signal is connected to a receiver 255. The receiver extracts the display system data 212, control and timing signals 208 and power 256 from the transmitted signal. These signals are then connected to the display system 257. The wireless display system is a self – contained system and does not require any external connections. All the data signals 212, control and timing signals 208 and the power are supplied via the wireless interface completely eliminating the need for a physical connector to the display system for the transmitted signal.

In Figure 23, the display system data source 202, transmitter system 210, receiver 255 and display system 257 may, for example, be implemented as described hereinbefore and illustrated in Figures 2, 4, 16.

Figure 24 shows an implementation of the transmit antenna 166 which takes the signal to be transmitted (RF IN 124) and launches it across the wireless interface. The antenna 166 comprises a parallel resonant circuit including a first inductor in the form of a parallel coil 120 and a series resonant circuit including a second inductor in the form of a series coil 116. The parallel capacitor 118 is used to tune the parallel resonance circuit while capacitor 122 is used to tune the series resonance circuit. By using the two transmitting coils, the amount of power transmitted from the antenna is increased significantly.

The tuning of the transmit antenna 166 in Figure 24 is dependent on the modulation scheme used as well as the signal data rate. Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), Phase Shift Keying (PSK) or, indeed, any higher order modulation scheme may be used. In this particular implementation ASK is used as an example. A suitable data rate for a mobile display may be 6.75 Mb/s. This corresponds to a wave of maximum frequency 3.375 MHz, assuming that non-return to zero (NRZ) data encoding is used. For ASK, the carrier frequency must be suitably higher than the data rate to reduce the complexity of the demodulation. A suitable value of the carrier frequency would be 8x or more the value of the data rate. In this case, 27 MHz is a reasonable choice for the carrier frequency.

Figure 25 shows the variation of the coupling magnetic field 65 of the transmit antenna with frequency 64. The response has two peaks at the lower sideband (Fc – Fdata 68) and at the upper sideband (Fc – Fdata 62), where Fc is the frequency of the power carrying signal and Fdata is the frequency of the data carrying signal. For Fc = 27 MHz and Fdata = 3.375 MHz, the lower and upper sidebands are at:

1. Fc – Fdata = 23.625 MHz
2. Fc + Fdata = 30.375 MHz

The antenna resonance peaks are tuned to these values. In this implementation, the series resonance is tuned to 23.625 MHz while the parallel resonance is tuned to 30.375 MHz. The Qs of two resonances are chosen to be sufficiently high so that the overlap at 27 MHz 400 (in Figure 25) has sufficient power to transmit the carrier. A suitable value for the Q for both resonances is 3 or higher.

Figure 26 shows an implementation of the receive antenna 211 which is based on a parallel resonance circuit. The antenna 211 comprises a third inductor in the form of an inductive coil 111 and the tuning capacitor 46 and is designed to resonate at a frequency which is a geometric mean of the two sideband frequencies, i.e., $((Fc+Fdata)(Fc-Fdata))^{1/2}$, which is approximately 27 MHz. A suitable Q for the receiver antenna is 3 or higher. The output signal (RF OUT 112) connects the signal to the rest of the receiver system. In use, the third inductor 111 is temporarily or permanently inductively coupled to the first and second inductors 120, 116.

Figure 27 shows the combined response of the transmit antenna 166 and receive antenna 211. It plots the variation of the coupling magnetic field 65 with frequency 64. The response is broadband with a high Q covering the range between the lower sideband (Fc - Fdata 68) and the upper sideband (Fc + Fdata 62) of the data carrying signal. Furthermore, the half-power level 66 is such that the lower sideband 68 and upper sideband 62 lie inside the response curve. This leads to the antenna response having a very high ‘Q’ to aid the transmission of power but also a very broadband response to ensure the transmission of high speed data substantially without any distortion.

While specific embodiments and applications of the present invention have been illustrated and described, it is to be understood that the invention is not limited to the precise configuration and components disclosed herein. Various modifications, changes, and variations which will be apparent to those skilled in the art may be made in the arrangement, operation, and details of the methods and systems of the present invention disclosed herein without departing from the spirit and scope of the invention.

CLAIMS

1. A wireless interface comprising a receiving section and a transmitting section arranged to supply signals and power exclusively wirelessly to the receiving section, the transmitting section comprising a transmitter arranged to modulate a carrier with the signals and connected to a transmit antenna comprising a parallel resonant circuit including a first inductor and a series resonant circuit including a second inductor, the receiving section comprising a receive antenna comprising at least one third inductor arranged to be inductively coupled to the first and second inductors.

2. An interface as claimed in claim 1, comprising a display.

3. An interface as claimed in claim 2, in which the receiving section includes an image display device.

4. An interface as claimed in claim 3, in which the device is a liquid crystal device.

5. An interface as claimed in claim 3 or 4, in which the receiving section includes a display backlight.

6. An interface as claimed in claim 1, comprising a radio frequency identification system.

7. An interface as claimed in claim 1, in which the first and second inductors are arranged to be substantially permanently inductively coupled to the at least one third inductor.

8. An interface as claimed in claim 1, in which the first and second inductors are arranged to be temporarily inductively coupled to the at least one third inductor.

9. An interface as claimed in claim 1, in which the carrier is a radio frequency carrier.

10. An interface as claimed in claim 1, in which the parallel resonant circuit and the series resonant circuit are connected in series.

11. An interface as claimed in claim 1, in which the first and second inductors are planar inductors.

12. An interface as claimed in claim 11, in which the first and second inductors are coplanar.

13. An interface as claimed in claim 12, in which one of the first and second inductors is disposed inside the other of the first and second inductors and coaxial therewith.

14. An interface as claimed in claim 13, in which the at least one third inductor is arranged to be coaxial with the first and second inductors.

15. An interface as claimed in claim 1, in which the at least one third inductor is a planar inductor.

16. An interface as claimed in claim 1, in which the parallel and series resonant circuits are tuned to different frequencies.

17. An interface as claimed in claim 16, in which the parallel and series resonant circuits are tuned substantially to respective sideband frequencies of the modulated carrier.

18. An interface as claimed in claim 1, in which the parallel and series resonant circuits have resonant frequencies and Q's such that the carrier and the sidebands of the modulated carrier are within the half power bandwidth of the transmit antenna.

19. An interface as claimed in claim 1, in which the receive antenna comprises a further resonant circuit including the at least one third inductor.

20. An interface as claimed in claim 19, in which the further resonant circuit is a parallel resonant circuit.

21. An interface as claimed in claim 19 or 20, in which the further resonant circuit is tuned to a frequency between the sidebands of the modulated carrier.

22. An interface as claimed in claim 21, in which the further resonant circuit is tuned to the geometric mean of the sideband frequencies.

23. An interface as claimed in claim 19, in which the further resonant circuit has a resonant frequency and a Q such that the carrier and the sidebands of the modulated carrier are within the half power bandwidth of the receiver antenna.

24. An interface as claimed in claim 1, in which the transmit and receive antennae are arranged such that the carrier and sidebands of the modulated carrier are within the half power bandwidth of the inductive coupling.

25. An interface as claimed in claim 1, in which the transmitter is arranged to perform one of amplitude modulation, frequency modulation and phase modulation.

26. An interface as claimed in claim 1, in which the receiving section comprises a demodulator for demodulating signals received by the receive antenna.

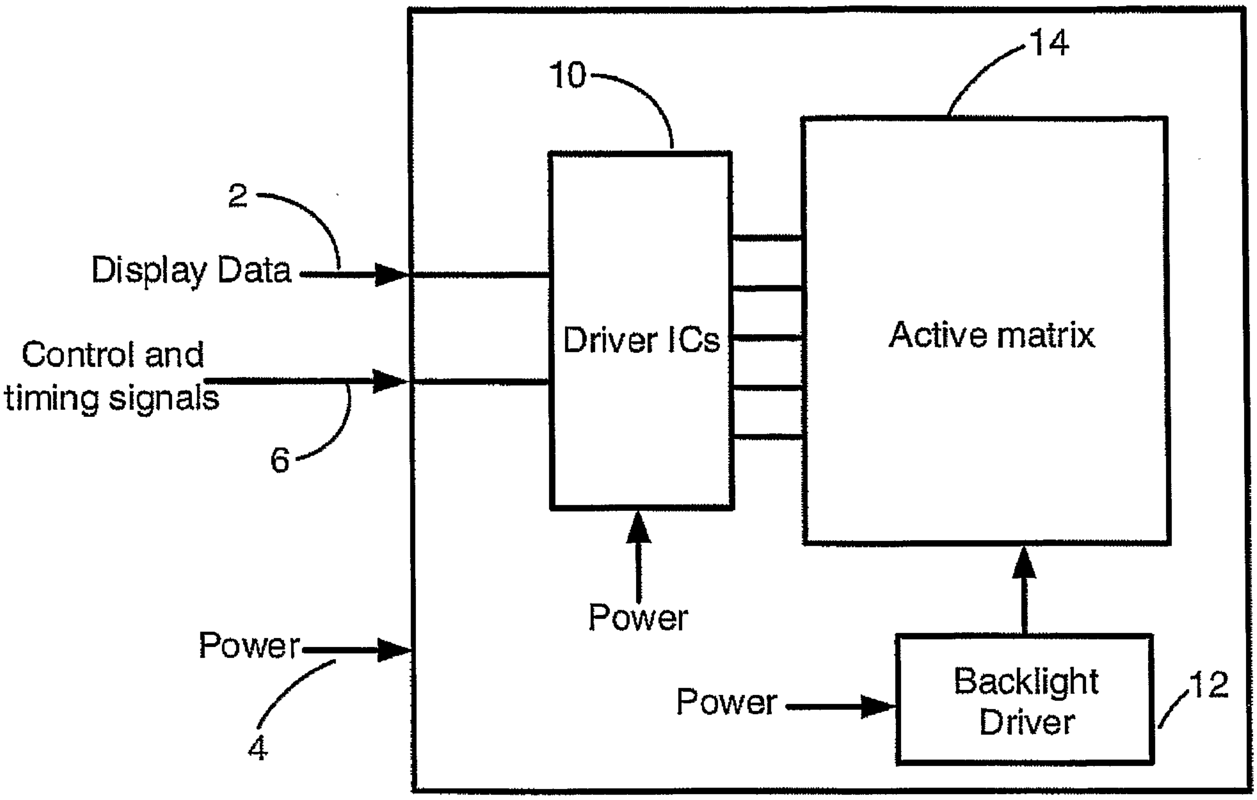
27. An interface as claimed in claim 1, in which the receiving section comprises a power supply arrangement arranged to power the whole of the receiving section exclusively from power received by the receive antenna.

28. A transmitting section for a wireless interface for supplying signals and power exclusively wirelessly to a receiving section of the interface, comprising a transmitter arranged to modulate a carrier with the signals and connected to a transmit antenna comprising a parallel resonant circuit including a first inductor and a series resonant circuit including a second inductor.

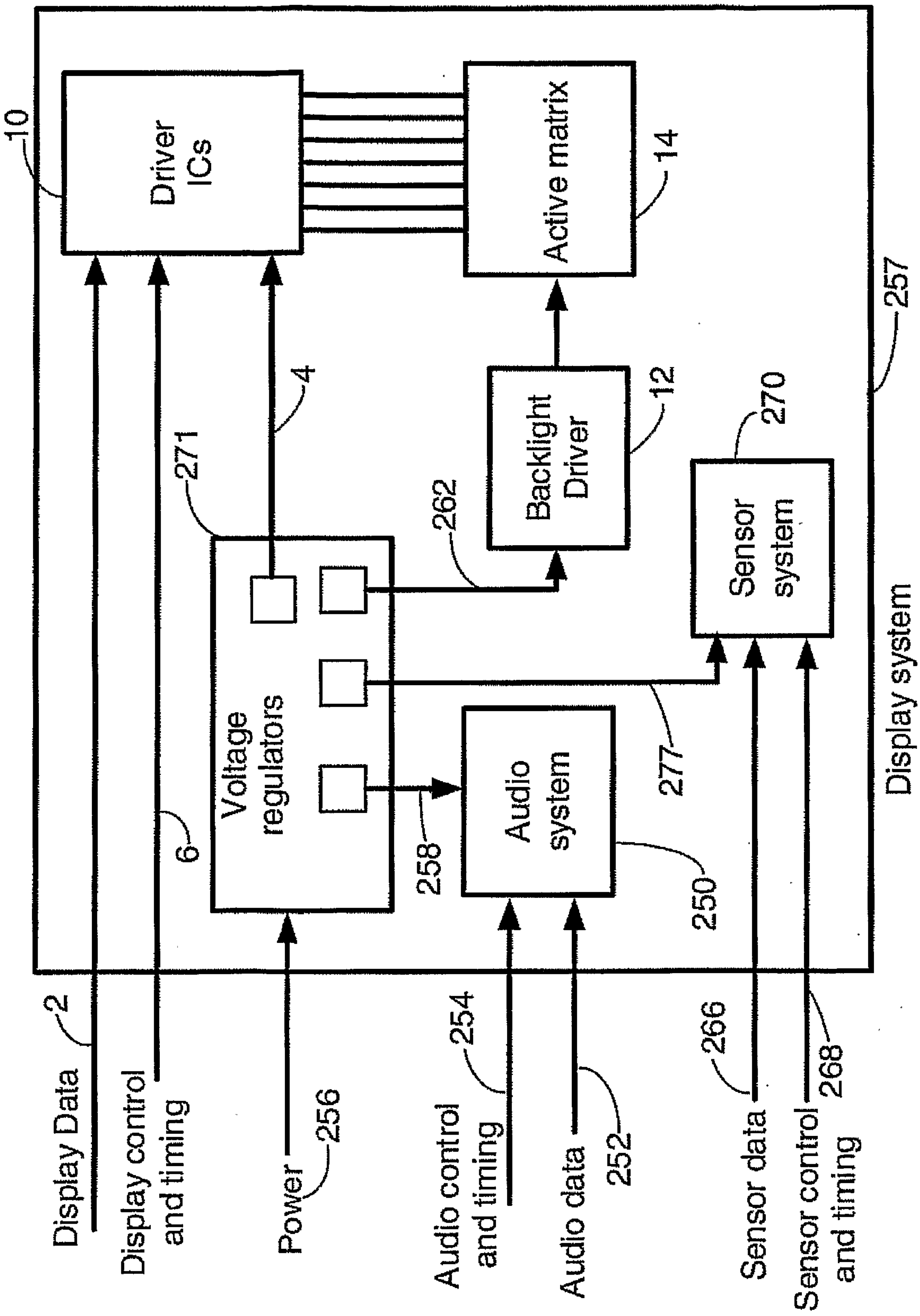
29. A receiving section for a wireless interface for receiving signals and power exclusively wirelessly from a transmitting section of the interface, comprising a receive

antenna comprising at least one third inductor arranged to be inductively coupled to first and second inductors of a transmit antenna of the transmitting section.

