B.Sc. in Computer Science and Engineering Thesis

Study on Microwave Life Detection System

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CERTIFICATION

This thesis paper titled **“Study on Microwave Life Detection System”**, submitted by the group as mentioned below has been accepted as satisfactory in partial fulfillment of the requirements for the degree B.Sc. in Computer Science and Engineering on December 2012.

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CANDIDATES’ DECLARATION

This is to certify that the work presented in this thesis paper is the outcome of the investigation and research carried out by the following students under the supervision of Engr. Md. Azmal Hossain, Instructor, Department of CSE, MIST, Dhaka, Bangladesh.

It is also declared that neither this thesis paper nor any part thereof has been submitted anywhere else for the award of any degree, diploma or other qualifications.

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ABSTRACT

Thousand of persons are being killed as a cause of earthquake. The disaster in the Dhaka City may claim thousands of lives due to Earthquake. It is said if survivors are found and rescued earlier the numbers of victims will be lower. There is no end to the number of lives lost as the result of such disasters as landslides, collapsed tunnels and avalanches.

The microwave life detection system is developed for the search and rescue of victims trapped under the rubble of collapsed building during the earthquake or other disasters. The proposed system utilizes L-band frequency which is able to detect respiratory and heart fluctuations. The operation principle is based on Doppler frequency shift of the electromagnetic wave reflected from the buried victim. The schematic diagram of microwave Transmitting/Receiving (T/R) and clutter cancellation subsystem are included in this report. In this report various parts of a microwave life detection system such as antenna, directional coupler, and splitter has been discussed. By advent of this system the world death rate as a cause of an earthquake may decrease to greater extent.

Keywords: Life under rubble, modulation due to body oscillations, Doppler shift, dual antenna system, clutter signals.

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LIST OF ABBREVIATION

MIMO : Multiple Input Multiple Output
SIMO : Single Input Multiple Output
ICA : Independent Component Analysis
FFT : Fast Fourier Transform
MCT : Microwave Coherent Transceiver
CW : Continuous Wave
FPM : Finger Pulse Monitor
CCS : Clutter Cancellation System
SPDT : Single Pole Double Throw
RF : Radio Frequency
DIFT : Inverse Discrete Fourier Transform
BSS : Blind Sources Separation

LIST OF SYMBOLS

ΔR : Resolution
ω_0 : Angular frequency
ϑ : Propagation velocity
A_x : Amplitudes to life signals
A_j : Amplitudes to life rubble
$R_s(t)$: Round trip distance of the survivor from the radar system
R_j : Round trip distance of the rubble from the radar system
ω_b : Frequencies due to the breathing
ω_h : Frequencies due to the heartbeat
A_b : Amplitudes due to the movement of the chest
A_h : Amplitudes due to the movement of the heart
$\varphi_x(t)$: Weakness of life signal
$E_Q(t)$: Quadrature Component
$E_I(t)$: Phase Component
Σ : Summation Notation

CHAPTER 1
INTRODUCTION

1.1 Overview

Most of the victims of earthquake or other natural disasters in the various parts of the worlds are trapped under rubble of the collapsed buildings. A detection of the victims can save his life. As in the radar application, the phase of the incident wave can be changed due the body vibrations. Depending upon this fact ”A Revolutionary System to Detect Human Being Buried under the Rubble” used to trap the buried victims under earthquake rubble or collapsed buildings by the utilization of microwave radio frequency has been design.

The interest to development of means and methods for through-obstacles detection and imaging systems has increased significantly among scientific and system design community in recent years. There’re lots of application areas for such type of systems. Most actual are natural disaster survivors’ location in rescue operations and in-building target detection and imaging during anti-terrorist operations or hostage rescue.

Acoustic and radio waves are mostly used due to their ability to penetrate through most of building materials or layer of ground. But application of radio waves much less intrusive to the environment as it requires much less radiation power comparably to acoustical methods.

Collapse of man-made structures, such as buildings and bridges, occur with varying frequency across the world. In such a case, survived human beings are often trapped in the cavities created by collapsed building material. The concept of microwave life detection system was emerged with the development in the systems for rescue operation. Initial dogs were used to detect presence of human then acoustic detectors and robot radar[1] come into existence. But these systems are having major drawbacks.

The history of ”Revolutionary System to detect Human Being Buried Under the Rubble” starts with K. M. Chen who brings out the concept of detection of buried victims using microwave beam in 1985. After the detailed study of microwave signals and Doppler's effect, Ku Mem chen had been proposed including the basic principle for the operation of life detection system in 1991[2]. A Low Power Hand-Held Microwave Device was made for the Detection of Trapped Human Personnel by W. S. Haddad in 1997. The device, called the Rubble Rescue Radar (RRR) incorporates Micro power Impulse Radar technology which was developed at Lawrence Livermore National Laboratory over the few years.

The researcher put their effort to study the various effect various bands of microwave signals and depending upon this, a system which detect human being with ka-band with double sidebands have been proposed, in 2006. It states that a short wavelength of ka-band increases the sensitivity of antenna which will detect the small body vibration. A paper on 'An X-band microwave life detection system' has been presented by Huey Ru in 2007. In this paper author present the idea of detecting human being located behind the wall using a microwave signal. The phase change of a reflected microwave signal will provide the precious information about the buried victim's heartbeat as well as breathing.

A rescue radar system is proposed by M. Donelli in 2011[3]. In radar system a SAW oscillator is used to generate 10GHz frequency signals. While receiving through patch antenna the signal is process by the ICA (Independent Component Algorithm).

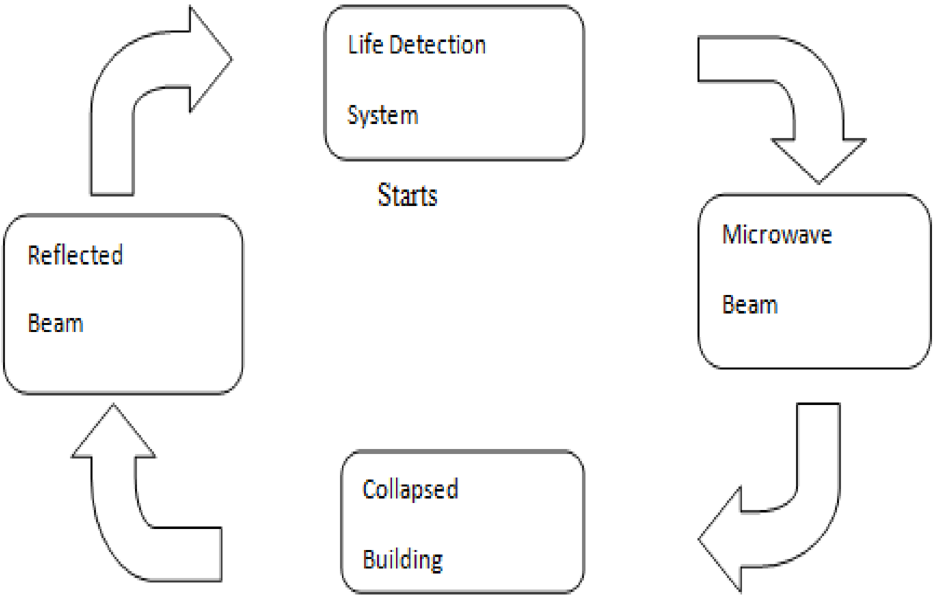

Figure 1.1: Principle of Microwave Operation

Since the early 1990's situations have been studied to determine if microwave frequency can be used to help detect survivors in avalanche and collapsed building situations. Initially early in the 90's, microwaves were used to remotely detect life signs from subjects lying on the ground (surface), up to 100feet away or behind a wall. This was initially facilitated through the use of frequencies in the L-band and X-band i.e. 2GHz and 10GHz respectively. So far results have showed great potential in such systems. Slow, vibratory signals created by the heart and the respiratory systems of a survivor would modulate a reflected microwave signal sent from the surface. This would in turn be Fourier analyzed to see if a heartbeat and breathing (of frequencies approximately 1.36 Hz and .3 Hz respectively), is present. Later, test were conducted with combinations of barriers such as wood, cider blocks, conventional bricks, reinforced concrete blocks and fine metallic wire mesh and wet soil. Because of new microwave technology, it does not mean that using dog and human sensors as detecting agents are futile.

Audio recognition and instinct still play a major role in the search for survivors. However, if the victim is being pinned down and unable to scream and shout, then the audio factor is non-existent. Seismic detectors too are not obsolete. This is because if and when victims are pinned down and unable to create audio noise, the next instinctive thing to do would be to grab something that can make the noise for them. This often comes in the form of hitting something hard against something solid (like a wall or beam). When this is done, not only is sound created but measurable seismic vibrations, which can be detected by search personnel. However, in situations such as collapsed buildings, often structures are unstable. Unstable structures often create stress noises that are audible and measurable. These sounds/vibrations can be counter-productive to human seismic detection attempts. In addition, hitting something solid against a wall of recently fallen structure is unsafe and may cause further disaster upon the survivor. So to aid in the detection of surviving humans, once this microwave technique is perfected many more lives may be saved with the additional time that this passive technology will buy for the rescuers.

1.2 Need of Life Detection System Over Conventional System

Existing ways to detect the human being under the earthquake rubble and collapsed buildings are utilization of the dogs, optical devices and acoustic life detectors and the rescue robot.

But the dogs can detect the dead persons and this occupies the precious time which can be utilize to detect alive victims. Also, the optical devices have a limited number of degree of freedom, require expert operators and cannot be used in inaccessible area. Acoustical detectors such as geophones are simple to use but they require quiet working environments, a condition difficult to reach especially in critical situations.

The Rescue Robot can navigate deep into the rubble to search for victim by the use of temperature sensor but they are unable to trap once they go out of range. Information about the location of buried person would be of great value for the rescue personnel, since it would help to reduce the time of operation and thus, help to save more lives. There is a need to construct a life detection system which can detect buried victims under earthquake or building debris most efficiently and as possible in short time. Such kinds of problems have been efficiently solved considering continuous wave or ultra wideband radars which offer good localization and spatial accuracy. In rescue mission and also in some surveillance operations there is not only the need of detect life signals but also the identification of people in a given area, to facilitate rescue team operations in case of emergencies. This task can be complied with through the wall surveillance techniques.

1.3 Working Principle of Life Detection System

The principle of detection is firstly, microwave is sent through rubble to detect vital signs of life. Microwave is having the property to penetrate through barriers and would reflect back from some objects. These objects include humans. When the beam hits the body, the signal reflected with an additional modulation created by movement of heart and lungs. So, the reception of modulated signals shows the presence of alive human inside the rubble. With the modulated signal there are some signal (commonly known as clutter signal) which are reflected from the immobile object such as rubble or debris. Thus in order to maintain a high sensitivity for this application, the clutter wave reflected from the rubble or the surface of the ground has to be cancelled as thoroughly as possible. For this an automatic clutter cancellation system is used. A Microwave life detection system operated on the radio frequency was proposed in the 1985[4]. This system detects the body oscillations occur due the breathing and heartbeat fluctuations. The system includes the additional subsystem to cancel the unwanted signals receive from the motionless objects such as rubble.

1.4 Frequency Bands of Microwave

The microwave life detection system can works on different range of frequencies from L-band (2GHz) to X- band (10GHz). But X- band microwave is unable to penetrate deep into the rubble. It can penetrate rubble up to 1.5 ft in the thickness (5 layers of bricks) while L-band can penetrate the rubble of about 3 ft in thickness (10 layers of bricks). Due to the fact that lower frequency will be more capable of detecting vital signs through very thick rubble, so frequency of an electromagnetic wave needs to be in the L-band or S-band range, For this reason, the a microwave life detection system which operates on the L-band frequency. This system is supposed to quite efficient to trap the breathing and heartbeat signals of victims who are completely trapped and too weak to respond.

Table 1.1 Microwave frequency bands

Letter Designation	Frequency range
L band	1 to 2 GHz
S band	2 to 4 GHz
C band	4 to 8 GHz
X band	8 to 12 GHz
Ku band	12 to 18 GHz
K band	18 to 26.5 GHz
Ka band	26.5 to 40 GHz
Q band	33 to 50 GHz
U band	40 to 60 GHz
V band	50 to 75 GHz
E band	60 to 90 GHz
W band	75 to 110 GHz
F band	90 to 140 GHz
D band	110 to 170 GHz

CHAPTER 2

LITERATURE REVIEW

2.1 Optical and Acoustical Life Detectors

Most of the victims of earthquakes, avalanches or other natural disasters in various parts of the world, including the 2011 earthquake and tsunami in Japan, are people trapped under rubble of collapsed buildings. An early detection of survivors can potentially reduce the mortality rate, so the development of survivor's detection systems is desirable. Optical and acoustical life detectors are widely used in search and rescue missions. Optical systems present a limited number of degrees of freedom, require expert operators and cannot be used in inaccessible area. Acoustical detectors such as geophones are simple to use but they require quiet working environments, a condition difficult to reach especially in critical situations.

Recently, microwave life-detection systems have been developed to remotely detect vital life signals for rescue missions. Such kind of problems has been efficiently solved considering continuous wave or ultra wideband Radars which offer good localization and spatial accuracy. In rescue mission and also in some surveillance operations there is not only the need of detect life signals but also the identification of people in a given area, to facilitate rescue team operations in case of emergencies. This task can be complied with through the wall surveillance techniques. These techniques could be effectively used with efficacy for medical applications like the monitoring of the breathing and heartbeat of critical patients in a clinic.

2.2 Low Frequency Rather than High Frequency

While high frequency radio waves give better resolution, the penetration depth is increased with low frequency waves. Thus there's a practically optimal range lying in a region of about

1/4 GHz. As it well known from the radar theory the resolution (ΔR) is directly defined by bandwidth of the radiated signal ΔR=v/2*B, there v is velocity in a medium and B=fh-fl is bandwidth. In a table below the relation of resolution to bandwidth is presented.

Table 2.1 Relation of resolution to bandwidth

B,MHz	≈100	≈200	≈500	≈1000
ΔR,cm	≈150	≈75	≈32	≈16

It's obvious that only ultra-wide band systems "$(bandwidth/centralfrequency > 0.3)$" may provide suitable resolution in frequency range 1/4 GHz[5]. Most of the developers rely on short pulse generation technique to achieve ultra-wide band operation, but in this contribution radar on alternative step-frequency technology is presented. The radar quickly sweeps through frequency range sequentially generating a set of equally distributed frequencies and collects received signal on each frequency. Applying several data processing sequences, including discrete inverse Fourier transform (DIFT), input signal is mapped to time domain providing reflectors' profile. Repeating sweep many times per second the procedure is applicable both for static and relatively slow moving reflectors (targets), such as moving human.

By our opinion the step-frequency radar has several important advantageous over short pulse radars:

- Higher dynamic range and processed mean power, thus higher range and resolving power;
- All radiated power is contained within the effective antenna bandwidth;
- Ability to apply "first reflection" suppression methods in hardware, thus further increasing sensitivity;
- High reliability, stability and relatively easy implementation;
- Low power consumption, thus long operation on internal buttery;
- Ability to operate in continuous wave (CW) mode, where the maximum detection sensitivity may be achieved by selecting the optimum frequency.

2.3 Doppler Radar Technology

A Doppler radar is specialized radar that makes use of the Doppler Effect to produce velocity data about objects at a distance[6,8]. It does this by beaming a microwave signal towards a desired target and listening for its reflection, then analyzing how the frequency of the returned signal has been altered by the object's motion. This variation gives direct and highly accurate measurements of the radial component of a target's velocity relative to the radar. Doppler radars are used in aviation, sounding satellites, meteorology, police speed guns, radiology, and biostatics radar (surface to air missile).

Partly because of its common use by television meteorologists in on-air weather reporting, the specific term ”Doppler Radar” has erroneously become popularly synonymous with the type of radar used in meteorology. Most modern weather radars use the pulse-Doppler technique to examine the motion of precipitation, but it is only a part of the processing of their data. So, while these radars use a highly specialized form of Doppler radar, the term is much broader in its meaning and its applications.

