Contents

1. Introduction

1.1. Application:

1. Non-contact detection and monitoring of human cardiopulmonary activity health care applications:
   - ❖ Microwave Doppler radar measurement of heart and respiration rates would be useful in situations where electrode and chest-strap monitors cause discomfort, skin irritation or are difficult to apply. E.g. burn victim.
   - ❖ It would be ideal in situations where individuals need to move between measurement stations without the restriction of electrodes, leads, or cuffs.
   - ❖ It reduces the need for patients to visit their physician's office for routine medical checkups.
   - ❖ Neonates, infants at risk of sudden infant death syndrome, adults with sleep disorders, and a non-contact heart and respiration rate monitor eliminate affixed electrodes for these patients.
2. Military battlefields: Allows soldiers to remotely detect vital signs of others within range, even behind a wall.
3. Research in medicine and biology: Enables researchers to remotely monitor vital signs of their subjects without subjects' noticing

1.2. Principle of the system:

Microwave Doppler radar has been used to sense physiologic movement since the early 1970.

Advancing in technology of micro fabrication made it possible to integrate a Doppler radar in a single chip to be compact, lightweight and cheap in the market.

Radar motion sensing systems usually transmit a continuous wave (CW) signal, which is reflected off the target and then demodulated in the receiver. A target with time-varying position reflects the signal and modulates its phase proportional to the target's time varying position. Therefore, CW radar with the chest as the target will receive a signal similar to the transmitted signal, with its phase modulated by the time-varying chest position. Demodulating the phase will then give a signal directly proportional to the chest position, which contains information about movement due to both heartbeat and respiration. Heart and respiration rates can be extracted from this data figure.1.

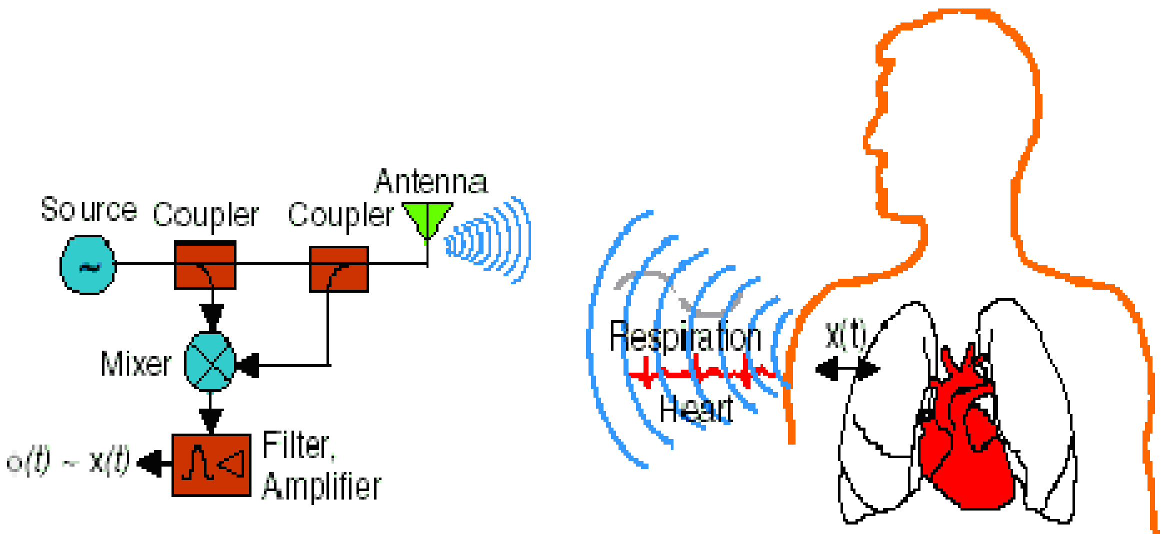
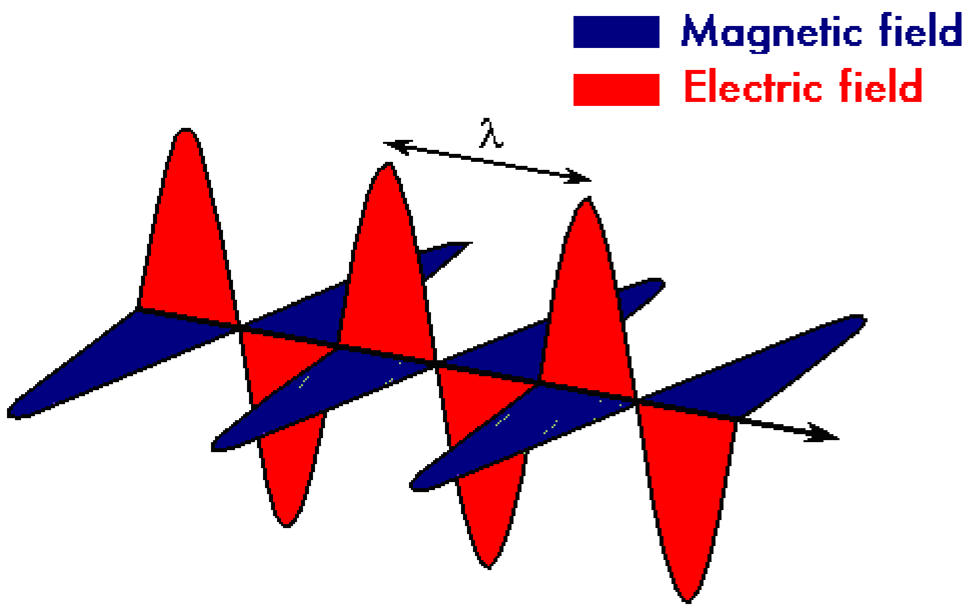


Fig.1 A single antenna system with a single subject. A homodyne radio is used to detect a phase shift proportional to chest displacement due to cardiopulmonary activity.

The peak-to-peak chest motion due to respiration in adults ranges from 4 mm to 12 mm, while the peak-to-peak motion due to the heartbeat is about 0.5 mm. When the wavelength is greater than twice the peak-to-peak motion, the signal can be demodulated by simply multiplying the signal with an unmodulated signal from the same source. When the wavelength is less than twice the peak-to-peak motion, a quadrature receiver is required and more advanced signal processing must be used to accurately demodulate the signal. At 1.6 and 2.4 GHz, the wavelength is 18.75 cm and 12cm respectively, so the wavelength is much greater than the chest motion for measurements made in this device.

1.3. Electromagnetic Waves

Electromagnetic (EM) radiation is a self-propagating wave in space with electric and magnetic components. These components oscillate at right angles to each other and to the direction of propagation, and are in phase with each other.



1.3.1. Frequency, wavelength and energy

Waves of the electromagnetic spectrum vary in size, from very long radio waves the size of buildings to very short gamma rays smaller than atom nuclei. Frequency is inversely proportional to wavelength, according to the equation:

$$\mathbf{v} = \mathbf{f}\,\boldsymbol{\lambda} \quad (1.1)$$

Where:

v is the speed of the wave (c in a vacuum, or less in other media),
f is the frequency.
λ is the wavelength.

As waves cross boundaries between different media, their speeds change but their frequencies remain constant.

The frequency of the wave is proportional to the magnitude of the particle's energy. Moreover, because photons are emitted and absorbed by charged particles, they act as transporters of energy. The energy per photon is:

$$\boldsymbol{E = h\,f} \quad (1.2)$$

Where:
E is the energy.
h is Planck's constant = 6.626×10^{-34} J.s
f is frequency.

1.3.2. Human safety:

We feel infrared light as heat and the radios pick up the messages encoded in radio waves emitted by radio stations.

Ultraviolet light has high enough energy to damage the skin cells. The special bulbs called ``black lights'' produce a lot of UV and were used by hospitals to kill bacteria, amoebas, and other micro-organisms. X-rays are produced by very hot things in space.

X-rays have more energy than UV, so they can pass through skin, muscles, and organs. They are blocked by bones, so when the doctor takes an X-ray, the picture that results is the shadow image of the X-rays that passed through the body. Because X-rays have such high energy, they can damage or kill cells.

Gamma rays are the most energetic form of electromagnetic radiation and are produced in nuclear reactions.

An often-cited concern with the use of radar technology for long-term health monitoring is the potential danger that the radiation could pose to patients.

Energy of radiation controls the selection of Electromagnetic Wave for medical purpose. Consequently, there are tradeoffs between several parameters including:

1. Duration of exposure.
2. Distance between medical device and the patient.
3. The cost of fabrication.

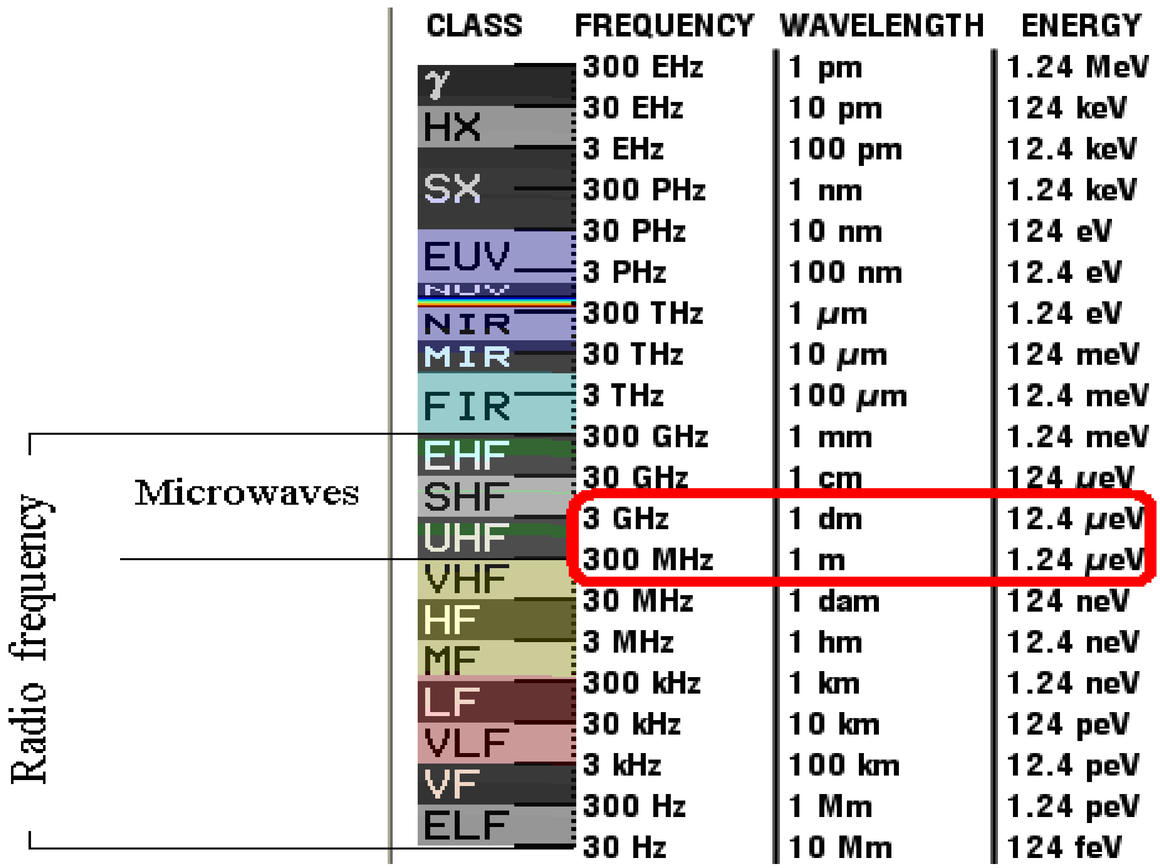


Table.1

As shown in table.1, the single-chip CMOS radar circuits emit radiation at a lower power than most consumer radio devices, and they are well within the FCC guidelines for operation in the 2.4-GHz unlicensed band. The Federal Communications Commission (FCC) Code of Federal Regulations (CFR), states that the maximum output power in the 2400-2435 MHz unlicensed band is one watt.

