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(71) Applicant: ASIC AHEAD [BE/BE]; Kempische Steenweg 305, B-3500 Hasselt (BE).

(71) Applicant and

(72) Inventor: OP 'T EYNDE, Frank [BE/BE]; Berg-Bo-gaertlaan 6, B-3012 Wilsele-leuven (BE).

(74) Agent: Pronovem-Office Van Malderen; Avenue Josse Goffin, 158, B-1082 Brussel (BE).

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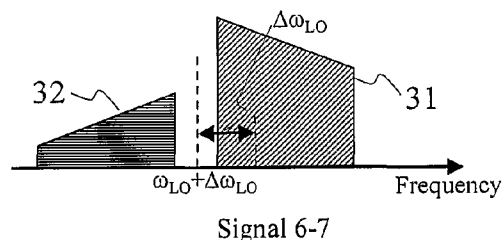
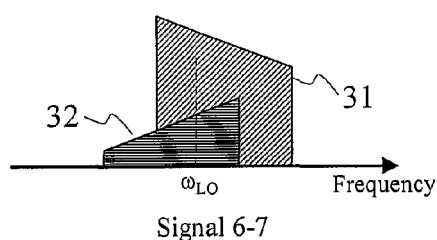
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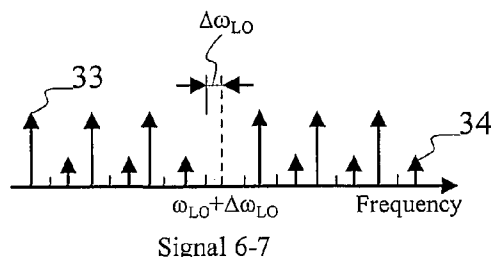
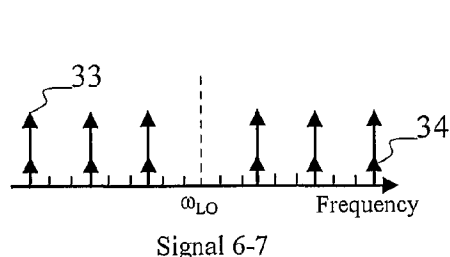
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(54) Title: METHOD FOR RADIO CALIBRATION



a)



b)

(57) Abstract: The present invention is related to a method for calibrating a radio receiver system provided with a frequency conversion circuit comprising local oscillator means operable at a first frequency. The method comprises the steps of - shifting the local oscillator means' frequency to a second frequency offset from that first frequency, - receiving a signal with the local oscillator means operable at the second frequency, - determining via the received signal calibration coefficients for compensating image signals of the received signal introduced in the radio receiver system.

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METHOD FOR RADIO CALIBRATIONField of the invention

10 [0001] The present invention relates to the field of calibration methods for radio signals.

State of the art

[0002] Receivers of electromagnetic radio signals
15 are used in a wide variety of applications. Examples are standard (music) radio broadcasting, TV broadcasting, digital voice communications such as GSM or DECT, digital data communications such as WiFi or Bluetooth and many others.

20 [0003] Modern radio receivers often incorporate a quadrature mixer to convert high-frequency signals into signals with another frequency (typically a lower frequency). The principle schematic of such a radio receiver is shown in Fig.1. An antenna signal is applied to
25 a first signal conditioning block called high-frequency section (1). In this first block, two derived signals are generated, namely an in-phase signal I (2) and a quadrature signal Q (3). These two signals are further conditioned by two signal conditioning blocks called I-path (4) and Q-path
30 (5). The resulting signals (6,7) are then combined in a signal demodulator block (8).

[0004] A practical implementation of this principle is shown in Fig.2. Here, the high-frequency section comprises a Low-Noise Amplifier (LNA) and two identical

mixers (i.e., signal multipliers) for frequency conversion. The mixers are driven by two local oscillator (LO) signals (10,11) with a phase difference of 90 degrees. The frequency converted mixer output signals (2,3) are applied to an I-path and Q-path, respectively. These paths each comprise low-pass filters (LPF), variable gain blocks (VGA) and Analogue-to-Digital Converters (ADC). The resulting signals (6,7) are then further demodulated by dedicated digital circuits.

10 [0005] Although the principle illustrated in Figs.1 and 2 is well known in the literature, it suffers from a major drawback. It is assumed that the signal gains (both in amplitude and in phase) of the I-path and the Q-path are essentially identical. Any difference between the gains (amplitude and phase) of these two signal conditioning blocks may degrade the quality of their output signals (6,7) and hence influence the demodulated output signal quality.

[0006] In order to explain this, a situation is considered wherein the antenna input signal is a sinusoidal signal. The signal (9) applied to the mixers in Fig.2 can then be expressed as:

$$V_9(t) = A_9 \cdot \sin(\omega_9 t) \quad (1)$$

The two Local Oscillator signals are given by:

$$25 \quad V_{10}(t) = \cos(\omega_{LO} t) \quad \text{and} \quad V_{11}(t) = \sin(\omega_{LO} t) \quad (2)$$

It can easily be calculated that:

$$V_2(t) = A_9 \cdot \sin(\omega_9 t) \cdot \sin(\omega_{LO} t) = \frac{A_9}{2} \cdot \cos\{(\omega_9 - \omega_{LO})t\} + \text{high-frequency terms} \quad (3a)$$

$$V_3(t) = A_9 \cdot \sin(\omega_9 t) \cdot \cos(\omega_{LO} t) = \frac{A_9}{2} \cdot \sin\{(\omega_9 - \omega_{LO})t\} + \text{high-frequency terms} \quad (3b)$$

The interpretation of these expressions is given in Fig.3(a-c). When the antenna input signal frequency (12) is larger than the local oscillator frequency (13) in Fig.3a

(i.e. $\omega_s > \omega_{LO}$), equation (3a) represents a sinusoidal signal that is leading 90° with respect to the signal expressed by (3b). These two signals are customarily represented as arrows (14,15) in an I-Q plane, as shown in Fig.3a, whereby the length of the arrows indicates signal magnitude, while their angles with respect to the horizontal axis represent their phases. The two arrows have equal lengths (hence, equal signal amplitudes) while they are placed perpendicularly to each other (indicating a 90° phase difference). The I-arrow is leading 90° with respect to the Q-arrow. A set of I and Q signals with equal amplitudes and with a phase difference of 90° is denoted as a perfect quadrature signal.