2.3.1 Doppler Effect

The Doppler effect (or Doppler shift), named after Austrian physicist Christian Doppler who proposed it in 1842, is the difference between the observed frequency and the emitted frequency of a wave for an observer moving relative to the source of the waves[4]. It is commonly heard when a vehicle sounding a siren approaches, passes and recedes from an observer. The received frequency is higher (compared to the emitted frequency) during the approach, it is identical at the instant of passing by, and it is lower during the recession. This variation of frequency also depends on the direction the wave source is moving with respect to the observer; it is maximum when the source is moving directly toward or away from the observer and diminishes with increasing angle between the direction of motion and the direction of the waves, until when the source is moving at right angles to the observer, there is no shift.

An analogy would be a pitcher throwing one ball every second in a person's direction (a frequency of 1 ball per second). Assuming that the balls travel at a constant velocity and the pitcher is stationary, the man will catch one ball every second. However, if the pitcher is jogging towards the man, he will catch balls more frequently because the balls will be less spaced out (the frequency increases). The inverse is true if the pitcher is moving away from the man; he will catch balls less frequently because of the pitcher's backward motion (the frequency decreases). If the pitcher were to move at an angle but with the same speed, the variation of the frequency at which the receiver would catch the ball would be less as the distance between the two would change more slowly. From the point of view of the pitcher, the frequency remains constant (whether he's throwing balls or transmitting microwaves). Since with electromagnetic radiation like microwaves frequency is inversely proportional to wavelength, the wavelength of the waves is also affected. Thus, the relative difference in velocity between a source and an observer is what gives rise to the Doppler Effect.

2.3.2 Doppler Application

The utility of microwave Doppler radar has increased for several applications. These include home health care applications, urgent conditions, and hospital needs. Affixed electrodes for traditional electrocardiograms are perturbing for long-duration home-monitoring, as well as for patients with conditions such as burn victims or newly born infants. In addition, a touch-less technique is necessary to detect life signs for people under rubble[4].

Based on the Doppler theory, a target with a quasi-periodic movement reflects the transmitted signal with its phase modulated by the time-varying position of the target. When the target is the person's chest, the reflected signal contains information about the chest displacement, due to heartbeat and respiration.

However, while holding breath, the reflected signal depends on the chest displacement due to heartbeat alone. At rest, the variation of the chest displacement, caused by respiration, is between 4 and 12 mm, and the chest displacement due to heartbeat alone ranges between 0.2 and 0.5 mm. The respiration rate corresponds to a frequency that varies between 0.1 and 0.3 Hz, while the heartbeat rate (HR) corresponds to a frequency that varies between 1 and 3 Hz. Previous works tend to detect life signs, respiration rates and heartbeat rates, using fixed frequency and fixed power of the transmitted signal. Direct-conversion Doppler radars, operating at 1.6 GHz and 2.4 GHz, have been integrated in 0.25 mm CMOS and BiCMOS technologies. Heart and respiration activities were detected using a modified Wireless Local Area Network PCMCIA card, and a module combining the transmitted and reflected signals. Other systems operating in the Ka-Band were described in using a low power double-sideband transmission signal. Recently, a new study shows the possibility of detecting the presence of a person through a wall using Ultra-Wideband (UWB) radar. Some experiments are performed for the detection of life signs using the 4 -7 GHz band with 1 mW power and around 7 dB antenna gains. Another system operating at 10 GHz showed the ability to detect the heart and the respiration activity of a person behind a wall.

In addition to the installation simplicity, the proposed system has the ability of tuning both frequency and power. As the transmission of a signal with minimum power would be safer for both the patient and the medical staff, the proposed system helps determining the optimal frequency with the minimum transmitted power before the implementation process. Both heartbeat rate and Heart Rate Variability (HRV) are extracted and compared to the values obtained by the ECG. The rest of the paper is organized as follows. Section II presents the proposed system and shows the heartbeat signal detected vs. the ECG signal. Section III shows the heartbeat signals detected by the proposed system at 16 GHz for several transmitted powers. Section IV shows the results for the extraction of the heartbeat rate and the Heart Rate Variability (HRV) for both original and smoothed signals.

2.4 Microwave Technology

Microwaves are radio waves with wavelengths ranging from as long as one meter to as short as one millimeter, or equivalently, with frequencies between 300 MHz (0.3 GHz) and 300 GHz.

The prefix ”micro-” in ”microwave” is not meant to suggest a wavelength in the micrometer range. It indicates that microwaves are ”small” compared to waves used in typical radio broadcasting, in that they have shorter wavelengths. The boundaries between far infrared light, terahertz radiation, microwaves, and ultra-high-frequency radio waves are fairly arbitrary and are used variously between different fields of study.

Microwave technology is extensively used for point-to-point telecommunications (i.e., non broadcast uses). Microwaves are especially suitable for this use since they are more easily focused into narrow beams than radio waves, and also their comparatively higher frequencies allow broad bandwidth and high data flow. Microwaves are the principal means by which data, TV, and telephone communications are transmitted between ground stations and to and from satellites. Microwaves are also employed in microwave ovens and in radar technology.

2.4.1 Microwave Sources

High-power microwave sources use specialized vacuum tubes to generate microwaves. These devices work in the density modulated mode, rather than the current modulated mode.

Low-power microwave sources use solid-state devices such as the field-effect transistor (at least at lower frequencies), tunnel diodes, Gunn diodes, and IMPATT diodes. Low-power sources are available as bench top instruments, rack mount instruments, embeddable modules and in card-level formats.

The sun also emits microwave radiation, although most of it is blocked by Earth's atmosphere.

2.4.2 Uses of Microwave Frequency

Communication

Before the advent of fiber-optic transmission, most long-distance telephone calls were carried via networks of microwave radio relay links run by carriers such as AT and T Long Lines.

Metropolitan area network (MAN) protocols, such as WiMAX (Worldwide Interoperability for Microwave Access) are based on standards such as IEEE 802.16, designed to operate between 2 to 11 GHz. Mobile Broadband Wireless Access (MBWA) protocols based on standards specifications such as IEEE 802.20 or ATIS/ANSI HC-SDMA (such as iBurst) operate between 1.6 and 2.3 GHz to give mobility and in-building penetration characteristics similar to mobile phones but with vastly greater spectral efficiency.

Microwave radio is used in broadcasting and telecommunication transmissions because, due to their short wavelength, highly directional antennas are smaller and therefore more practical than they would be at longer wavelengths (lower frequencies).

Most satellite communications systems operate in the C, X, Ka, or Ku bands of the microwave spectrum. These frequencies allow large bandwidth while avoiding the crowded

UHF frequencies and staying below the atmospheric absorption of EHF frequencies. Satellite TV either operates in the C band for the traditional large dish fixed satellite service or Ku band for direct-broadcast satellite. Military communications run primarily over X or Ku-band links, with Ka band being used for Military.

Radar

Radar uses microwave radiation to detect the range, speed, and other characteristics of remote objects. Now radar is widely used for applications such as air traffic control, weather forecasting, navigation of ships, and speed limit enforcement.

Heating and Power Application

A microwave oven passes (non-ionizing) microwave radiation (at a frequency near 2.45 GHz) through food, causing dielectric heating primarily by absorption of the energy in water. Microwave heating is used in industrial processes for drying and curing products. Many semiconductor processing techniques use microwaves to generate plasma for such purposes as reactive ion etching and plasma-enhanced chemical vapor deposition (PECVD).Microwaves can be used to transmit power over long distances.

2.4.3 Health Effects of Microwave Frequency

Microwaves do not contain sufficient energy to chemically change substances by ionization, and so are examples of no ionizing radiation. The word ”radiation” refers to energy radiating from a source and not to radioactivity. It has not been shown conclusively that microwaves (or other no ionizing electromagnetic radiation) have significant adverse biological effects at low levels. Some, but not all, studies suggest that long-term exposure may have a carcinogenic effect. This is separate from the risks associated with very high intensity exposure, which can cause heating and burns like any heat source, and not a unique property of microwaves specifically.

2.4.4 Microwave Transmission System

Microwave transmission refers to the technology of transmitting information or energy by the use of radio waves whose wavelengths are conveniently measured in small numbers of centimeter; these are called microwaves. This part of the radio spectrum ranges across frequencies of roughly 1.0 gigahertz (GHz) to 30 GHz. These correspond to wavelengths from 30 centimeters down to 1.0 cm.

Microwaves are widely used for point-to-point communications because their small wavelength allows conveniently-sized antennas to direct them in narrow beams, which can be pointed directly at the receiving antenna. This allows nearby microwave equipment to use the same frequencies without interfering with each other, as lower frequency radio waves do. Another advantage is that the high frequency of microwaves gives the microwave band a very large information-carrying capacity; the microwave band has a bandwidth 30 times that of all the rest of the radio spectrum below it. A disadvantage is that microwaves are limited to line of sight propagation; they cannot pass around hills or mountains as lower frequency radio waves can. Microwave radio transmission is commonly used in point-to-point communication systems on the surface of the Earth, in satellite communications, and in deep space radio communications. Other parts of the microwave radio band are used for radars, radio navigation systems, sensor systems, and radio astronomy.

Parabolic (Microwave) Antenna

To direct microwaves in narrow beams for point-to-point communication links or radiolocation (radar), a parabolic antenna is usually used. This is an antenna that uses a parabolic reflector to direct the microwaves. To achieve narrow beam widths, the reflector must be much larger than the wavelength of the radio waves. The relatively short wavelength of microwaves allows reasonably sized dishes to exhibit the desired highly directional response for both receiving and transmitting

Microwave Link

A microwave link is a communications system that uses a beam of radio waves in the microwave frequency range to transmit video, audio, or data between two locations, which can be from just a few feet or meters to several miles or kilometers apart. Microwave links are commonly used by television broadcasters to transmit programs across a country, for instance, or from an outside broadcast back to a studio. Mobile units can be camera mounted, allowing cameras the freedom to move around without trailing cables. These are often seen on the touchlines of sports fields on Stead cam systems.

Properties of Microwave Links

- Involve line of sight (LOS) communication technology
- Affected greatly by environmental constraints, including rain fade
- Have very limited penetration capabilities through obstacles such as hills, buildings and trees
- Sensitive to high pollen count
- Signals can be degraded during Solar proton events

Uses of Microwave Links

- In communications between satellites and base stations
- As backbone carriers for cellular systems
- In short range indoor communications
- Telecommunications, in linking remote and regional telephone exchanges to larger (main) exchanges without the need for copper/optical fiber lines.

Microwave Power Transmission

Microwave power transmission (MPT) is the use of microwaves to transmit power through outer space or the atmosphere without the need for wires. It is a sub-type of the more general wireless energy transfer methods.

Common Safety Concerns

The common reaction to microwave transmission is one of concern, as microwaves are generally perceived by the public as dangerous forms of radiation - stemming from the fact that they are used in microwave ovens. While high power microwaves can be painful and dangerous as in the United States Military's Active Denial System, MPT systems are generally proposed to have only low intensity at the antenna. Though this would be extremely safe as the power levels would be about equal to the leakage from a microwave oven, and only slightly more than a cell phone, the relatively diffuse microwave beam necessitates a large antenna area for a significant amount of energy to be transmitted. Research has involved exposing multiple generations of animals to microwave radiation of this or higher intensity, and no health issues have been found.

2.5 Backscattered Electromagnetic Field

Backscatter (or backscattering) is the reflection of waves, particles, or signals back to the direction from which they came[9,11]. It is a diffuse reflection due to scattering, as opposed to secular reflection like a mirror. Backscattering has important applications in astronomy, photography and medical ultra-sonography.

Radar

Backscattering is the principle behind radar systems. In weather radar, backscattering is proportional to the 6th power of the diameter of the target multiplied by its inherent reflective properties. Water is almost 4 times more reflective than ice but droplets are much smaller than snowflakes or hail stones. So the backscattering is dependent on a mix of these two factors. The strongest backscatter comes from hail and large grapple (solid ice) due to their sizes. They often show up as much higher rates of precipitation than actually occurring in what is called a bright band. Rain is a moderate backscatter, being stronger with large drops (such as from a thunderstorm) and much weaker with small droplets (such as mist or drizzle). Snow has rather weak backscatter.

Backscatter in Waveguides

The backscattering method is also employed in fiber optics applications to detect optical faults. Light propagating through a fiber optic cable gradually attenuates due to Rayleigh scattering. Faults are thus detected by monitoring the variation of part of the Rayleigh backscattered light. Since the backscattered light attenuates exponentially as it travels along the optical fiber cable, the attenuation characteristic is represented in a logarithmic scale graph. If the slope of the graph is steep, then power loss is high. If the slope is gentle, then optical fiber has a satisfactory loss characteristic. The loss measurement by the backscattering method allows measurement of a fiber optic cable at one end without cutting the optical fiber hence it can be conveniently used for the construction and maintenance of optical fibers.

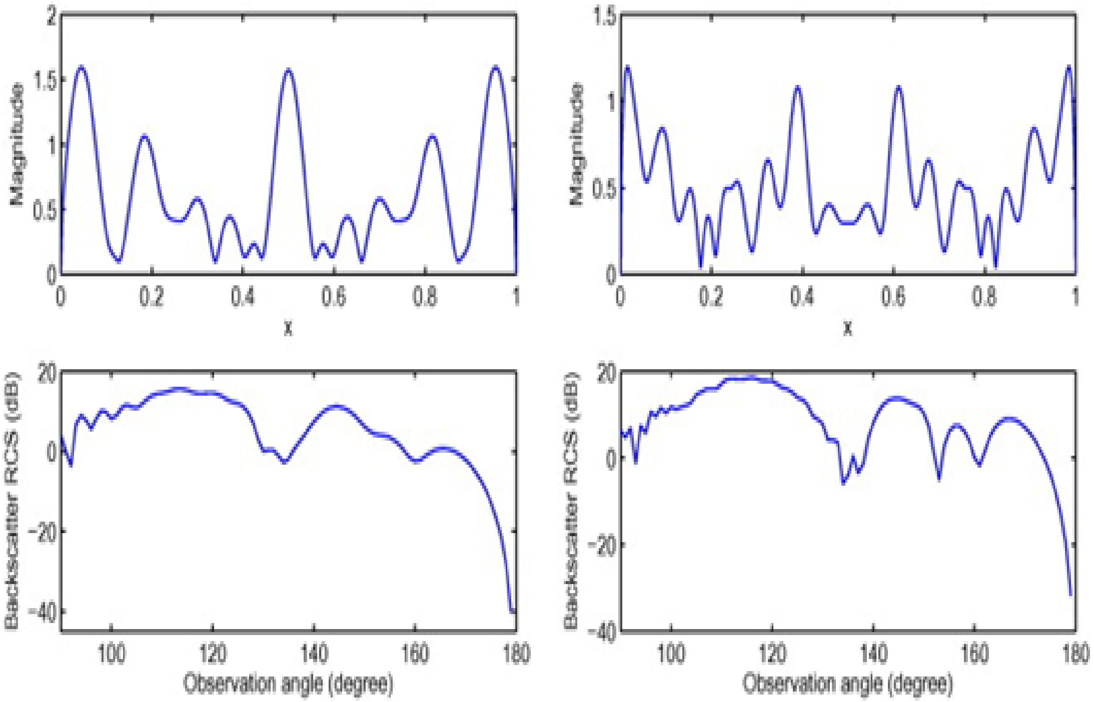

Figure 2.1: The magnitude of the electric field (normal incidence)(RCS-Radar Cross Section)

2.6 Independent Component Analysis (ICA)

Independent Component Analysis (ICA) is a statistical technique for decomposing a complex dataset into independent sub-parts. Here, we demonstrate ICA for solving the Blind Source Separation (BSS) problem[16].

We are given two linear mixtures of two source signals which we know to be independent of each other, i.e. observing the value of one signal does not give any information about the value of the other. The BSS problem is then to determine the source signals given only the mixtures. Putting this into mathematical notation, we model the problem by

x = A_s

where s is a two-dimensional random vector containing the independent source signals, A is the two-by-two mixing matrix, and x contains the observed (mixed) signals.