1.3.3. Definitions:

Microwaves are electromagnetic waves with wavelengths shorter than one meter and longer than one millimeter, or frequencies between 300 megahertz and 300 gigahertz**.**

Ultra high frequency (UHF) designates a range (band) of electromagnetic waves whose frequency is between 300 MHz and 3 GHz, which is 300 MHz to 3,000 MHz. wavelengths range from ten to one decimeter.

1.4. CMOS

CMOS, an acronym for Complementary metal oxide semiconductor**,** is a type of semi-conductor chip that holds data without requiring an external power source. In a personal computer (PC), CMOS holds the basic instructions the computer needs to initialize its hardware components and boot up. These settings are known as the *basic input output settings BIOS*, also referred to as *CMOS settings*.

Advantage of CMOS:

1. High input impedance (high noise immunity).
2. Fast switching speeds.
3. Lower operating power (low static power consumption).

2.Physiology And Measurement

As we discussed in previous sections, the Doppler radar must detect motion (displacement) of chest which occurs due to physiological action. In order to know the relationship between the received signal and skin surface motion, we firstly have to figure out the relationship between the cardiopulmonary system and this displacement.

2.1 Cardiac system:

2.1.1 Physiology:

As the heart beats and drives blood into the arteries it moves and its size changes, causing motion of the chest wall that can be detected at the skin surface, both by palpation and with non-contact sensors. The greatest motion occurs at the 4th and 5th intercostals pace when the left ventricle strikes the chest wall as it contacts. The maximum motion detected at the apex with non-contact sensors has an average of 0.6 mm, and this value is expected to vary widely over population due to differences in physiology, health, fitness and age. However, this average motion is sufficient to provide detection with a Doppler radar system.

2.1.2 Measurement:

Clinically, the pulse is examined to establish cardiac rate and rhythm, and the pattern of the palpation can be used for further diagnosis of cardiac and circulatory disease. The normal resting heart rate in adults is 50 to 90 beats per minute. A heart rate outside the normal range can indicate either a cardiac abnormality or another condition that causes abnormal heart rate. An irregular pulse is usually indicative of a cardiac abnormality. The amplitude and contour of the pulse, such as a small, weak pulse, a large bounding pulse, or an irregularly shaped pulse can be indicative of a pathophysiologic state.

2.2 Respiratory system:

2.2.1 Physiology:

For gas exchange to occur in the lungs, air with CO_2 needs to be removed from the lungs and air with O_2 needs to be inspired. In respiration, muscles contract to generate changes in thorax volume, which create pressure differences between the thorax and the external environment, causing air to move in and out of the lungs, from areas of high pressure to areas of low pressure. The motions of the thorax and the abdomen cause significant displacements at the skin surface that are measurable with Doppler radar, allowing non-contact measurement of respiration rates.

2.2.2 Measurement:

Clinically, Most studies indicate 16 to 24 breaths per minute is a normal adult respiratory rate, but some studies indicate that rates as low as 8 breaths per minute are normal . Respiratory rate and volume of respiration together are a strong indicator of respiratory physiology. The respiratory rate is typically measured through observation or palpation of the chest. An accurate reading requires counting for a full minute, because the rates are so low. The measurement of respiratory rate by different examiners can vary significantly.

2.3 Conclusion:

Doppler radar simultaneously measures heart and respiration rates. In order to measure the heart rate, it is necessary to use filters to attenuate the respiration signal relative to the heart signal so that the heart signal is dominant. This measurement is non-contact and works through clothing.

3. technical part

3.1 Radar Introduction:

Radar, an acronym for **RAdio Detection And Ranging**, describes a system that transmits an electromagnetic signal and senses the echo from reflecting objects, thereby gaining information about those objects. The time delay between the transmitted and received signals indicates the distance to the target, the frequency shift of the received signal enables calculation of the target's velocity, and the strength of the signal gives information about the target's radar cross section, which provides information about its size, geometry, and composition. A major advantage of radio and microwave frequency radar systems is that these waves can penetrate through some objects that light cannot penetrate, allowing detection of objects that cannot be seen. However, radar systems developed for different applications may operate at many different frequencies, varying from a few MHz to optical frequencies. As shown in Figure 2, a radar system typically consists of a transmitter, an antenna, a receiver, and signal processing hardware and/or software.

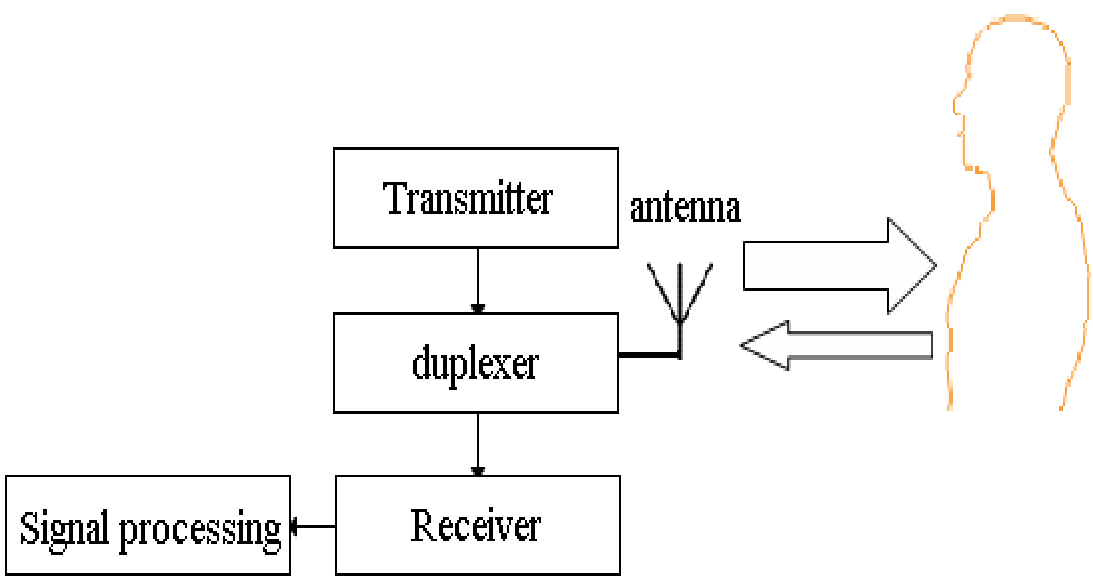


Fig.2: Radar system

1. The transmitter creates waveform and amplifies it to the required transmission power.
2. A directional antenna both concentrates the beam in the direction of the target and enables determination of the direction of the target; electronically tunable antenna arrays are often used for this purpose.
3. The duplexer isolates the receiver from the transmitter while permitting them to share a common antenna.
4. The receiver converts the signal from the transmission frequency to either an intermediate frequency or baseband, separates the signal from both noise and interferers, and amplifies the signal enough for digitization and/or display.
5. Signal processing is used to reject clutter and out-of-band noise, while passing the desired signal, and to derive information from the signal.

3.2 System architecture:

In a Doppler radar for monitoring cardiopulmonary motion, there are tradeoffs between several parameters, including signal-to-noise ratio, cost, weight, size, and bandwidth, which need to be weighed when making design choices at al levels of system architecture.

1-Radar configuration, there are two main types:

- Pulsed wave
- Continuous wave

Each of which has advantages and disadvantages for different applications. For Doppler cardiopulmonary monitoring, measurement of motion is critical and measurement of the range to the target is not; therefore a continuous-wave radar topology is chosen.

2-receiver architecture, the choice is between

- A heterodyne receiver
- A homodyne receiver

Homodyne receiver converts the signal directly to baseband. Factors in the choice of receiver for an integrated design include filtering requirements, circuit complexity, die size and noise levels; these corresponds to tradeoffs between cost and signal quality. The homodyne receiver is the simplest and least expensive architecture, and this was chosen.

3-The transceiver portion of the architecture. A quadrature receiver provides an improvement in phase demodulation over a single channel receiver at the price of additional die size (which corresponds to a cost increase) and increased power consumption.

4-The frequency and power of the transmitted signal need to be selected. discussed in section 1.3

2.2.1Continuous Wave (CW) Radar:

Continuous-wave radar system transmits and receives a very narrow bandwidth signal. A pure continuous-wave (CW) system can readily detect moving targets via the Doppler shift of the received signal.

A pulsed radar system switches between transmitting and receiving, and the signal has a somewhat wider bandwidth because of the pulse.

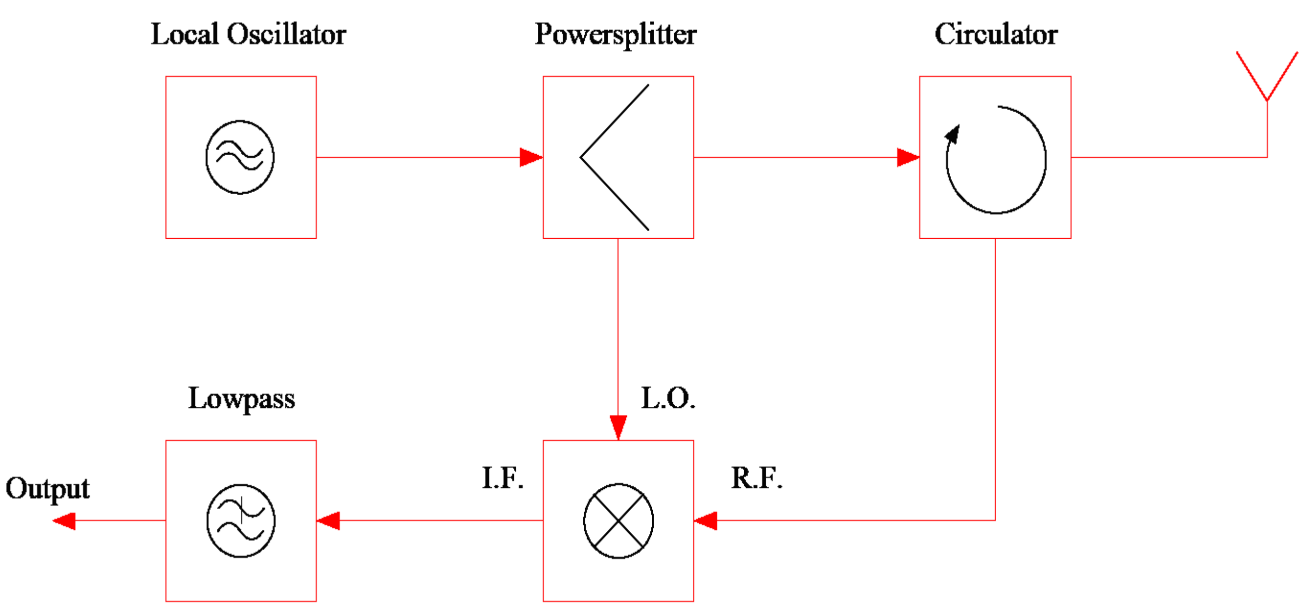


Fig.3 Simple block diagram of CW Doppler radar

Circulator is used to route outgoing and incoming signals between the antenna, the transmitter and the receiver. In a simple system, this function could be performed by a switch that alternates between connecting the antenna to the transmitter and to the receiver.

Advantage:

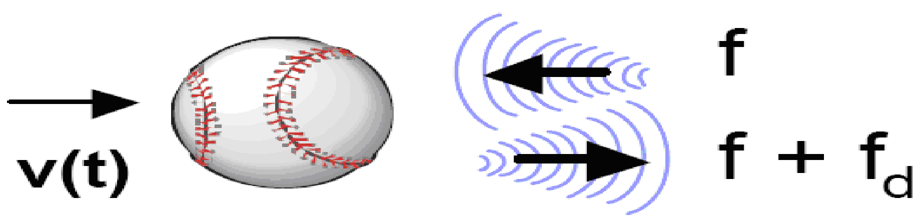
A continuous-wave (CW) radar topology is the simplest radar topology for two reasons:

1. A single channel transducer oscillator can be used for both the transmitter and the receiver.
2. The extremely narrow signal bandwidth avoids interference and eases filtering requirements.

