The circuit comprises an RLC tank (106, 108, 206, 208) whose inductance (106) forms part of an antenna of the device. The circuit comprises multiple class-D amplifiers (202, 204) for driving the antenna. Each different one of the amplifiers drives the antenna with a different one of multiple components representative of the digital signal modulating a carrier in a phase-shifted keying modulation scheme.

Fig. 2
Declaration under Rule 4.17:
— as to applicant’s entitlement to apply for and be granted a patent (Rule 4.17(H))

Published:
— with international search report
POWER-EFFICIENT TRANSMITTER FOR MAGNETIC LINK

FIELD OF THE INVENTION

The invention relates to a device with an electronic circuit for wireless communication of a digital signal using a magnetic link. The invention further relates to an integrated circuit for use in such a device. The invention is in particular, but not exclusively, relevant to hearing-aids.

BACKGROUND ART

The principle of magnetic induction technology for wireless data communication is basically that of an inductively coupled transformer. This inductively coupled transformer has a very low coupling factor, i.e., the mutual inductance is very small. The transmitter side of the inductively coupled transformer is explained with reference to Fig. 1.

Fig.1 is a block diagram of a circuit 100, comprising a driving voltage source 102, and a series connection of a capacitor 104, an inductance 106 and a resistor 108. The antenna is formed by inductance 106, implemented by an external coil that is used for both transmitting and receiving, e.g., on a time-division multiplex basis. An RLC tank is formed by resistor 108, capacitor 104 (both on-chip), and external coil 106. Node 110 provides a signal voltage representative of the signal transmitted via inductance 106. The tank needs to have a center frequency equal to the channel frequency. When circuit 100 is used as a transmitter, the tank needs to efficiently transmit an adjustable level. The most power-efficient way to do this is using a non-linear class-D amplifier. As known, a class-D amplifier is a power amplifier wherein the output stage is operated in an on/off mode. Advantages of a class-D amplifier include small size, low power dissipation and a high power-conversion efficiency. The high efficiency is based on having the output stage never operate a linear region. Instead, the output devices are either on or off. Since the RLC-tank is a band-pass filter, only the fundamental signal of the square wave is transmitted.

The type of modulation used in the magnetic link is binary frequency-shift keying (FSK). As known, FSK is a frequency-modulation technique wherein the signal is used to
modulate a carrier wave by shifting the frequency between values determined in advance. The link transmits digital data at a bit-rate of 300 kbit/s. The modulation frequency can be, e.g., 10.6 MHz or 13.56 MHz. The modulation index is unity, meaning that there is 300 kHz between the two tones that represent a digital zero and a digital one. During a transmission of a single bit one of two frequencies is transmitted, depending on the bit's value.

SUMMARY OF THE INVENTION

FSK modulation is less efficient than phase-shift keying (PSK). PSK is a modulation technique that conveys data by modulating the phase of the carrier. PSK uses a finite number of phases, each respective one thereof representing a unique pattern of binary bits. Quadrature phase-shift keying (QPSK) uses four different phases. FSK with a modulation factor of unity, uses a factor of 2.6 more bandwidth than QPSK, and also needs a higher $E_b/\mathcal{N}_0$ (energy-per-bit / noise density) for demodulation than QPSK. Depending on the modulation index, using the same bandwidth, an, up to four times higher, data-rate can be implemented consuming the same power. Especially for mobile applications, low power-consumption is very important.

However when using quadrature modulation, the in-phase (I) and quadrature (Q) components of the signal should be added, which is difficult when using a non-linear amplifier. Usually the I components and Q components are added using linear amplifiers. This, on the other hand, goes at the cost of the efficiency of the transmitter. This is a very important issue since the transmit power is typically the larger part of the total power used in the link (depending on the distance to cover).

However, the inventors propose a device with an electronic circuit for wireless communication of a digital signal. The circuit comprises an RLC tank whose inductance forms part of an antenna of the device. The circuit comprises multiple class-D amplifiers for driving the antenna. Each different one of the amplifiers drives the antenna with a different one of multiple components representative of the digital signal modulating a carrier in a phase-shifted keying modulation scheme.