This first plot (below) shows the signal mixtures on the left and the corresponding joint density plot on the right. That is, at a given time instant, the value of the top signal is the first component of x, and the value of the bottom signal is the corresponding second component. The plot on the right is then simply constructed by plotting each such point x. The marginal densities are also shown at the edge of the plot.

Independent component analysis (ICA) is a computational method for separating a multivariate signal into additive subcomponents supposing the mutual statistical independence of the non-Gaussian source signals. It is a special case of blind source separation.

When the independence assumption is correct, blind ICA separation of a mixed signal gives very good results. It is also used for signals that are not supposed to be generated by a mixing for analysis purposes. A simple application of ICA is the ”cocktail party problem”, where the underlying speech signals are separated from a sample data consisting of people talking simultaneously in a room. Usually the problem is simplified by assuming no time delays or echoes. An important note to consider is that if N sources are present, at least N observations (e.g. microphones) are needed to get the original signals. This constitutes the square case (J = D, where D is the input dimension of the data and J is the dimension of the model). Other cases of underdetermined ”$(J < D)$” and over determined ”$(J > D)$” have been investigated.

Component Independence

ICA finds the independent components (aka factors, latent variables or sources) by maximizing the statistical independence of the estimated components. We may choose one of many ways to define independence, and this choice governs the form of the ICA algorithms. The two broadest definitions of independence for ICA are-

The Minimization-of-Mutual information (MMI) family of ICA algorithms uses measures like Kullback-Leibler Divergence and maximum-entropy. The Non-Gaussianity family of ICA algorithms, motivated by the central limit theorem, uses kurtosis and negentropy.

Typical algorithms for ICA use centering, whitening (usually with the eigenvalue decomposition), and dimensionality reduction as preprocessing steps in order to simplify and reduce the complexity of the problem for the actual iterative algorithm. Whitening and dimension reduction can be achieved with principal component analysis or singular value decomposition. Whitening ensures that all dimensions are treated equally a priori before the algorithm is run. Algorithms for ICA include Informix, FastICA, and JADE, but there are many others.

In general, ICA cannot identify the actual number of source signals, a uniquely correct ordering of the source signals, nor the proper scaling (including sign) of the source signals.

ICA is important to blind signal separation and has many practical applications[16]. It is closely related to (or even a special case of) the search for a factorial code of the data, i.e., a new vector-valued representation of each data vector such that it gets uniquely encoded by the resulting code vector (loss-free coding), but the code components are statistically independent.

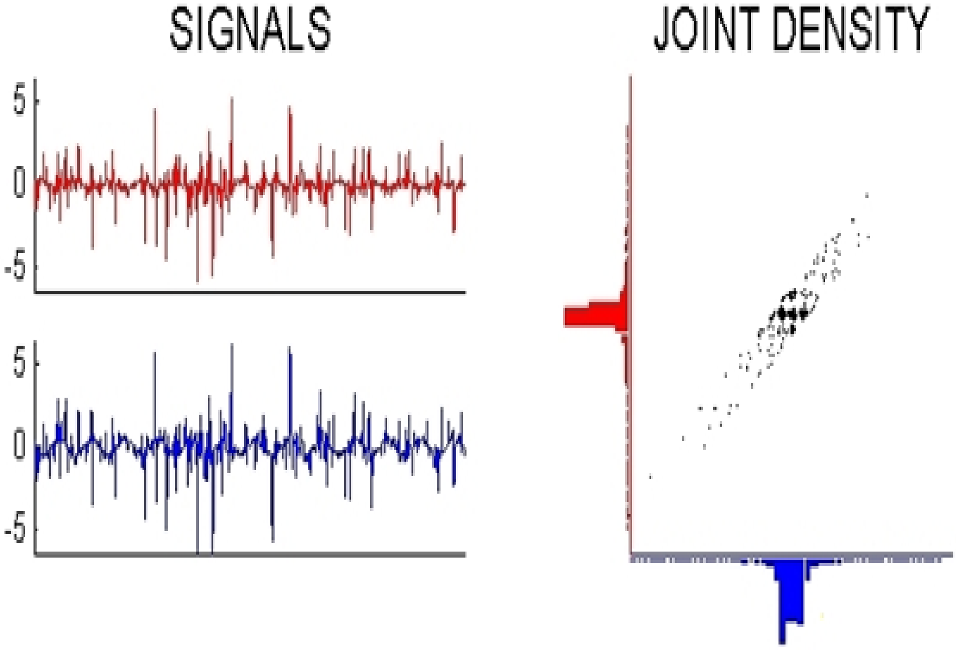

Figure 2.2: Input Signals and Density

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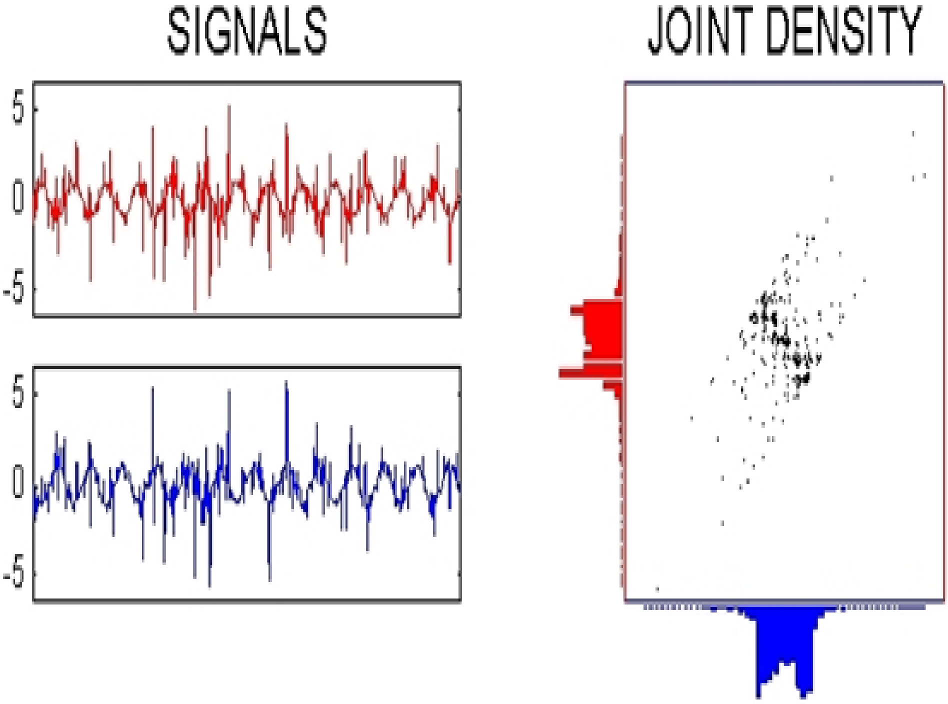

Figure 2.3: Whitened Signals and Density

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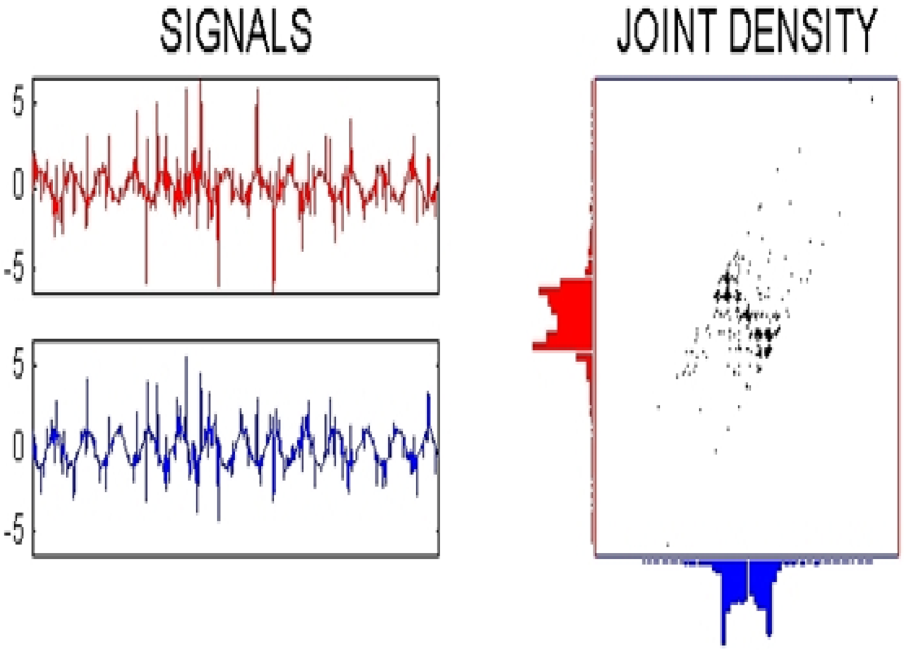

Figure 2.4: Separated Signals after step 1 of FastICA

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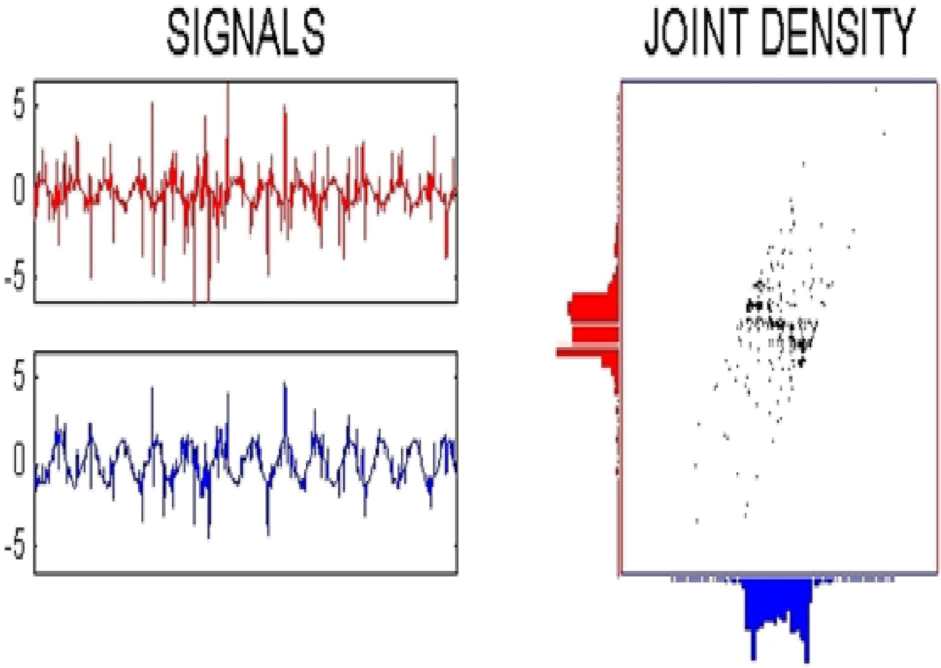

Figure 2.5: Separated Signals after step 2 of FastICA

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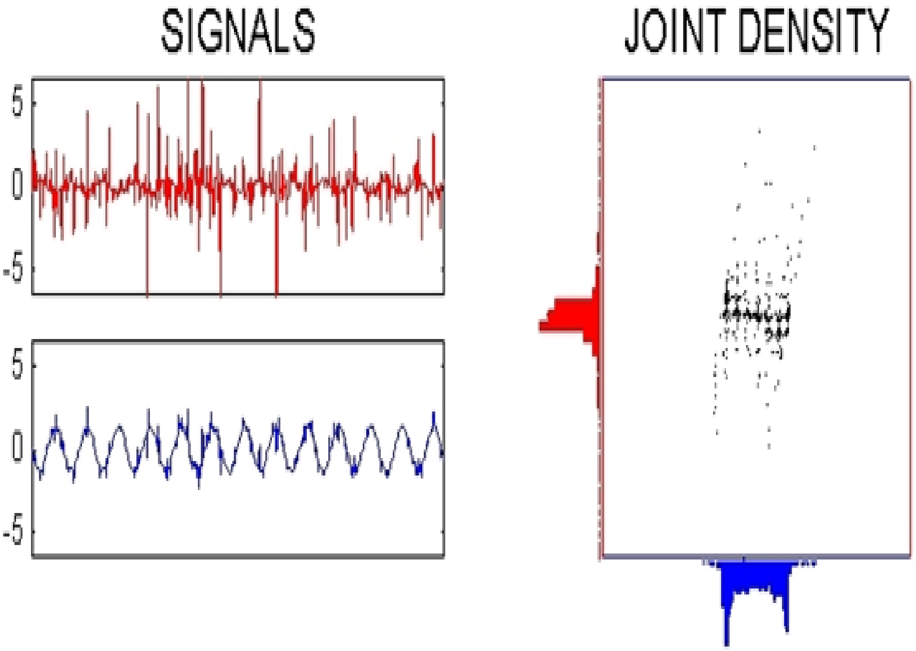

Figure 2.6: Separated Signals after step 3 of Fast ICA

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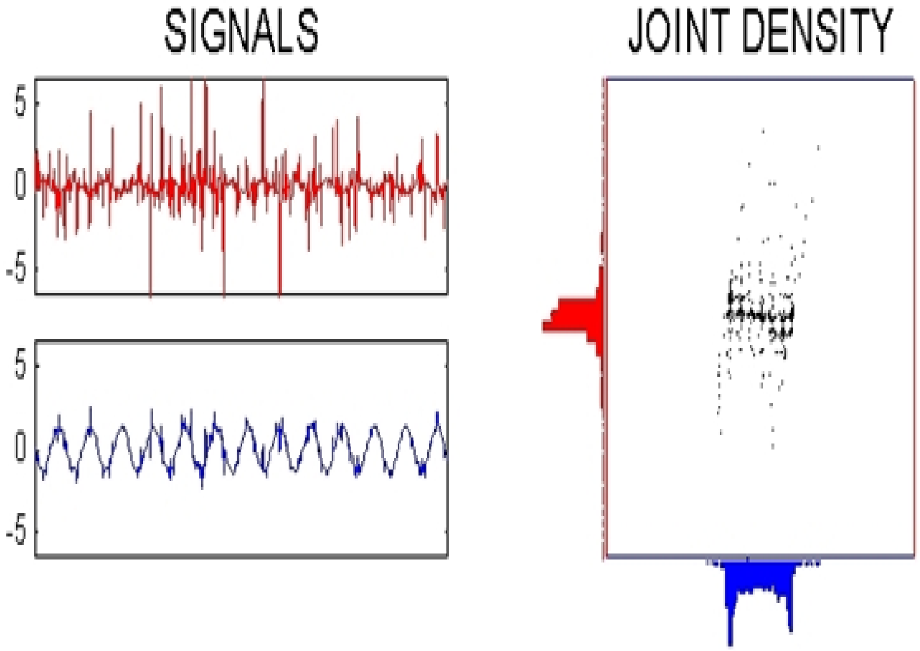

Figure 2.7: Separated Signals after step 4 of Fast ICA

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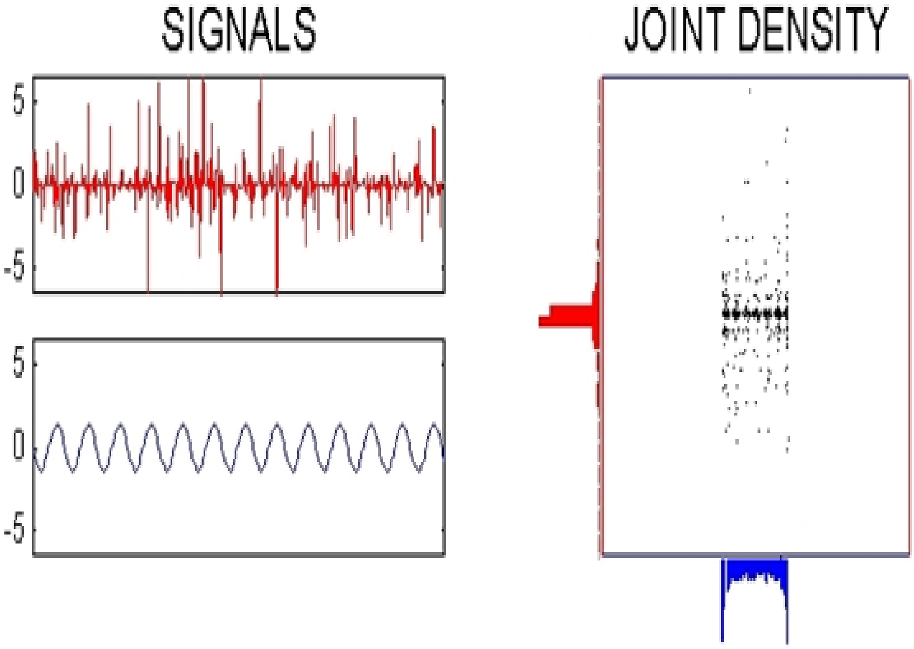

Figure 2.8: Separated Signals after step 5 of Fast ICA

Applications of ICA

- Separation of Artifacts in MEG Data

  Magneto encephalography (MEG) is a noninvasive technique by which the activity or the cortical neurons can be measured with very good temporal resolution and moderate spatial resolution. When using a MEG record, as a research or clinical tool, the investigator may face a problem of extracting the essential features of the neuromagnetic signals in the presence of artifacts. The amplitude of the disturbances may be higher than that of the brain signals, and the artifacts may resemble pathological signals in shape.

