A NEW RADIO RECEIVER SYSTEM FOR PERSONAL COMMUNICATIONS

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Abstract

A new radio receiver system for personal communications is described. This technology incorporates direct conversion into an integrated circuit in such a way that the need for discrete IF filters is avoided. It also employs a second IF functional circuit that contains a carrier leak detector and an adjustment-free system. The carrier leak detector suppresses the level of unwanted carrier leak and the adjustment-free system automatically compensates for any variation in circuit response that corrupts the performance of the receiver. The resulting design is particularly suitable for use in wireless devices such as pagers and cordless telephones.

Introduction

Wireless personal communication devices like pagers and cellular and cordless telephones are getting smaller, more compact, and more lightweight in design. These design features are realized due to improvements in device-mount technology and developments of various kinds of devices. The devices are generally integrated

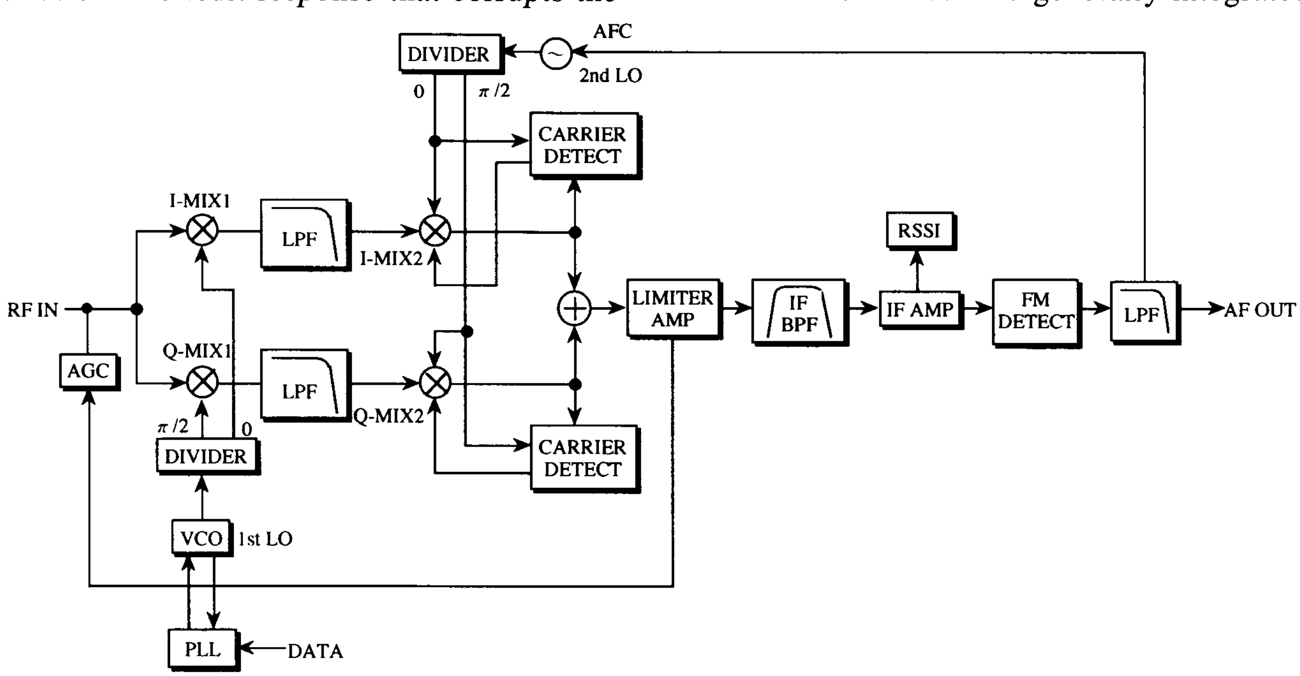

Fig. 1 A New Radio Receiver System for Personal Communications

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circuits or ICs that pack more of the necessary system functions, thereby eliminating the need for more discrete components, or discrete devices where size is reduced as much as possible. In other words, it is the same system technology with just less device compositions. It is merely an optimization of available physical space and by no means a revolutionary technological change.