[0007] Next, the situation depicted in Fig.3b is considered. The antenna input frequency (16) is now smaller than the Local Oscillator frequency ($\omega_s < \omega_{LO}$). Expression (3a) represents a sinusoidal signal that is lagging 90° with respect to the signal expressed by (3b). This can again be represented by two arrows in the I-Q plane, whereby the I-arrow (17) is lagging 90° with respect to the Q-arrow (18).

[0008] It is important to understand that the demodulator block (8) can only distinguish between antenna signal frequencies larger than ω_{LO} and frequencies smaller than ω_{LO} by means of the phases difference between I and Q signal.

[0009] A more complex situation is shown in Fig.3c where an antenna signal with signal components at both sides of the local oscillator frequency is depicted. The I-signal (19) and the Q-signal (20) have different amplitudes and/or the phase difference is not 90° . They are not a perfect quadrature signal. Again, this can be represented in the I-Q plane. Such a non-perfect quadrature signal can

be decomposed in two perfect quadrature signals, represented by sets of arrows 21-22 and 23-24, respectively. In one set, the I-arrow (21) is leading with respect of the Q-arrow (22) while in the other set the I-arrow (23) is lagging. Hence, the non-perfect quadrature signal can be decomposed into two components, one originating from the left antenna signal component and one originating from the right antenna signal component.

[0010] In Fig.4 a situation is depicted where the signal gains and/or phases of the I-path and Q-path are not identical. As a result, a perfect quadrature signal at the inputs of these signals paths (i.e., signals (2) and (3) have the same amplitude and a phase difference of exactly 90°) is transformed into output signals 6 and 7 with unequal amplitude and/or with a phase difference that differs from 90°. This is shown in Fig.4c. In a similar way, if the two mixers of Fig.2 exhibit unequal signal gains or if the phase difference between the two Local oscillator signals 10 and 11 is not exactly 90°, a perfect quadrature signal is deformed into I and Q signals with unequal amplitudes and/or a non-90° phase difference.

[0011] Such a non-perfect quadrature signal can be decomposed into a quadrature signal with I leading Q plus another quadrature signal with I lagging Q. Hence, the deformed signals 6 and 7 are interpreted by the signal demodulator (8) as if the antenna signal is composed of two signal components situated at both sides of the local oscillator frequency (see Fig.4e). The frequency of the image component (26) is given by:

$$\omega_{image} = 2\omega_{LO} - \omega_g \quad (4)$$

This effect is called image signal generation. Due to image signal generation, an input signal at a frequency (25) above (or below) the local oscillator frequency is

interpreted as if there was a second small signal component at the image frequency (26), which is smaller (or larger) than the local oscillator frequency. The magnitude of the image frequency signal component is function of the gain error and/or the phase error.

[0012] This effect is highly undesirable, because large out-of-band signals can be interpreted as if there was an undesired in-band signal that prevents the correct demodulation of the desired in-band signals. Also, in multi-carrier systems, signals on one carrier frequency can be interpreted as if there was an image signal on another carrier frequency. This undesired image signal can influence the real signal information present on this image carrier.

[0013] Recently, methods have been developed to autocalibrate the gain and/or phase errors. Indeed, if the difference between the gains of both signal paths is known, it can be corrected by (digital) postprocessing (i.e. by multiplying the I and/or Q signal with a correction factor). Similarly, if the phase error is known, it can be corrected by postprocessing the signals 6 and 7.

[0014] Since gain and phase errors can be compensated for, the next question is to determine how much compensation or correction needs to be applied. In other words, the problem of autocorrecting the image signal generation mainly reduces to the problem of measuring the gain and phase errors and determining the appropriate correction coefficients. One approach to solve this problem is depicted in Fig.5. Here, the radio receiver is coupled to a radio transmitter. Transmitted signals are converted back to LF signals by the receiver. By applying proper test signals to the transmitter inputs (27,28), the generated image signals can be measured by observing signals 6 and 7. With a suitable search algorithm, calibration coefficients

can be determined that minimise the image signals after postprocessing.

[0015] However, this method assumes that no image signals are generated by the transmitter of Fig.5. In practice, this transmitter can suffer from an image signal generation problem, comparable to the image signal generation problem in the receiver. It is then impossible to distinguish between image signals generated by errors in the receiver or by errors in the transmitter. If the receiver would have been calibrated upfront, this method could be used to calibrate the transmitter, or vice versa. However, when receiver and transmitter both generate image signals, the set-up of Fig.5 does not allow determining separate correction coefficients for receiver and transmitter.

[0016] An alternative approach is depicted in Fig.6. Here, the receiver is calibrated by means of test signals obtained from a reference transmitter. For example, a base station in a cellular network can be assumed to contain a transmitter of superior quality, with virtually no image signal generation. When such a transmitter provides a test signal comparable to the signal of Fig.4a, the receiver output signals (6 and 7 in Fig.6) are as shown in Fig.4c-e. With proper search algorithms, the receiver circuitry can now attempt to search for correction coefficients such that after signal postprocessing, the amplitude of the image signal (26) in Fig.4e is minimised. Once these coefficients are known, they can be applied to other received signals.