- Finding Hidden Factors in Financial Data

  It is a tempting alternative to try ICA on financial data. There are many situations in that application domain in which parallel time series are available, such as currency exchange rates or daily returns of stocks, that may have some common underlying factors. ICA might reveal some driving mechanisms that otherwise remain hidden.

- Reducing Noise in Natural Images

  The third example deals with finding ICA filters for natural images and, based on the ICA decomposition, removing noise from images corrupted with additive Gaussian noise. A set of digitized natural images were used. Denote the vector of pixel gray levels in an image window by x. Note that, contrary to the other two applications in the previous sections, we are not this time considering multivalve time series or images changing with time; instead the elements of x are indexed by the location in the image window or patch. The sample windows were taken at random locations. The 2-D structure of the windows is of no significance here: row by row scanning was used to turn a square image window into a vector of pixel values. Each window in this Figure corresponds to one of the columns ai of the mixing matrix A. Thus an observed image window is a superposition of these windows, with independent coefficients[13].

  Now, suppose a noisy image model holds:

  z= x+n

  where n is uncorrelated noise, with elements indexed in the image window in the same way as x, and z is the measured image window corrupted with noise

- Telecommunications

  Finally, we mention another emerging application area of great potential: telecommunications. An example of a real-world communications application where blind separation techniques are useful is the separation of the user's own signal from the interfering other users' signals in CDMA (Code-Division Multiple Access) mobile communication.

2.7 Modulation Technique

The conventional analog I/Q demodulator[17], shown in figure 2.9, uses two matched demodulator circuits to convert the RF input signal directly to baseband analog I and Q signals that are subsequently converted to digital data. The functionality of this circuit is based upon the RF input signal being split and mixed with two local oscillator (LO) signals that have a 900 phase shift between them. This 900 phase shift provides the mechanism to distinguish the I and Q components of the RF signal. The mixer outputs are lowpass filtered to remove the high-frequency mixing products, providing baseband analog I and Q signals that are sampled and converted to digital values. The parallel nature of the analog I/Q demodulator requires the two legs to be very closely matched to each other for accurate I/Q measurements. Also, the quadrature phase shift must be exactly 900 at all frequencies. This nature of the conventional analog I/Q detector makes it susceptible to errors associated with gain matching, DC offsets, quadrature phase errors, carrier leakage, and impedance matching. These errors can be difficult to completely eliminate or compensate for, causing RF measurement errors.

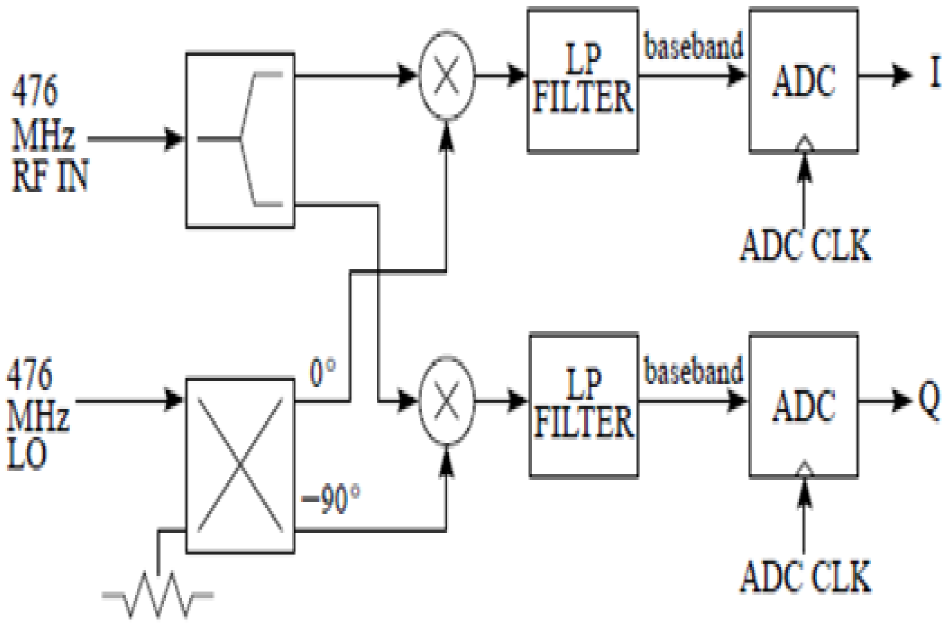

Figure 2.9: Conventional Analog I/Q Demodulator

As an alternative to the analog I/Q demodulator[17,18,19], figure 2.10 shows a digital I/Q demodulator implementation that inherently improves performance. Within this implementation, the RF input is down converted to an IF of 4.9 MHz by mixing the RF with a 471.1 MHz LO. The resulting signal is bandpass filtered to remove the high-frequency component that results from mixing and also limit the signal bandwidth to avoid aliasing. Aliasing is discussed in detail in a following section of this paper. The 4.9 MHz IF output is directly sampled with an analog-digital converter (ADC) operating at 19.6 MSPS[19]. The time period between consecutive ADC samples is 50.95 ns which corresponds to exactly900 at the 4.9 MHz IF. The sampled data reflects the amplitude of the original RF signal sampled at intervals. If we define the first sample at1800 as I, the next sample at 2700 is Q, the following sample at 3600 is -I, the next sample at is -Q, the following sample at is again I, and so on. The ADC output provides a data stream consisting of the repeating pattern of measurements of I, Q, -I, and -Q. The I and Q variables within this digital data stream are separated by a multiplexer that switches every other sample into two parallel digital paths. The sign inversion in each path is removed by multiplying each data stream by +1 and -1 alternately. The resulting outputs correspond to the measured I and Q of the input RF signal.

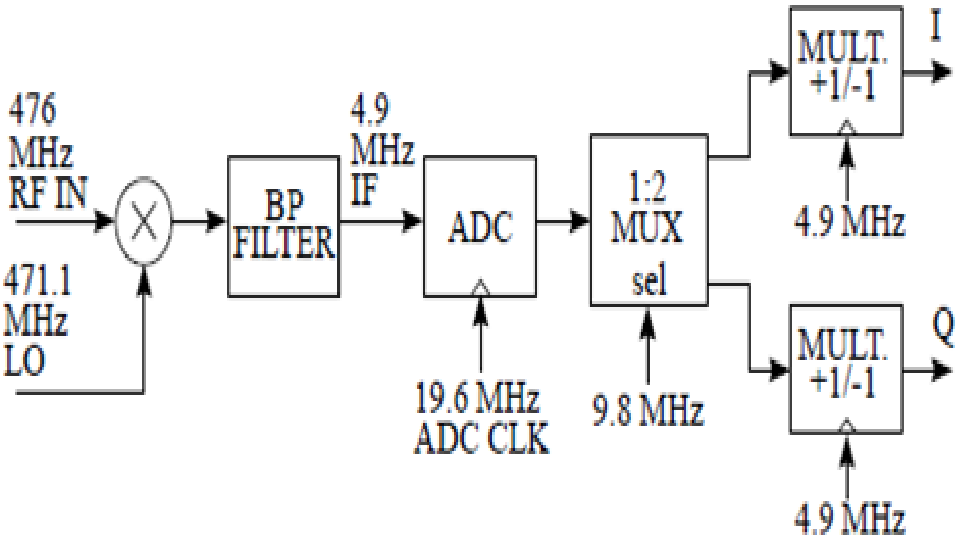

Figure 2.10: Digital I/Q Demodulator

The advantages of the digital I/Q demodulator are significant. The single path for the RF and IF processing insures per- fect gain-matching between the two I and Q signals. The two paths are applied to separate circuitry only after they have been converted to digital data. All digital processing can be easily matched for the two signals. The concerns of gain balancing and impedance matching for all the RF and analog components are obviated. Also, because the IF signal is sampled without ever being down converted to baseband, DC signals are not measured by the demodulator. Consequently, analog DC offsets and drifts do not affect the digital I/Q demodulator. The quadrature phase shift is dependent upon the precise timing of the ADC. The aperture jitter of the selected ADC is inconsequential, and stable clock circuitry has been designed into the PEP-II low level RF (LLRF) system. The one source of error for the digital I/Q demodulator results from the nature of the sampling process. The ADC clock period of 50.95 ns provides an exact phase shift 900 at the center frequency only. Signal frequencies not equal to the center frequency contain a quadrature phase error when measured. For a limited signal bandwidth, this quadrature phase error is maintained at insignificant levels, well below that achievable by conventional means. Narrow-band signals within 5 kHz of the RF carrier are detected with better than 0.05 quadrature error. Signals within the detection bandwidth of the I/Q demodulator (50khz) are detected with better than 0.5 quadrature error.

2.8 Mathematical Model

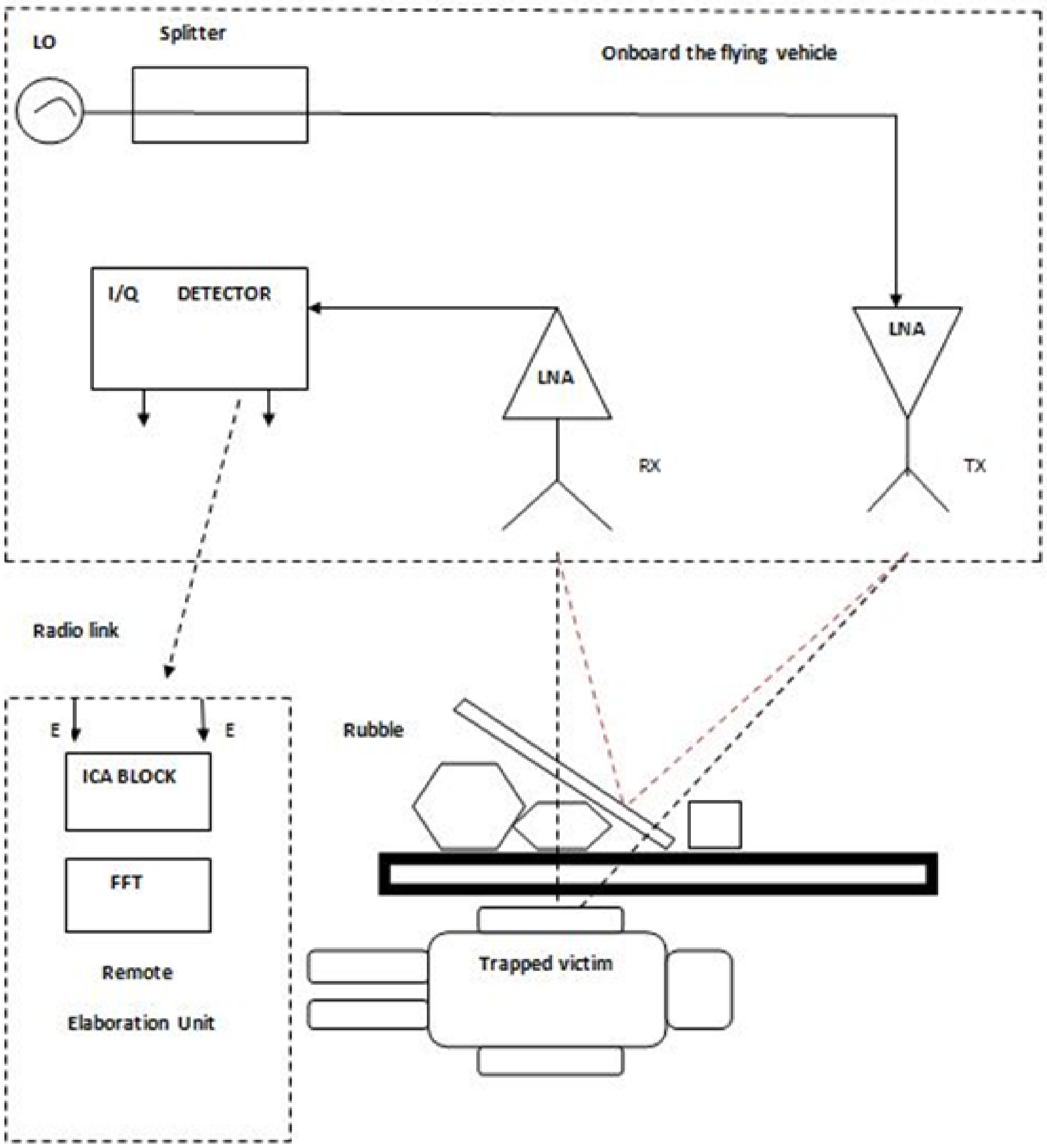

Figure 2.11: Diagram of the microwave life detection system

Let us consider the schema of the system shown in Figure 2.10. The main component is bi-static continuous wave (CW) radar consisting of a local oscillator which produces a sinusoidal signal of 10.45 GHz, a low noise amplifier, and a two patches array as transmitting antenna. The radar irradiates an electromagnetic wave and collects the reflected signal that contains the breathing and the heartbeat information coming from a human detected target. The backscattered signal is received by a two patches antenna, amplified and led to an I/Q detector.

The orthogonal detector is mandatory because the ICA requires a number of observation points equal to the number of the original signals and we exploit I/Q signals as two independent sources of information[14]. Then the output I/Q signals are given as input to a remote elaboration system by means of a low frequency wireless channel. As stated previously the amplitude and the phase of the received backscattered wave are modulated in accordance with the movement of breathing and heartbeat. The information associated to amplitude is generally negligible and only the phase variation is considered. The signal at the receiving antenna can be expressed considering the following relation.

$$E_{rx}(t) = A_x \cos(\omega_0 (t-2R_s(t)/\vartheta)) +\sum_{j=1}^{J} A_j \cos (\omega_0 (t-2R_s(t)/\vartheta)) \text{ ....} (1)$$

Where ω_0 is the angular frequency and v is the propagation velocity of the radio waves, A_x, A_j are the amplitudes associated to life signals and rubble respectively. $R_s(t)$ and R_j are the round trip distance of the survivor and rubble from the radar system. The second term describes the constant contributes due to the rubble and it can be easily removed with a simple Filtering procedure while the first term contains information related to life-signals. The small movement of the survivor body caused by breathing and heartbeat can be seen as a fluctuation around a mean distance Rs and modeled at the output of the orthogonal phase detector as:

$$\varphi_x(t) = (\omega_0/\vartheta(R_s + A_b \cos(\omega_b\, t) +A_h \cos(\omega_h t))) \text{ ....} (2)$$

Where, ω_b and ω_h are the frequencies due to the breathing and the heartbeat respectively. A_b, A_h are the amplitudes due to the movement of the chest and heart respectively. The weak received backscattered field, which is a mixture of vital signals, noise and clutter contribute, is amplified down-converted with an orthogonal detector, and processed with an analog-to-digital converter. The I/Q signals at the output of the orthogonal detector are led to a remote elaboration unit by means of a low frequency transmission module. The received signals must be post-processed to separate the life signals from the noise and the clutter contributes. ICA algorithm has been chosen to accomplish this task.