The invention is based on the insight that non-linear amplifiers, e.g., logic inverters, can be used instead of linear amplifiers, the RLC tank then functioning as a band-pass filter. For example, the inverters or non-linear amplifiers cause the capacitances of the tank to be
connected to low-ohmic nodes (signal ground or power supply voltage), thereby guaranteeing the
band-pass functionality of the RLC tank.

In an embodiment of the device in the invention, the circuit has a first class-D
amplifier and a second class-D amplifier. The RLC tank comprises the inductance connected with
a first node to a resistor of the RLC tank. The first class-D amplifier drives the antenna via a first
capacitance of the RLC tank connected to a second node of the inductance. The second class-D
amplifier drives the antenna via a second capacitance of the RLC tank also connected to the
second node of the inductance. By means of connecting the two inverters (or two class-D
amplifiers) to the RLC tank using the same amount of capacitance per inverter, the signals from
the inverters are summed. Consider a QPSK scenario. If, for instance, the I-inverter is kept quiet
and the Q-inverter is switched, a certain peak-to-peak voltage is obtained at the RLC tank. Now,
if the Q-inverter is kept quiet and the I-inverter is switched, one gets exactly the same peak-to-
peak voltage. So if both are switched, the voltages add up. And this is what is needed for, e.g.,
QPSK. As mentioned before, an advantage of using inverters or class-D amplifiers is the efficient
transfer of energy (i.e., low power-consumption).

Another embodiment of a device in the invention relates to a device, wherein the
circuit has a first class-D amplifier, a second class-D amplifier, a third class-D amplifier and a
fourth class-D amplifier. The first class-D amplifier is connected to a first node of the inductance
via a first capacitance of the RLC tank. The second class-D amplifier is connected to the first
node via a second capacitance of the RLC tank. The third class-D amplifier is connected to a
second node of the inductance via a third capacitance of the RLC tank. The fourth class-D
amplifier is connected to the second node via a fourth capacitance of the RLC tank. A resistance
of the RLC tank is connected between the first and second nodes. Again, the capacitances are
used so as to guarantee the band-pass filtering function of the RLC tank.

The invention also relates to an integrated electronic circuit for use in a device for
wireless communication of a digital signal. The circuit comprises an RC network with a first
node and a second node for connecting an inductance there-between, the inductance then forming
part of an antenna in operational use of the device. The circuit comprises multiple class-D
amplifiers for driving the antenna in operational use of the device. Each different one of the
amplifiers drives the antenna with a different one of multiple components representative of the
digital signal modulating a carrier in a phase-shifted keying modulation scheme.

In an embodiment, the circuit has a first class-D amplifier and a second class-D amplifier. The first class-D amplifier drives the antenna via a first capacitance of the RC network, the first capacitance being connected to the first node. The second class-D amplifier drives the antenna via a second capacitance of the RC network, the second capacitance being connected to the first node.

In another embodiment, the circuit has a first class-D amplifier, a second class-D amplifier, a third class-D amplifier and a fourth class-D amplifier. The first class-D amplifier is connected to the first node via a first capacitance of the RC network. The second class-D amplifier is connected to the first node via a second capacitance of the RC network. The third class-D amplifier is connected to the second node via a third capacitance of the RC network. The fourth class-D amplifier is connected to the second node via a fourth capacitance of the RC network. A resistance of the RC network is connected between the first and second nodes. Preferably, each class-D amplifier comprises a logic inverter stage.

The integrated circuit of the invention is a commercial entity interesting to, e.g., set-makers. The set-maker connects an inductance to the circuit so as to complete the RLC tank. The combination is then built into a physical device, e.g., a hearing-aid, a wireless headphone, wireless body sensors, etc.