This paper describes a new radio receiver system that promises to reduce the size and weight of personal communication devices. The new system combines and incorporates into an IC the concept of direct conversion and a second IF (Intermediate Frequency) functional circuit. It allows the inclusion into the design approach of a circuit that functions as a discrete IF filter and know-how in traditional IC-discrete filter interface. No more discrete IF filters are needed.

The second IF functional circuit contains a carrier leak detector and an adjustment-free system. The carrier leak detector suppresses the level of unwanted carrier leak and the adjustment-free system guarantees that the receiver works properly under any variation in circuit response.

The new system also has the same image frequency cancel function, selectivity, and AMRR (Amplitude Modulation Rejection Ratio) characteristic with that of the conventional double-conversion radio receiver system.

The Configuration of the New Radio Receiver System

Fig. 1 shows the block diagram of the new radio receiver system. Compared with a conventional double-conversion radio receiver system shown in Fig. 2, there are no discrete IF filters. There is no discrete discriminator, either, because the FM (Frequency Modulation) detector implements the double-pulse count method. In the double-conversion receiver system, the frequency of the second local oscillator is high (over 10 MHz) because the first IF is high. The second

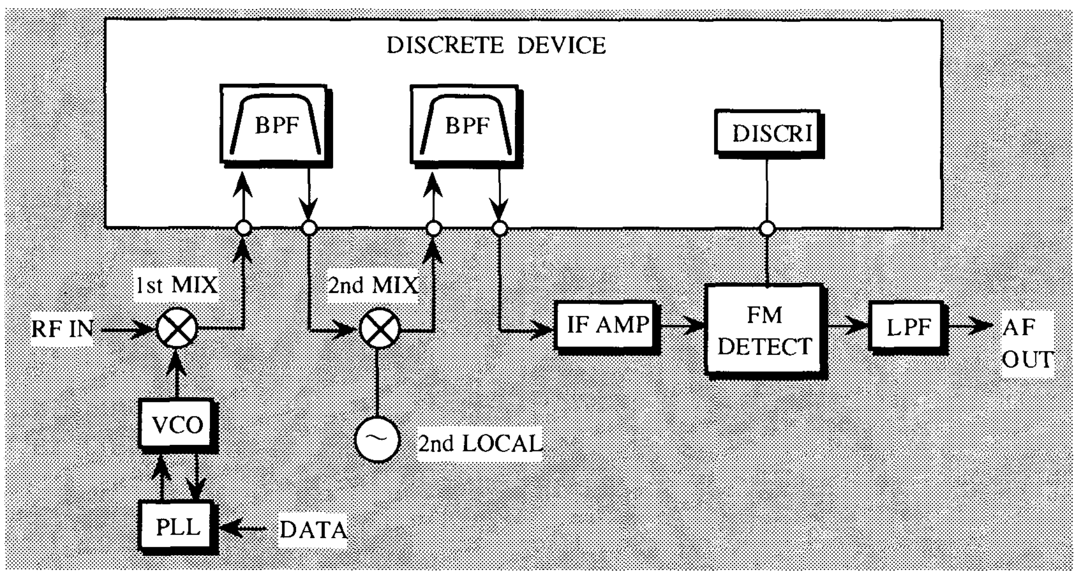

Fig. 2 Conventional Double-Conversion System

local oscillator requires stability and necessitates a crystal oscillator which adds to the number of discrete components. On the other hand, in the new system, since the frequency of the second local oscillator is just tens of kilohertz, it does not require much stability and can be built inside the IC.

This is how the new system works. The received RF (Radio Frequency) signal is fed into two subsystems we call I (for in-phase) and Q (for quadrature phase). The I subsystem consists of mixers I-MIX1 and I-MIX2 and a LPF (Low-Pass Filter), while the Q subsystem consists of mixers Q-MIX1 and Q-MIX2 and another LPF. In the I subsystem, the RF signal is mixed with a signal of the same frequency and phase from the first local oscillator in mixer I-MIX1. I-MIX1 in effect converts the received RF signal into a baseband signal. The output of I-MIX1 then passes through an active LPF which eliminates the image frequency leaving only the baseband signal. (Image frequencies will be explained in detail in the next section.) The baseband signal is then mixed in another mixer I-MIX2 with a signal from the second local oscillator which is in-phase but with a frequency of about 65 kHz $\pm$ 30%. The output of I-MIX2 is the output of the I subsystem.