Description:

Since the CW system constantly transmits and receives, there is no need for a transmit/receive switch. The extremely narrow-band nature of the CW radar means that the filters at each stage of the receiver can be quite simple.

When the goal of the measurement is target motion rather than distance to the target, a pure CW radar system is ideal. When the CW signal is directed at a target, it is reflected and frequency-modulated by the target motion. If the target is moving at velocity v(t) in m/s, the frequency of the reflected signal is shifted by an amount known as the Doppler shift .



$$f_d = 2f\,v(t)/c$$

Fig.4 the frequency of a wave form dependent upon the relative velocity between the emitter and the receptor (Johan Christian Doppler 1803- 1853)

$$fd(t) = \frac{2 f v(t)}{c} = \frac{2 v(t)}{\lambda} \quad (2.1)$$

Where:
f_d is the Doppler shift frequency in Hz.
f is the transmitted frequency in Hz.
c is the signal propagation velocity in m/s .
λ is the wavelength of the transmitted signal in meters .

When the target undergoes a periodic movement x(t) with no net velocity, the Doppler shift of the reflected signal can be better described as a phase modulation as shown in figure.5

$$\theta(t) = \frac{2 f (2\pi x(t))}{c} = \frac{4\pi x(t)}{\lambda} \quad (2.2)$$

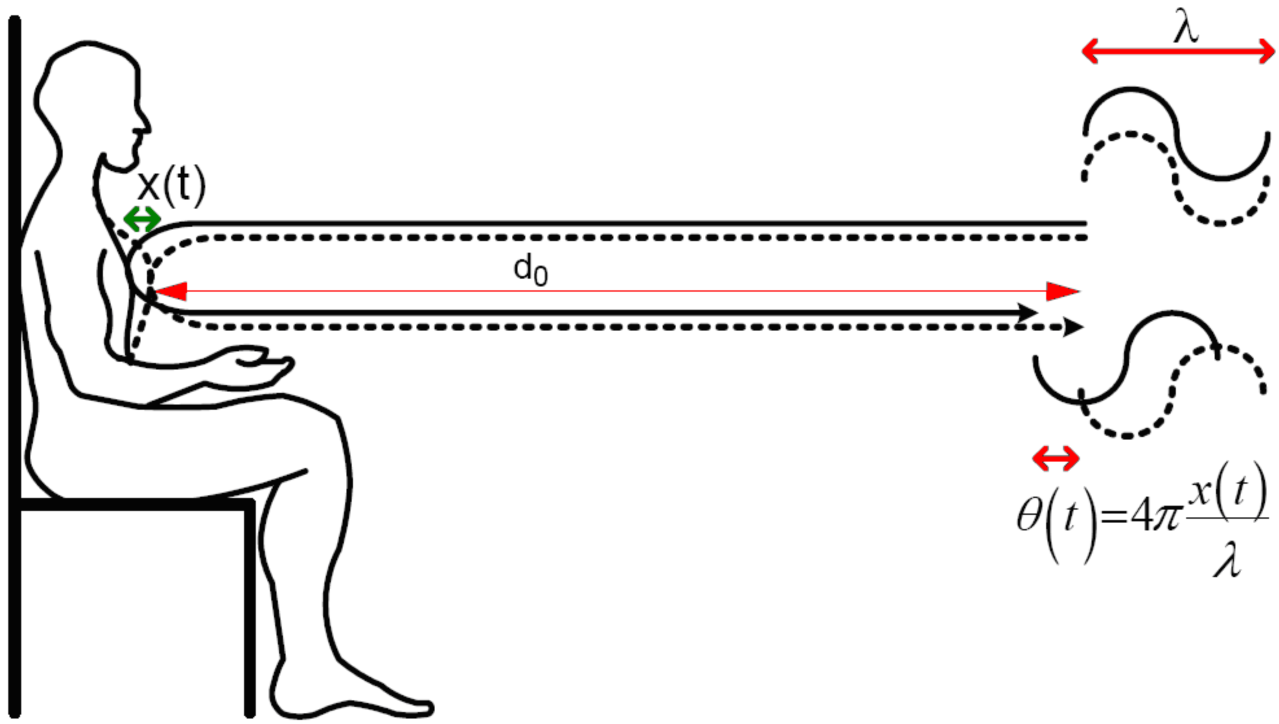


Fig.5

When a person's chest is the target, as shown in Figure 5, the phase is modulated in direct proportion to the chest displacement. When the phase is demodulated, the resulting signal is proportional to the time-varying chest position, from which the heart and respiration rates can be determined.
Neglecting amplitude variations, CW radar typically transmits a single tone signal,

$$T(t) = \cos(2\pi \; f t + \phi(t)) \quad (2.3)$$

Where f is the oscillation frequency and $\phi(t)$ is the phase noise of the oscillator. If the transmitted signal is reflected by a target at a nominal distance d_o having a time-varying displacement given by *x(t)*, the distance between the transmitter and target is

$$d(t) = d_o + x(t) \quad (2.4)$$

The time delay between the transmitter and target is the distance traveled by the signal, d(t), divided by the signal's propagation velocity c. Since the chest moves while the signal is traveling, the distance between the antenna and the chest at the time of reflection is:

$$d\left(t - \frac{d(t)}{c}\right) \quad (2.5)$$

Therefore, the round-trip time delay in seconds, t_d, is:

$$t_d = \frac{2d\left(t - \frac{d(t)}{c}\right)}{c} = \frac{2\left(d_0 + x\left(t - \frac{d(t)}{c}\right)\right)}{c} \quad (2.6)$$

The signal at the receiver, R(t), is a time-delayed version of the transmitter signal, with its amplitude reduced by A_R:

$$R(t) = A_R \cos[2\pi f(t - t_d) + \phi(t - t_d) + \theta_0] \quad (2.7)$$

Substituting for t_d in (2.6):

$$R(t) = A_R \cos\left[2\pi f t - \frac{4\pi d_0}{\lambda} - \frac{4\pi x\left(t - \frac{d(t)}{c}\right)}{\lambda} + \phi\left(t - \frac{2d_0}{c} - \frac{2x\left(t - \frac{d(t)}{c}\right)}{c}\right) + \theta_0\right] \quad (2.8)$$

Where the wavelength is $\lambda = c / f$.

Assuming that:

- $(d(t))/c$ in the $x(t - (d(t))/c)$ term is negligible because the chest moves with a period $T \gg d_o/c$.
- $\frac{2x\left(t - \frac{d(t)}{c}\right)}{c}$ term is negligible in the phase noise term, because $x(t) \ll d$.

So, the received signal can be approximated as:

$$R(t) \approx A_R \cos\left[2\pi f t - \frac{4\pi d_0}{\lambda} - \frac{4\pi x(t)}{\lambda} + \phi\left(t - \frac{2d_0}{c}\right) + \theta_0\right] \quad (2.9)$$

3.2.2 Homodyne receiver

The simplest phase detector involves mixing the received signal with a signal at the same frequency as its carrier, so that the RF frequency is converted directly to baseband. This type of receiver is known as either direct conversion or homodyne. (Homodyne is sometimes used to describe a system where the local oscillator is synchronized in phase with the incoming carrier) A heterodyne receiver instead mixes the received signal with a local oscillator (LO) signal at a different frequency, so the information is modulated on a non-zero intermediate frequency (IF) rather than being converted directly to baseband.

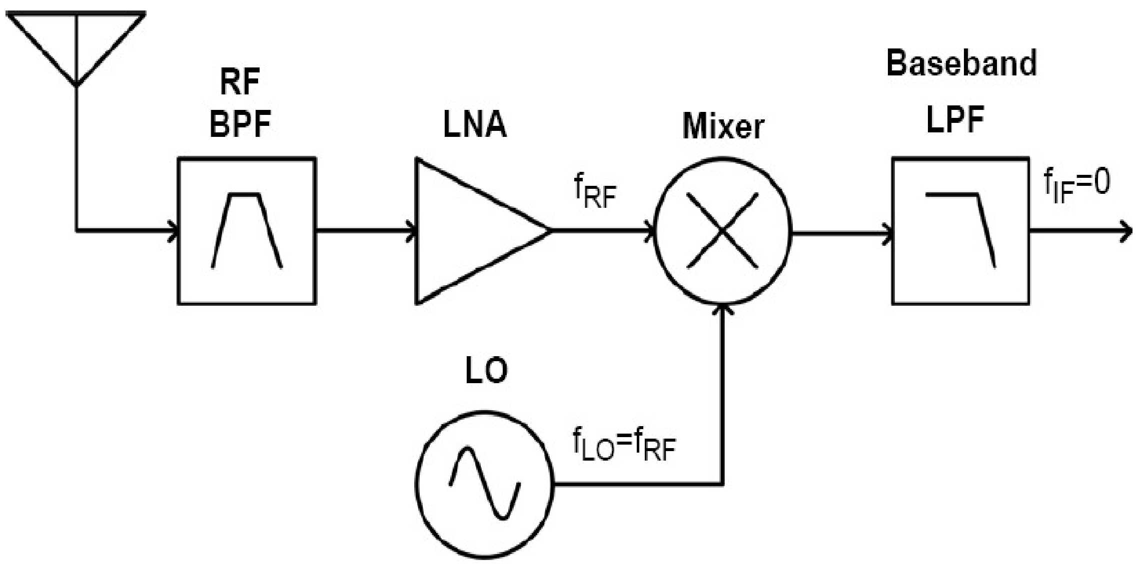


Fig.6 Typical homodyne, or direct-conversion, architecture

In a homodyne receiver, as shown in Figure 6, the received signal is sometimes bandpass filtered to remove noise and amplified with a low noise amplifier (LNA) to decrease the receiver noise figure. The local oscillators at the same frequency as the RF carrier, and when mixed with the received signal after the baseband low-pass filter, the signal is at baseband. The baseband LPF is an anti-aliasing filter that must be applied to the signal before it is digitized.

A homodyne receiver is selected for this application due to its simplicity and its straightforward use as a phase detector.