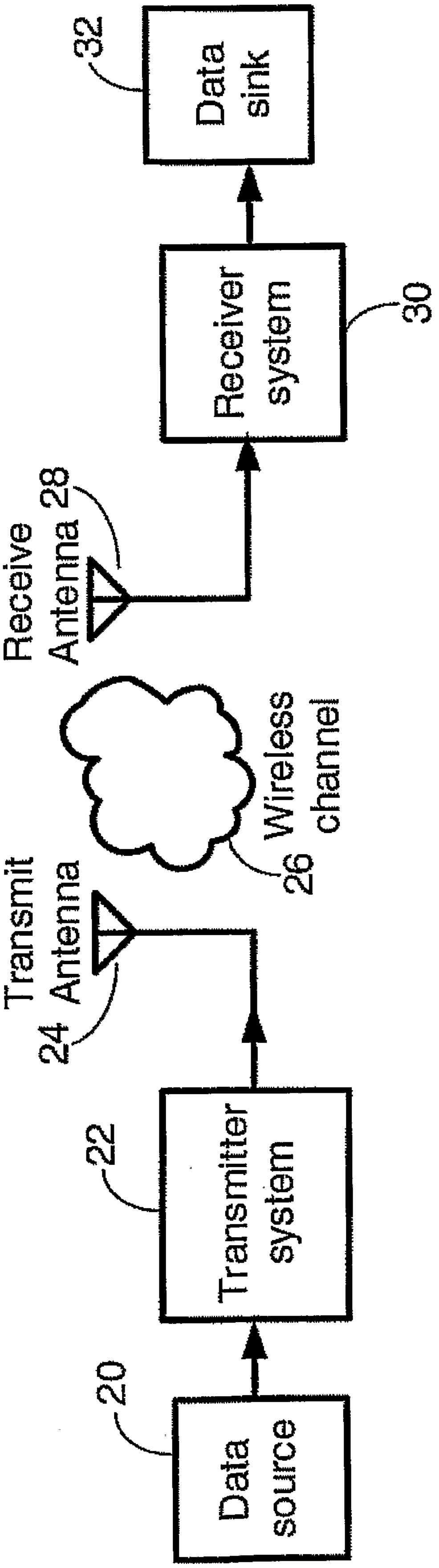
F I G. 1


14
10
2
Display Data
Control and timing signals
6
Driver ICs
Active matrix
Power
Power
4
Power
Backlight Driver
12

F I G. 2

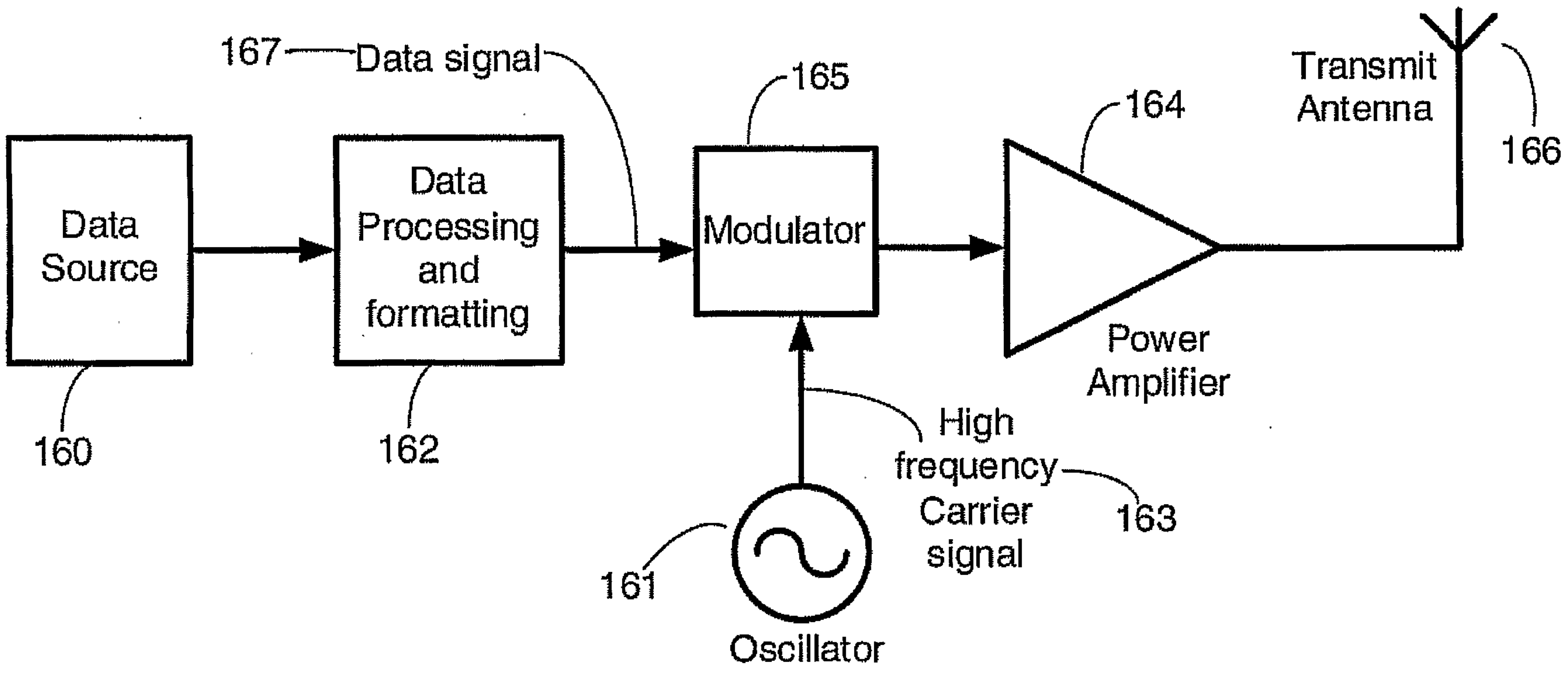

Display Data
2
Display control and timing
Power
256
Audio control and timing
254
Audio data
252
Sensor data
266
Sensor control and timing
268
Driver ICs
10
Active matrix
14
4
271
Voltage regulators
6
262
Backlight Driver
12
258
Audio system
250
277
Sensor system
270
Display system
257

F I G. 3

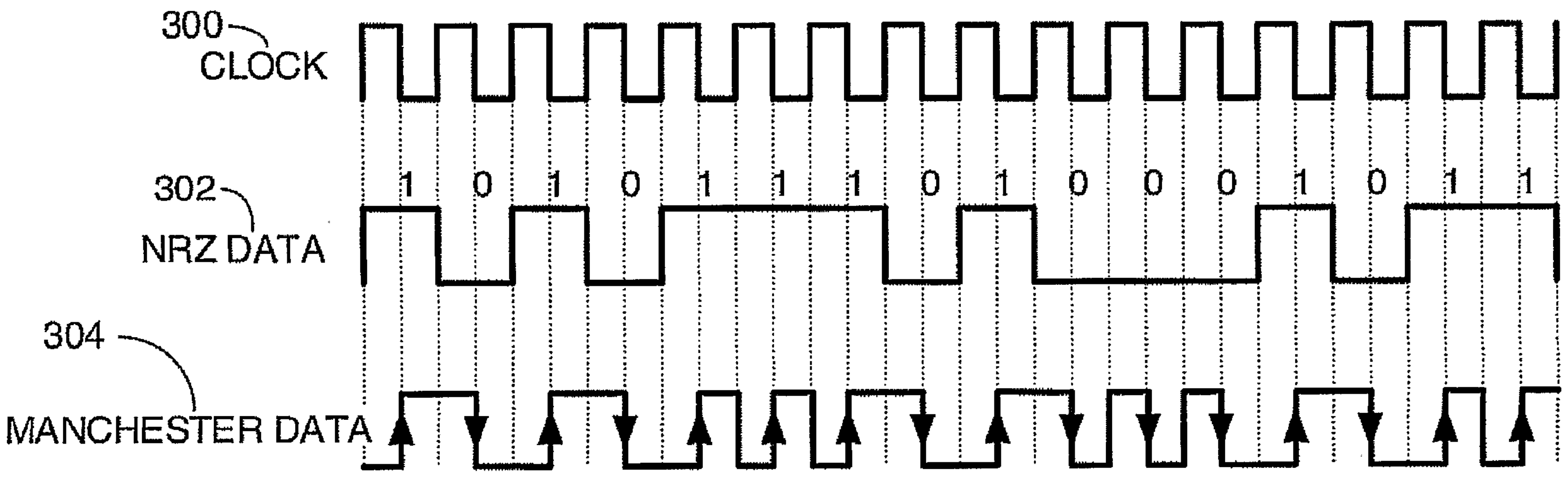


Data source
20
Transmitter system
22
Transmit Antenna
24
Wireless channel
26
Receive Antenna
28
Receiver system
30
Data sink
32

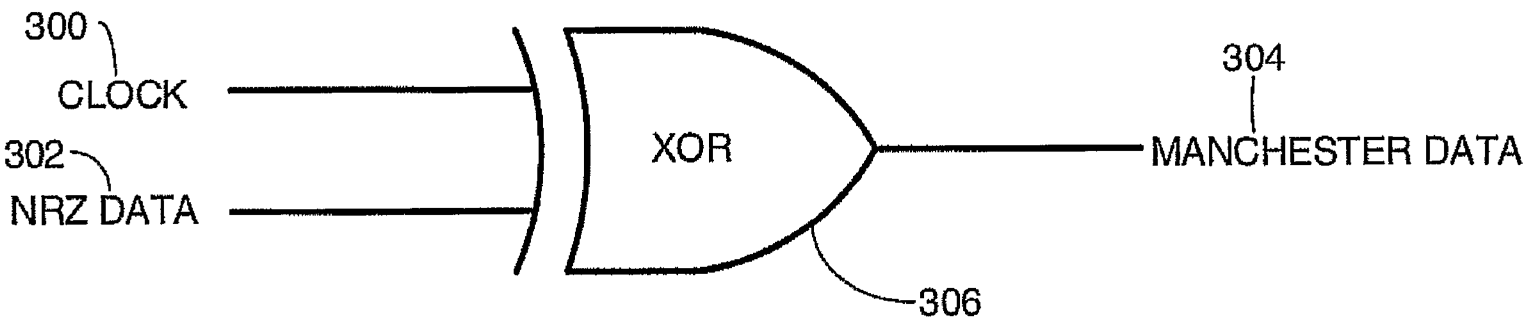
F I G. 4


167
Data signal
165
164
Transmit
Antenna
166
Data
Source
Data
Processing
and
formatting
Modulator
Power
Amplifier
160
162
High
frequency
Carrier
signal
163
161
Oscillator