The ICA is a method for separating mixed data (such as MRI images, biomedical data, sounds, telecommunication channels or signals) into underlying informational components. The ICA belongs to a class of methods called blind sources separation (BBS). The classical example is two people speak at the same time in a room. Two microphones, placed in different points inside the room collect a mixture of the two voice signals. From these two signal mixtures, ICA can recover the two original source signals. One of the most important facts about standard BSS methods like ICA is that the number of independent source of information (i.e., the receivers) must be greater than the number of overlapped source signals. For the problem at hands this implies that there must be at least two probes to detect the life signals and for this reason we use an orthogonal detector generating EI and EQ these two signal mixtures collected at the output of the orthogonal phase detector and sent to the remote elaboration system for the post-processing could be expressed as:

$$E_I(t) = a_{11}\,\varphi_x(t) + a_{12}\,N(t) \tag{3}$$

$$E_Q(t) = a_{21}\,\varphi_x(t) + a_{22}\,N(t) \tag{4}$$

where $E_I(t) = A_I \cos(\varphi_x(t)) + N(t)$ and $E_Q(t) = A_Q \cos(\varphi_x(t)) + N(t)$, N(t) represents the noise contribution due to the clutter and other interfering sources. The terms a_{11}, a_{12}, a_{21}, and a_{22}, are parameters that depend from the phase shift. The two original signals N(t) and $\varphi_x(t)$ are assumed to be statistically independent at each time instant: for this reason it is possible to estimate the original signals processing the mixed signals $E_I(t)$, $E_Q(t)$ observed at the orthogonal detector. Let us consider the following metrical representation

$$\begin{pmatrix} E_I(t) \\ E_Q(t) \end{pmatrix} = |A| \begin{pmatrix} \varphi_x(t) \\ N(t) \end{pmatrix} \tag{5}$$

After estimating the coefficients matrix [A] and its inverse $[A]^{-1}$, it is possible to obtain the original signals as shown in the following equation

$$\begin{pmatrix} \varphi_x(t) \\ N(t) \end{pmatrix} = |A|^{-1} \begin{pmatrix} E_I(t) \\ E_Q(t) \end{pmatrix} \tag{6}$$

This goal is accomplished by using the ICA algorithm. After the ICA application, the cleaned signals N(t) and $\varphi_x(t)$ are separated. Only $\varphi_x(t)$ contains information related to the weak life signal while N(t) is negligible. $\varphi_x(t)$ is then further processed with a FFT algorithm in order to estimate the heartbeat and the breath rate.

CHAPTER 3

PROCEDURE OF IDENTIFYING VICTIMS

3.1 Material and Method

This section includes detail description of block diagram of ”Revolutionary System to Detect Human Being Buried under the Rubble.” Also with this there is explanation of various parts of microwave system. The working of clutter cancellation system is included in this section.

3.1.1 Block Diagram of the System

The microwave life detection system has three major components. They are a microwave circuit which generates, amplifies and distributes microwave signals to different microwave components. A dual antenna system, which consists of two antennas, energized sequentially. A microwave controlled clutter cancellation system, which creates an optimal signal to cancel the clutter from the rubble.

3.2 A Microwave Circuit

The microwave circuit in the fig.3.1 consists of phase locked oscillator, directional couplers and circulator[8,9]. The phase locked oscillator is used to generate a very stable electromagnetic wave of 2GHz range. The SAW (Surface Acoustic Wave) oscillator can generates 1150 MHz frequency with output power 400mW. Power dividers and directional couplers are passive devices used in the field of radio technology. In microwave life detection system 10 dB and 3dB couplers are used. 10dB coupler is used to divide the power into 1/10th and 9/10th part while 3dB coupler divides power into two equal parts.

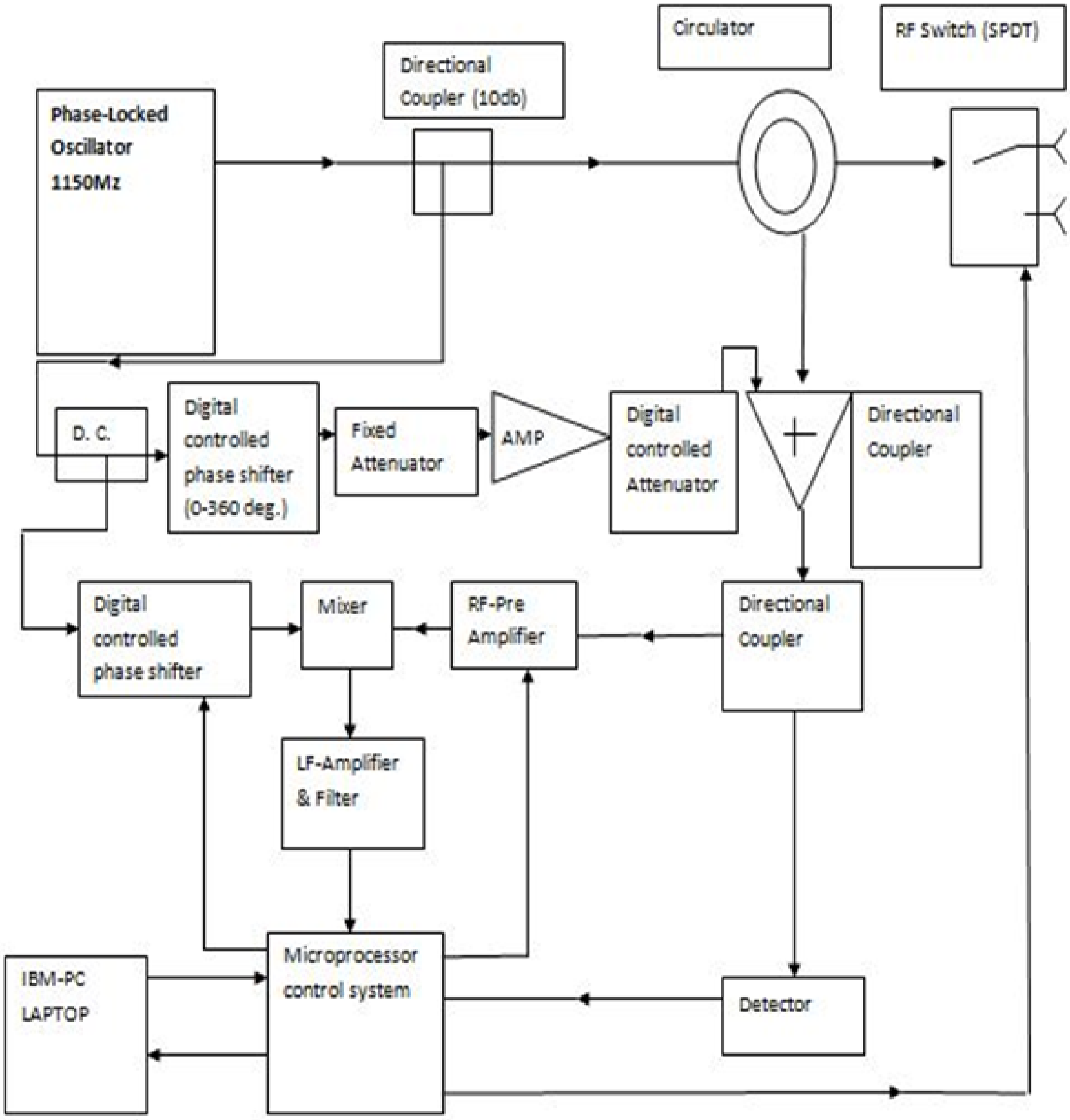

Figure 3.1: Schematic diagram of the 1150-MHz microwave life-detection system

3.2.1 Antenna

The dual antenna system has two antennas, which are energized sequentially by an electronically controlled microwave single-pole double-throw (SPDT) switch. The switch turns on and off at a frequency of 100 Hz which is much higher than the frequency range of the breathing and heartbeat signals between 0.2 Hz and 3 Hz. Thus, we can consider that the two antennas essentially sample their respective objects at the same time. In this dual-antenna system, the two antenna channels are completely independent. The algorithm[6] and flowcharts for the antenna is as follows:

1. Initially the switch is kept in position 1 (signal is transmitted through the antenna 1)
2. Wait for some predetermined sending time, T_s
3. Then the switch is thrown to position 2 (signal is received through the antenna 2)
4. Wait for some predetermined receiving time, T_r
5. Go to step 1
6. Repeat the above procedure for some predetermined time, T.

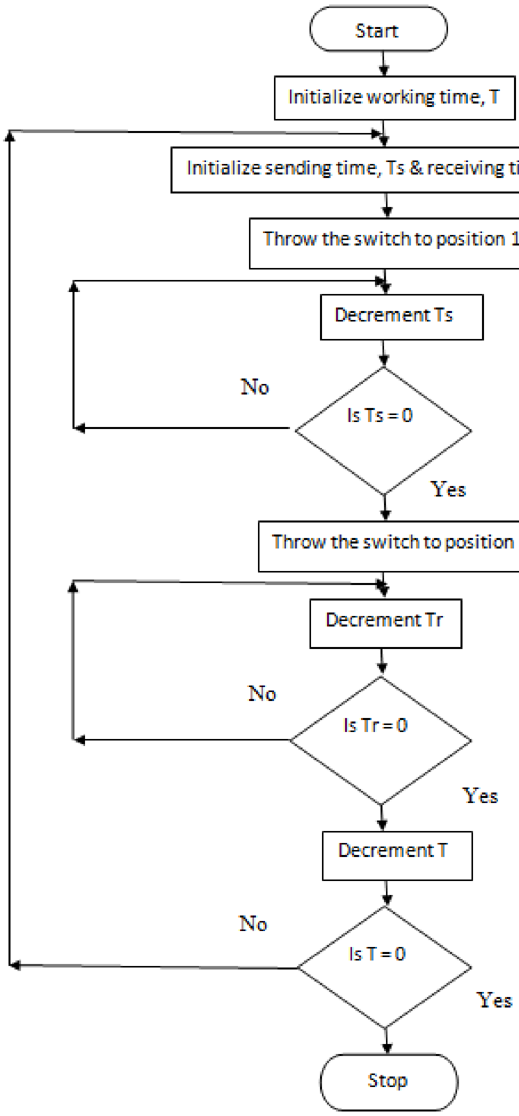

Figure 3.2: Flow chart for antenna system

3.2.2 A Clutter Cancellation Circuit

In any remote sensing instrument the clutter caused by undesirable objects surrounding the detectable subject must be cancel to the optimum level. The clutter canceller forms the heart of life detection system. It consists of Programmable Phase Shifters, Programmable Attenuator, a RF Amplifier a Microprocessor based control unit [11,12].

Canceller Operation

The clutter signal is passed through a detector as shown in fig. 3.3 which outputs a DC voltage of few tens mV. Then it is amplified by an operational amplifier and fed to A/D converter whose outputted to the Port A of microprocessor. The output port C and port B are connected to the phase attenuator and phase shifter respectively. The controller uses different combination of attenuation and phase shifting to achieve optimum level.

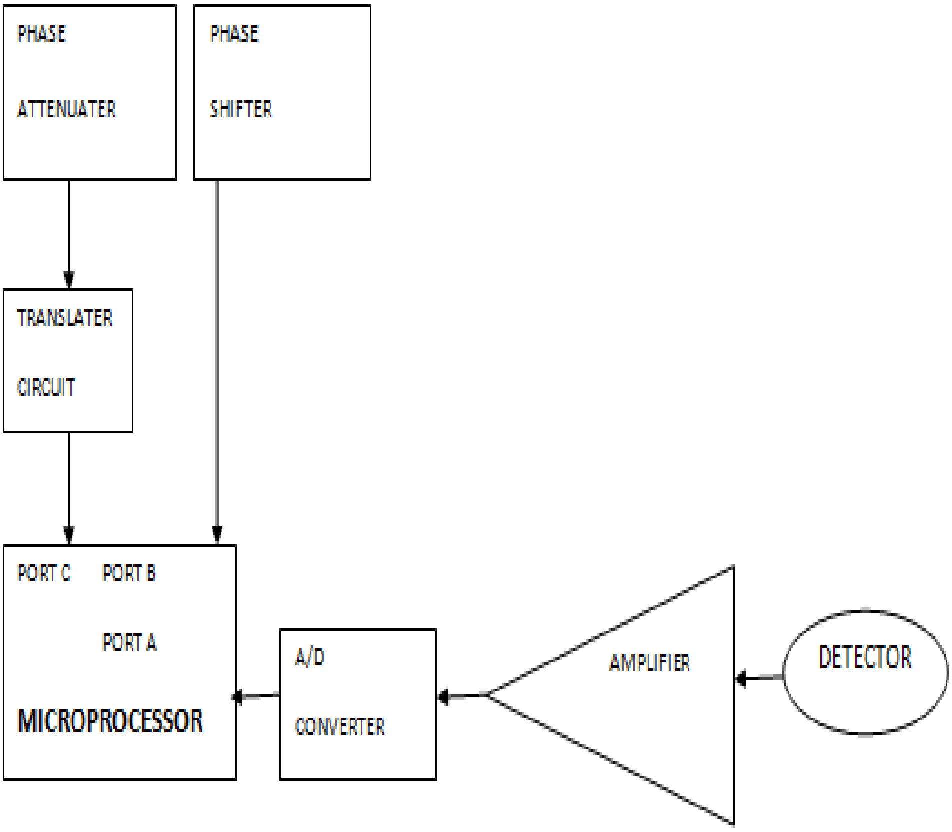

Figure 3.3: Schematic of clutter canceller

It starts with the initial clutter signal as a reference. The microcontroller sets 1 dB as a minimum attenuation in the attenuator and tries all phase settings from 00 to 3600 in the phase shifter and repeats the procedure until it gets the minimum DC output of detector and sets attenuator and phase shifter control switches accordingly. Maximum cancellation depends on the resolution of attenuator and phase shifter and properties of rubble like constituents of the barrier, shape, size, its orientation with respect to the direction of incident radio wave etc.

3.3 Working of Life Detection System

The circuit diagram of the microwave life-detection system is shown in Fig. 3.1 A phase-locked oscillator generates a very stable EM wave at 1150 MHz with an output power of 400mW (25.6 dBm). This wave is fed through a 10-dB directional coupler and a circulator before reaching a radio-frequency (RF) switch, which energized the dual antenna system sequentially. The 10-dB directional coupler branches out one-tenth of the wave (40 mW) which is then divided equally by a 3-dB directional coupler. One output of the 3-dB directional coupler (20 mW) drives the clutter cancellation circuit and the other output (20 mW) serves as a local reference signal for the double-balanced mixer. The wave radiated by an antenna penetrates the earthquake rubble to reach a buried human subject.

The reflected wave received by the same antenna consists of a large reflected wave (clutter) from the rubble and a small reflected wave from the subject's body. The large clutter from the rubble can be cancelled by a clutter canceling signal. However, the small reflected wave from the subject's body cannot be cancelled by a pure sinusoidal, canceling signal because it is modulated by the subject's motions. The dual-antenna system has two antennas, which are energized sequentially by an electronic switch. It will act as transmitter as well as receiver according to its programming.

The clutter cancellation circuit consists of a digitally controlled phase-shifter (0-3600), a fixed attenuator (4 dB), a RF amplifier (20 dB), and a digitally controlled attenuator (0-30 dB). The output of the clutter cancellation circuit is automatically adjusted to be of equal amplitude and opposite phase as that of the clutter from the rubble. Thus, when the output of the clutter cancellation circuit is mixed with the received signal from the antenna, via the circulator, in a 3-dB directional coupler, the large clutter from the rubble is completely canceled, and the output of the 3-dB directional coupler consists only of the small reflected wave from the subjects body. This output of the 3-dB directional coupler is passed through a 6-dB directional coupler. The 1/4th of this output is amplified by a RF preamplifier (30 dB) and then mixed with a local reference signal in a double balanced mixer. The other 3/4th of the output is detected by a microwave detector to provide a dc voltage, which serves as the indicator for the degree of the clutter cancellation.

At the double-balanced mixer, the amplified signal of the reflected wave from the subject's body is mixed with a local reference signal. The phase of the local reference signal is controlled by another digitally controlled phase-shifter (0 -1800) for an optimal output from the mixer. The output of the mixer consists of the breathing and heartbeat signals of the human subject plus unavoidable noise. This output is fed through a low-frequency (LF) amplifier (20-40 dB) and a bandpass filter (0.1-4 Hz) before being displayed on the monitor of a laptop computer. The function of a digitally controlled phase-shifter (0 - 1800) installed in front of the local reference signal port of the double balanced mixer to control the phase of the local reference signal for the purpose of increasing the system sensitivity.