Theory for Doppler radar monitoring using a CW radar with a homodyne receiver is shown in Figure 2.5. The information about the periodic target motion can be readily demodulated if this signal is multiplied by a local oscillator (LO) signal that is derived from the same source as the transmitted signal in direct-conversion architecture. Because the phase noise of the received signal is correlated with that of the LO, ignoring amplitude variations, the LO signal is expressed by

$$L(t) = \cos(2\pi \ f t + \phi(t))$$

When the received and LO signals are mixed and the output is low pass filtered the resulting baseband signal B(t) is shown in fig.7

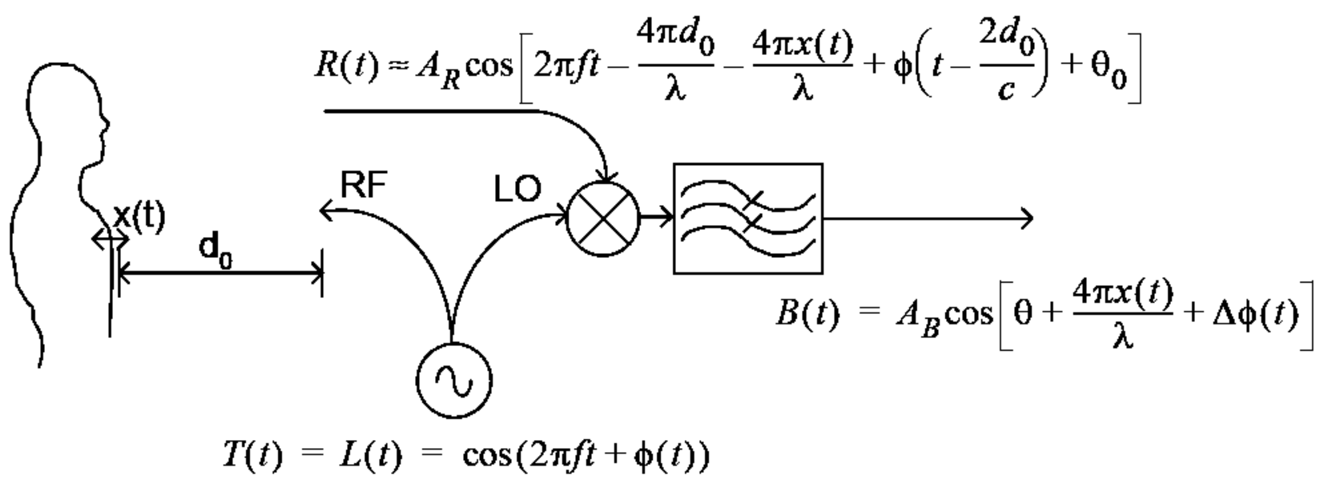


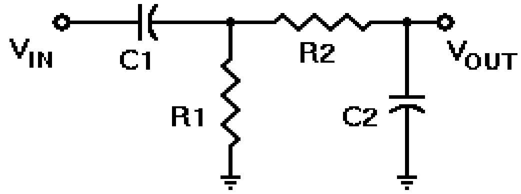
fig.7

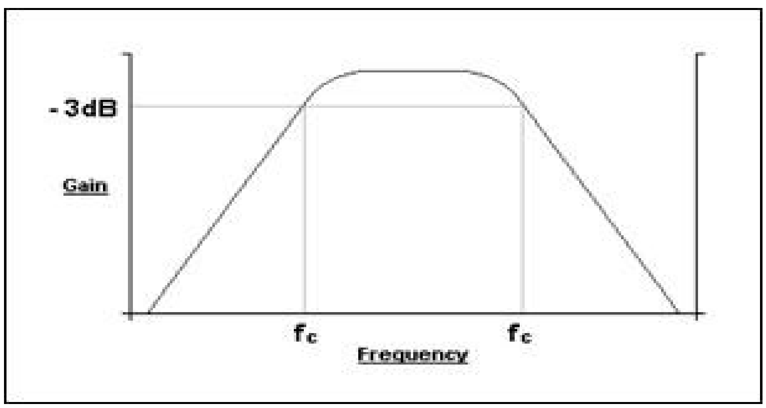
Where:

- A_B is the baseband amplitude which depends on the receiver gain and the mixer gain.
- $\Delta\phi = \phi(t) - \phi\left(t - \frac{2d_0}{c}\right)$ is the residual phase noise.
- $\theta = \frac{4\pi d_o}{\lambda} - \theta_0$ is the constant phase shift dependent on the nominal distance to the target, d_0.

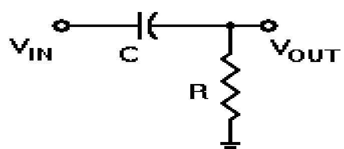
Description of component in homodyne receiver

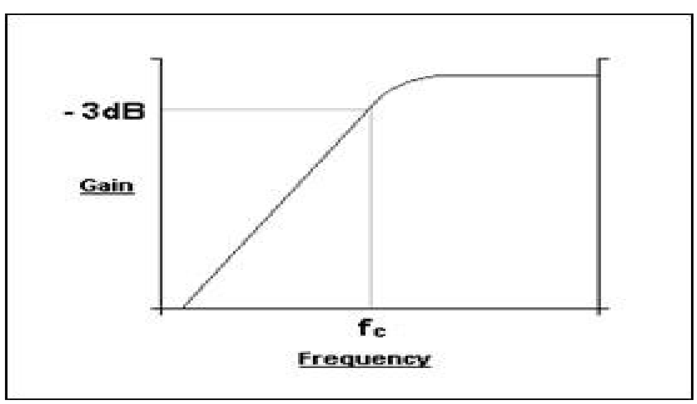
1. A band-pass filter is a device that passes frequencies within a certain range and rejects (attenuates) frequencies outside that range. This filter can be created by combining a low-pass filter with a high-pass filter.





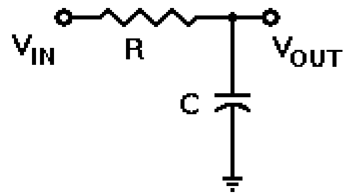
A high-pass filter is a filter that passes high frequencies well, but attenuates (reduces the amplitude of) frequencies lower than the cutoff frequency.

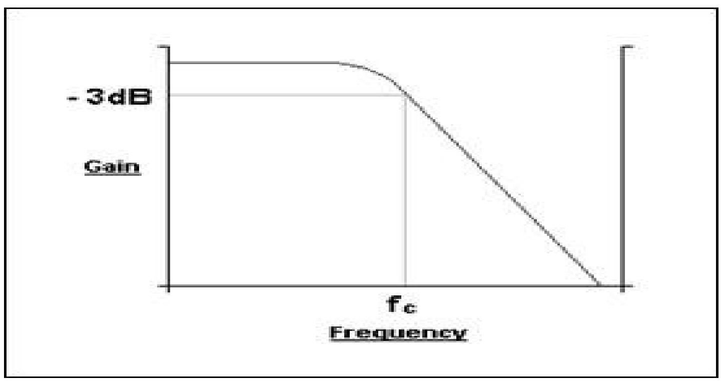




$$f_c = \frac{1}{2\pi\tau} = \frac{1}{2\pi RC}$$

A low-pass filter is a filter that passes low-frequency signals but attenuates (reduces the amplitude of) signals with frequencies higher than the cutoff frequency.





$$f_c = \frac{1}{2\pi\tau} = \frac{1}{2\pi RC}$$

2. Local Oscillator (LO) is a device used to generate a signal which is beat against the signal of interest to mix it to a different frequency. The oscillator produces a signal which is injected into the mixer along with the signal from the antenna.

3. Low noise amplifier (LNA) is a special type of electronic amplifier or amplifier used in communication systems to amplify very weak signals captured by an antenna.

4. Mixer is a device for mixing two or more electronic signals. There are two basic types of mixer. Additive mixers add two signals together, and are used for such applications as audio mixing. Multiplying mixers multiply the signals together, and produce an output containing both original signals, and new signals that have the sum and difference of the frequency of the original signals.

5. An anti-aliasing filter

Is a filter used before a signal sampler, to restrict the bandwidth of a signal to approximately satisfy the sampling theorem which says that for a unique correspondence between an analog signal and the version reconstructed from its samples, the sampling rate must exceed twice the highest signal frequency f_{max}. The critical rate $S=2f_{max}$ is called Nyquist rate or Nyquist frequency.

For an analog sinusoid $x(t)=cos(2\pi f_0+\theta)$,a sampling rate $S>2f_0$ ensures that the digital frequency of the sampled signal falls in the principal period $-0.5 \le F \le 0.5$.
An analog anti-aliasing filter must be a low-pas filter with a cutoff frequency greater than the signal bandwidth, but les than half the sampling frequency.

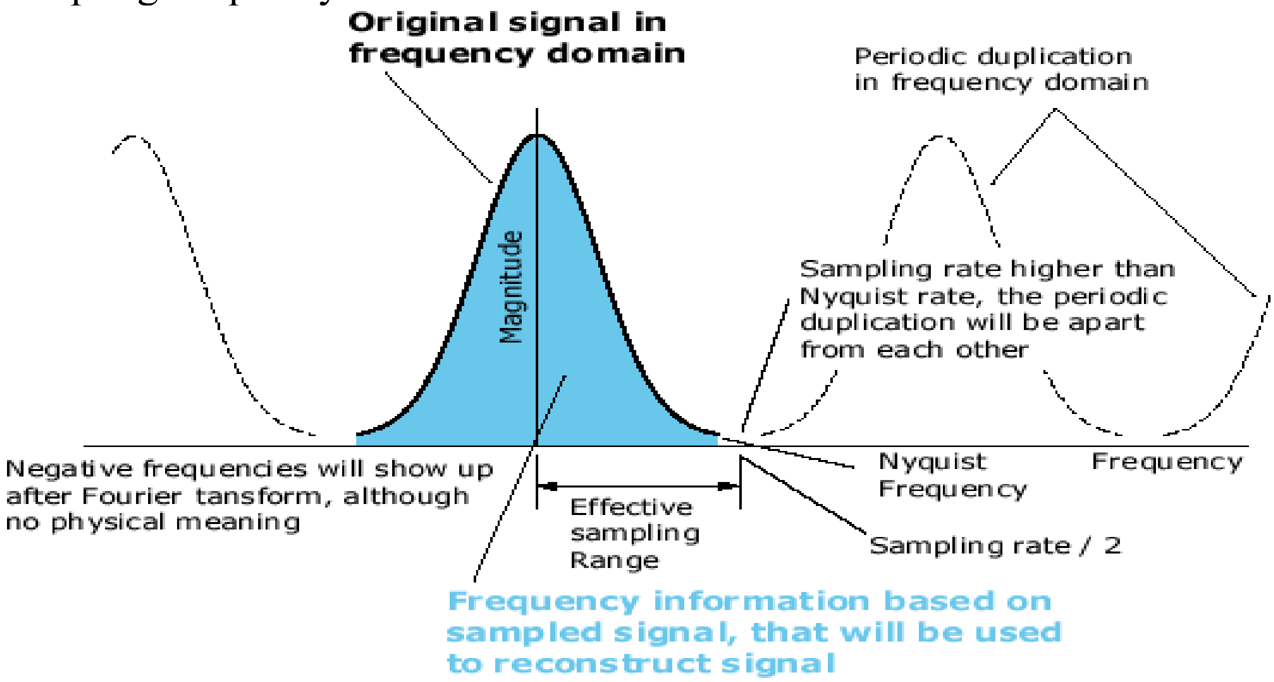


fig.8 (engineering fundamentals electronic web site -efunda.com-)

The anti-aliasing filter is lowpass filter because it attenuates the higher frequencies (greater than the Nyquist frequency), it prevents the aliasing components from being sampled. Because at this stage (before the sampler and the ADC) you are still in the analog world, the anti-aliasing filter is an analog filter.

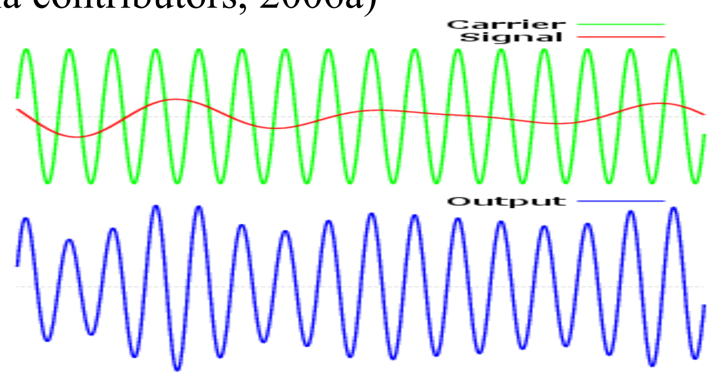
6. Baseband

is an adjective that describes signals and systems whose range of frequencies is measured from 0 to a maximum bandwidth or highest signal frequency; it is sometimes used as a noun for a band of frequencies starting at 0.

Before a signal is digitized, it must be low-pass filtered to avoid having out-of-band interference alias onto the desired signal. The properties of the analog-to-digital converter (ADC) and the signal determine what other pre-processing steps are necessary. If the ADC's least-significant bit is too small to resolve the heart signal, the signal must be amplified to a level where the heart signal can be resolved. If the dc offset is sufficiently large that this level of amplification will saturate either the amplifier or the ADC, the dc-offset must be removed, before or simultaneously with amplification. When the signal amplitude is significantly below the full-scale voltage of the ADC, the signal is typically amplified to near this level in order to take advantage of ADC's full resolution. When the signal's amplitude varies significantly over time and environment, a gain-controlled amplifier is typically used to fine-tune the signal's amplitude to keep it close to the full-scale voltage.