F I G. 5 a


300
CLOCK
302
NRZ DATA
304
MANCHESTER DATA
1 0 1 0 1 1 1 0 1 0 0 0 1 0 1 1

F I G. 5 b


300
CLOCK
302
NRZ DATA
XOR
306
304
MANCHESTER DATA

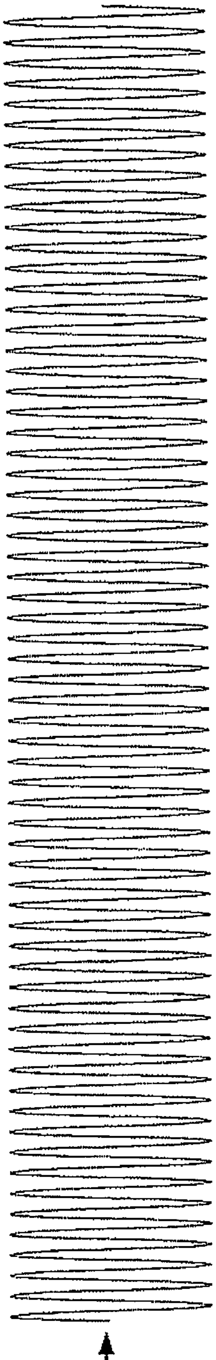


FIG. 6a

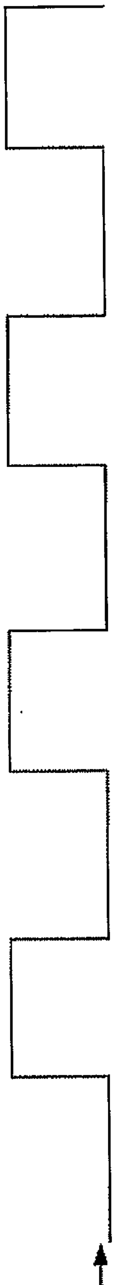


FIG. 6b

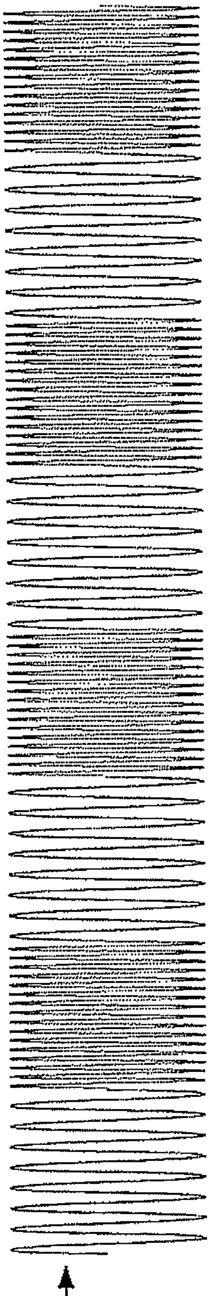


FIG. 6c

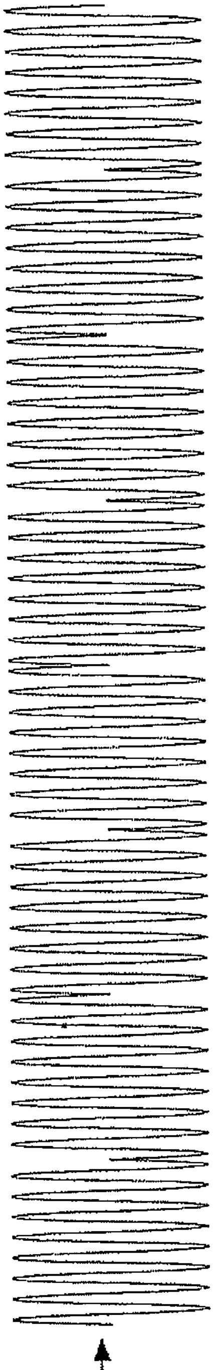


FIG. 6d

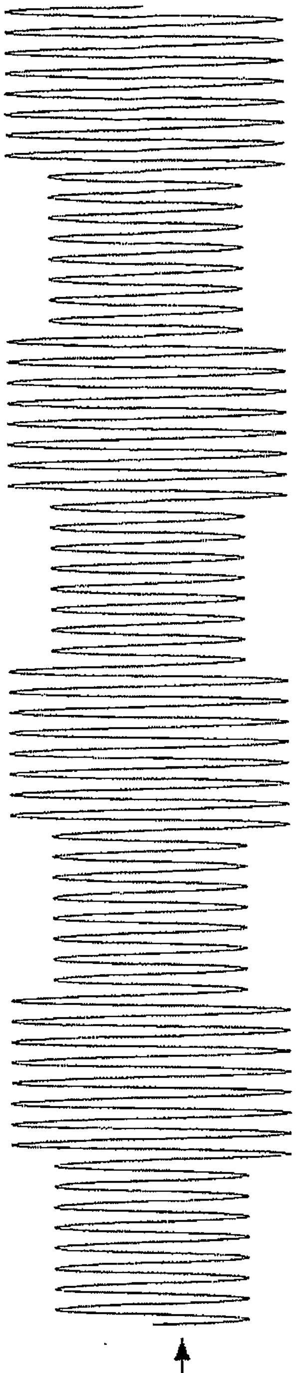
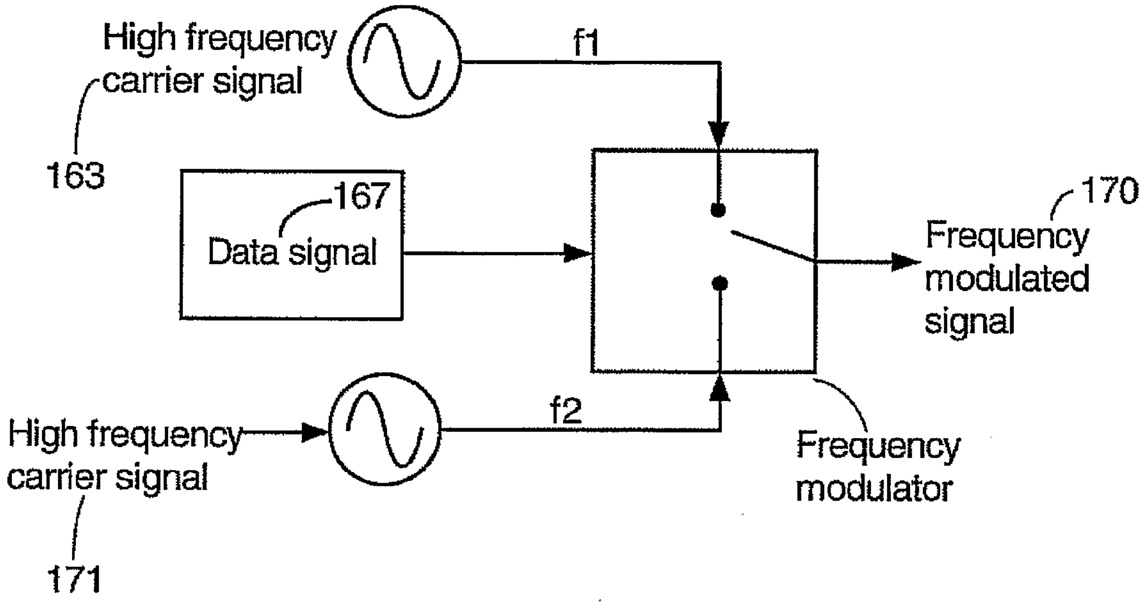
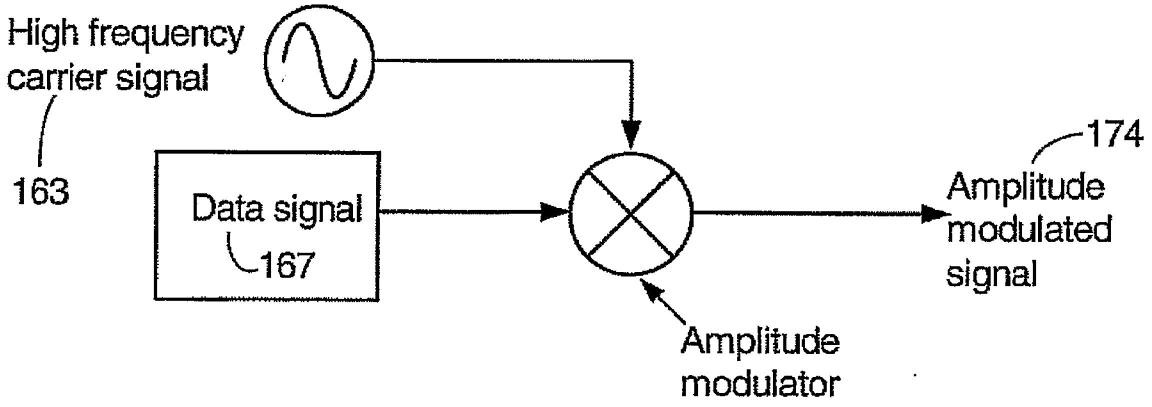