The local reference signal is assumed to be AL cos (ωt + OL) where AL is the amplitude and OL are the phase, respectively[7.8]. While the other input to the mixer, the reflected signal from the human subject, is assumed to be Ar cos (ωt + OE+ PO(t)) where Ar is the amplitude and PO(t) the phase, respectively, and (OE+ PO(t)) is the modulated phase due to the body movement of the human subject. ω is the angular frequency and t is the time. When these two inputs are mixed in the double-balanced mixer, the output of the mixer will be

AL A_r cos(OL - OE - PO(t))

From this expression of the mixer output, it is easy to see that

If OL - OE = (n +1/2) S , n= 0,1,2,.

The system has a maximum sensitivity and

If OL - OE = n S , n= 0,1,2,.

The system has a minimum sensitivity because (U/U(- PO(t)) cos(OL - OE - PO(t))= sin (OL - OE - PO(t)).PO (t) is usually a small phase angle perturbation created by the body movement of the human subject. OE is the constant phase associated with the reflected signal from the human subject and it cannot be changed OL. is the phase of the local reference signal and it can be controlled by the digitally controlled phase-shifter (0 -180). In the operation, the phaseshifter will automatically shift OL in such a way that OL - OE is nearly (n + 1/2) to attain maximum system sensitivity. The microprocessors control circuit and the LF amplifier/ filter circuit of the microwave life-detection system are described in detail elsewhere.

3.4 Modulation

The microwave beam incident into the rubble gets phase modulated due to body vibration. The phase modulation is occurs according to the Doppler Shift. The use of Doppler radar was demonstrated for detection of respiratory rate, and heart rate, using commercially available waveguide X-band Doppler transceivers.

Doppler Shift Effect

When a source generating waves moves relative to an observer, or when an observer moves relative to a source, there is an apparent shift in frequency. If the distance between the observer and the source is increasing, the frequency apparently decreases, whereas the frequency apparently increases if the distance between the observer and the source is decreasing. This relationship is called Doppler Effect (or Doppler Shift) after Austrian Physicist Christian Johann Doppler (1803-1853). By the Doppler Effect, microwave beam reflected from a moving surface undergoes a frequency shift proportional to the surface velocity. If the surface is moving periodically, such as the chest surface of person due to breathing, this can be termed as a phase shift proportional to the surface displacement. If the movement is small compared to the wavelength, the system will mixed received signal with transmitted signal which gives output proportional to the body oscillation of human subject.. Fig.5 illustrates this concept. Internal body reflections are greatly attenuated and will not be considered here. We assume that a continuous wave (CW) radar system transmits a signal of frequency f. The actual working of Doppler shift starts with reflected beam from a target at a distance do, with a time-varying displacement given by x(t)[11].

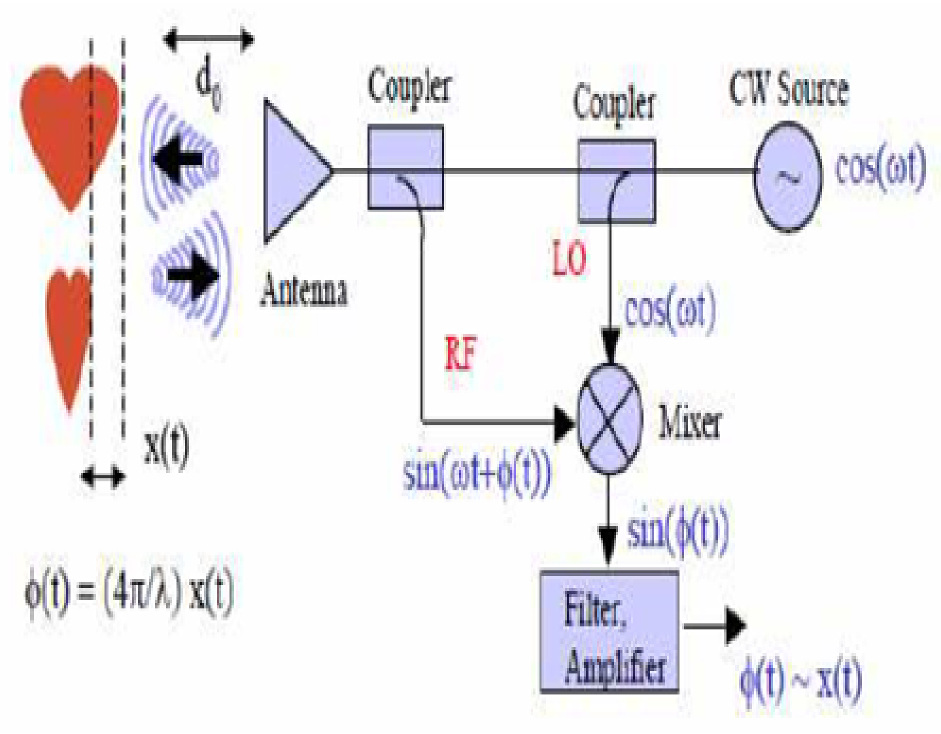

Figure 3.4: Vital signs remote monitoring Doppler radar system

Doppler radar shown in Fig. 3.4 is a single channel, direct conversion, CW radar. Major limitations of the single channel configuration is detection sensitivity to target position due to a periodic phase relationship between the received signal and local oscillator, resulting in ”optimum” and ”null” extreme target positions.

3.5 Mutual Coupling

Mutual coupling is a common problem in the applications of antenna arrays. It significantly affects the operation of almost all types of antenna arrays[6,7]. The study of mutual coupling problem started several decades ago and attracted the interest of not just antenna engineers and researchers but also many researchers from other disciplines such as communications and biomedical imaging where antenna arrays are frequently used. Compared with a single antenna, an antenna array is able to provide spatial information of the signal distributions. However, this function critically relies on the independence or distinctiveness of the signals received or transmitted from different antenna elements in the array.

In reality, this is simply impossible because antenna elements will interact with each other, i.e., they will mutually couple with each other. In order to restore the independent signals received or transmitted from the antenna elements, the coupled effect has to be removed or reduced. Hence, it is very important to find ways to decouple the array signals received or transmitted from antenna arrays. Over the past years, there have been many different kinds of methods suggested to decouple the coupled array signals.

The effectiveness of these methods varied and depended upon the types of antenna arrays being considered and the applications in which the antenna arrays were used. In this paper, we present a brief review of these decoupling methods (also known as compensation methods in some cases) for antenna arrays which have been suggested in the literature. Many of these decoupling methods have not been patented but some of these, especially those found in magnetic resonance imaging (MRI), are almost all patented. We shall review those non-patented ones first while those patented ones will be later. In the review, the various methods will be first briefly described and their operation principles explained. Then some comments on their scopes of application, their comparisons, or their relations to other methods will be given. The problems associated with these methods will also be analyzed. It should be noted that for a detailed understanding or for a direct reference to the specific results regarding a particular method, readers have to be referred to the particular paper or patent in which the method was first reported. In our review, citations of previous literature or patents will be grouped under the same method and will not be individually addressed for the sake of brevity.

3.5.1 Review of Decoupling Method

There have been many decoupling methods suggested to tackle the mutual coupling problem in antenna arrays. Each bases on different principles and is designed for different applications. It is necessary to categorize them so that they can be analyzed and reviewed together with other similar methods. We first review those methods designed for conventional antenna arrays, i.e., those found in communications. In the next section, we will review those methods designed especially for magnetic resonance imaging (MRI) antenna arrays.

S-Parameter Method

In the s-parameter method (typically represented by), the receiving or transmitting antenna array is modeled as an N-port network and the mutual coupling between antenna elements is modeled using scattering parameters. Once the s-parameters are all determined, the decoupled signals can be computed from the coupled measurable terminals signals.

However, by using this method, only the transmitting array is modeled correctly with respect to the handling of the mutual coupling effect. For a receiving array, because the definition of s-parameters requires that the antenna elements be driven by an active source connected at the terminals of one of the antennas in the array, it fails to correctly model the array whose antenna elements are all driven by an external source outside the array. The consequence of this method is that the mutual coupling in the receiving array is independent of the external source (the impinging wave) which is incorrect as explained in Section 2.1. Hence the performance of this method (which can be measured by its decoupling power = 20log—coupled signal/uncoupled signal—) is similar to that of the open-circuit voltage method and it suffers from the same problems as that method

Full-Wave (Moment) Method

The full-wave method (typically represented by) seeks to solve the entire boundary value problem of the electromagnetic field for the whole antenna array by the moment method. It uses the known array measurable quantities, such as terminal voltages and currents (which come with mutual coupling), to calculate the incident field on the array, which is coupling free. However, since only terminal voltages or currents are known but not the entire current or voltage distributions on the antenna elements, this method results in an under-determined system of equations. In order to solve the under-determined system, usually some approximations have to be made, such as an assumed current distribution, a known coming direction of the incident field, or solving the under-determined system directly using a compromised method. The performance of this method depends on the approximations made, which sometimes may not be realistic, and its scope of application is therefore limited. On the other hand, if we assume the incident field is completely known, then this method can serve as an accurate analysis tool to investigate mutual coupling effect on the performance of an antenna array.

Isolated Element Pattern Method

This method was first proposed by Steyskal and Herd in 1990. The terminal voltage (coupled voltage) developed on a particular antenna element is expressed as a sum of two parts. The first part is due to the response of the isolated radiation pattern of that particular element to the incoming signal. The second part is a linear combination of the responses of the isolated radiation patterns of all the other antenna elements in the array to the incoming signal. The mutual coupling between the particular antenna element and the other elements in the array is modeled by a set of combination coefficients, cmn, which, when taken together for all the antenna elements, form a coupling matrix relating the coupled and decoupled voltages. Once the combination coefficients are all known, decoupled voltages can be obtained from the coupled terminal voltages.

The problem with this method is the determination of the combination coefficients (the coupling coefficients). One method to determine the coupling coefficients is through the s-parameter measurement. However, this again detaches mutual coupling from the incident signal and this method will be similar to the open-circuit voltage method.

Coupled Element Pattern Method

A similar method to the isolated element method is the coupled element method. In this method, the aim is to obtain the coupled voltages from the antenna elements instead of the coupling free voltages. More specifically, the aim is to be able to predict the received coupled voltages through the responses of the so-called coupled radiation patterns of the antenna elements. The coupled radiation pattern of an antenna element is its radiation pattern obtained in the presence of all other antenna elements in the array (but which are not excited). That is, all the mutual coupling effect is taken into account. By using this method, the total array response will be expressed as a function of the coupled radiation patterns instead of the isolated radiation patterns. Hence this method does not decouple the coupled signals but rather takes the mutual coupling effect into account. All signal processing algorithms working with this method must be redesigned using coupled radiation patterns instead of isolated radiation patterns. A disadvantage of this method is the need to have a huge memory to store all the coupled radiation patterns for the signal processing algorithms because these coupled radiation patterns are in general 2D patterns. This method is suitable for analysis purposes in which real time processing is not required.

Calibration Method

In the calibration method (typically represented by), a coupling matrix is usually formed first. This coupling matrix relates the coupled signals to the uncoupled signals and is similar to the impedance matrix. The important step in this method is to determine this coupling matrix by a carefully designed experimental procedure or by an iterative calculation method based on some known initial conditions. Once the coupling matrix is known, decoupled signals can be obtained from the coupled signals through a transformation using the coupling matrix. The performance of this method critically depends on the accuracy in measuring or calculating the coupling matrix which is usually not an easy task because the number of unknowns to be determined can be very large. A problem faced by this method is the tedious measuring procedure or iterative steps to determine the coupling matrix which are required to be carried out again once there is a change to the antenna array configuration or a change to the external signal environment.

Decoupling by Antenna Design

Mutual coupling in arrays can be reduced or minimized by a proper design of the antenna elements and/or the array configuration. For example, in a two-element planar Yagi antenna array shows a very low mutual coupling "$(S21 < -22dB)$" when the Yagi antennas were aligned in a co-linear form rather than in a parallel form. When the Yagi elements are in the co-linear form, they are almost in the radiation null of the near field pattern of the other element and these results in a low mutual coupling level. In, an antenna array was designed to minimize the parasitic current on the antenna elements by changing the load impedances so that the parasitic radiation fields caused by adjacent elements are reduced. This results in the active (coupled) element patterns of the antenna elements similar to that of a single (uncoupled) element pattern, i.e., mutual coupling is substantially reduced. Note that this method, though rather effective and simple (requiring no additional processing procedure), is only applicable to specific types of antenna elements.

Decoupling Methods for MRI

Decoupling methods for MRI phased arrays deserves some special attention because most of the patented decoupling methods belong to this category. Some recent ones can be found in. In MRI, antenna arrays are found increasingly important because of the rapid development in parallel MRI which can substantially shorten the imaging time and increase the image signal-to-noise ratio (SNR) for imaging over larger areas. In MRI, antenna arrays are called phased arrays and they bear some distinct differences from the antenna arrays in communications. These include:

(i) They receive in the near-field region rather than in the far-field region as in communication arrays.

(ii) Their inter element spacing's (around 0.1 wavelength) are much smaller than those in communication arrays (around 0.5 wavelength) because of the much lower operation frequencies in MRI arrays.

(iii) They use magnetic field antennas rather than electric field antennas as in communication arrays.

These differences make MRI arrays even more susceptible to the mutual coupling effect than communication arrays and most of their decoupling methods are also different from those for communication arrays. Basically, for MRI arrays, such as phased coil arrays, there are three categories of decoupling methods:

(i) overlapping of adjacent coils combined with low input impedance pre-amplifiers.

(ii) capacitive or inductive decoupling networks.

(iii) Open-circuit voltage method. They are discussed below.

3.5.2 Capacitive or Inductive Decoupling Networks

An inductive decoupling network was reported in which two small inductor coils are connected to two large imaging coils. The two small inductor coils are for decoupling the mutual coupling between the two large imaging coils. The small inductor coils are placed very close to each other so that their mutual coupling can counteract the mutual coupling of the imaging coils. Capacitive decoupling networks, on the other hand, employ capacitors rather than inductor coils to decouple the mutual coupling effect. This can be seen in the patents in . Adjacent coils and non-adjacent coils are connected together through a capacitor network whose capacitor values, when carefully chosen, can decouple the mutual coupling between adjacent coils as well as non-adjacent coils.

The capacitive decoupling networks are applicable to surface coils or volume coils. In a capacity decoupling network works at a high-field condition of 14.1 T and a decoupling power of around -20 to -40 dB could be achieved. The method using inductive or capacity decoupling networks requires an accurate determination of the decoupling inductor or capacitor values which is sometimes a formidable task, especially for large phased arrays.

Looking from a broader perspective, the inductive or capacitive decoupling network is actually to realize (or approximately realize) the impedance matrix obtained in the open-circuit voltage method or the impedance matrix obtained in the receiving mutual impedance method. Hence depending on how the capacitor or inductor values in the decoupling networks are determined, this method is basically similar to either the open-circuit voltage method or the receiving mutual impedance method.

Open-Circuit Voltage Method

The open-circuit voltage method was proposed by Lee et al.. It is basically the open-circuit voltage method applied to MRI phased arrays. In the impedance matrix was realized as a 2N-port circuit network: N input ports from the phased coil array and N output ports to the signal processing circuits. The inputs from the phased coil array to the decoupling network are coupled signals while those output from the decoupling network to the processing circuits are decoupled signals. In MRI, as the coils are separated much closer together than the antenna elements in communication arrays, these problems become even more serious in MRI phased arrays.

Receiving Mutual Impedance Method

The receiving mutual impedance method is a more accurate method than the open-circuit voltage method. Actually this method is even more suitable for MRI phased arrays, this method takes into account the external source. This is done through the definition of the receiving mutual impedance in which the current distribution on the exciting antenna is excited by an external source. In MRI, the external source for the phased array is the active slice excited by the RF pulse. The position of the active slice is accurately controlled by the static magnetic field and the gradient magnetic fields.