Definitions

Carrier wave is a waveform (usually sinusoidal) that is modulated (modified) with an input signal for the purpose of conveying information. This carrier wave is usually of much higher frequency (green) than the baseband modulating signal (the signal which contains the information) (red). (Wikipedia contributors, 2006a)



Intermediate frequency (IF) is a frequency to which a carrier frequency is shifted as an intermediate step in transmission or reception).

2.2.3. Quadrature transceiver:

Block diagram quadrature CW radar transceiver is shown in figure.9.

- **Construction**

1. The signal source is split into the carrier from the transmitter and the local oscillator for the receiver.
2. The LO is split with a 90 degree phase shift between the two LO outputs.
3. The RF input signal is split with a 0 degree phase shift.
4. The transmitter couples the output signal to the antenna.
5. The receivers convert the signal to baseband.
6. The in-phase and quadrature receiver channels each provide an output.

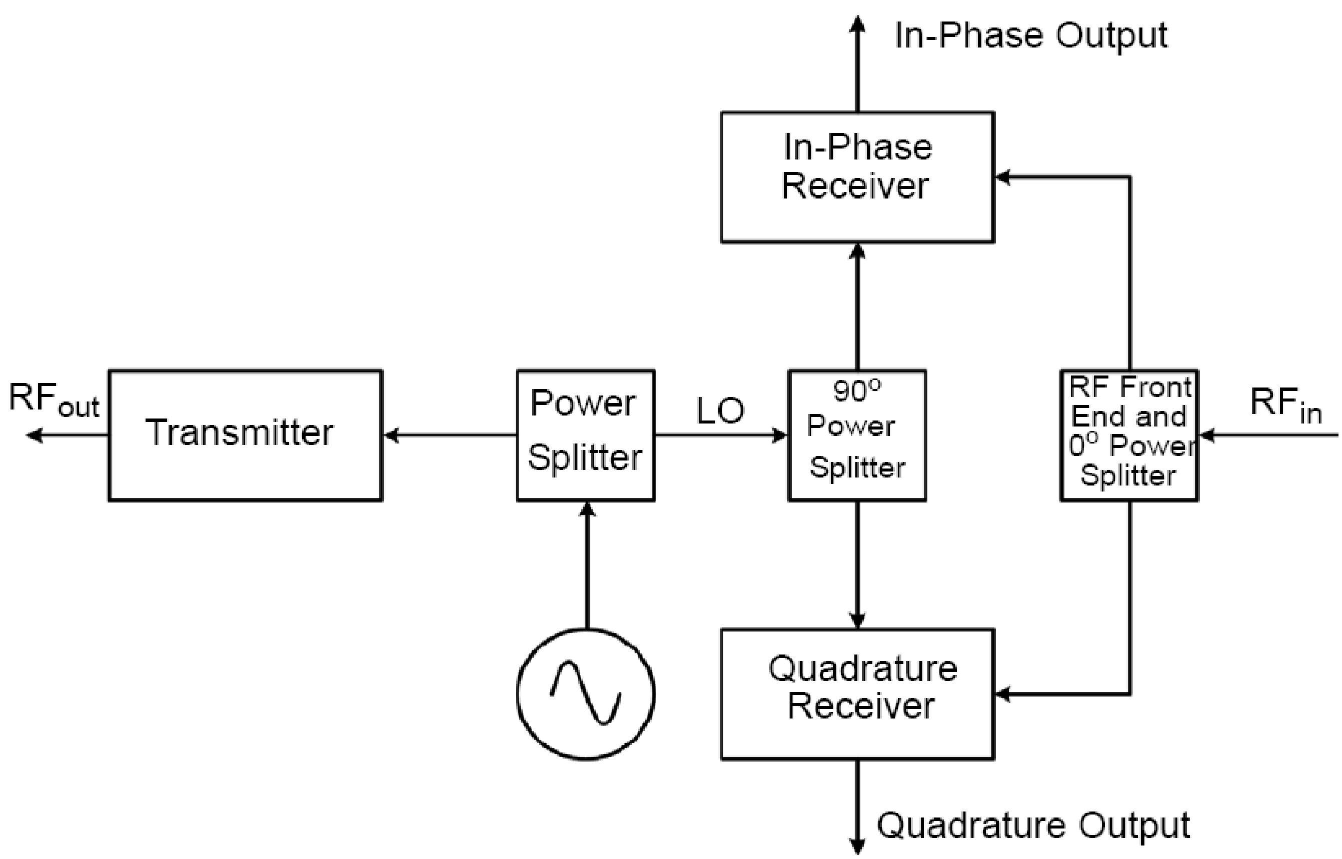


fig.9

2.2.4 In-phase (I) and Quadrature (Q) data

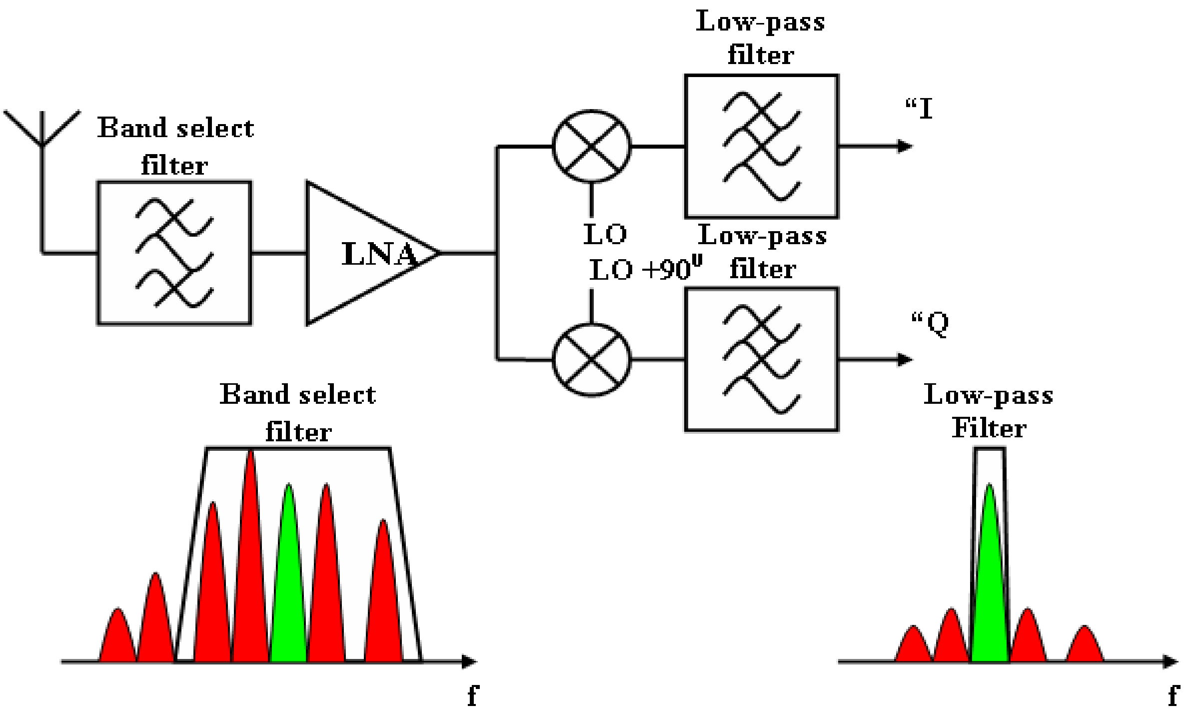
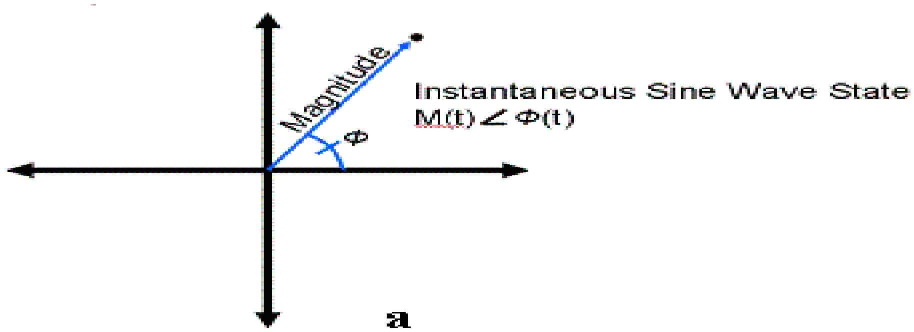


Fig.10



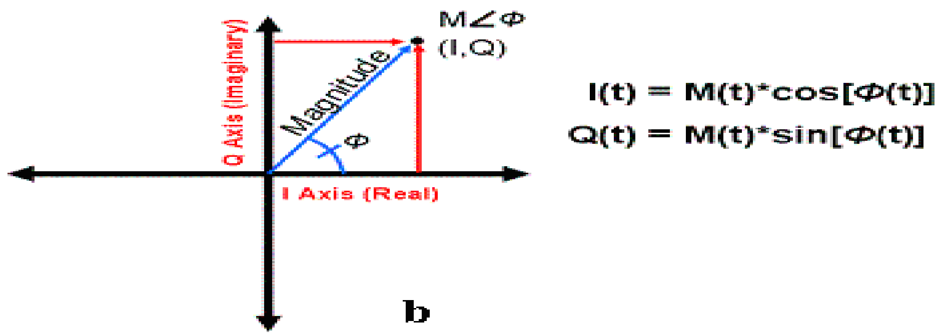


Fig.10

a) Polar Representation of a Sine Wave.

b) I and Q Represented in Polar Form.

The vector of the resulting signal is described as:

$$|Signal| = \sqrt{I^2 + Q^2}$$

$$\arg(Signal) = \varphi = arctg\frac{Q}{I}$$

For Doppler radar sensing of chest motion with a quadrature receiver. The oscillator signal as shown in Figure 11 provides both the transmitted RF and LO signals, T(t) and L(t). The transmitted signal travels a total distance $2d(t)=2(d_0+x(t)$ and becomes the received signal, R(t). The LO is split into two quadrature LO signals, which have phases $\pi/2$ apart. The received signal is split into signals for the two receiver chains, and each is mixed with the one LO signal and lowpass filtered to give the baseband outputs, $B_Q(t)$and $B_I(t)$. These two baseband signals can be I to Q t combined to directly demodulate the phase, or the better of the two signals can be chosen.