FIG. 6e

F I G. 7 a



F I G. 7 b



F I G. 7 c

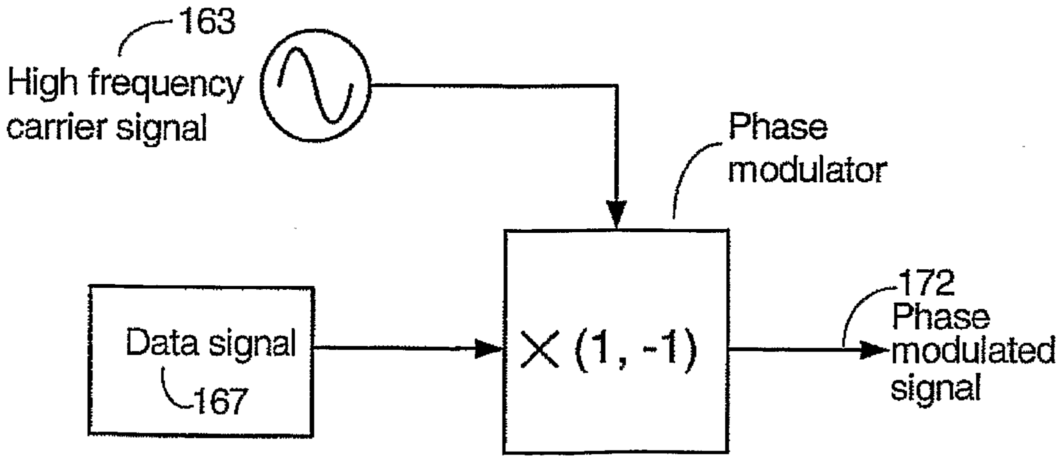


FIG. 8a

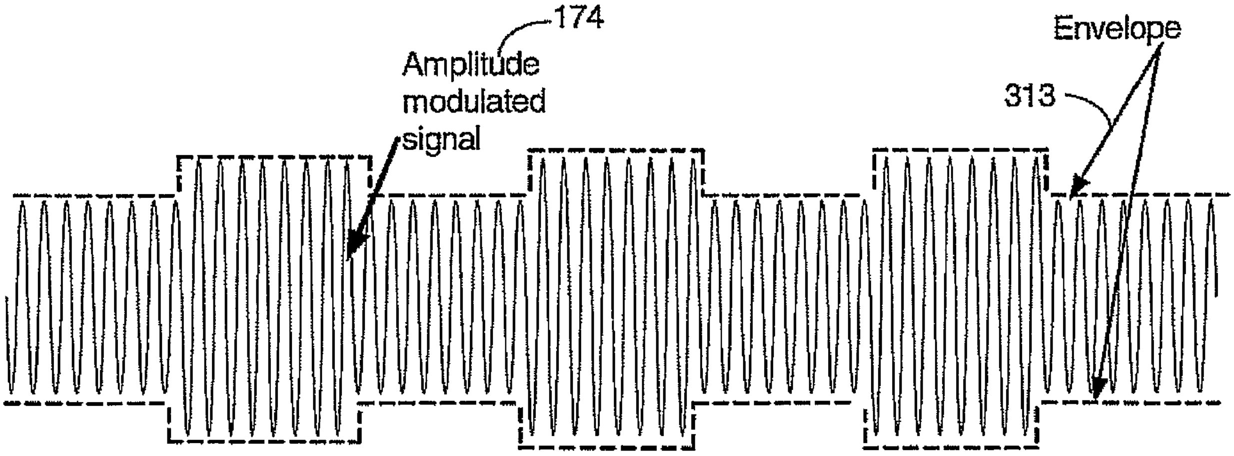


FIG. 8b

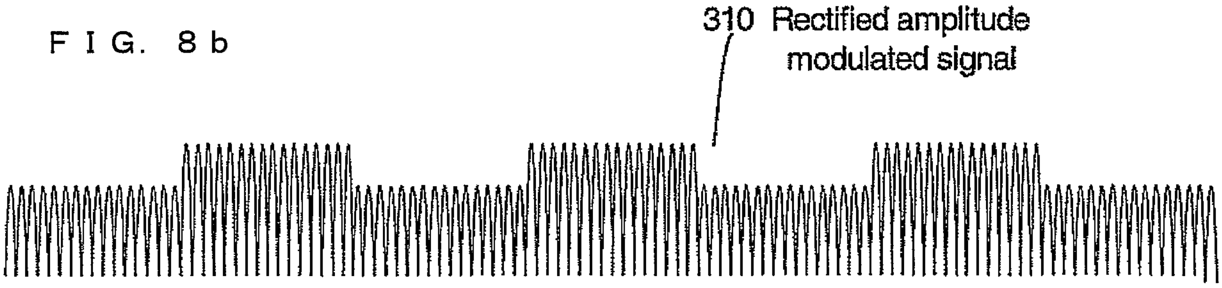


FIG. 8c

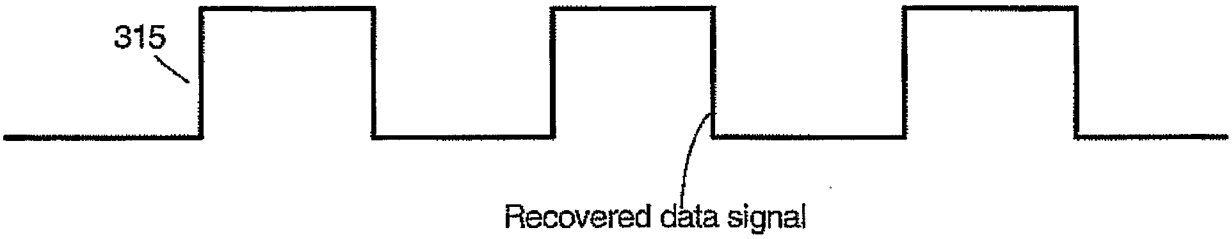
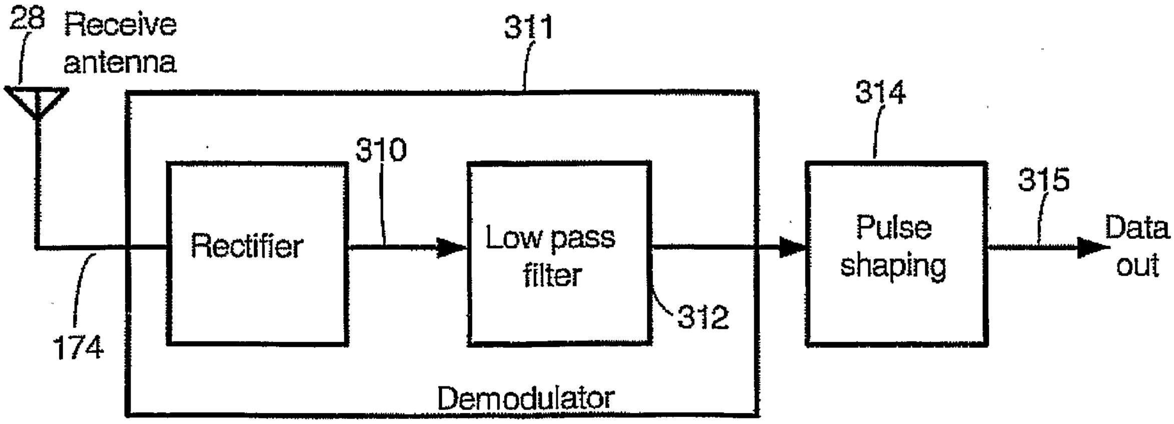


FIG. 8d



F I G. 9

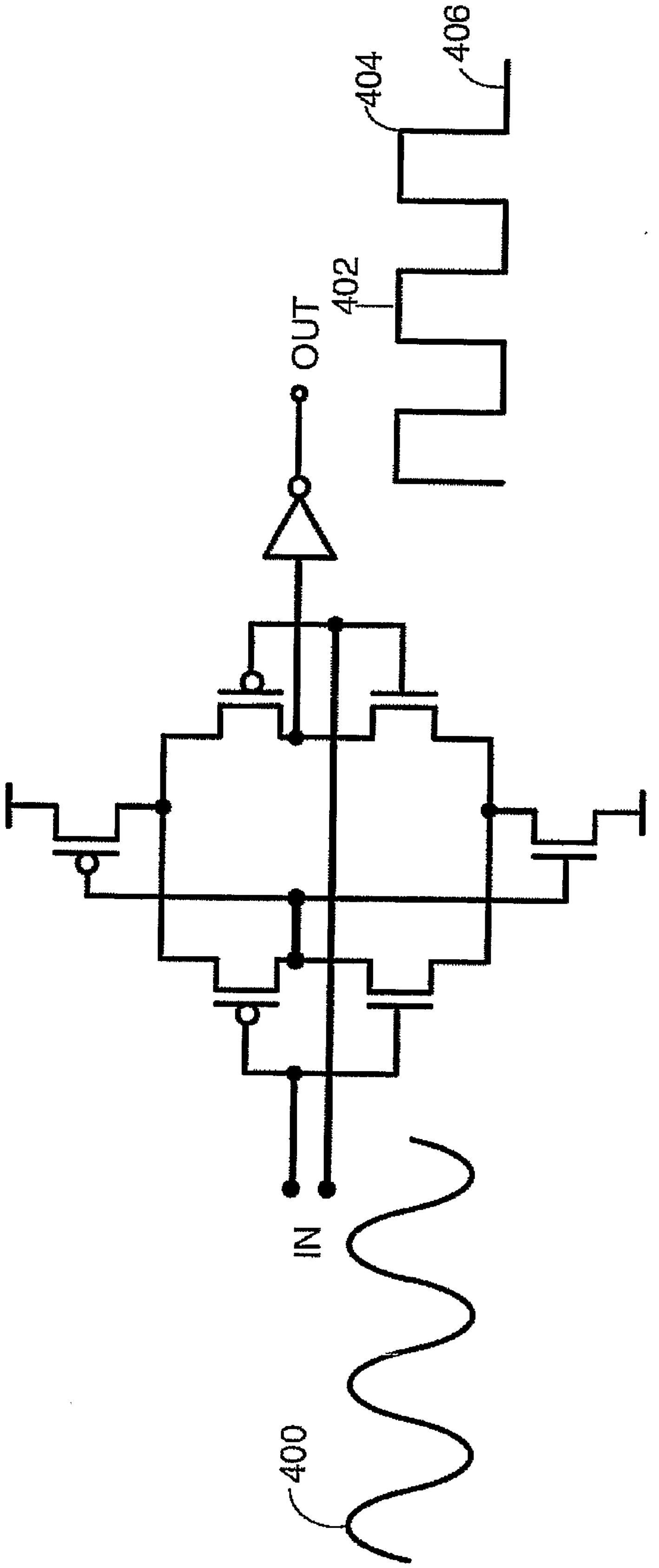


FIG. 10

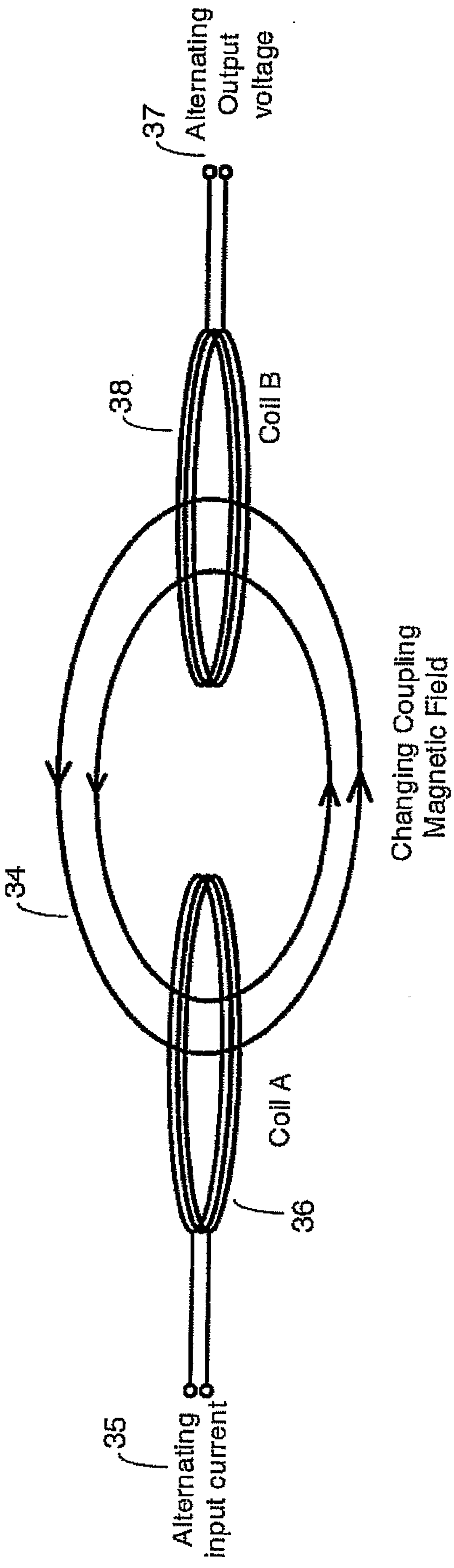

37
Alternating Output voltage
38
Coil B
Changing Coupling Magnetic Field
34
Coil A
36
35
Alternating input current

FIG. 11

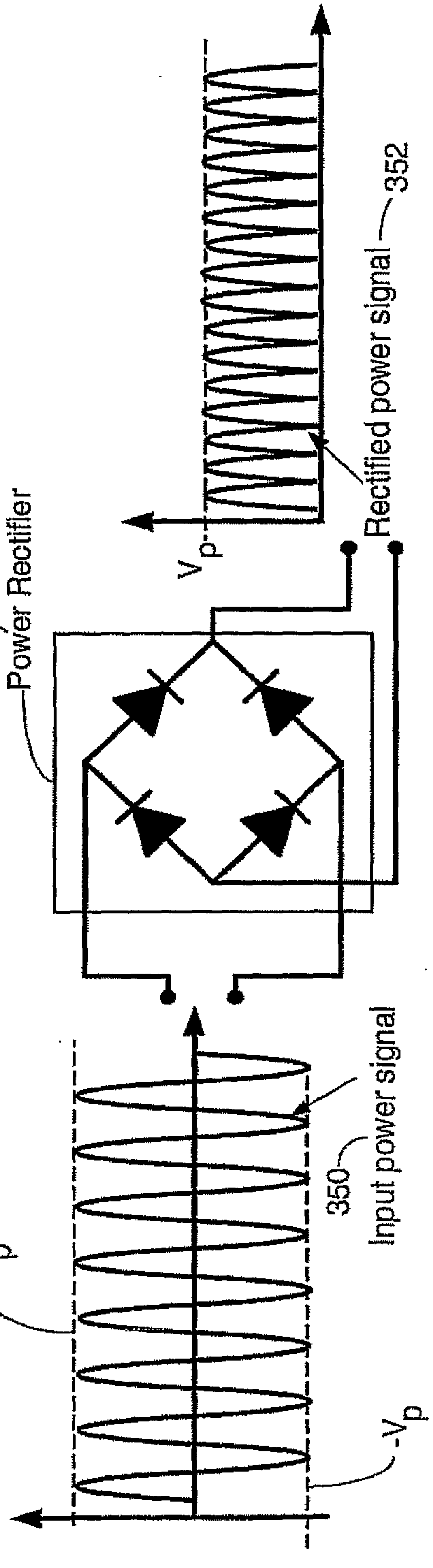
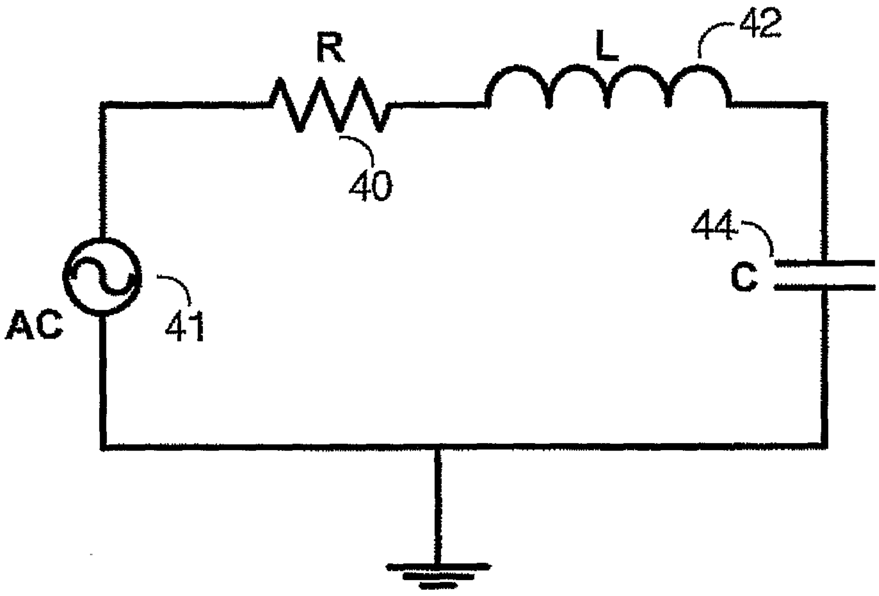
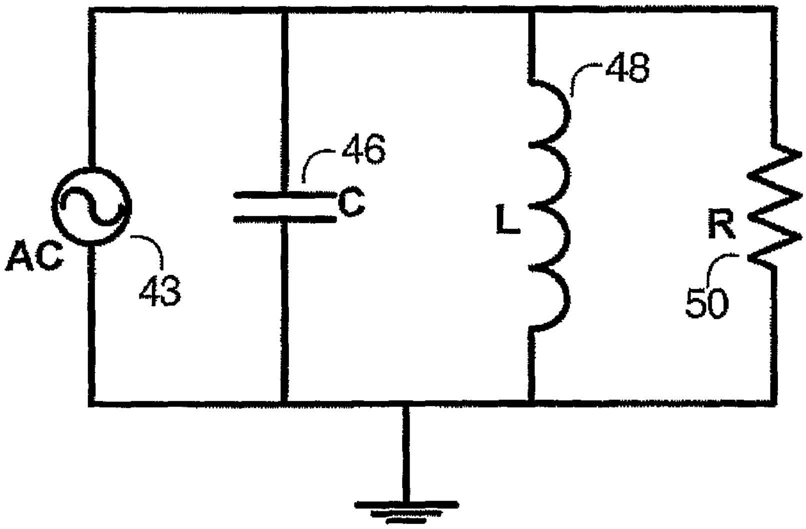