The Q subsystem functions exactly like the I subsystem. The only difference is that the signal from the first and second local oscillator is in quadrature phase or 90° out-of-phase. In the first local oscillator, the VCO (Voltage Control Oscillator) and PLL (Phase-Locked Loop) which is controlled by a set of data from a microcomputer generates a signal twice the frequency of the RF signal. The divider then divides the frequency of the signal into two and produce two signals that are in quadrature phase. On the other hand, in the second local oscillator, the divider divides the frequency of the signal from the oscillator into four and produces the two in-quadrature-phase signals.

The IF outputs from the I and Q subsystem are added, cancelling another set of image frequencies as will be explained in the next section. The resulting sum of the signals is then fed to the limiter amplifier or limiter amp. The limiter amp suppresses any AM signal component that are due to effects of fading and multipath. It guarantees an AMRR of 40 dB for the system. The limiter amp is also coupled with an overload AGC (Automatic Gain Control) to form a loop. The AGC makes sure that the received RF signal does not exceed the dynamic range of the mixers and the active LPFs in the I and Q subsystem. With the AGC, nonlinearity does not occur in the operation of the active LPFs.

The output of the limiter amp is fed to the IF BPF (Band-Pass Filter). The IF BPF is a biquad-type filter that uses an operational amplifier or op amp. It determines the selectivity of the system. After passing the IF BPF, the IF signal is amplified in the IF amplifier and then fed to the RSSI (Radio Signal Strength Indicator) amplifier and FM detector. The FM detector employs a double-pulse count method. Unlike the quadrature detector circuit, it does not need a discrete discriminator. In the case of a double-pulse count detector, the distortion of the signal is small because the f-v characteristic is a straight line. Also, the detection efficiency is high because of the low frequency (65 kHz $\pm$ 30%) of

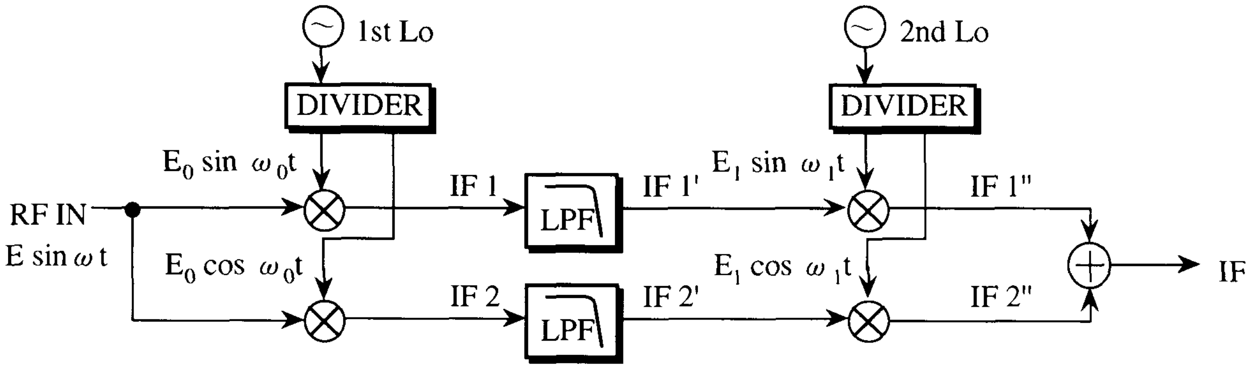

Fig. 3 New Image Frequency Signal Canceling System

the IF. After detection, the signal is converted to a baseband signal and passes through a LPF. The output is then fed to the baseband processing block of a personal communication device. The LPF is also coupled with the second local oscillator and acts as an AFC (Automatic Frequency Controller) and stabilizes the generated frequency.

The Direct Conversion for the Off-Chip-Filter-Less System

As mentioned in the previous section, in both the I and Q subsystem, the received RF signal is mixed with a signal of equal frequency generated by the PLL. The output is a so-called zero IF and the received signal is converted to a baseband signal. After passing through the LPF, it will be remodulated with a carrier from the second local oscillator (65 kHz ± 30%). Adding together the output of the two subsystems, an image frequency signal suppression of more than 40 dB can be achieved without any adjustment.