[0017] In digital communications systems well-defined signals are transmitted during the pre-amble of communications bursts. Indeed, at the start of each transmit burst, the base station is transmitting a well-defined signal that allows the receivers of the other stations to detect a transmission burst start. For

standards such as GSM or DECT, these pre-ambls can be used to determine correction coefficients for autocalibration of image signal generation. This is shown in Fig.7a.

[0018] However, for multi-carrier systems such as
5 WiFi or WiMax, the pre-amble has a signal spectrum as shown in Fig.7b (left). It contains a number of signal tones (29), placed symmetrically around the centre frequency. Image tones (30) generated by receiver gain errors or phase errors coincide with the signal tones at the opposite side
10 of the centre frequency. Hence, these image signals are very difficult to detect. In other words, some existing communications standards do not provide adequate test signals for autocalibration of image signal generation. Introducing such test signals would require modifications
15 to existing communications standards. This is a very difficult process.

[0019] There is thus a need for a method for determining calibration coefficients wherein image signal generation is properly dealt with, irrespective of the
20 applied modulation scheme or of where the image signals are created.

Aims of the invention

[0020] The present invention aims to provide a
25 calibration method that overcomes the problems encountered in the prior art solutions.

Summary of the invention

[0021] The present invention relates to a method for
30 calibrating a radio receiver system provided with a frequency conversion circuit comprising local oscillator means operable at a first frequency. The method comprises the steps of

- shifting the local oscillator means' frequency to a second frequency offset from the first frequency,
- receiving a signal with the local oscillator means operable at the second frequency,
- 5 - determining via the received signal calibration coefficients for compensating image signals of the received signal introduced in the radio receiver system.

[0022] In a preferred embodiment said signal is a
10 test signal from a reference transmitter. The reference transmitter is advantageously a base station transmitter from a wireless communications network. The test signal preferably contains the pre-amble of a transmission burst.

[0023] In a preferred embodiment the test signal is
15 a multi-carrier signal. The second frequency is then preferably offset from said first frequency by an amount equal to an integer multiple of half of the carrier frequency spacing.

[0024] In a further aspect the invention relates to
20 a method for correcting a received signal converted in frequency in a frequency conversion circuit of a radio receiver system, whereby the frequency converting circuit comprises local oscillator means operating at a first frequency. The method comprises the steps of

- 25 - determining correction information by applying the method as previously described,
- shifting the local oscillator means' frequency back to the first frequency,
- receiving a signal in the radio receiver system and
30 converting the received signal in frequency with the frequency conversion circuit, and
- correcting the frequency converted received signal by means of the correction information.

Short description of the drawings

- [0025] Fig. 1 represents a quadrature radio receiver scheme.
- [0026] Fig. 2 represents an implementation of a quadrature radio receiver.
- [0027] Fig. 3 represents some input signals and their corresponding I-Q signals.
- [0028] Fig. 4 represents deformed quadrature components.
- 10 [0029] Fig. 5 represents autocalibration with a loopback.
- [0030] Fig. 6 represents autocalibration with a reference antenna signal.
- [0031] Fig. 7 represents some autocalibration signal spectra.
- 15 [0032] Fig. 8 represents the LO frequency shifting during autocalibration.
- [0033] Fig. 9 represents a flow chart of the image signal reduction autocalibration algorithm according to the invention.
- 20

Detailed description of the invention

- [0034] A way to overcome the above-mentioned problem according to the present invention is depicted in Fig.8.
- 25 Fig.8a (left) shows an antenna signal spectrum (31) that contains energy at frequencies on both sides of the local oscillator frequency. The image signal spectrum (32) coincides (entirely or partially) with the original antenna signal spectrum. As a result, it is very difficult to distinguish this image signal from the original signal and hence, it is very difficult to determine autocalibration coefficients that minimise this image signal. However, when during the calibration process the local oscillator frequency is changed, the frequencies of the image signals
- 30

are changed (see expression (4)). The local oscillator frequency can be changed in such a way that the image signal spectrum is moved away from the original antenna signals. This is depicted in Fig.8a (right). The image
5 signals can now be observed and calibration coefficients can be determined to minimise the image signals.

[0035] A more concrete example is shown in Fig.8b. This drawing (left) shows the signal spectrum of an IEEE802.16 (WiMax) signal (33), during the pre-amble. WiMax
10 is a wireless communications standard that is using multi-carrier signals, i.e. signals that contain a number of well-defined tones. During the pre-amble, signal energy is transmitted on every third tone, while no signal energy is present on the other two-third of the tones. Image signals
15 (34) generated due to gain or phase imbalance between the I and Q paths coincide with existing tones. They are very difficult to measure.

[0036] When during the procedure for determining the calibration coefficients the local oscillator frequency is
20 shifted by an amount, equal to the frequency difference ($\Delta\omega$ in Fig.8b) between two tones, the image signals are shifted in frequency by an amount of $2\Delta\omega$ (see Fig.8b, right). (Note that the term 'frequency' is used or the pulsation ω , which actually equals, as generally known, frequency multiplied
25 by a factor 2π .) Hence, they fall on frequencies that are allocated to signal tones with no energy during the pre-amble. In this way, the image signals can be measured easily. With the method as previously explained the proper gain corrections and phase corrections can be determined to
30 minimise the image signals after signal postprocessing. During normal operation (i.e., not during the autocalibration test phase), the local oscillator frequency can be set back to the original value. The calibration

coefficients determined during the test phase (i.e., the calibration method) can now be used for postprocessing signals 6 and 7. This results in signals with minimised image signals.