+V_p
-V_p
350 Input power signal
354 Power Rectifier
V_p
Rectified power signal 352

FIG. 12a



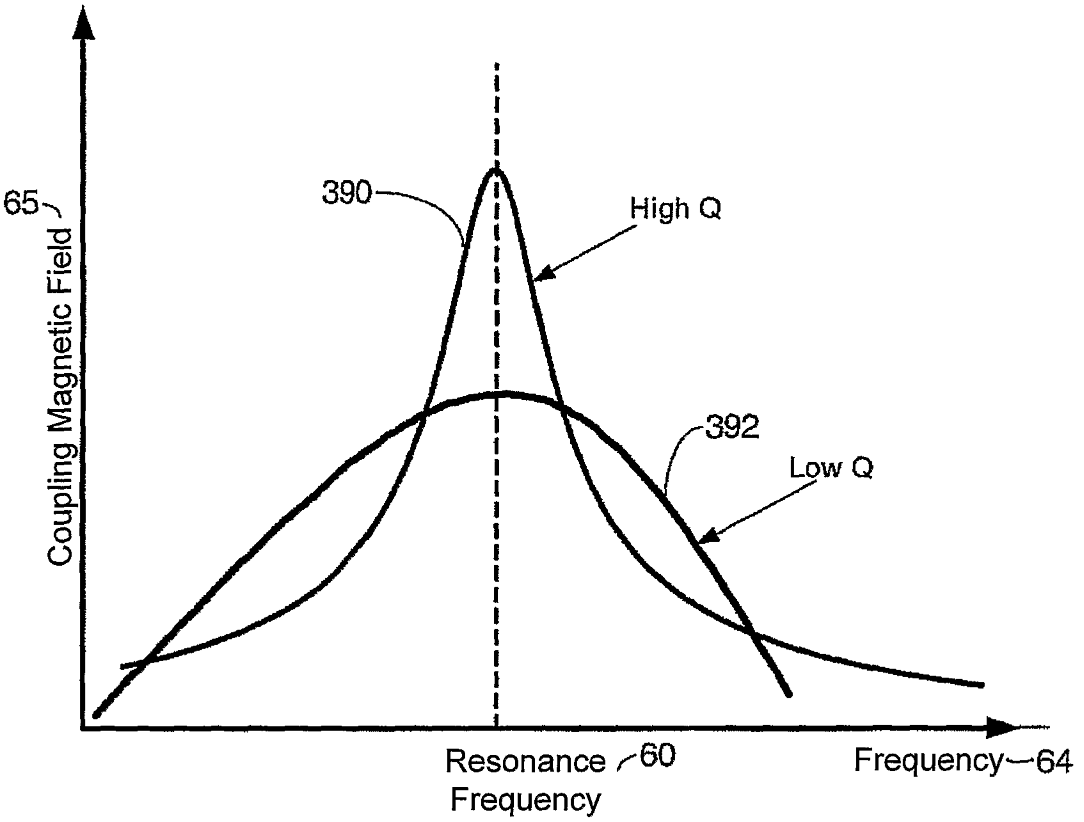
Series Resonance circuit

FIG. 12b

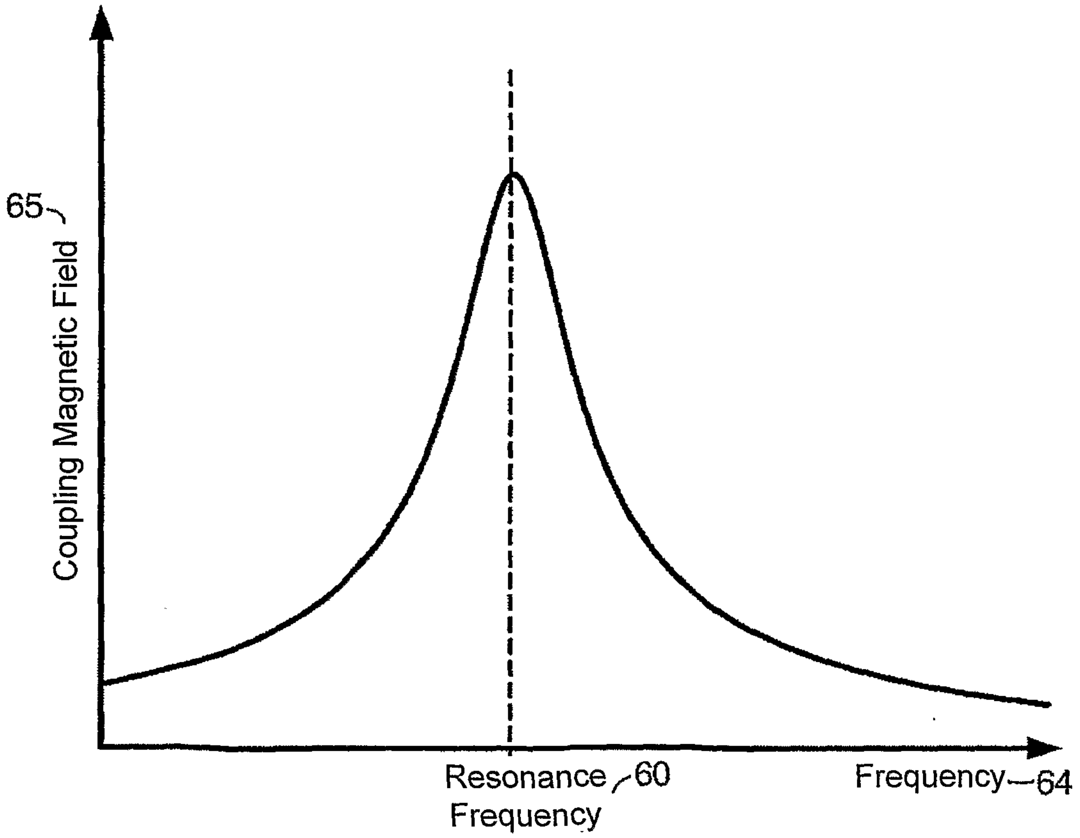


Parallel Resonance circuit

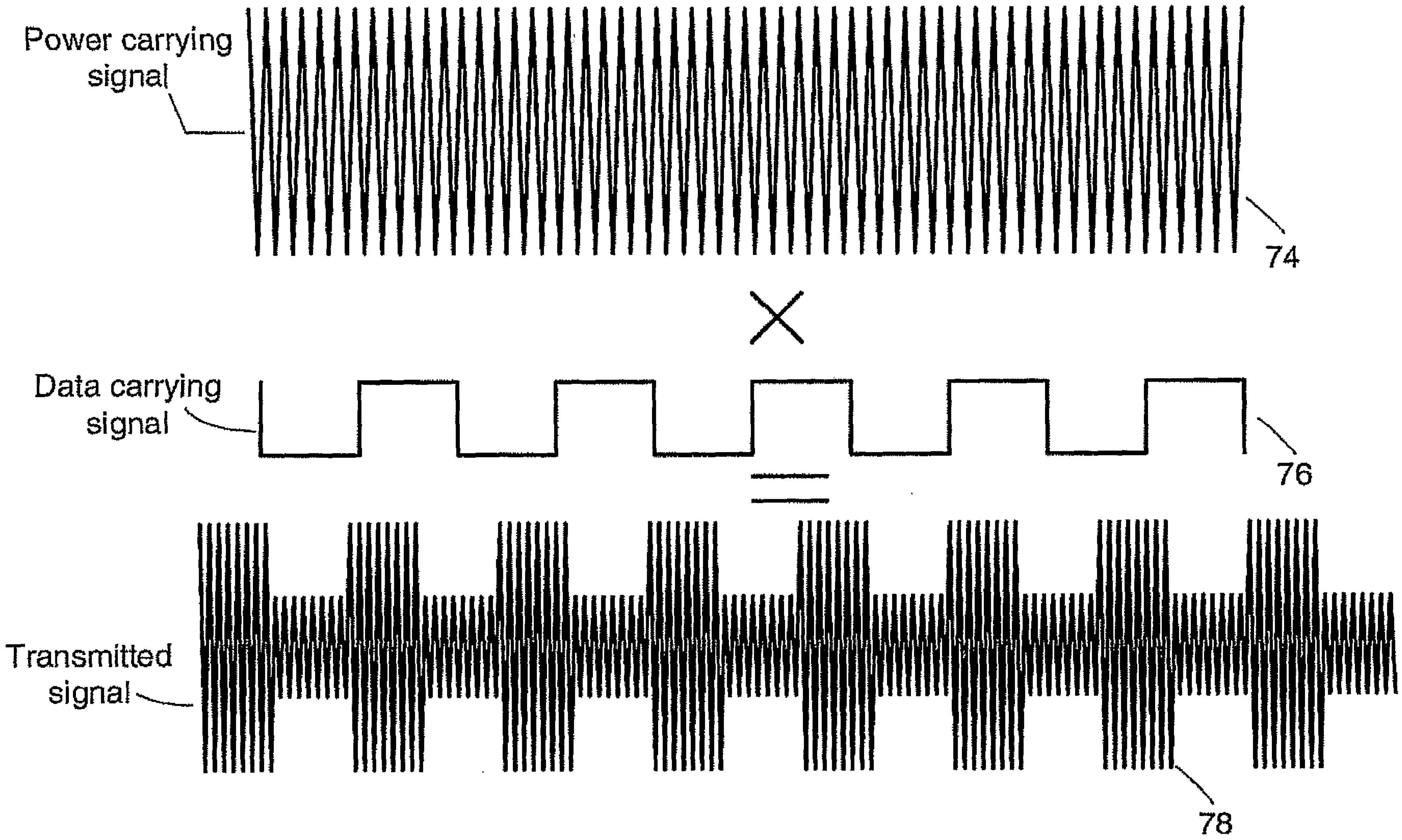
F I G. 1 3


65
Coupling Magnetic Field
390
High Q
392
Low Q
Resonance Frequency
60
Frequency
64

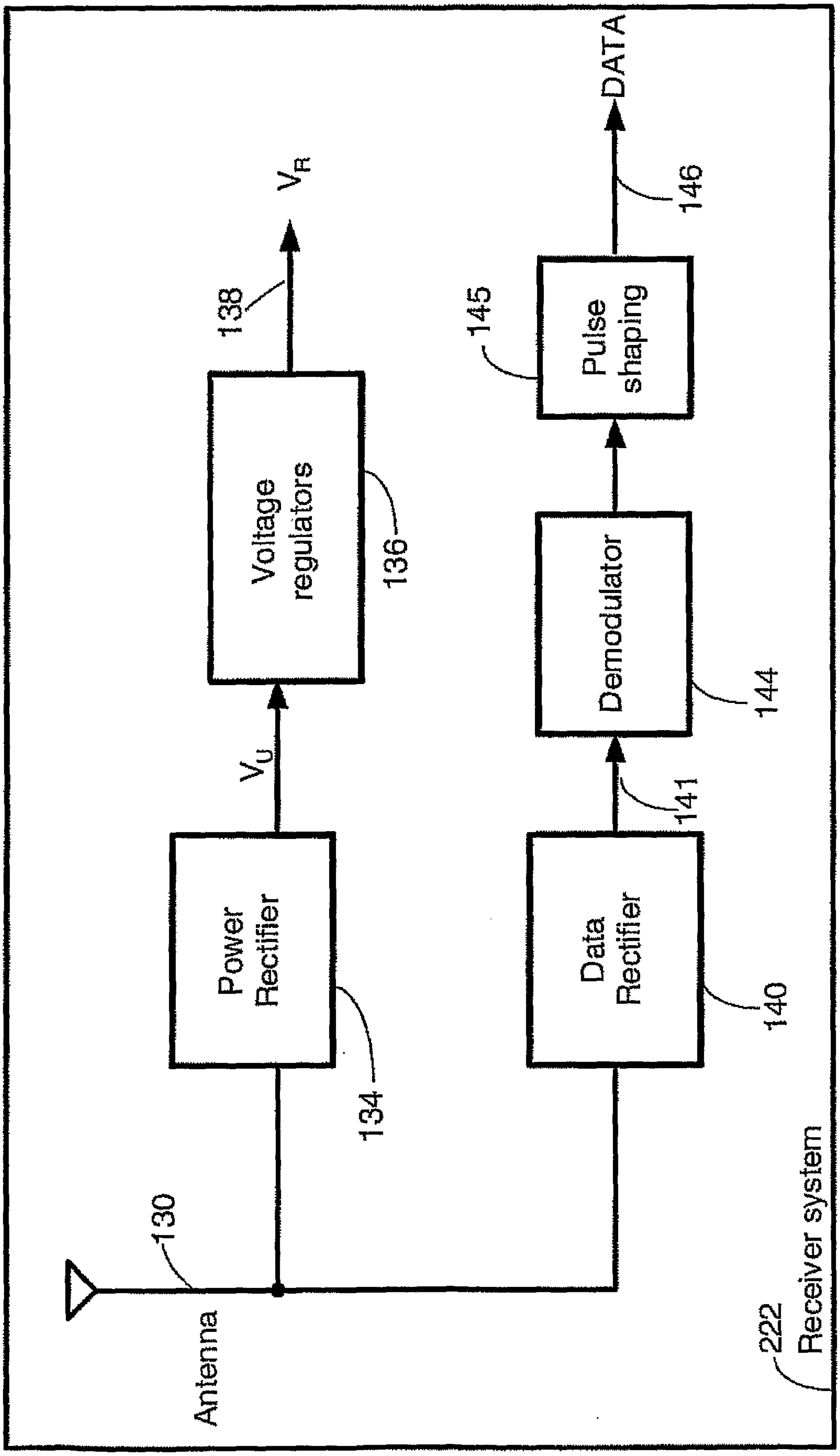
F I G. 1 4


65
Coupling Magnetic Field
Resonance Frequency
60
Frequency
64

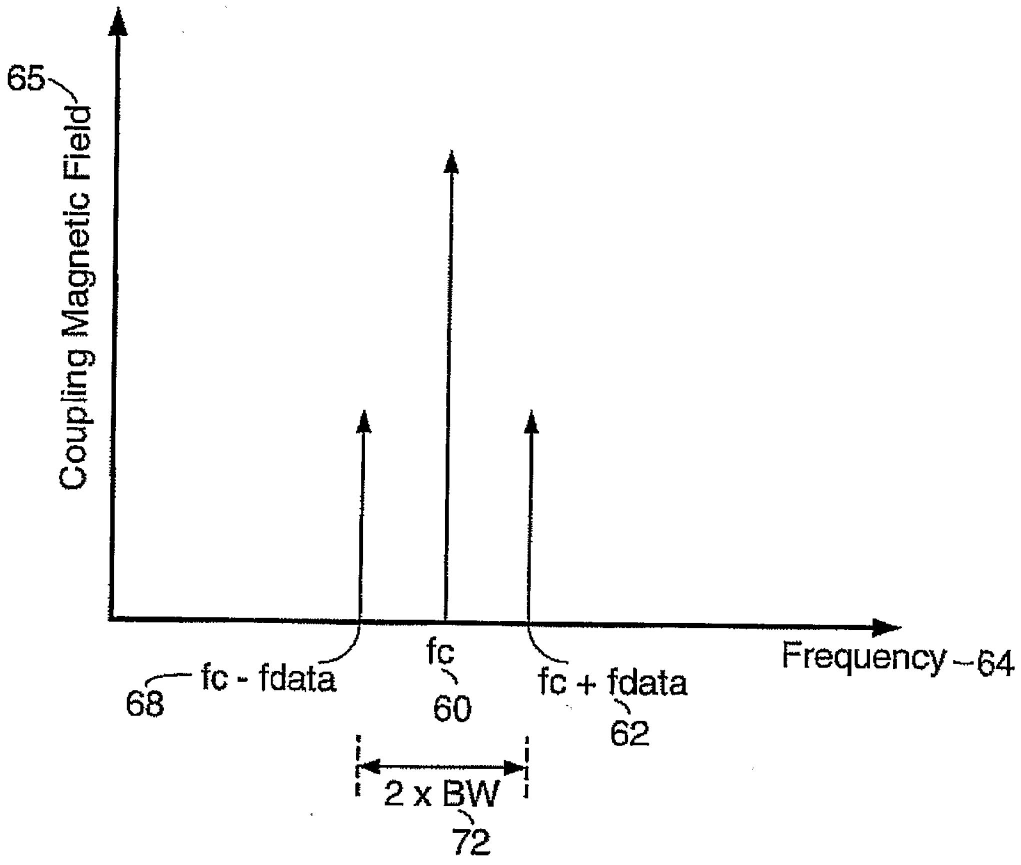
F I G. 1 5


Power carrying signal
74
Data carrying signal
76
Transmitted signal
78

F I G. 1 6


Antenna
130
Power Rectifier
134
V_U
Voltage regulators
136
138
V_R
Data Rectifier
140
141
Demodulator
144
Pulse shaping
145
146
DATA
222
Receiver system