Let us suppose that an RF signal $E \sin \omega t$ enters the system as shown in Fig. 3. This is mixed with the output from the first local oscillator $E_0 \sin \omega_0 t$ and $E_0 \cos \omega_0 t$ which are in quadrature phase. The outputs IF1 and IF2 become

$$\mathrm{IF\,1} = \frac{E \cdot E_0}{2}\left\{-\cos(\omega+\omega_0)t + \cos(\omega-\omega_0)t\right\}$$

$$\mathrm{IF\,2} = \frac{E \cdot E_0}{2}\left\{\sin(\omega+\omega_0)t + \sin(\omega-\omega_0)t\right\}$$

IF 1 and IF2 pass through LPFs and become IF1' and IF2'.

$$\mathrm{IF\,1'} = \frac{E \cdot E_0}{2}\cos(\omega-\omega_0)t$$

$$\mathrm{IF\,2'} = \frac{E \cdot E_0}{2}\sin(\omega-\omega_0)t$$

The higher frequency component $\omega+\omega_0$ in IF1 and IF2 is eliminated. This is the first set of image frequency.

Again mixing IF1' and IF2' with the signals from the second local oscillator $E_1 \sin \omega_1 t$ and $E_1 \cos \omega_1 t$ results to IF1" and IF2".

$$\mathrm{IF\,1''} = \frac{E \cdot E_0 \cdot E_1}{4}\left\{\sin(\omega-\omega_0+\omega_1)t + \sin(-\omega+\omega_0+\omega_1)t\right\}$$

$$\mathrm{IF\,2''} = \frac{E \cdot E_0 \cdot E_1}{4}\left\{\sin(\omega-\omega_0+\omega_1)t - \sin(-\omega+\omega_0+\omega_1)t\right\}$$

Adding IF1" and IF2" gives us IF

$$\mathrm{IF} = \frac{E \cdot E_0 \cdot E_1}{2}\left\{\sin(\omega-\omega_0+\omega_1)t\right\}$$

The lower frequency component $\omega_1-(\omega-\omega_0)$ is cancelled in the addition process. This is the second set of the image frequency.

When $\omega=\omega_0$, IF becomes

$$IF = \frac{E \cdot E_0 \cdot E_1}{2} (\sin \omega_1 t)$$

If the RF signal is modulated, IF will be the carrier for the intelligence (data or audio) in the modulated signal.

The Carrier Leak Detector and the Adjustment-Free System

As mentioned previously, the new system incorporates a second IF functional circuit. It contains a carrier leak detector and an adjustment-free system.

(1) Carrier Leak Detector

I-MIX2 and Q-MIX2 in the I and Q subsystem are coupled with a carrier leak detector. The carrier leak detector suppresses the level of the carrier leak from the second local oscillator at the output of the mixer. It is the most important circuit in this new system. And without it, sensitivity is lost and the receiver can not pick up signals at very low level. How much the carrier leak is suppressed determines the sensitivity of the receiver. The carrier leak also degrades the circuit response of the system from the IF down to the end of the system. If there is a carrier leak, even though there is no RF signal received, the system will function as if there is one and will cause a system error.

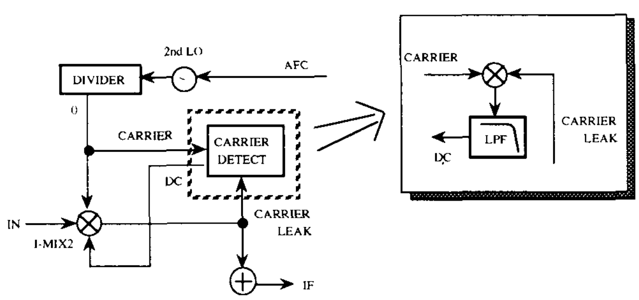

Fig. 4 Carrier Leak Suppressing System

Fig. 4 shows the carrier leak detector. Carrier leak occurs when there is a DC offset in MIX2 caused by unbalance between transistors that receives input signal and reference (input bias) in differential amplifier. This DC offset is also a result when the input signal has already received DC offset from previous circuit stage. When there is a DC offset, carrier from the second local oscillator leaks at the output of MIX2. To cancel this DC offset, the carrier leak is detected and amplified in the synchronous detector inside the carrier leak detector with the carrier as reference. The output of the synchronous detector passes through a LPF leaving only a DC signal.