- 5 [0037] The algorithm representing the autocalibration method and the method for correcting a received signal as described above is depicted in Fig.9.

CLAIMS

1. Method for calibrating a radio receiver system provided with a frequency conversion circuit comprising local oscillator means operable at a first frequency, said method comprising the steps of

- shifting said local oscillator means' frequency to a second frequency offset from said first frequency,
- receiving a signal with said local oscillator means operable at said second frequency,
- determining via said received signal calibration coefficients for compensating image signals of said received signal introduced in said radio receiver system.

2. Method for calibrating as in claim 1, wherein said signal is a test signal from a reference transmitter.

3. Method for calibrating as in claim 2, whereby said reference transmitter is a base station transmitter from a wireless communications network.

4. Method for calibrating as in claim 2 or 3, whereby said test signal contains the pre-amble of a transmission burst.

5. Method for calibrating as in any of the previous claims, whereby said test signal is a multi-carrier signal.

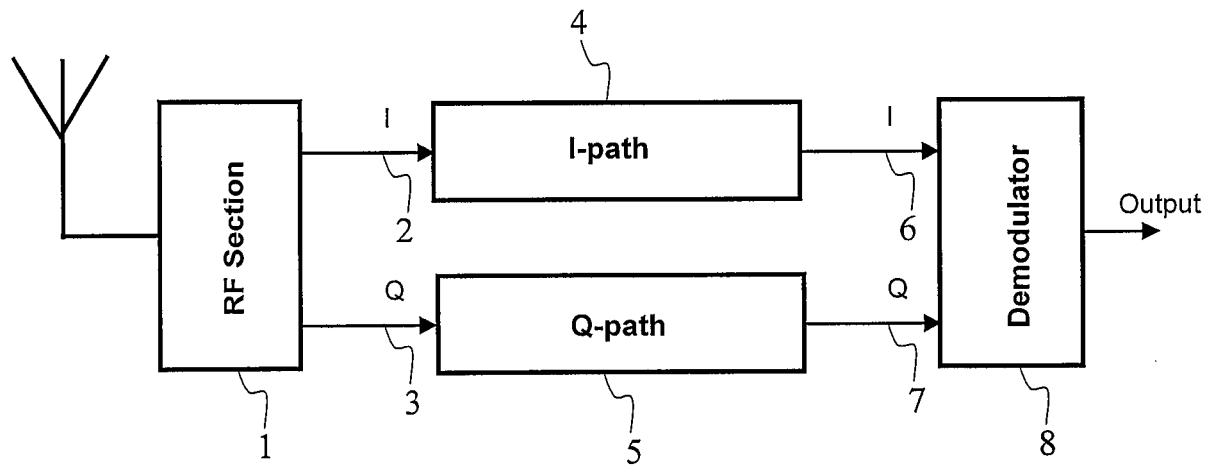
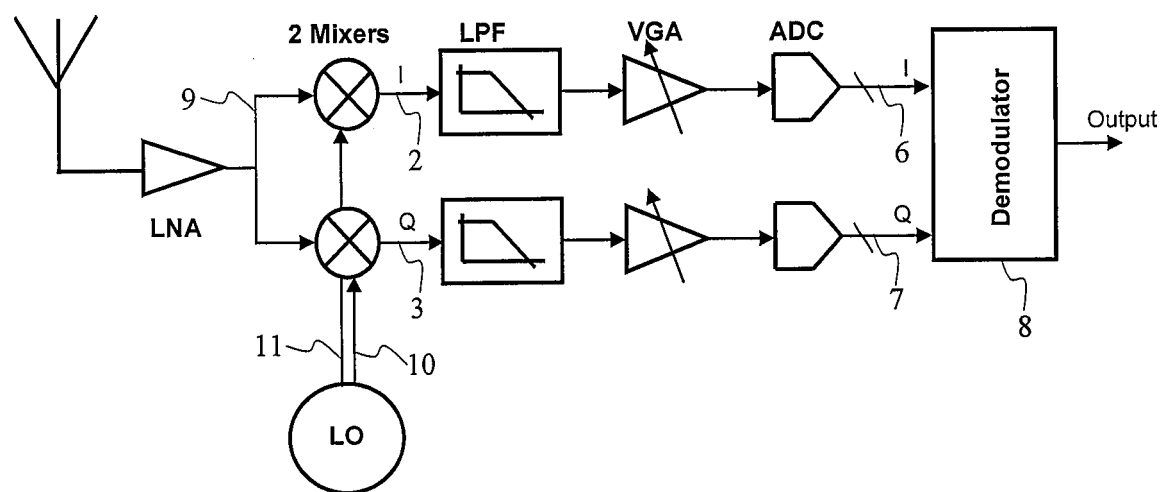
6. Method for calibrating as in claim 5, whereby said second frequency is offset from said first frequency by an amount equal to an integer multiple of half of the carrier frequency spacing.