CHAPTER 4

DATA SHEET AND DISCUSSION

4.1 Data Sheet

In this section, a preliminary experimental result is reported in order to assess the capabilities of the proposed rescue system[3,5,8]. Let us assume, the test site is a hollow pipe of concrete with a diameter of 1.5m and a thickness of 0.15 m. A person is located inside the concrete pipe, and the flying vehicle with has been used to place more close as possible the onboard rescue system is positioned on the top of the pipe at about 1.3m from the victim chest. The signal is generated by means of a low power compact SAW oscillator able to generate a microwave signal at 10.45 GHz with a power of 5mW. The signal is amplified and then transmitted by means of a two elements patch antenna array. The backscattered field is collected with a similar receiving antenna array. The transmitting and receiving arrays are arranged on the same dielectric substrate and they have been designed to avoid mutual coupling and keep ”$VSWR < 2$” in transmitting as well as in receiving mode. The received backscattered signal is amplified and down converted with an orthogonal detector in order to obtain two signals sources for the ICA algorithm. Then the down converted backscattered signals are transmitted with a 400MHz AUREL transmitting module toward a remote elaboration unit which provides the post processing by applying the ICA algorithm. Figure 4.1(a) shows the mixed signals: the life signals are too much weak to be clearly identified because the strong corruption due to the noise, the clutter and other interfering signals.

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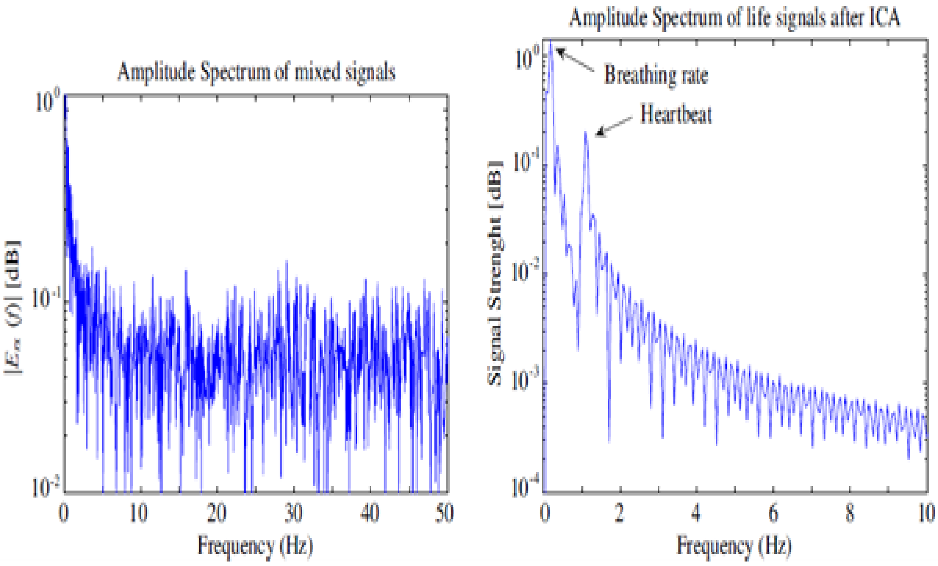

Figure 4.1: Experimental results. Frequency spectrum of the measured (a) mixed signals noise plus signals life obtained from experimental setup, (b) signals life extracted after the application of the ICA algorithm.

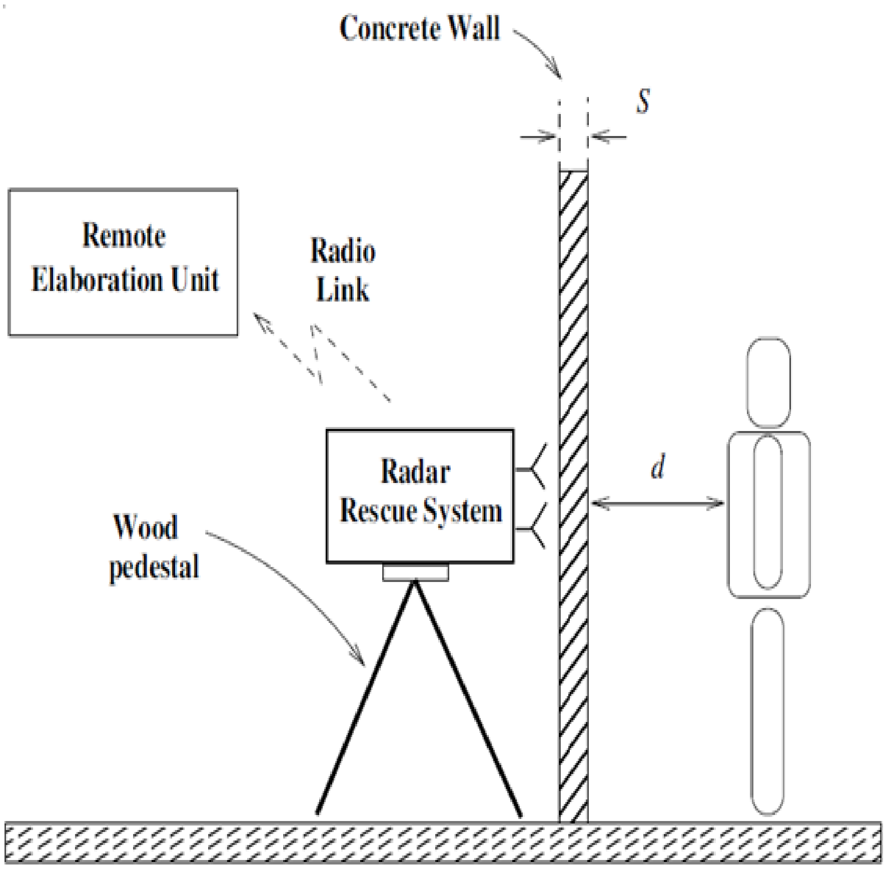

Figure 4.2: Schema of the last experimental scenario.

Figure 4.1(b) put in evidence how the life signals are efficiently detected after the application of the ICA algorithm and the FFT. The frequency spectrum clearly indicates a breathing rate of 0.2 Hz (or 12 breath/minute), whereas the heartbeat is 1.11 Hz (or 67 beats/minute). The heartbeat measure has been compared with a finger pulse monitor to verify experimental results. As can be noticed from the data reported in Figure 4.1(b), the ICA provided an efficient separation of the original signals. Thank to ICA all the noise contributions have been removed and the life signals clearly identified despite of the corruption due to the clutter and noise. To further assess the robustness of the proposed rescue system, the last experiment deal with a scenario in which a person is placed behind a concrete wall. In particular the rescue system has been placed next to the concrete wall by means of a wood pedestal, the person is standing behind the concrete wall, the thickness of the concrete wall is about S = 20 cm. The distance between the concrete wall and the person's chest was d = 150 cm. Figure 4.2 shows the considered experimental scenario. The data have been acquired to send to the remote elaboration unit and post processed with the ICA algorithm in order to remove the clutter and then processed with a FFT algorithm. Also in this experiment for the sake of comparisons, the heartbeat has been monitored with finger pulse monitor in order to verify the experimental data. Also in this scenario the system is able to correctly detect the life signals, in particular the breathing rate was 0.17 Hz (or 10 breath/minute), whereas the heartbeat is 1.16 Hz (or 70 beats/minute). Also in this experiment the system is able to correctly detect and identify the life signals with a reasonable degree of accuracy despite the low intensity of the interrogating signal.

A several experiments are performed with the life detection system. Various layers of bricks were used to simulate the thickness W of rubble or barrier and the distance between the victim and the barrier of rubble D was a variable parameter for the experiment. In the graphs, the heartbeat signal (when the human subject holding his breath), the breathing signal, and the background noise were include. Firstly, the heartbeat and breathing signals were detected for each position. When the thickness of this wall increases to eight layers (about 90 cm), the performance of the L band life-detecting system became marginal. For the distance D =16 m, the system was marginal. Fig.4.3 to Fig.4.9 is the Fast Fourier Transform (FFT) of the time-domain signal, which shows the frequency components of the time domain signal. Fig.4.4 to Fig.4.6 show the same result performed on the same distance D for the different thickness as shown respectively. The frequency domain FFT results show the peaks of heartbeat signal (0.8 Hz to 2.5Hz) and breathing signal (0.2 Hz to 0.5 Hz). Other small peaks are probably due to noises or the second harmonic of the breathing signal. When all these result were compared it is found that the amplitude of the breathing signal is becoming smaller with the increase of the wall's thickness. The heartbeat signal peak also decreases with the increase of the wall's thickness. Fig.4.7 to Fig.4.9 show the FFT results behind the same wall. The distance (D) is 4m, 8m and 12m accordingly. It can be concluded from the result, thickness affects breathing signal whereas distance D affects heartbeats signals. The L band system performs better enough for remotely buried victims signals. Our experiments prove that a buried victim can be efficiently detected using lower band frequency.

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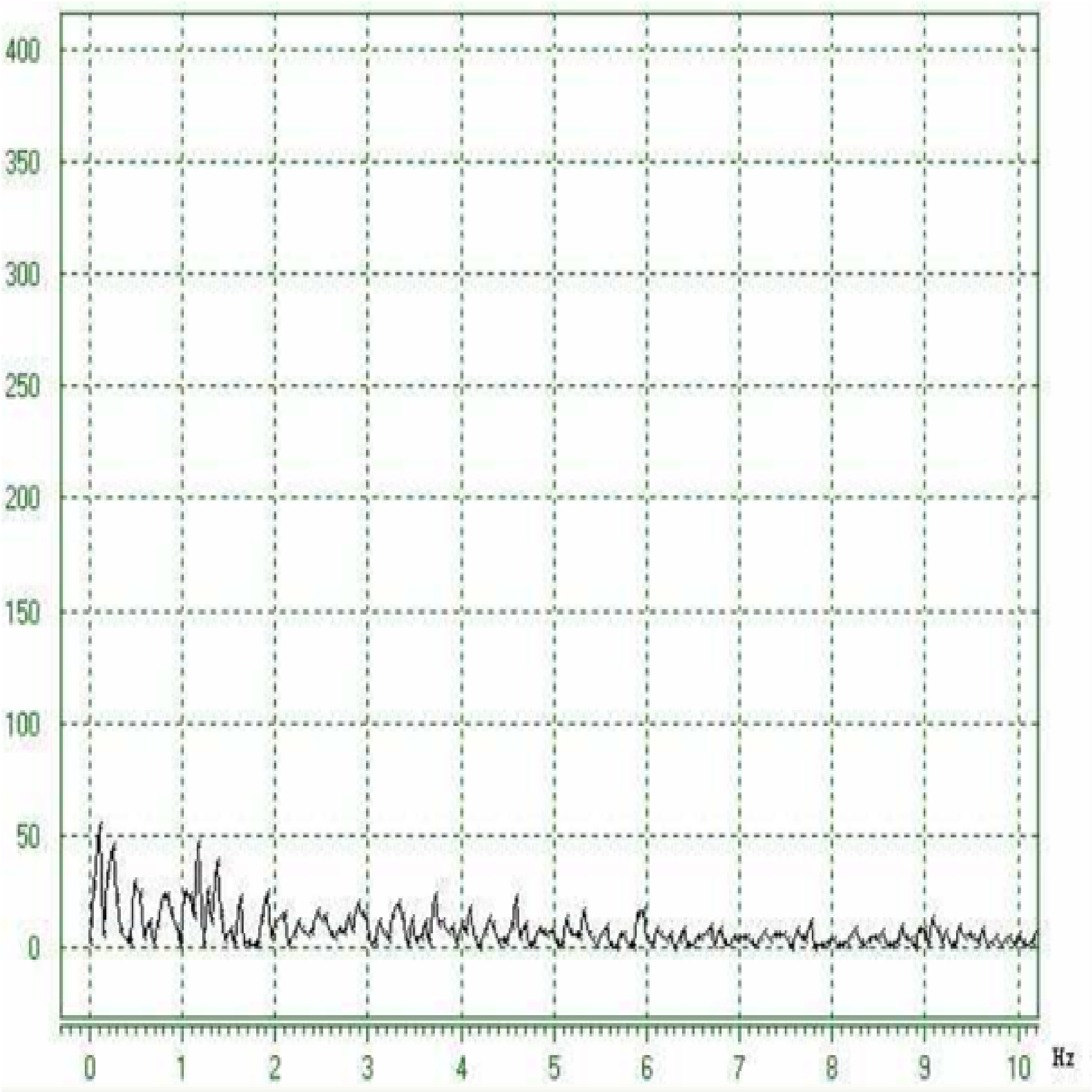

Figure 4.3: Frequency spectrum of background noise

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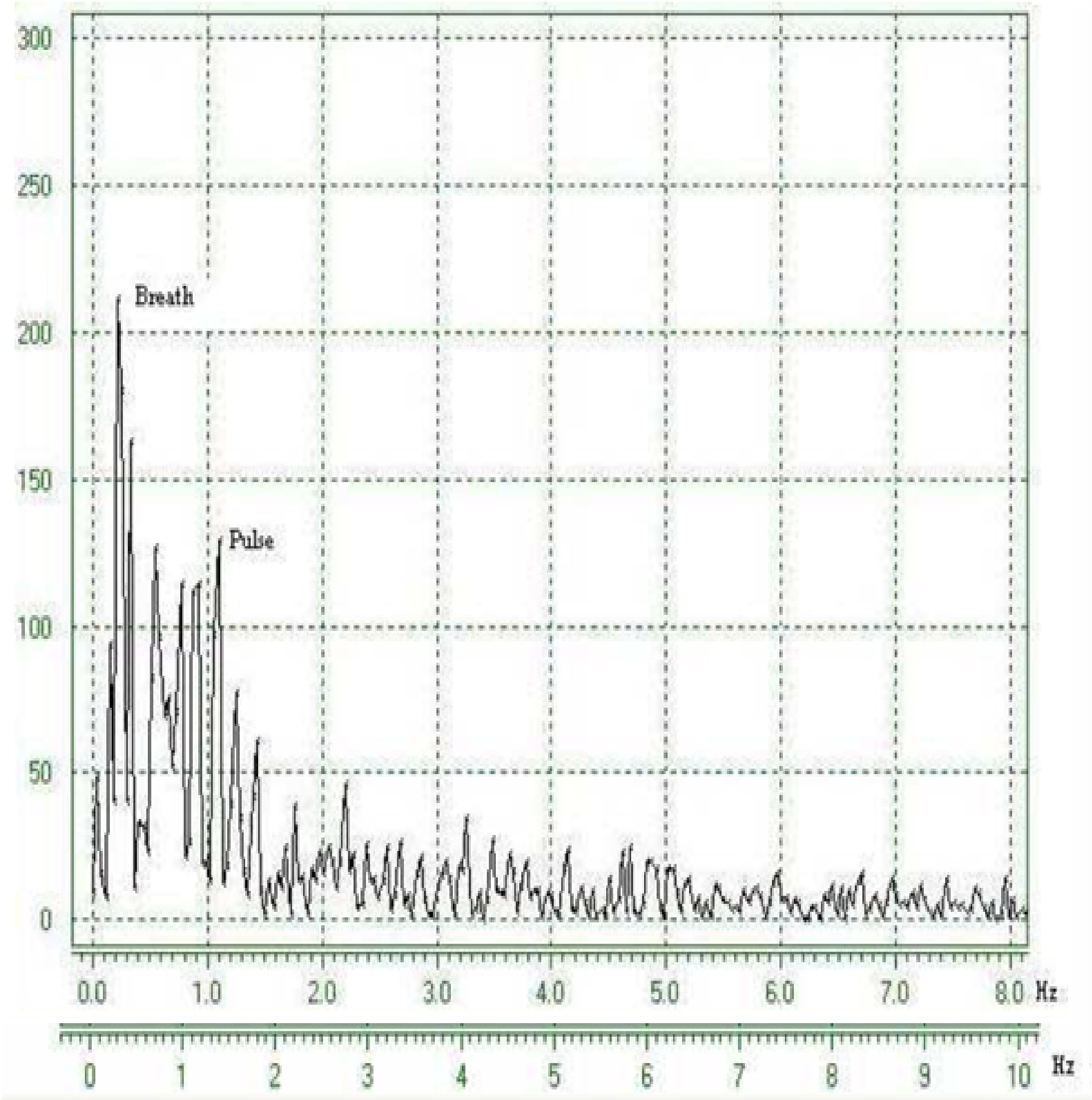