In the figure, let us suppose that

carrier : $E_1 \sin \omega_1 t$
carrier leak : $K \sin \omega_1 t$

$E1 \sin \omega 1t$ and $K \sin \omega 1t$ are mixed in the synchronous detector. Thus

$$E_1 \sin \omega_1 t \cdot K \sin \omega_1 t$$
$$= \frac{E_1 K}{2} \left\{ -\cos(\omega_1+\omega_1)t + \cos(\omega_1-\omega_1)t \right\}$$
$$= -\frac{E_1 K}{2} \cos 2\omega_1 t + \frac{E_1 K}{2}$$

When this passes through a LPF, the frequency component $2\omega 1$ disappears. Therefore,

$$E_1 \sin\omega_1 t \cdot K \sin\omega_1 t = \frac{E_1 K}{2}$$

and becomes a DC signal that is directly proportional to the level of the carrier leak. This DC signal is used as feedback to the reference of MIX2 and cancels the DC offset caused by the unbalance. The carrier leak can be suppressed up to more than 60 dB and as a result, a sensitivity of -118 dBm can be guaranteed.

(2) Adjustment-Free System

The IF signal is demodulated in the FM detector after passing through the IF BPF. Because variations in the absolute value of resistors and capacitors due to the wafer manufacturing process and temperature changes affect circuit response, the FM detector and IF BPF forms a closed loop with the second local oscillator. The resistors and capacitors that determine the circuit response of the FM detector, IF BPF, and second local oscillator are designed with the same material, layout and geometry so that the closed loop will perform accordingly to changes in circuit response without compromising the characteristics of the whole system. Moreover, after demodulation, AFC is applied to the second local oscillator to eliminate the relative variation between the devices of the different circuits in order to assure a more stable system characteristic. All the adjustments to the system characteristics is done automatically by the system itself. No manual adjustment in the external discrete device is necessary to change and optimize the system characteristics. Thus, it is an adjustment-free system.

Selectivity

Since the new system is an off-chip-filter-less system, the selectivity is determined by the characteristics of the on-chip filters. The LPF of the I and Q subsystem is a fourth-order Butterworth LPF that uses an op amp. It is shown in Fig. 5 with its frequency characteristics in Fig. 6. There is a 30 dB attenuation at the point where the adjacent channel exists (at 15kHz).

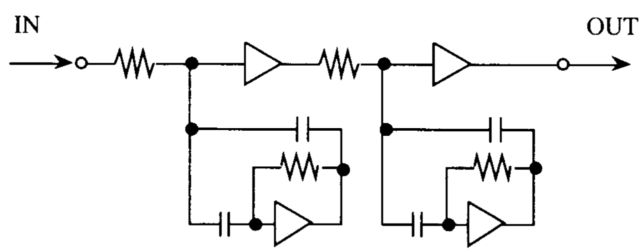

Fig. 5 LPF_I/LPF_Q
Fourth-Order Butterworth

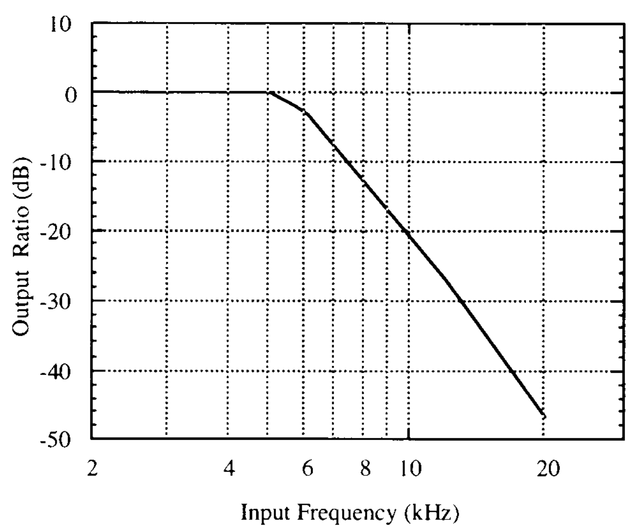

Fig. 6 LPF Frequency Characteristic

The IF BPF shown in Fig. 7 is also a biquad-type filter that uses an op amp. By combining low-pass, high-pass, and band-pass filter in its construction, there is a 50 dB attenuation at the adjacent channel point. This frequency characteristic is shown in Fig. 8.