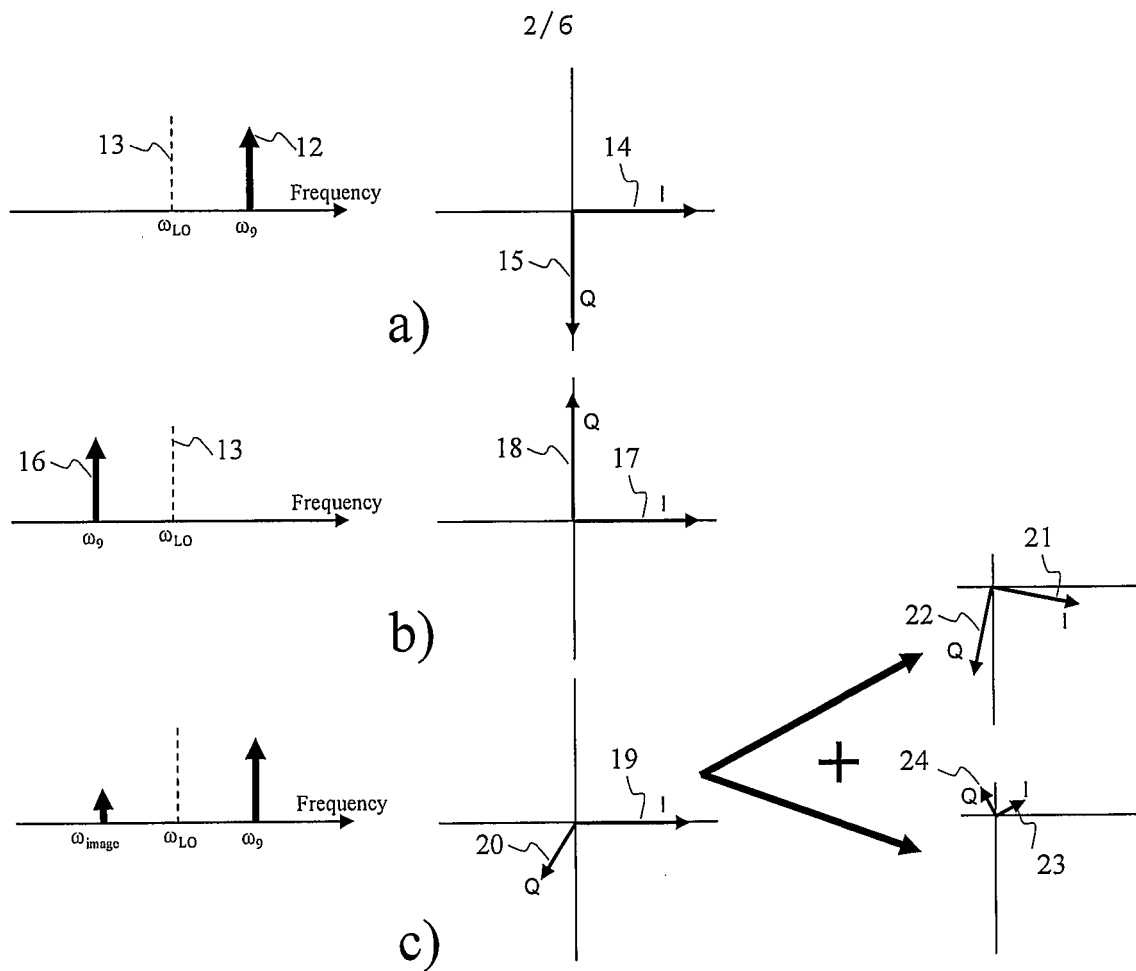
7. Method for correcting a received signal converted in frequency in a frequency conversion circuit of a radio receiver system, said frequency converting circuit

comprising local oscillator means operating at a first frequency, said method comprising the steps of

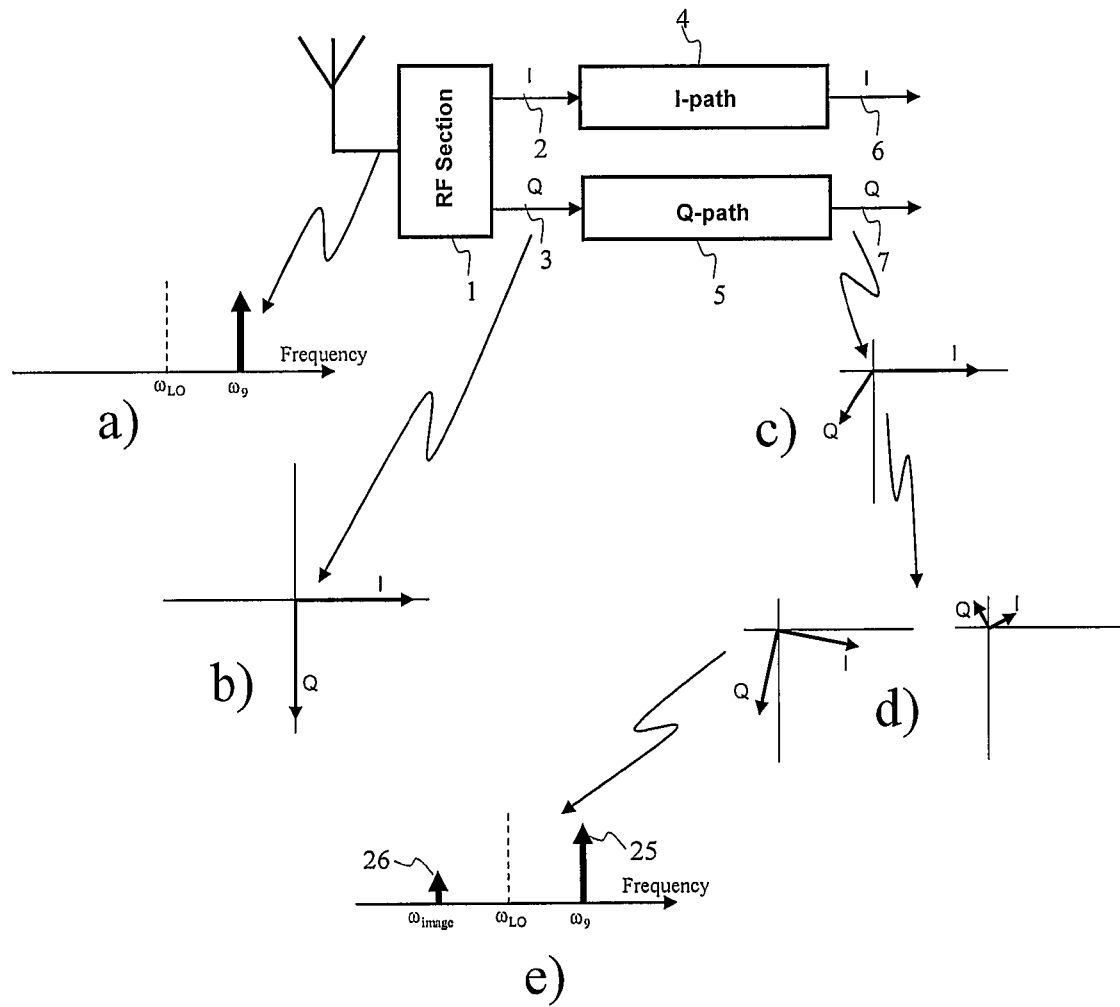
- determining correction information by applying the method as in any of claims 1 to 6,
- 5 - shifting said local oscillator means' frequency back to said first frequency,
- receiving a signal in said radio receiver system and converting said received signal in frequency with said frequency conversion circuit, and
- 10 - correcting said frequency converted received signal by means of said correction information.