F I G. 1 7


65
Coupling Magnetic Field
Frequency
64
fc - fdata
68
fc
60
fc + fdata
62
2 x BW
72

F I G. 1 8

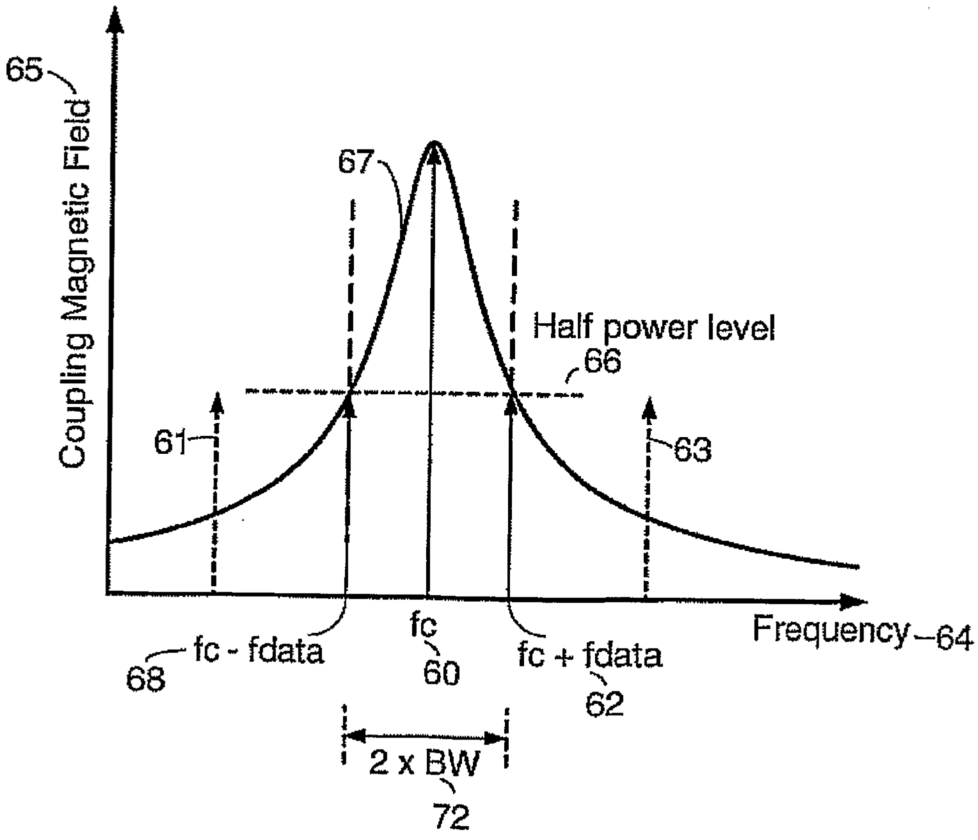

65
Coupling Magnetic Field
67
Half power level
66
61
63
Frequency
64
fc - fdata
68
fc
60
fc + fdata
62
2 x BW
72

FIG. 19

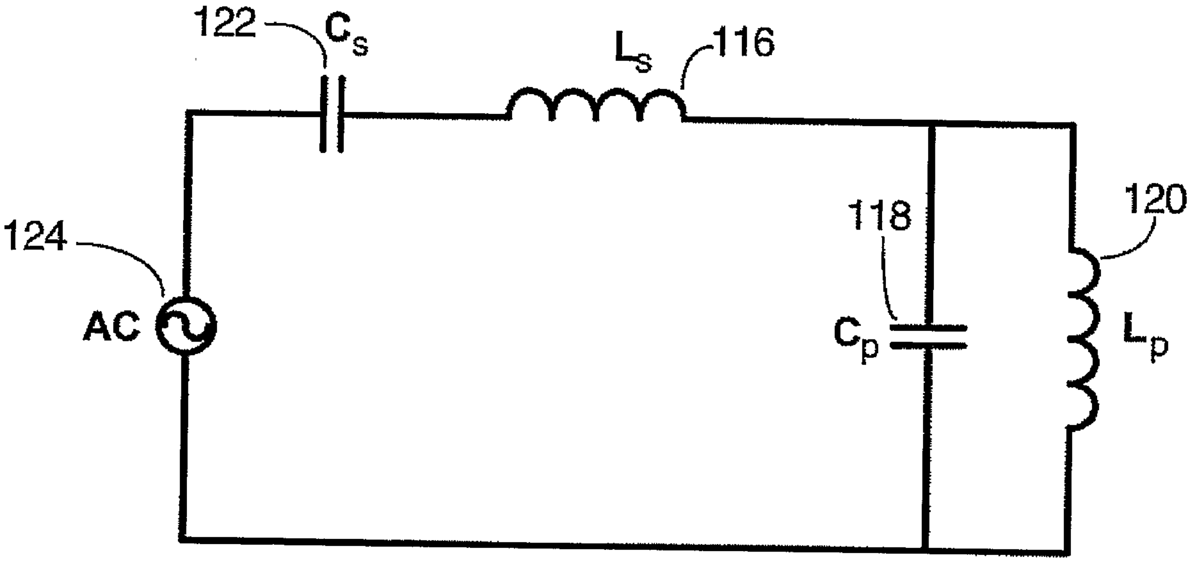

122
C_s
L_s
116
124
AC
118
120
C_p
L_p

FIG. 20

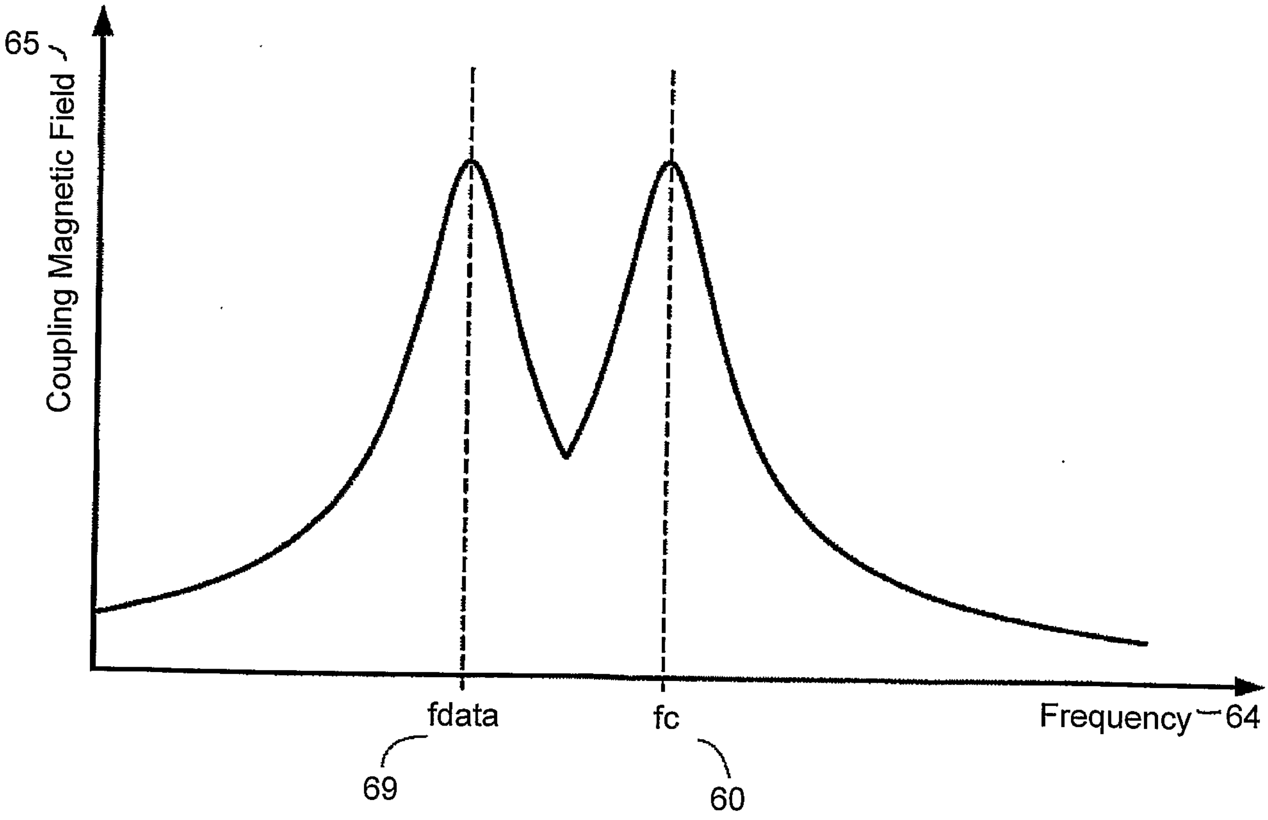
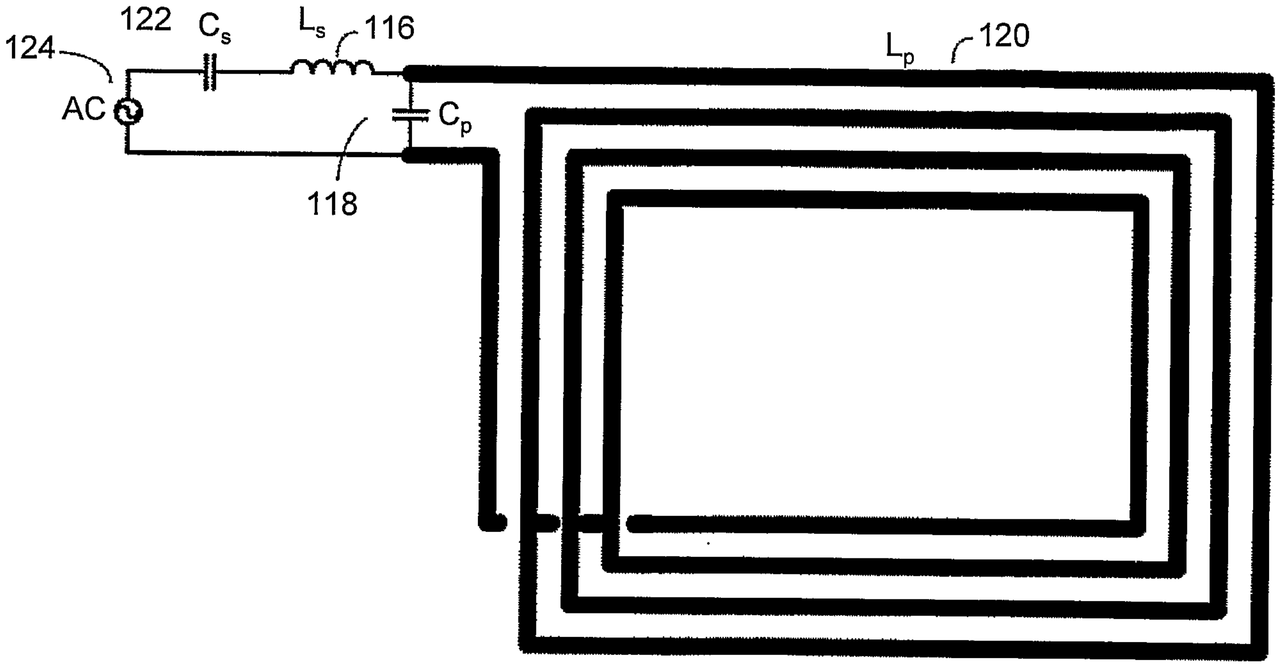
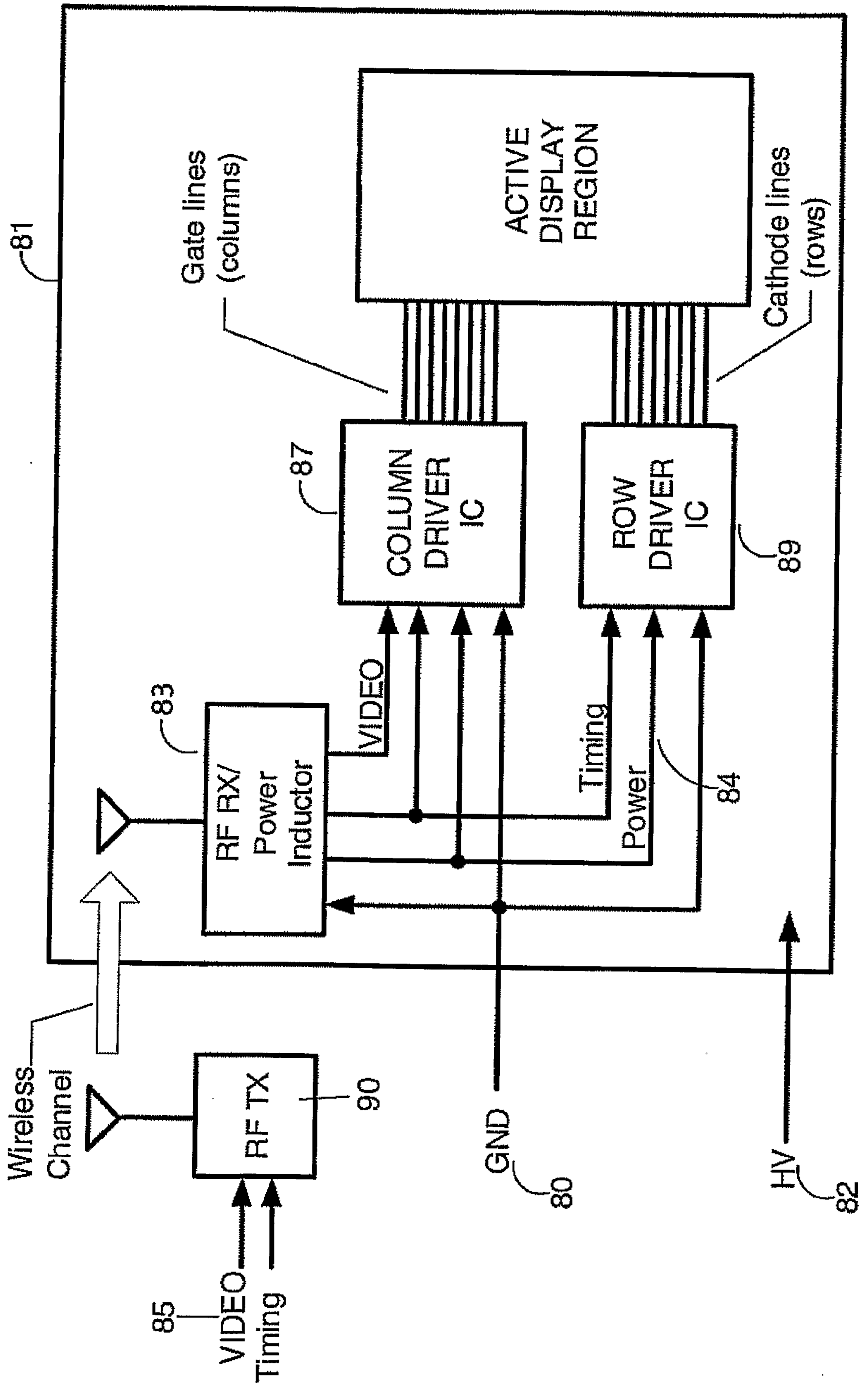

65
Coupling Magnetic Field
fdata
fc
Frequency
64
69
60

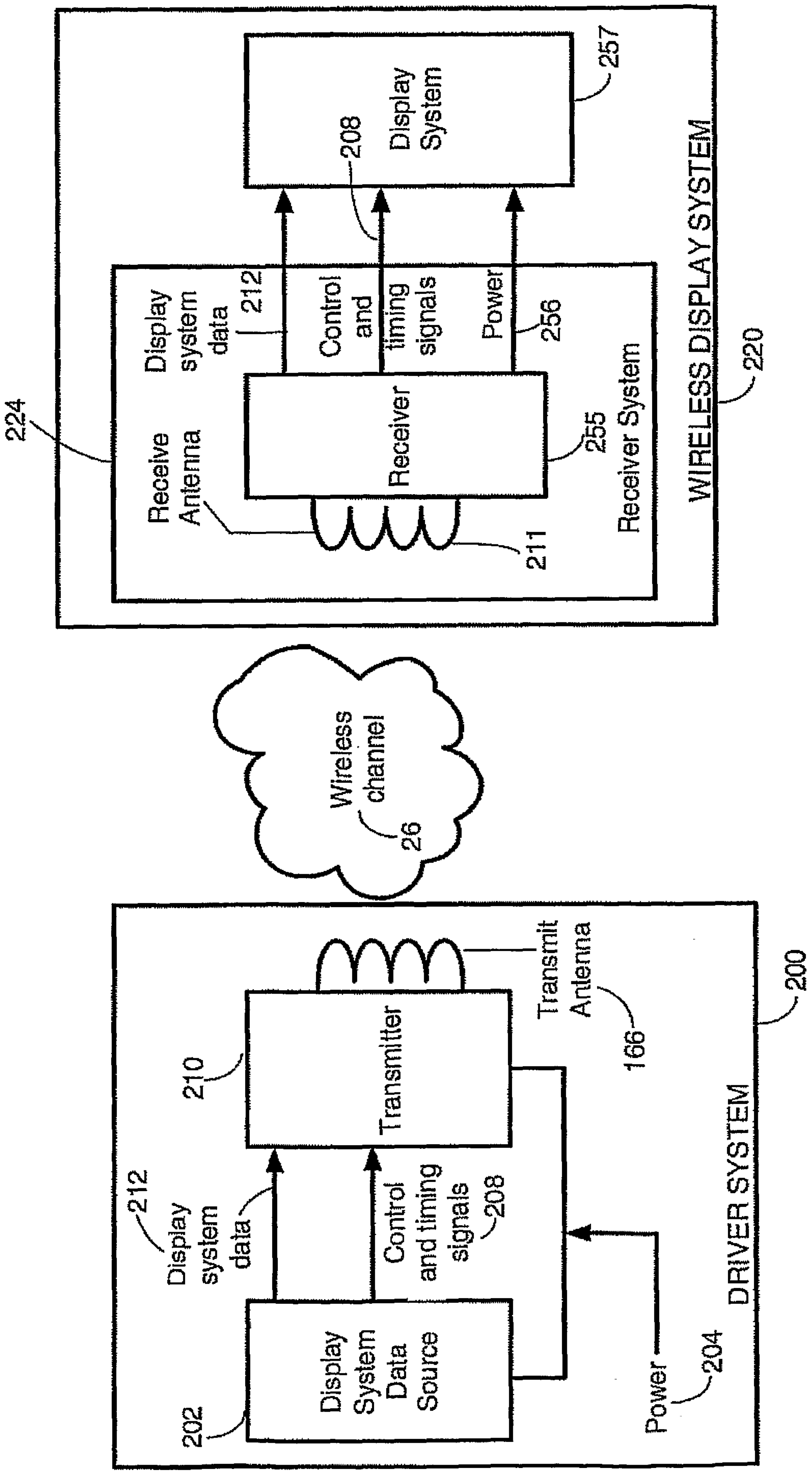
FIG. 21



F I G. 22


81
ACTIVE DISPLAY REGION
Gate lines (columns)
Cathode lines (rows)
COLUMN DRIVER IC
87
ROW DRIVER IC
89
RF RX/ Power Inductor
83
VIDEO
Timing
Power
84
Wireless Channel
RF TX
90
GND
80
HV
82
VIDEO
Timing
85

F I G. 2 3


Display System Data Source
202
Display system data
212
Control and timing signals
208
Transmitter
210
Transmit Antenna
166
Power
204
DRIVER SYSTEM
200
Wireless channel
26
Receive Antenna
211
Receiver
255
Receiver System
224
Display system data
212
Control and timing signals
Power
256
Display System
208
257
WIRELESS DISPLAY SYSTEM
220