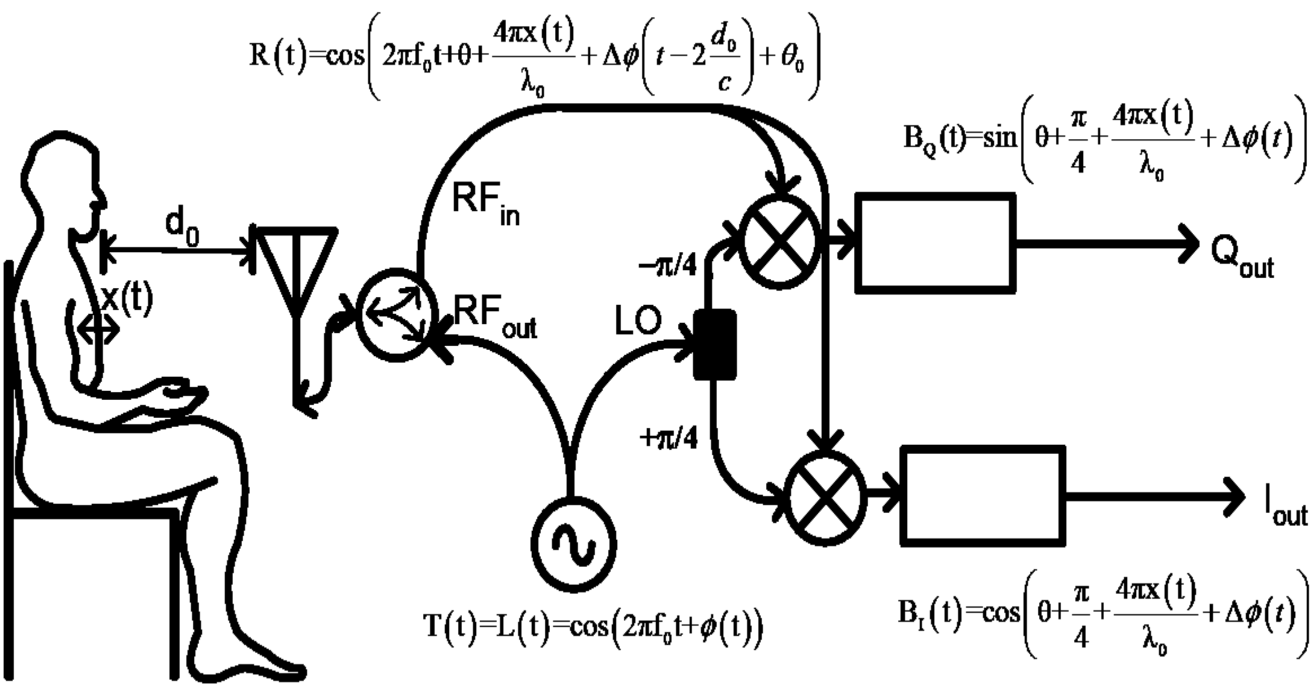


Fig.11

2.2.5. Frequency:

An important feature in frequency choice is the resolution. The signal-to-noise ratio is dependent on the wavelength of the carrier, λ , mostly because the amount the of phase modulation in radians is:

$$= \frac{4\pi \ x(t)}{\lambda}$$

Where x(t) is the chest motion.
The higher the frequency, the shorter the wavelength, and therefore the greater the phase modulation.
If the phase noise is the same across different frequencies, increasing the frequency increases the signal-to-noise ratio.

4. Signal processing

4.1. Introduction:

The Doppler radar heart and respiration monitoring system transmits a continuous-wave (CW) signal, which is reflected of the subject and then demodulated in the receiver. In accordance with Doppler theory, when the subject has no net velocity but the chest and pulse points move with respiration and heartbeat, the phase of the reflected signal is modulated proportionally to the time-varying position of the body's surface. Demodulating the phase then gives a signal directly proportional to the body motion.

Since the body motion contains information about the movement due to heartbeat and respiration, heart and respiration signatures and rates can be determined from the demodulated signal. Since the heart and respiration information is encoded in the phase of the signal, the phase noise of the transmitted signal can be a limiting factor in the system. In the direct-conversion radar receiver, the same source issued for the transmitted signal and the local oscillator signal in the receiver, which means the received signal is a time-delayed version of the local oscillator signal. Therefore, the phase noise of the received signal is correlated with that of the local oscillator, with the level of correlation dependent on the time delay between the two signals.

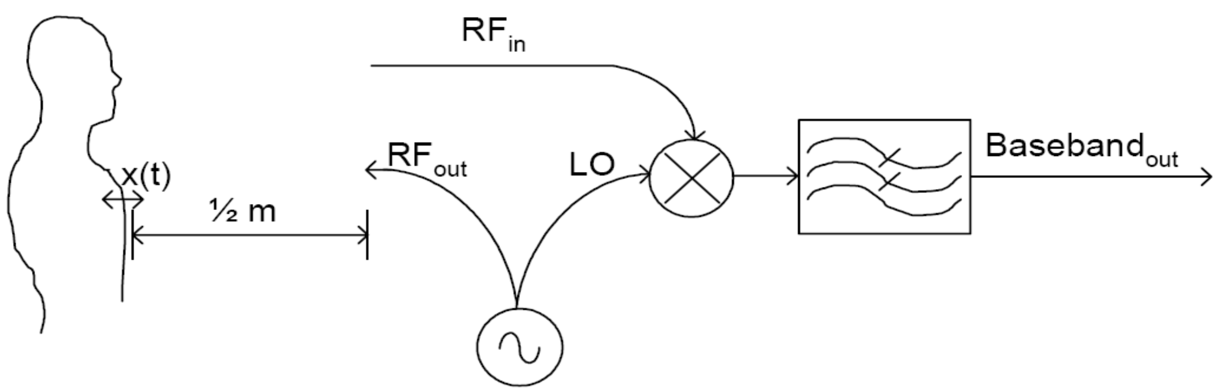


Fig.12

When the two signals are mixed, as shown in figure.12 the correlated portion of the phase noise effectively cancels, leaving a residual phase noise spectrum at baseband that is far below the phase noise spectrum at RF.

In a radar application, this time delay is the time it takes the signal to travel to the target and back, which is proportional to the target range. Range correlation is particularly important when measuring the motion due to the heartbeat and respiration since the information is encoded in phase modulations of 0.03 to 10 Hz, where the phase noise is near its peak.

The radar transmitted signal = LO signal =

$$T(t) = \cos(2\pi\ f t + \phi(t))$$

The received signal:

$$R(t) = \cos\left[2\pi f\left(t - t_d\right) + \phi\left(t - t_d\right) + \theta_0\right]$$

4.2. Separation of heart beat and breathing

In the Doppler radar cardiopulmonary motion monitoring system, the heartbeat and respiration signals are superimposed on each other. Because the chest moves a much greater distance due to breathing than it does due to the heart beating and a greater area of the chest moves for respiration, the amplitude of the respiration signal is typically about 100 times greater than that of the signal due to the heartbeat. Therefore, the respiration rate can be detected without filtering, but the heart signal must be isolated from the respiration signal to detect heart rate. Once the heart and respiration signals are separated, both need to be processed in order to determine heart and respiration rates, and for optimal accuracy, the stages before the rate determination should add minimal amounts of in-band noise.

with heart rates varying from 43 to 94 beats per minute (1 to 1.67 Hz) and respiration rates varying from 5 to 21 breaths per minute (0.08 to 0.35 Hz).This requires a highpass filter with a transition between 0.70 Hz and 0.35 Hz to isolate the heart signal.

Bibliographic Entry	**Result (w/surrounding text)**	**Standardized Result**
The New Book of Popular Science. Connecticut: Grolier Inc, 1996.	"It beats or contracts about 70 times per minute."	1.17 Hz
Magill, Frank. Magill's Survey of Science. New Jersey: Salem, 1991.	"so the resting heart rate (70 beats per minute)"	1.17 Hz
Bender, Lionel. Human Body. New York: Crescent, 1992.	"It beats roughly 70 times a minute throughout one's life"	1.17 Hz
Lietz, Gerald & Anne White. Secrets of the Heart and Blood. Illinois: Gerrard, 1965.	"A baby's heart beats 120 times a minute. A man's heart beats 72."	2.00 Hz 1.20 Hz
Berkow, Robert. The Merck Manual of Medical Information. New Jersey: Merck, 1997.	"The normal heart rate at rest is usually between 60 and 100 beats per minute."	1.00 to 1.67 Hz

Table.2

Generally the heart and respiration rates track together, when a person exercises, as the heart rate rises, the respiration rate tends to rise, so it is unlikely that the heart and respiration fundamental signals will overlap. The heart signal isolated with an analog high pass filter with a 1-Hz cutoff frequency shown in Figure 13.

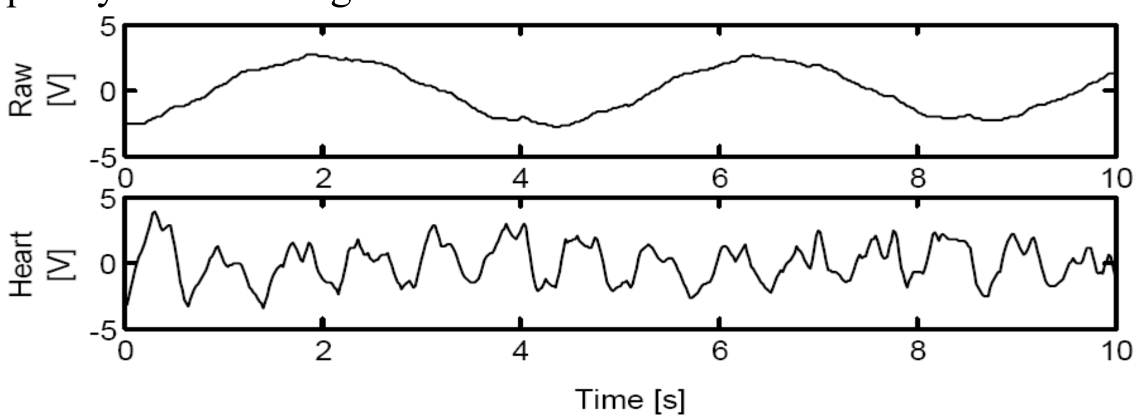


fig.13

The incoming demodulated voltage waveform was filtered in such a way as to separate the two components. The subject’s normal (resting) respiration lay somewhere in the order of 20 breaths per minute. The chosen range for the respiration was between 0 and 40 breaths per minute.

A low-pass filter with cutoff frequency at 0.7 Hz selected signals in the mentioned range. The resting heart rate of the subject varied anywhere between 60 and 120 beats per minute. A bandpass filter with cutoff frequencies at 1 and 3Hz selected an adequate range of 60-180 beats per minute. *Figure 14 shows the block diagram of separation and figure 15 shows the result with comparison to pressure pulse reference signals.*