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Fig. 1Fig. 2

**Fig. 3**

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**Fig. 4**

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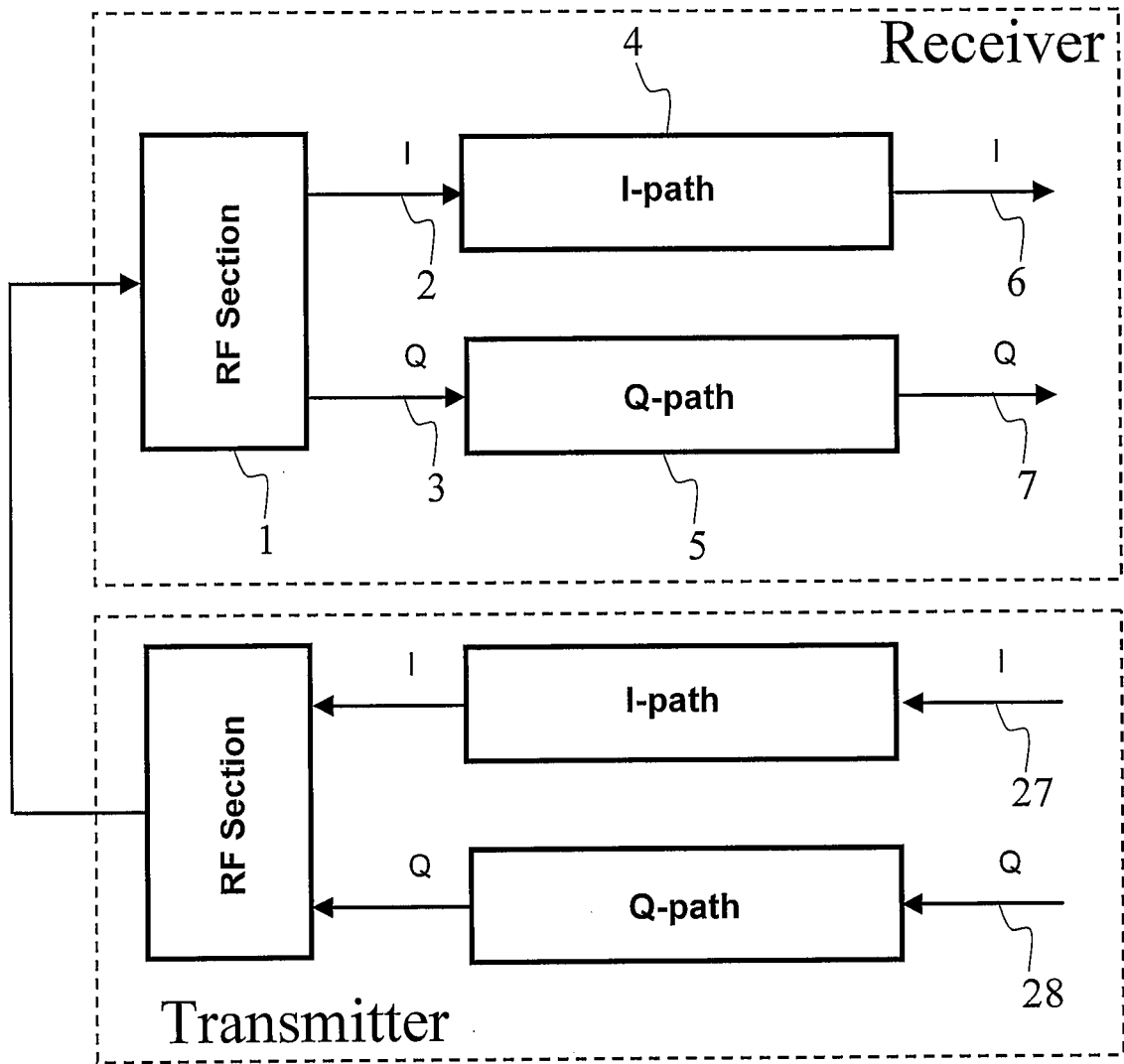