The invention also relates to a data processing system comprising a plurality of devices as specified above. Each respective one of the devices comprises a respective electronic circuit for wireless communication of a respective digital signal. The respective circuit comprises a respective RLC tank whose respective inductance forms part of a respective antenna of the respective device. The respective circuit comprises multiple respective class-D amplifiers for driving the respective antenna. Each different one of the respective amplifiers drives the respective antenna with a different one of multiple components representative of the respective digital signal modulating a carrier in a phase-shifted keying modulation scheme. For example, a hearing-aid using the invention typically has a pair of such devices that communicate wirelessly, e.g., in order to implement an audio zooming functionality. One or both of the devices operates as transmitter and receiver on a time-multiplexed basis.
BRIEF DESCRIPTION OF THE DRAWING

The invention is explained in further detail, by way of example and with reference to the accompanying drawing, wherein:

Fig. 1 is a block diagram of a circuit for wireless communication of a digital signal using a magnetic link;

Figs. 2 and 3 are diagrams of circuits in the invention.

Throughout the Figures, similar or corresponding features are indicated by same reference numerals.

DETAILED EMBODIMENTS

An embodiment of the invention relates to an IC for a wireless magnetic link that covers distances in the order of 10 cm to 1 m. Such an IC can be used in, e.g., hearing instruments, wireless headphones, wireless headsets, wireless sensors to sense e.g., heart rate, blood pressure, etc.

As an example, wireless ear-to-ear communication is implemented through the magnetic link in order to implement audio zoom functionality. Hearing-aids users would like to be able to zoom in on a certain audio source, e.g. the person they are talking to, when there is a lot of background noise present ("cocktail party" effect). In order to do this, two audio sources are needed with a relatively large distance between them. In this case, the two hearing instruments are used (a single instrument being referred to above as "device"), one in each ear, and typically located 16 cm apart. Combining the two signals received, the zoom functionality can be implemented (i.e., the attenuation of the background noise with respect to the desired audio source). The bi-directional wireless link is used to implement this zoom functionality. Now the two audio signals are present in each ear and can be combined, thus realizing zoom functionality. As a result, the hearing-impaired person experiences improved communication in a noisy environment.

Fig. 2 is a diagram of a first embodiment of a circuit 200 in the invention. Circuit 200 comprises a first non-linear driver (or non-linear amplifier) 202 and a second non-linear driver (or non-linear amplifier) 204. Driver 202 is connected to inductance 106 via a capacitance 208, and driver 204 is connected to inductance 106 via a capacitance 206. Driver 202 supplies a
signal to inductance 106 representing one component in a phase-shift keying modulation scheme of the initial digital signal, and driver 204 supplies another signal to inductance 106 representing another component in the phase-shift keying modulation scheme of the initial digital signal. Inductance 106, resistor 108 and capacitances 206 and 208 together form an RLC tank. Owing to the connection of capacitances 206 and 208 to a low-ohmic node (here: ground) the RLC tank functions as a proper band-pass filter for the signals and the drivers’ signals are properly summed at node 110.

Fig. 3 is a diagram of a second embodiment of a circuit 300 in the invention. Circuit 300 comprises non-linear amplifiers 302, 304, 306 and 308 to implement a QPSK modulation scheme. Amplifiers 302-308 in this example are logic inverters. Inverter 302 supplies the positive in-phase QPSK signal. Inverter 304 supplies the positive quadrature-phase QPSK signal. Inverter 306 supplies the negative in-phase QPSK signal. Inverter 308 supplies the negative quadrature-phase QPSK signal. Inverter 302 is connected to a node 310 of inductance 106 via a capacitance 312. Inverter 304 is connected to node 310 via a capacitance 314. Inverter 306 is connected to a node 316 of inductance 106 via a capacitance 318. Inverter 308 is connected to node 316 via a capacitance 320. Resistors 322 and 324 are connected in series, and the series arrangement is connected in parallel with inductance 106. A common mode supply source 326 is connected between resistors 322 and 324. Resistors 322-324 enable to control the Q of the RLC tank and also determine the common mode voltage of the tank. Again, owing to the connection of capacitances 312, 314, 318 and 320 low-ohmic nodes (here: ground) the RLC tank functions as a proper band-pass filter for the signals, and the drivers' signals are properly summed at nodes 310 and 316. Note that circuit 300 operates in a differential mode, and that inductance 106 is driven from both sides. This increases the common-mode rejection.