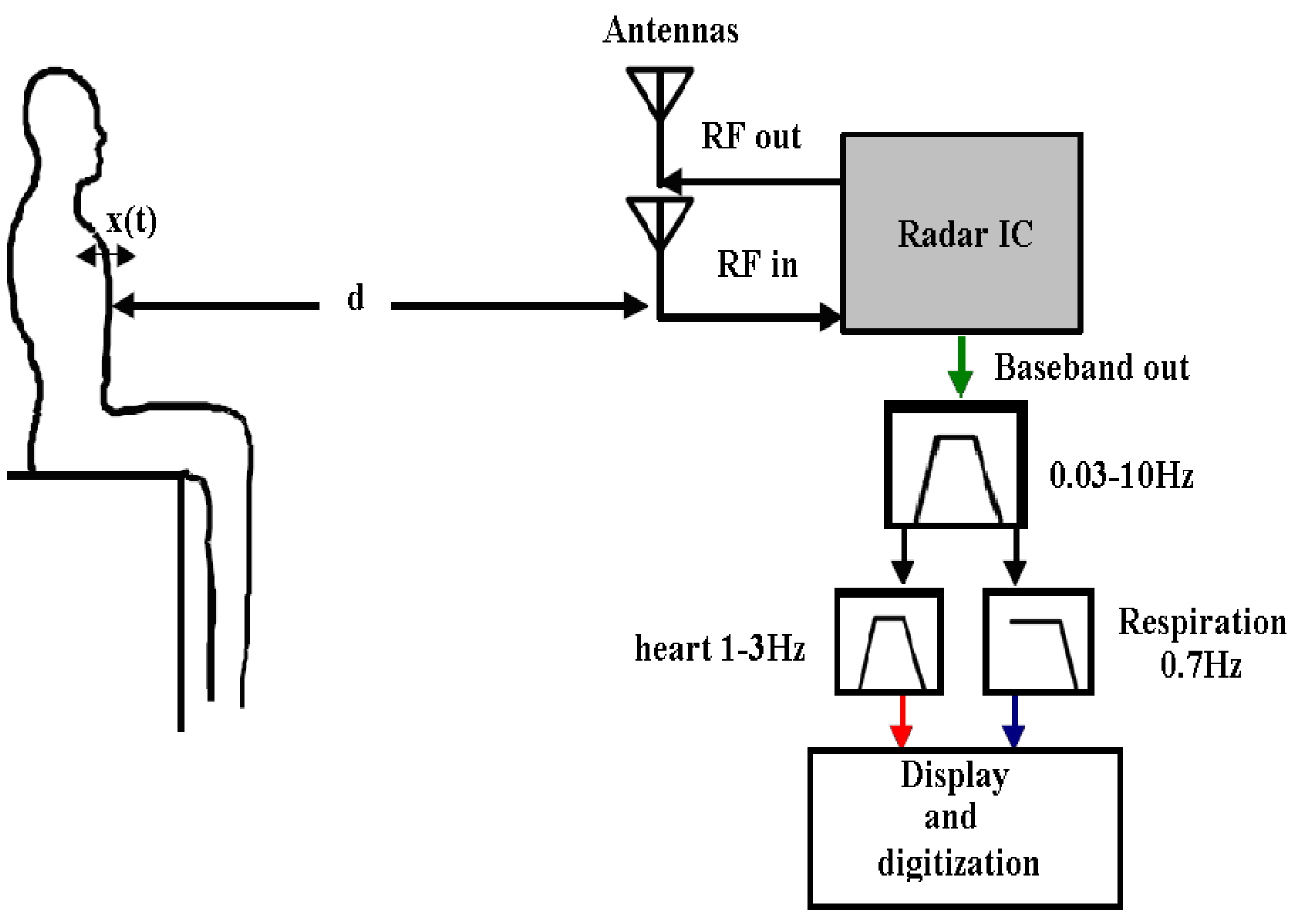


Fig.14

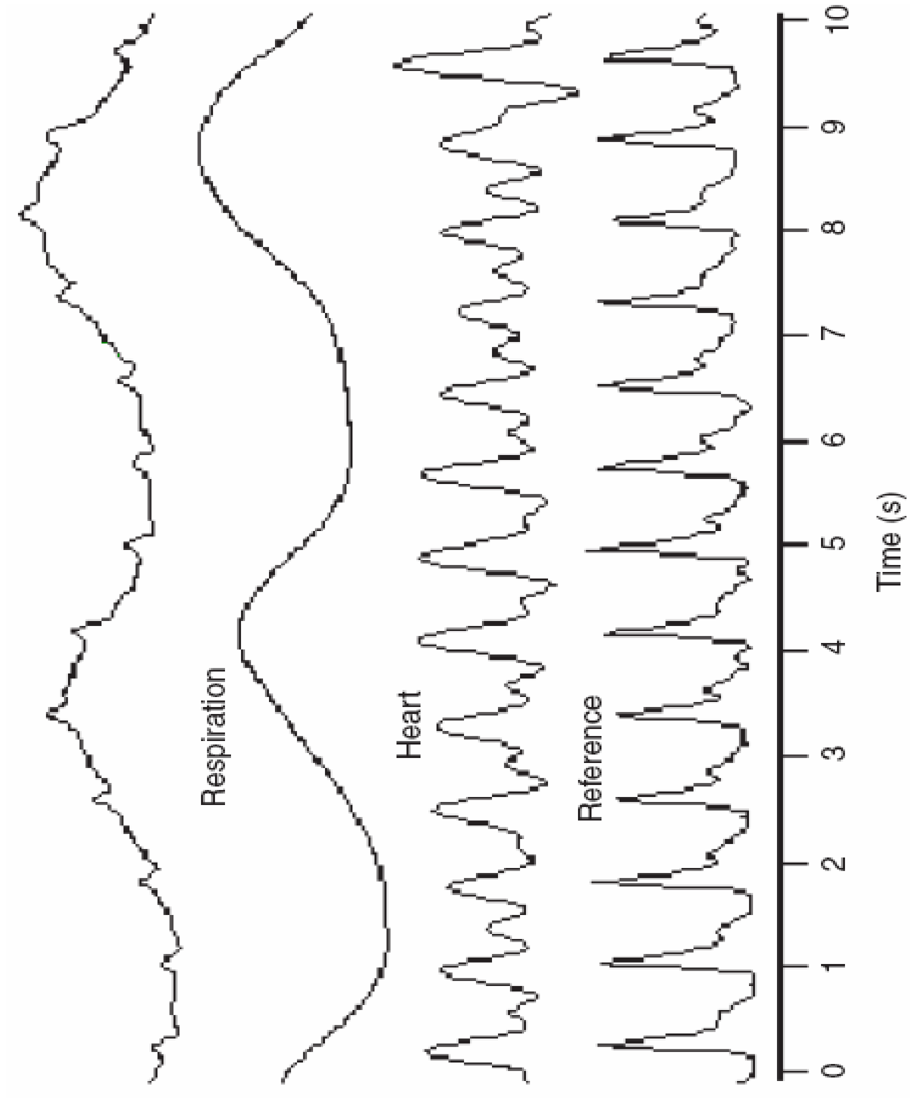
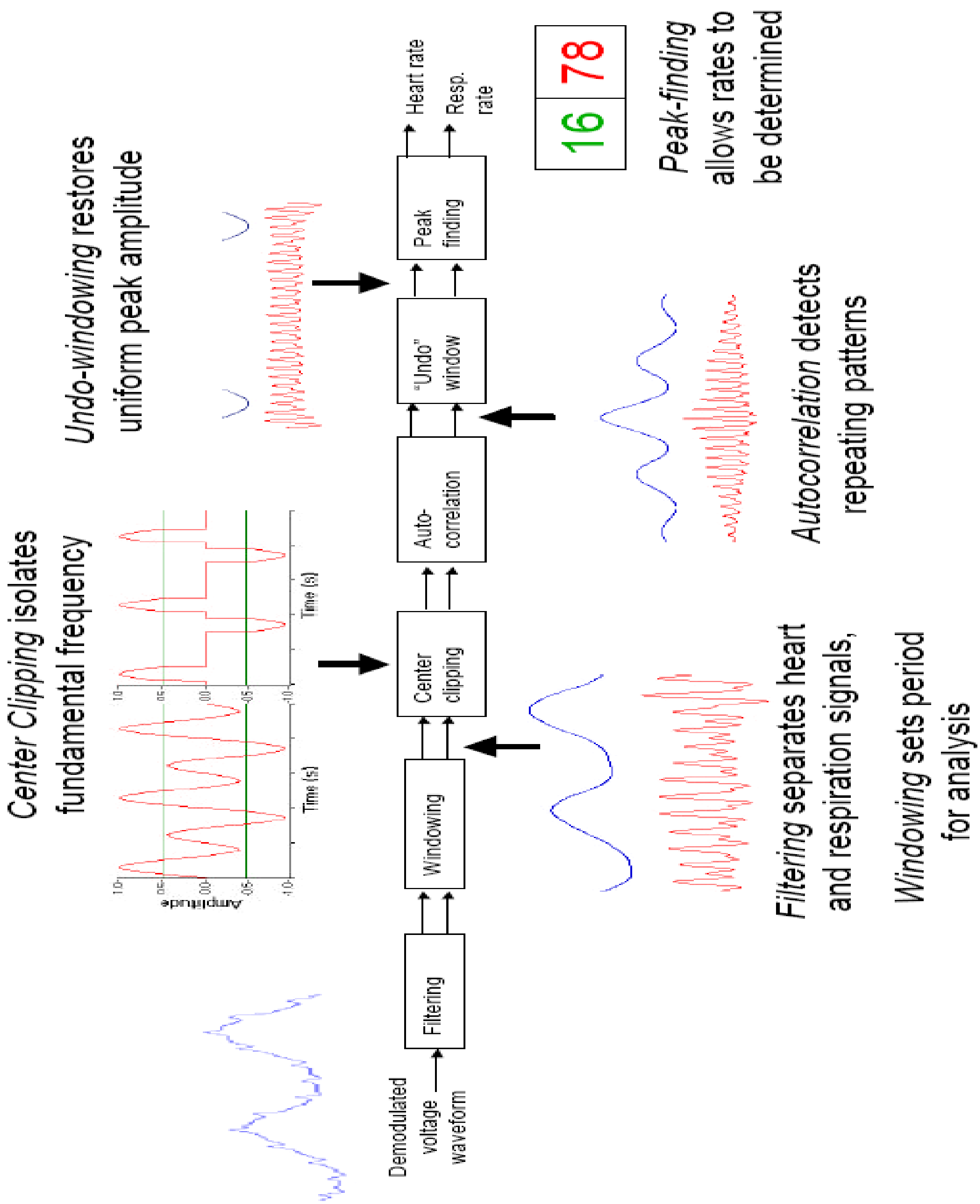


Fig.15

4.3. Digital Signal Processing

Since different windows are optimal for heart and respiration signals, they need to be separated before windowing and rate-finding. This can be accomplished with digital filters. When isolating the heart signature from the combined heart and respiration signature by its frequency, the simplest technique is a fixed-frequency highpass filter. This filter must attenuate the respiration signal at least 50 dB more than the heart signal. Digital filters multiply the input (and sometimes also the output) samples by the filter coefficients that are chosen to give a desired frequency response.



Demodulated voltage waveform
Filtering
Windowing
Center clipping
Auto-correlation
"Undo" window
Peak finding
Heart rate
Resp. rate
16
78
Center Clipping isolates fundamental frequency
Amplitude
Time (s)
Undo-windowing restores uniform peak amplitude
Peak-finding allows rates to be determined
Autocorrelation detects repeating patterns
Filtering separates heart and respiration signals,
Windowing sets period for analysis

Fig.16

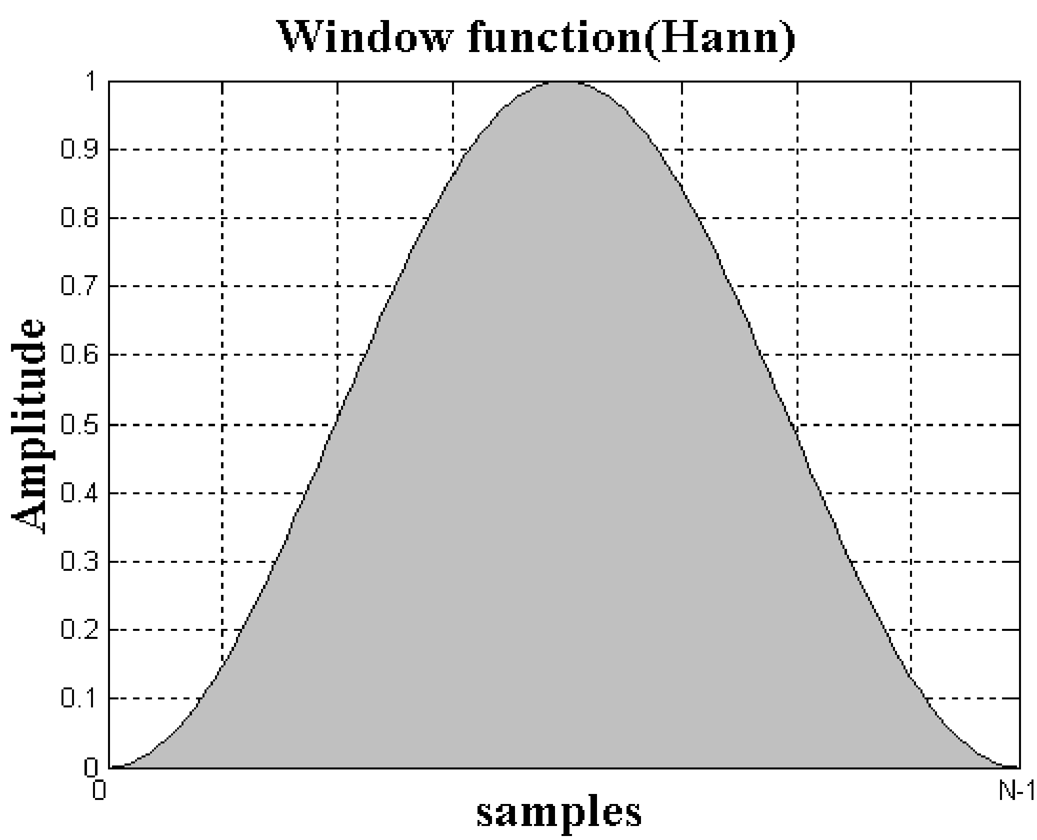
4.3.1. Windowing

A function of time that is multiplied by a data segment. It is mainly used before computing the FFT spectrum of the data segment, and its purpose is to smooth or otherwise shape the resulting spectrum.