Fig. 5

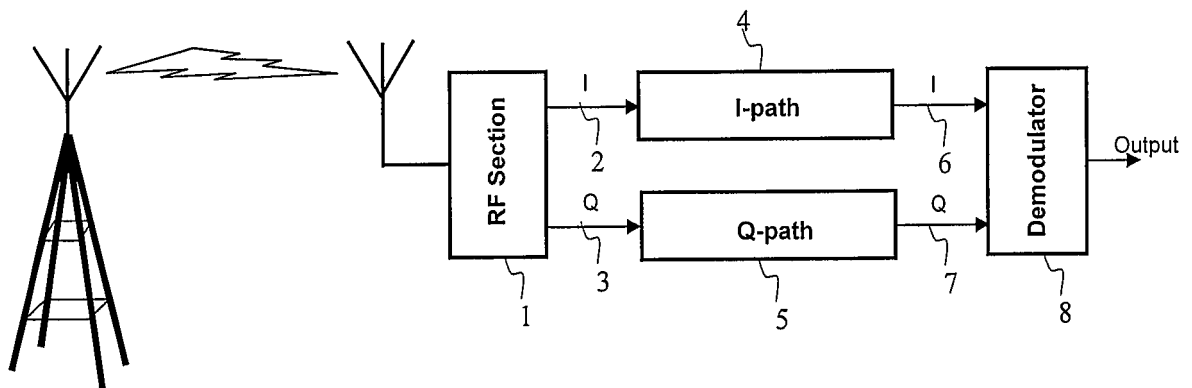


Fig. 6

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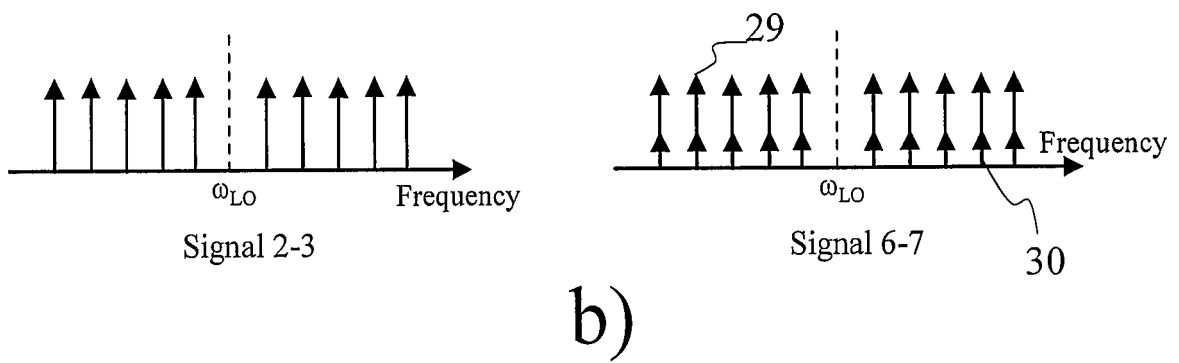
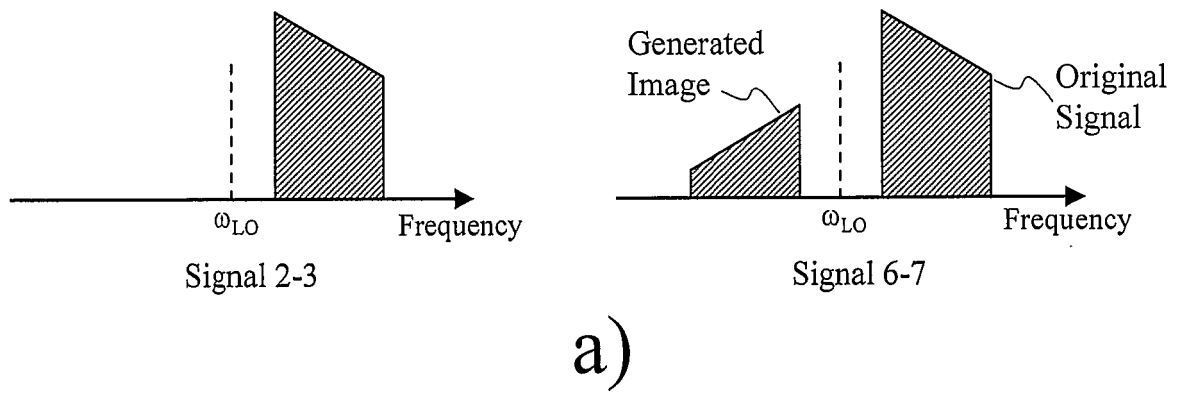