Circuits 200 and 300 are used as transmitters. The circuits could be used in a time-multiplexed manner to also function as receivers (additional active receiver circuitry not shown). In order to receive data, the switching/transmitting is stopped and a low-noise amplifier (LNA) plus additional demodulation circuitry is connected to node 110 (in a single-ended signaling configuration) or to nodes 310 and 316 (in a differential signaling configuration). The voltage at the RLC tank of the receiver is supplied to a demodulator, in the example of Fig. 3 to a QPSK demodulator to extract the digital signal.
CLAIMS

1. A device with an electronic circuit for wireless communication of a digital signal, wherein:
   - the circuit comprises an RLC tank whose inductance forms part of an antenna of the device;
   - the circuit comprises multiple class-D amplifiers for driving the antenna; and
   - each different one of the amplifiers drives the antenna with a different one of multiple components representative of the digital signal modulating a carrier in a phase-shifted keying modulation scheme.

2. The device of claim 1, wherein:
   - the circuit has a first class-D amplifier and a second class-D amplifier;
   - the RLC tank comprises the inductance connected with a first node to a resistor of the RLC tank;
   - the first class-D amplifier drives the antenna via a first capacitance of the RLC tank connected to a second node of the inductance;
   - the second class-D amplifier drives the antenna via a second capacitance of the RLC tank connected to the second node of the inductance.

3. The device of claim 1, wherein:
   - the circuit has a first class-D amplifier, a second class-D amplifier, a third class-D amplifier and a fourth class-D amplifier;
   - the first class-D amplifier is connected to a first node of the inductance via a first capacitance of the RLC tank;
   - the second class-D amplifier is connected to the first node via a second capacitance of the RLC tank;
   - the third class-D amplifier is connected to a second node of the inductance via a third capacitance of the RLC tank;
the fourth class-D amplifier is connected to the second node via a fourth capacitance of the RLC tank;
a resistance of the RLC tank is connected between the first and second nodes.

4. The device of claim 1, 2 or 3, wherein each class-D amplifier comprises a logic inverter stage.

5. An integrated electronic circuit for use in a device for wireless communication of a digital signal, wherein:
the circuit comprises an RC network with a first node and a second node for connecting an inductance there-between, the inductance then forming part of an antenna in operational use of the device;
the circuit comprises multiple class-D amplifiers for driving the antenna in operational use of the device; and
each different one of the amplifiers drives the antenna with a different one of multiple components representative of the digital signal modulating a carrier in a phase-shifted keying modulation scheme.

6. The circuit of claim 5, wherein:
the circuit has a first class-D amplifier and a second class-D amplifier;
the first class-D amplifier drives the antenna via a first capacitance of the RC network, the first capacitance being connected to the first node; and
the second class-D amplifier drives the antenna via a second capacitance of the RC network, the second capacitance being connected to the first node.

7. The circuit of claim 5, wherein:
the circuit has a first class-D amplifier, a second class-D amplifier, a third class-D amplifier and a fourth class-D amplifier;
the first class-D amplifier is connected to the first node via a first capacitance of the RC network;
the second class-D amplifier is connected to the first node via a second capacitance of the RC network;
the third class-D amplifier is connected to the second node via a third capacitance of the RC network;
the fourth class-D amplifier is connected to the second node via a fourth capacitance of the RC network;
a resistance of the RC network is connected between the first and second nodes.

8. The circuit of claim 5, 6 or 7, wherein each class-D amplifier comprises a logic inverter stage.

9. A data processing system comprising a plurality of devices, each respective one of the devices comprising a respective electronic circuit for wireless communication of a respective digital signal, wherein:
   the respective circuit comprises a respective RLC tank whose respective inductance forms part of a respective antenna of the respective device;
   the respective circuit comprises multiple respective class-D amplifiers for driving the respective antenna; and
   each different one of the respective amplifiers drives the respective antenna with a different one of multiple components representative of the respective digital signal modulating a carrier in a phase-shifted keying modulation scheme.
### A. CLASSIFICATION OF SUBJECT MATTER

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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):

- H03F
- H04B
- H04L
- H03H

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

### C. DOCUMENTS CONSIDERED TO BE RELEVANT

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

* Special categories of cited documents:
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**Date of the actual completion of the international search**

3 September '08

**Date of mailing of the international search report**

11/09/2008

Name and mailing address of the ISA/

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