Therefore, the whole system guarantees a selectivity of 80 dB (at 15 kHz).

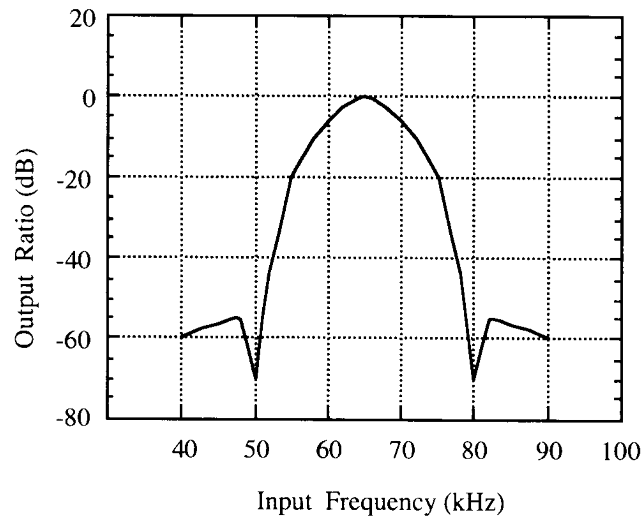

Fig. 8 IF BPF Frequency Characteristic

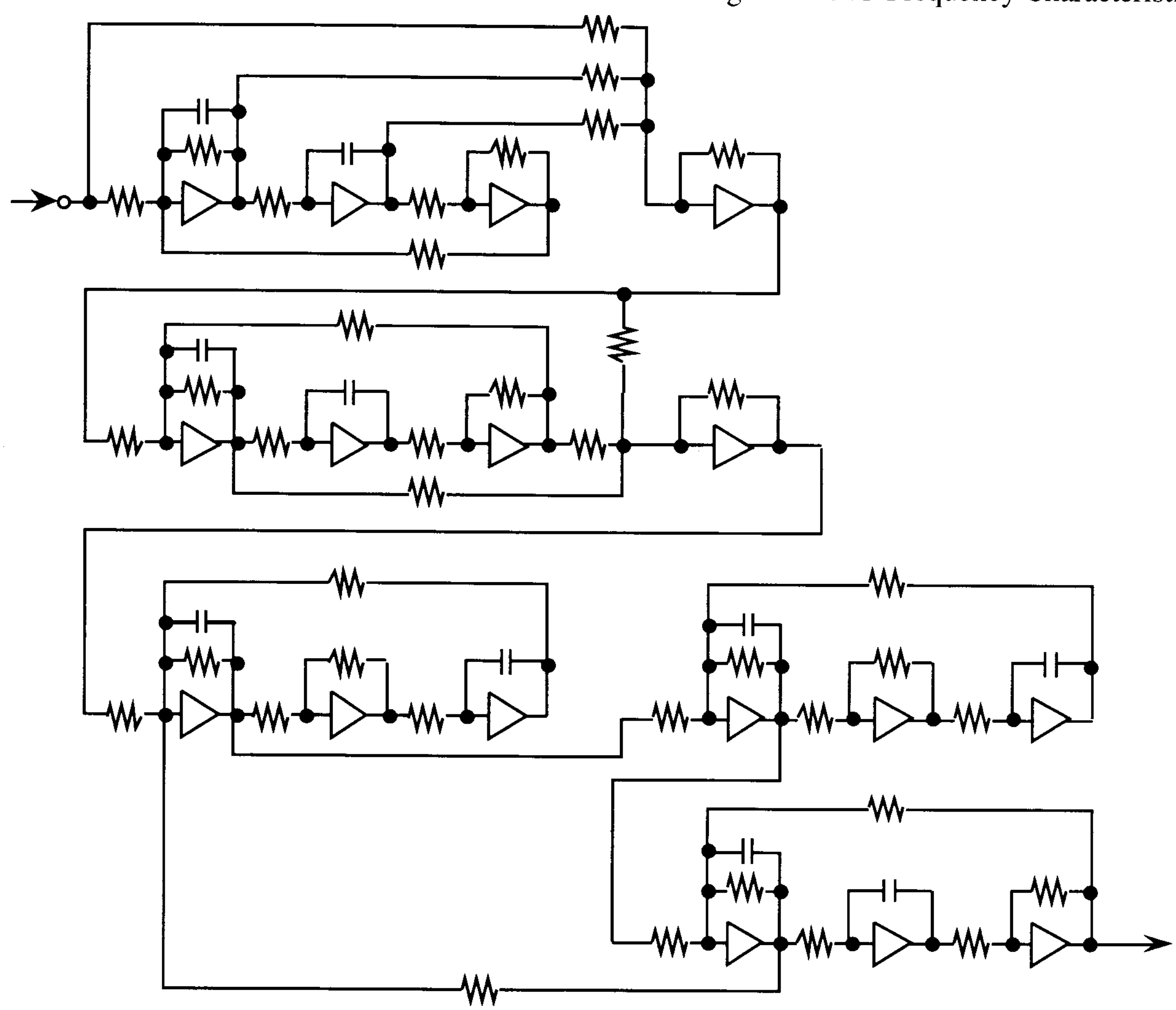

Fig. 7 Biquad-Type IF BPF

Characteristics of the New System

This section describes characteristics of the new radio receiver system as applied to analog cordless telephone operating at 46/49 MHz band in the U.S.A. The same characteristics hold for other types of personal communication devices.

Input-output characteristics is shown in Fig. 9. It also shows the THD (Total Harmonic Distortion) and RSSI voltage output. SINAD is -118 dBm, maximum S/N ratio is 60 dB, and THD is below 1%. The RSSI has an operating range of about 60 dB.