Fig.7

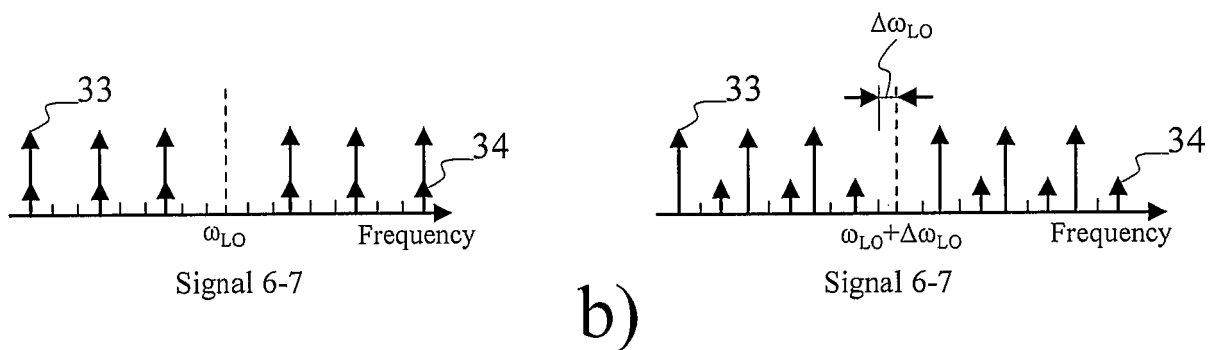
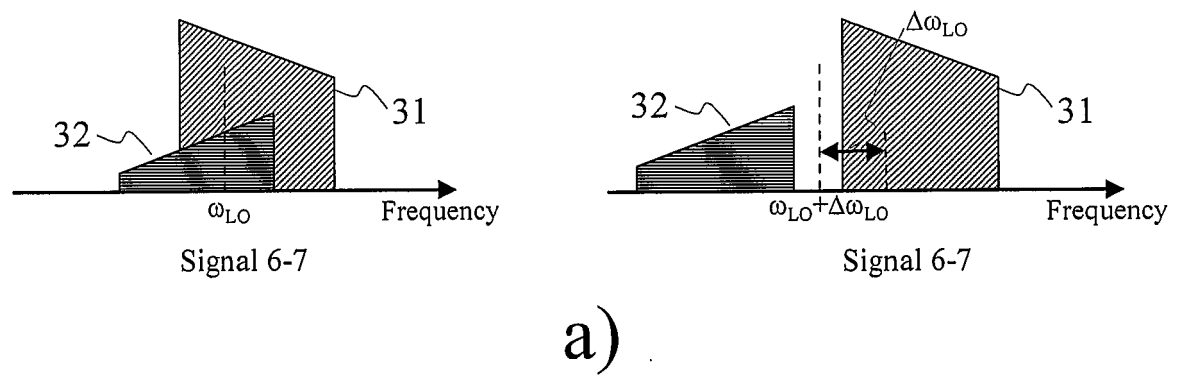
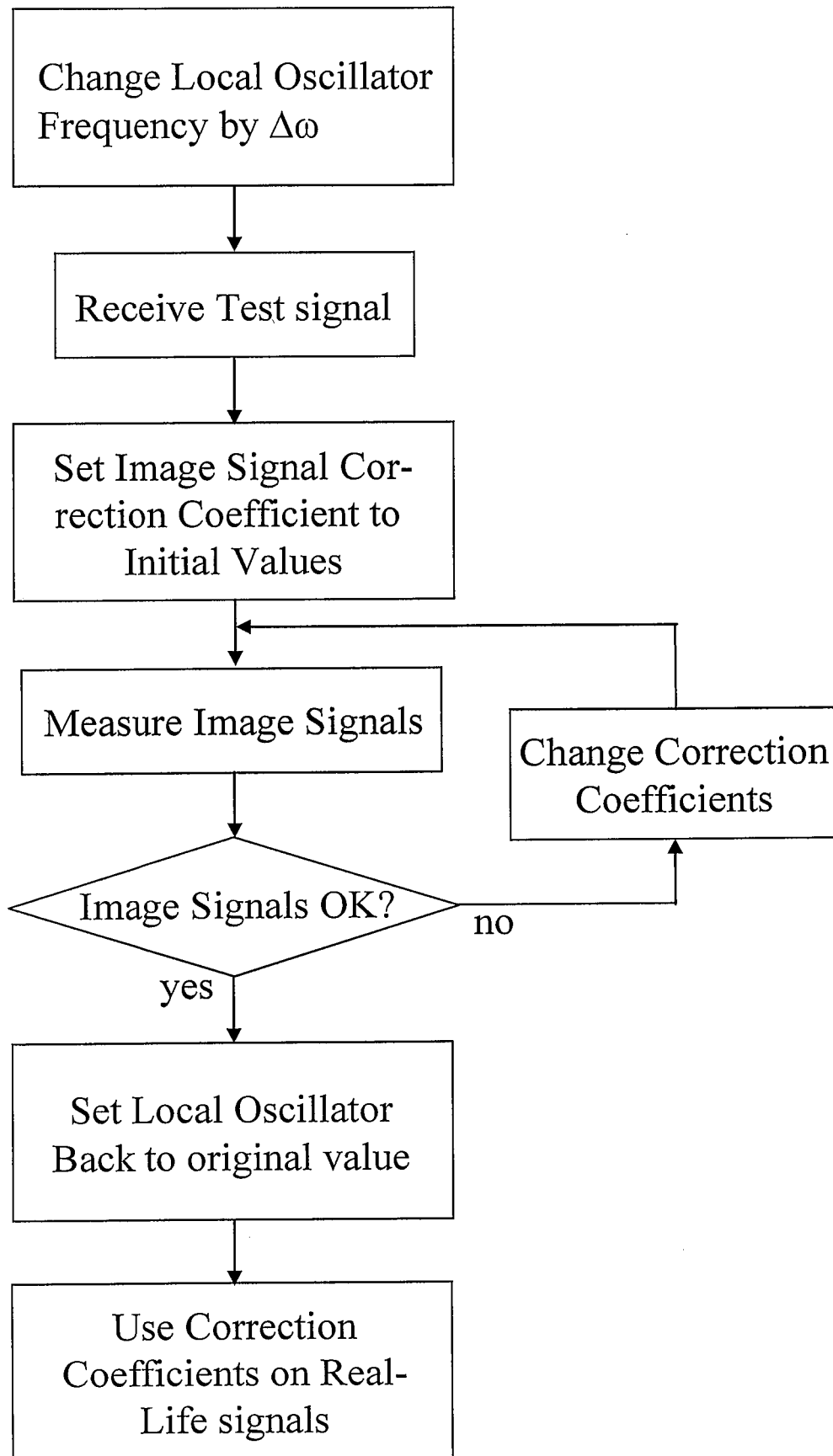


Fig.8

Fig. 9