The Hann window (sometimes also called the hanning window)

$$w(\mathrm{k}) = \tfrac{1}{2}\left(1 - \cos\frac{2\mathrm{k}\pi}{\mathrm{N}-1}\right) \qquad 0 \le \mathrm{k} \le \mathrm{N}-1$$

It has a main-lobe width (about at the -3 dB level and between the two zeros surrounding the main lobe) considerably larger than the rectangular window, but the largest side-lobe peak is much lower, at about -31.5 dB. The side-lobes also taper off much faster. For a given length, this window is worse than the boxcar window at separating closely-spaced spectral components of similar magnitude, but better for identifying smaller-magnitude components at a greater distance from the larger components.



4.3.2. Center clipping

Another enhancement technique used was a center clipper. This function, commonly used in the processing of audio data, was used to remove unwanted peaks in the signal. The center clipper function was defined as follows:

$c(n)=0 \qquad if\ |s(n)| \leq k\ .\ a_{max}$

$(c(n)=s(n \qquad if\ |s(n)\ | > k\ .\ a_{max}$

Where $c(n)$ was the output signal, $s(n)$ the input signal, and a_{max} was the maximum amplitude of the signal in the specified window. The user could set the factor k, and it determined the threshold at which the signal was cut off.

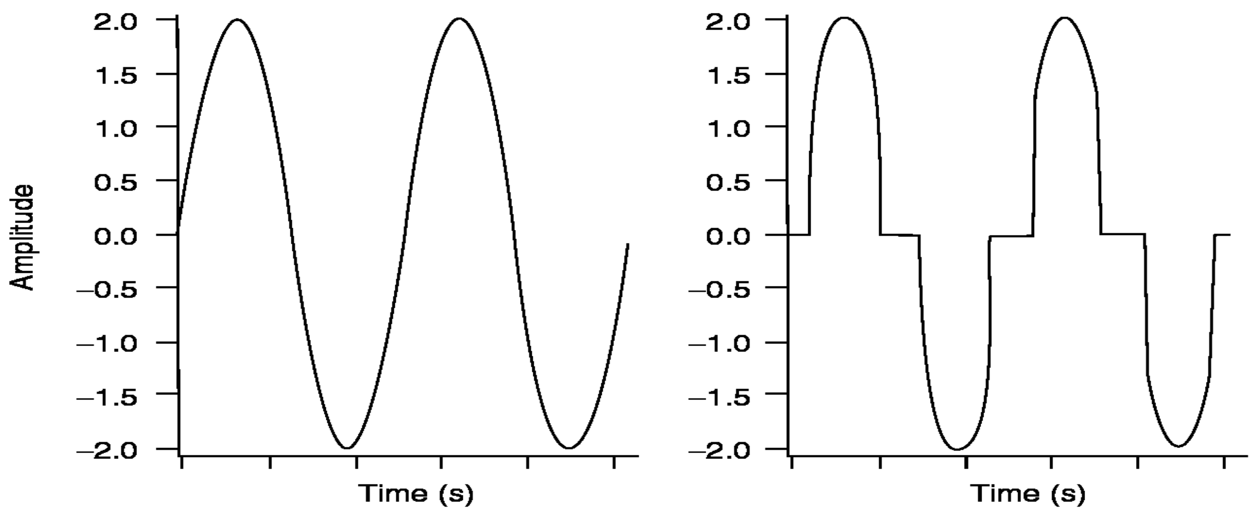


Fig.17. Illustration of the process of center clipping.

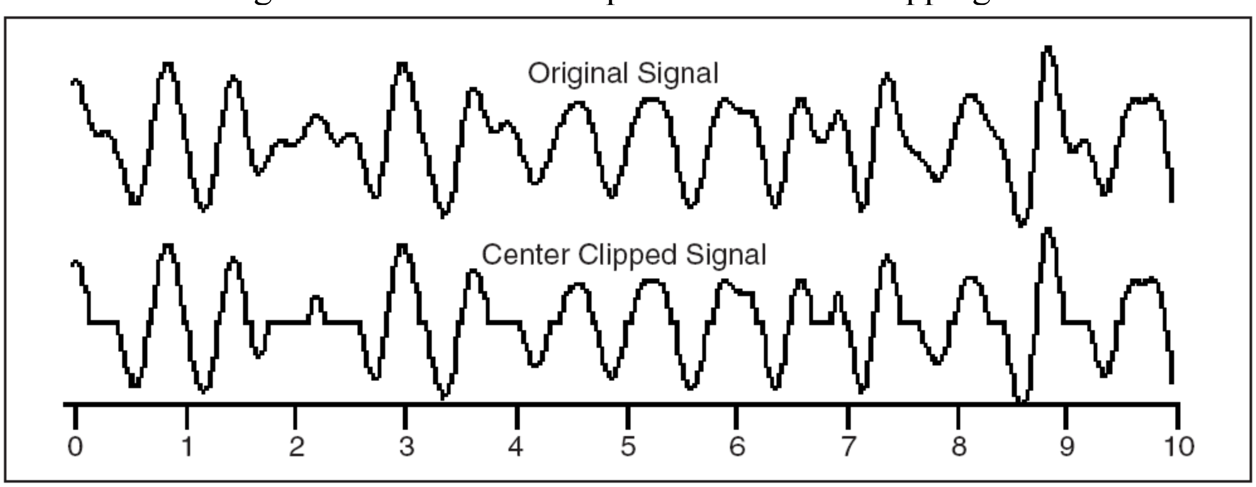
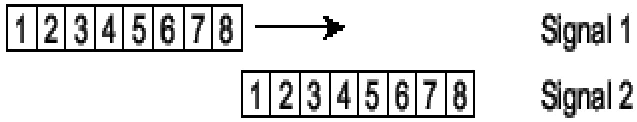


Fig.18 Center-clipped heart rate signal

4.3.3. Autocorrelation

It is a mathematical tool used frequently in signal processing for analyzing functions or series of values, such as time domain signals. Informally, it is the strength of a relationship between observations as a function of the time separation between them. The correlation $r_{xx}[n]$ of a signal x[n] with itself is called *autocorrelation*.



It is an even symmetric function ($r_{xx}[n] = r_{xx}[-n]$) with a maximum at the Origin n=0.Autocorrelation can give information about repeating events. The actual determination of the respiration and heart rate starts.

One of the properties of the autocorrelation function is that if the input signal contains a periodic component, the autocorrelation function will contain a periodic component with the same frequency. The resulting output signal after autocorrelation contained peaks at integer intervals of the period of the signal. The peak finding used an algorithm that fitted a quadratic polynomial to a sequential group of three samples.

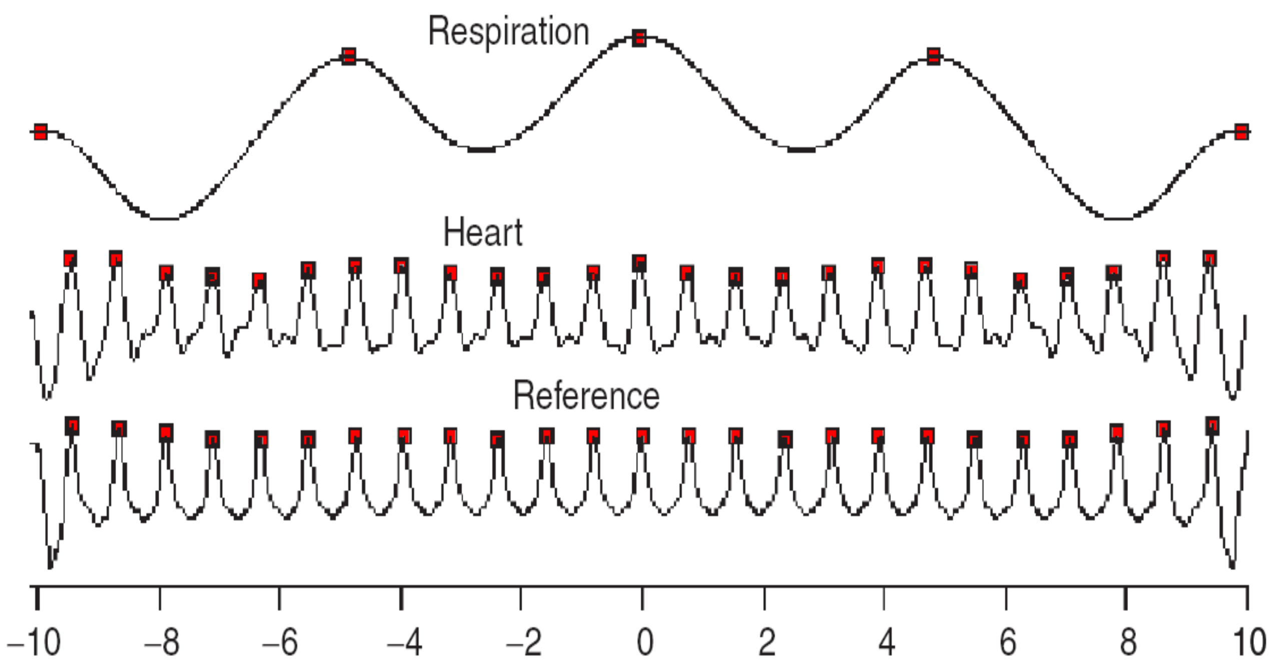


Fig .19 Autocorrelated signals corresponding to the respiration, heart, and reference signals

5. Conclusion

Non-contact monitoring could be a powerful tool for sensing cardiopulmonary activities where it is discomfort or difficult to apply electrode (e.g. causes skin irritation, burn patient).

Inexpensive mass production of single chip non-contact vital signs monitors has become feasible through leveraging of CMOS base station technology.

Radar system, based on Doppler theory, transmits continuous (CW) electromagnetic signal that is reflected from the target and receives the signal with its phase shift proportional to time varying motion of the patient's chest.

Quadrature transceiver is used to improve the phase demodulation of the signal and to avoid null points. The homodyne receiver used to provide baseband.

The chest moves due to Heart contraction, extending and relaxing of lungs which are affected by expiration and inspiration.

Heart rate varying from 43 to 94 beat per minute with frequency range from 1 Hz to 1.67 Hz while the respiration rate varying from 5 to 21 breaths per minute with frequency range from 0.08 Hz to 0.35 Hz. The amplitude of the respiration signal is typically about 100 times greater than that of the signal due to the heartbeat.

Before any information can be extracted from the demodulated voltage waveform, the heart and respiration signals need to be separated. This can be done by using hardware such as analog filters and amplifiers. Bandpass filter with cutoff frequency (1 Hz- 3 Hz) is used to separate heart signal while lowpass filter with cutoff frequency 0.7 Hz.

The separation can be also done by using digital signal processing software. Digital processing offers implementation flexibility, filters with closer tolerances, utilizes fewer components, and has an overall lower price. DSP software not only replaces hardware filters for separation of heart and breathing signals but also provides convenient means of extracting heart and breathing rates.

This project focused on separation of signals that come from a single subject. The presence of multiple subjects limits the usefulness of using this technique, so we have to find a signal processing method to isolate the signals from multiple subjects.

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