Fig. 10 shows the C/N ratio of the first local oscillator. C/N ratio is about 80 dB.

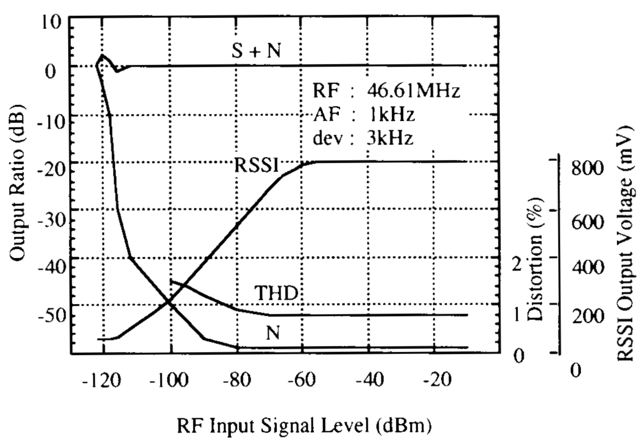

Fig. 9 I/O Characteristic

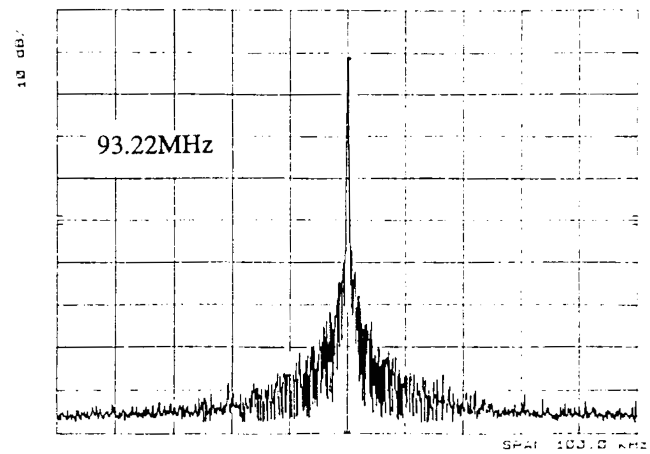

Fig. 10 First Local Oscillator VCO Spectrum

Conclusion

In conclusion, a new revolutionary technology in radio receiver system for personal communications is developed. This technology eliminates the need for external discrete IF filters by effectively implementing the concept of direct conversion and introducing new circuits that take into account the characteristics of semiconductor devices.

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Biographies

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