F I G. 2 4

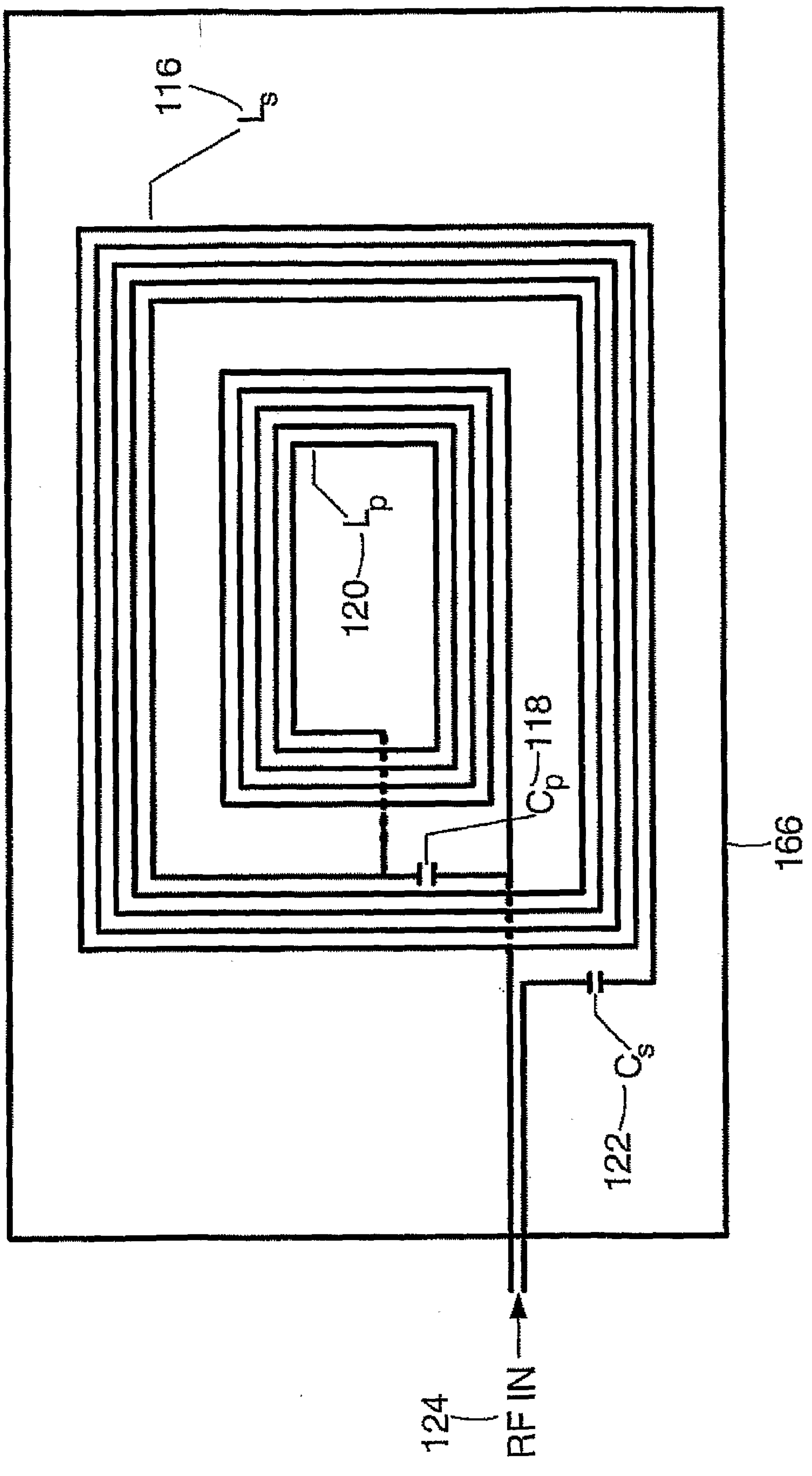


FIG. 25

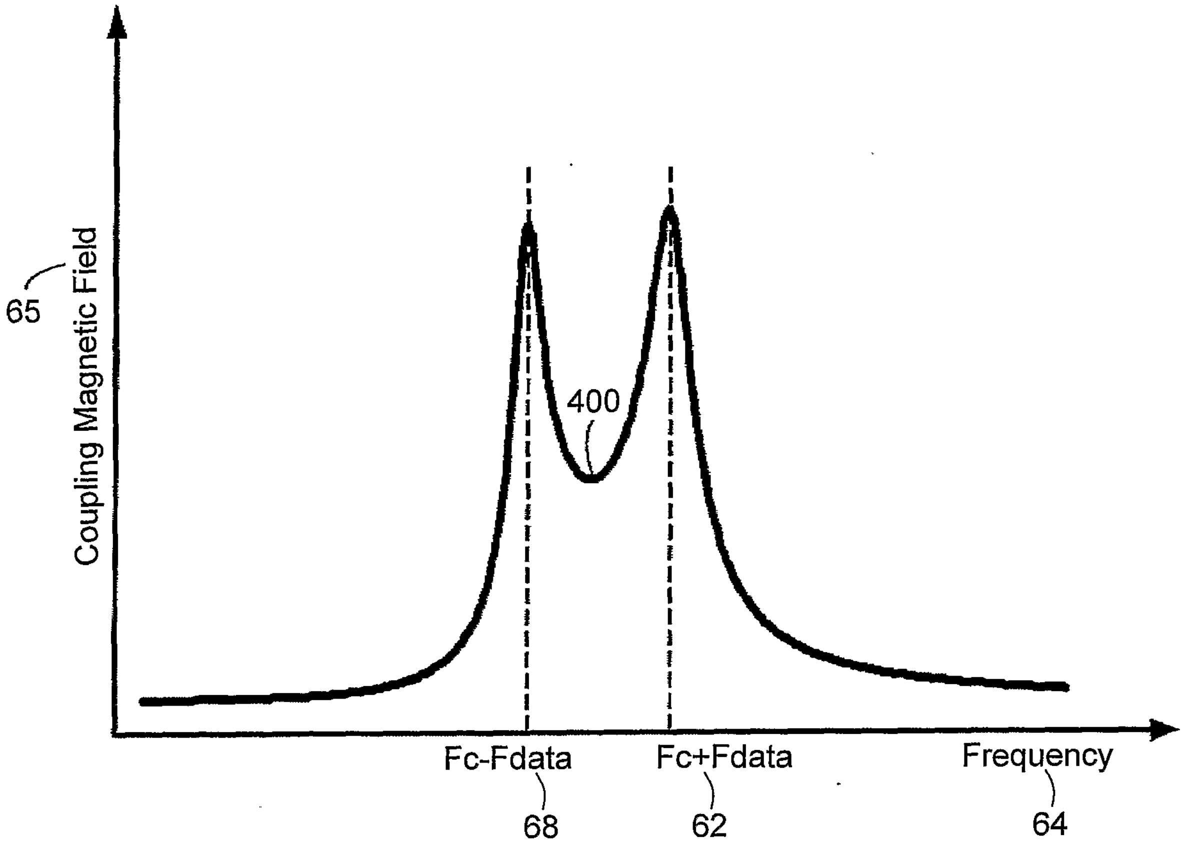
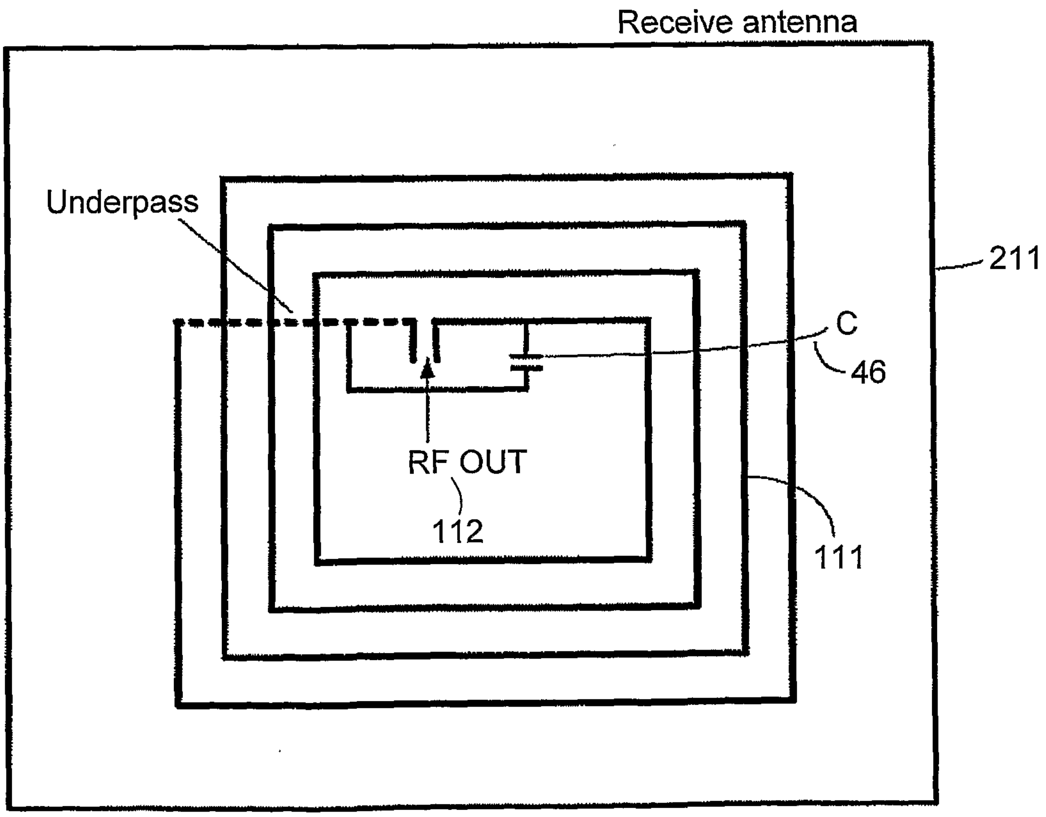
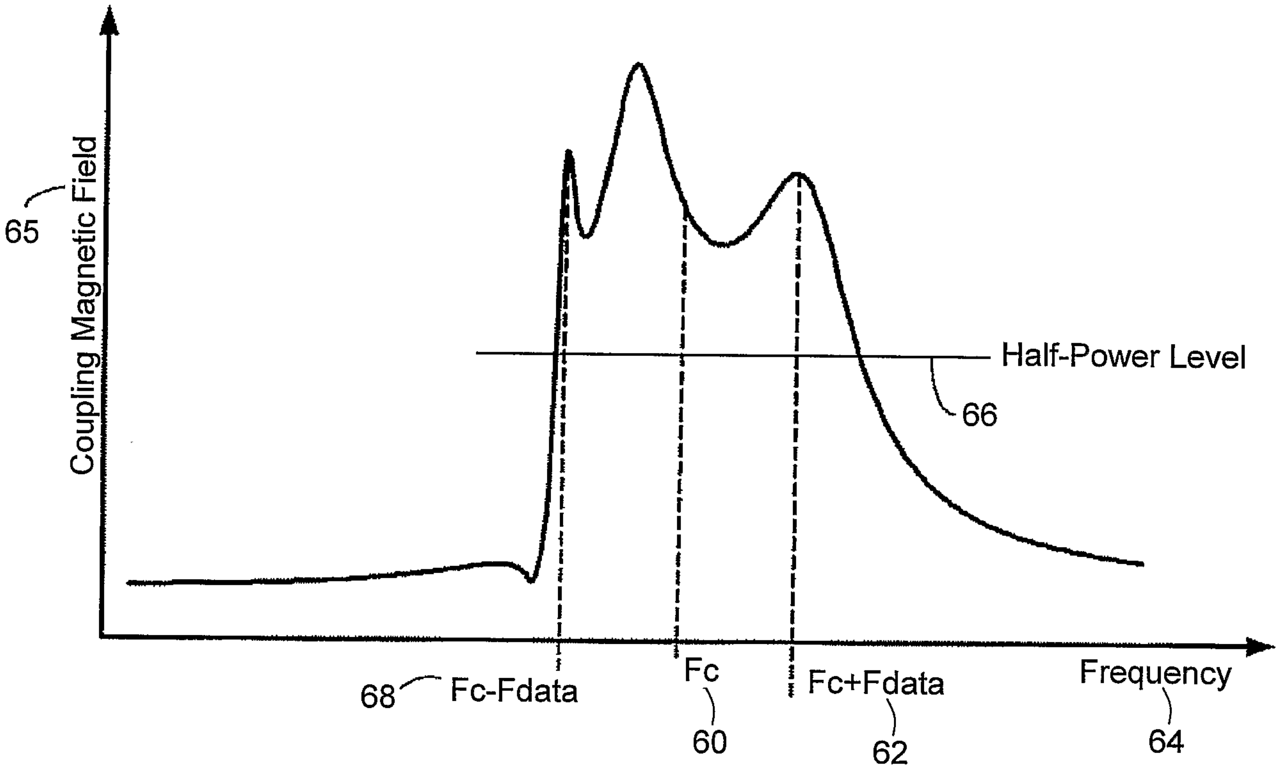

Coupling Magnetic Field
65
400
Fc-Fdata
68
Fc+Fdata
62
Frequency
64

FIG. 26


Receive antenna
Underpass
211
C
46
RF OUT
112
111

F I G. 2 7


65
Coupling Magnetic Field
Half-Power Level
66
68
Fc-Fdata
Fc
60
Fc+Fdata
62
Frequency
64

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2008/051901

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. H01Q23/00(2006.01)i, G06K17/00(2006.01)i, G06K19/07(2006.01)i, H01Q1/38(2006.01)i, H01Q7/00(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl. H01Q23/00, G06K17/00, G06K19/07, H01Q1/38, H01Q7/00

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

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2008
Registered utility model specifications of Japan 1996-2008
Published registered utility model applications of Japan 1994-2008

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

IEEE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 1538558 A2 (Hitachi, Ltd.) 2005.06.08, paragraph 0022 & JP 2005-165703 A & US 2005/0122211 A1 & CN 1624716 A	1-29
A	JP 2006-121789 A (Hitachi ULSI systems co., Ltd. and Hitachi, Ltd.) 2006.05.11, paragraph 0029-0030 & US 2006/0083955 A1	1-29
A	M. Ghovanloo and K. Najafi, "A wideband frequency-shift keying wireless link for inductively powered biomedical implants", IEEE Transactions on Circuits and Systems, 2004.12, Vol. 51, No. 12, pp. 2374-2383	1-29

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search 07.05.2008	Date of mailing of the international search report 20.05.2008
Name and mailing address of the ISA/JP **Japan Patent Office** 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Authorized officer 5T 3784 Masahide SATO Telephone No. +81-3-3581-1101 Ext. 3568