Figure 4.4: Frequency spectrum of background noise

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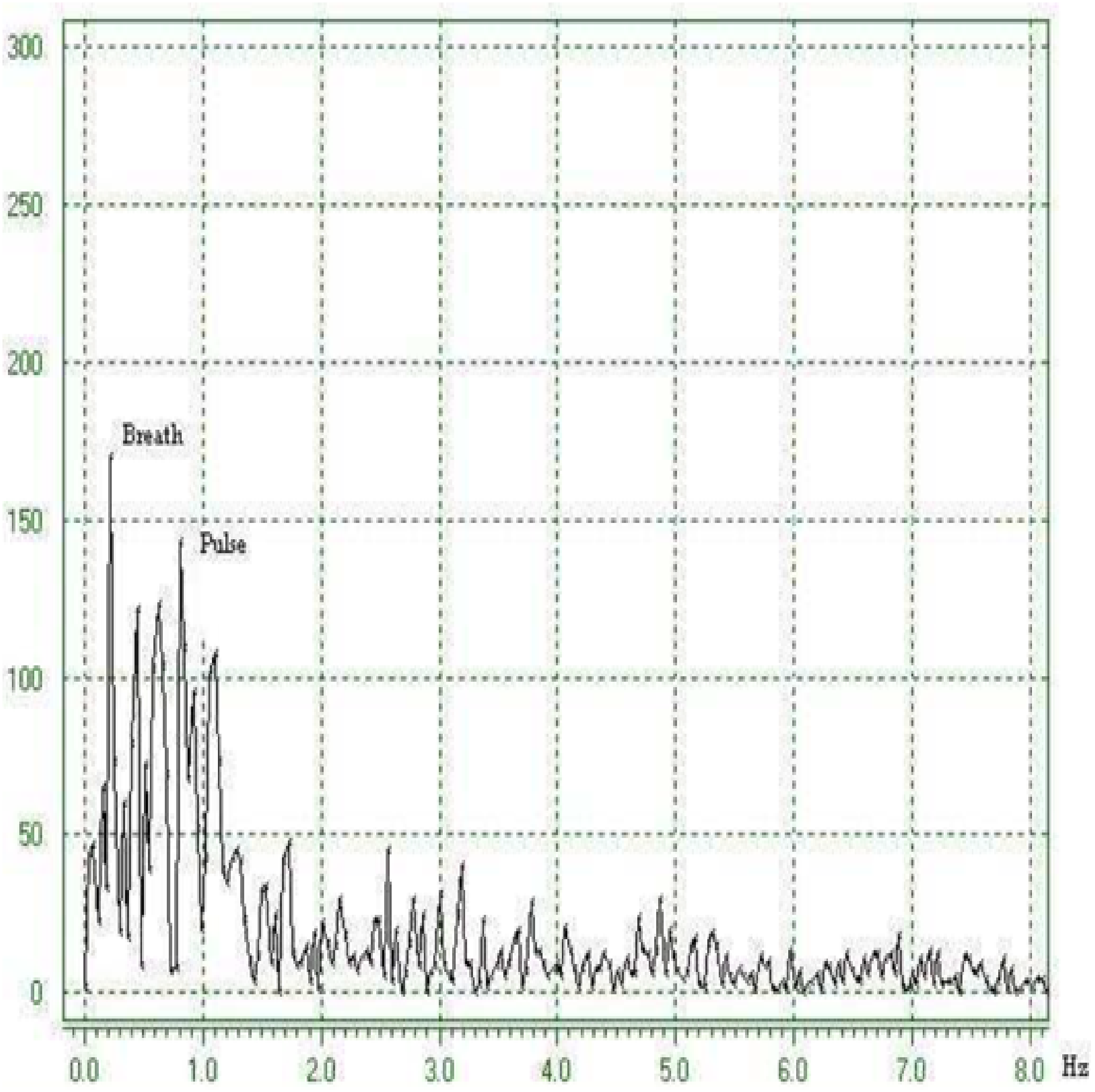

Figure 4.5: Frequency spectrum of breathing and heartbeat, D=1m, W=48cm

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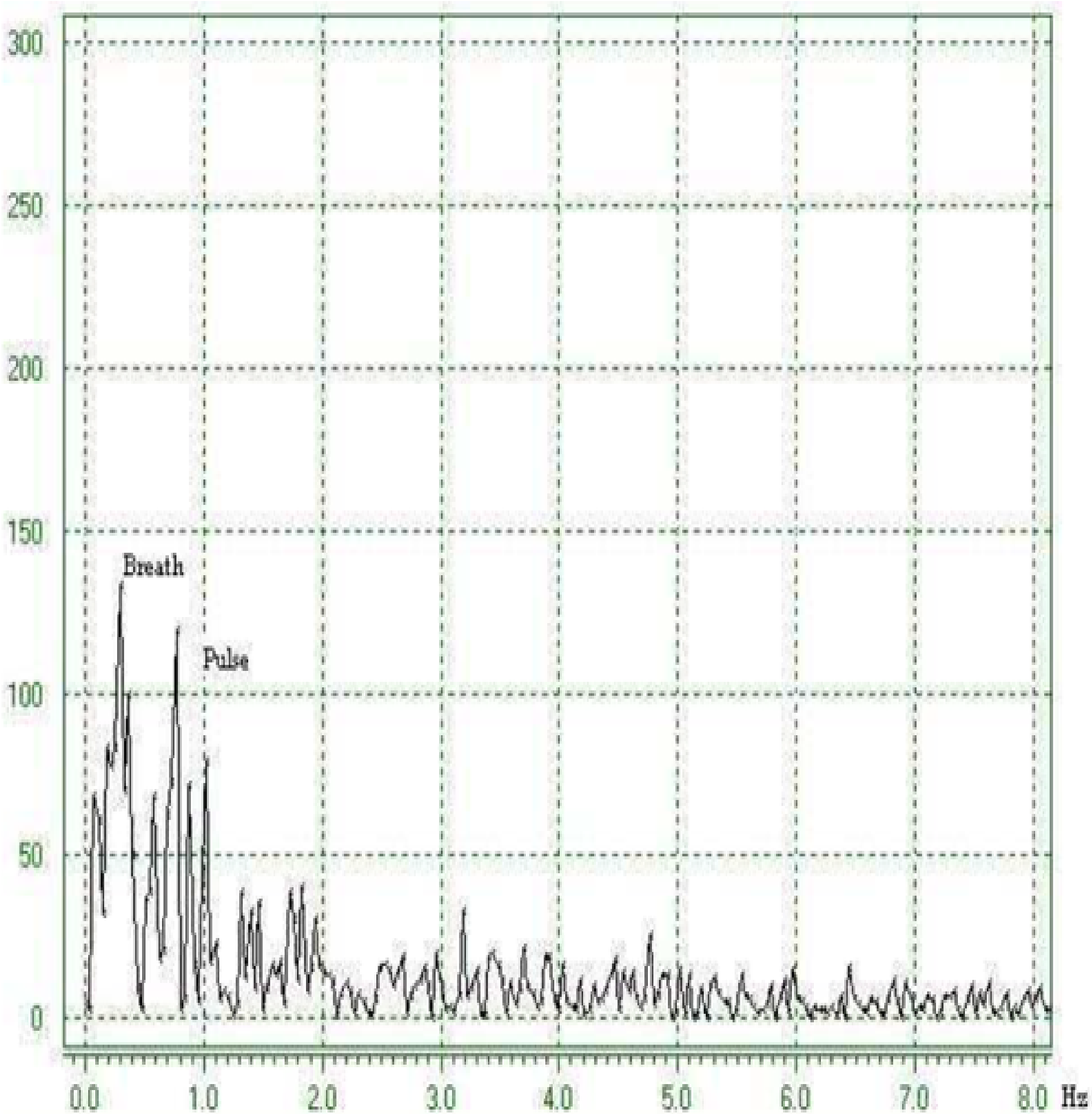

Figure 4.6: Frequency spectrum of breathing and heartbeat, D=1m, W=60cm

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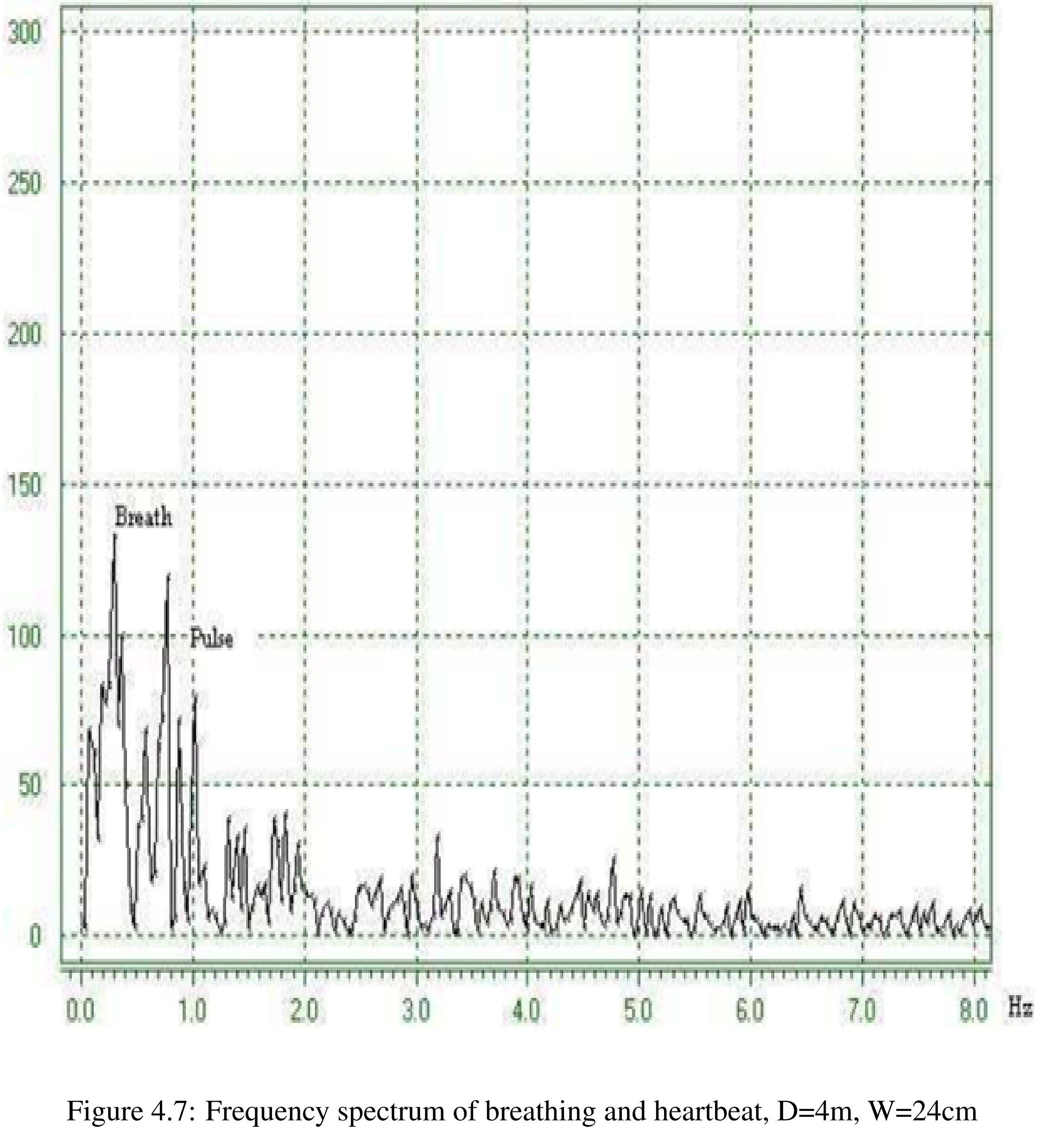

Figure 4.7: Frequency spectrum of breathing and heartbeat, D=4m, W=24cm

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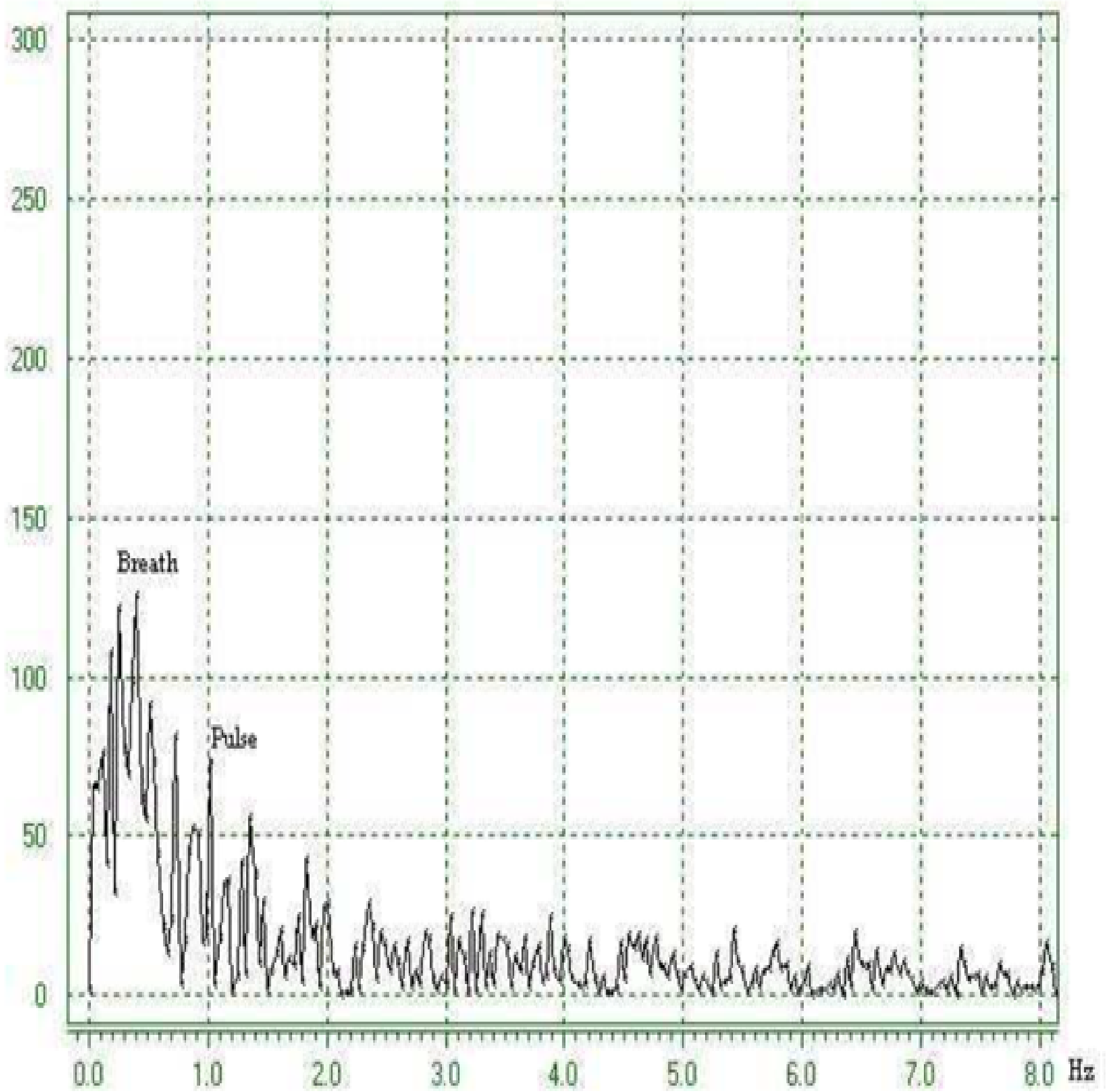

Figure 4.8: Frequency spectrum of breathing and heartbeat, D=8m, W=24cm

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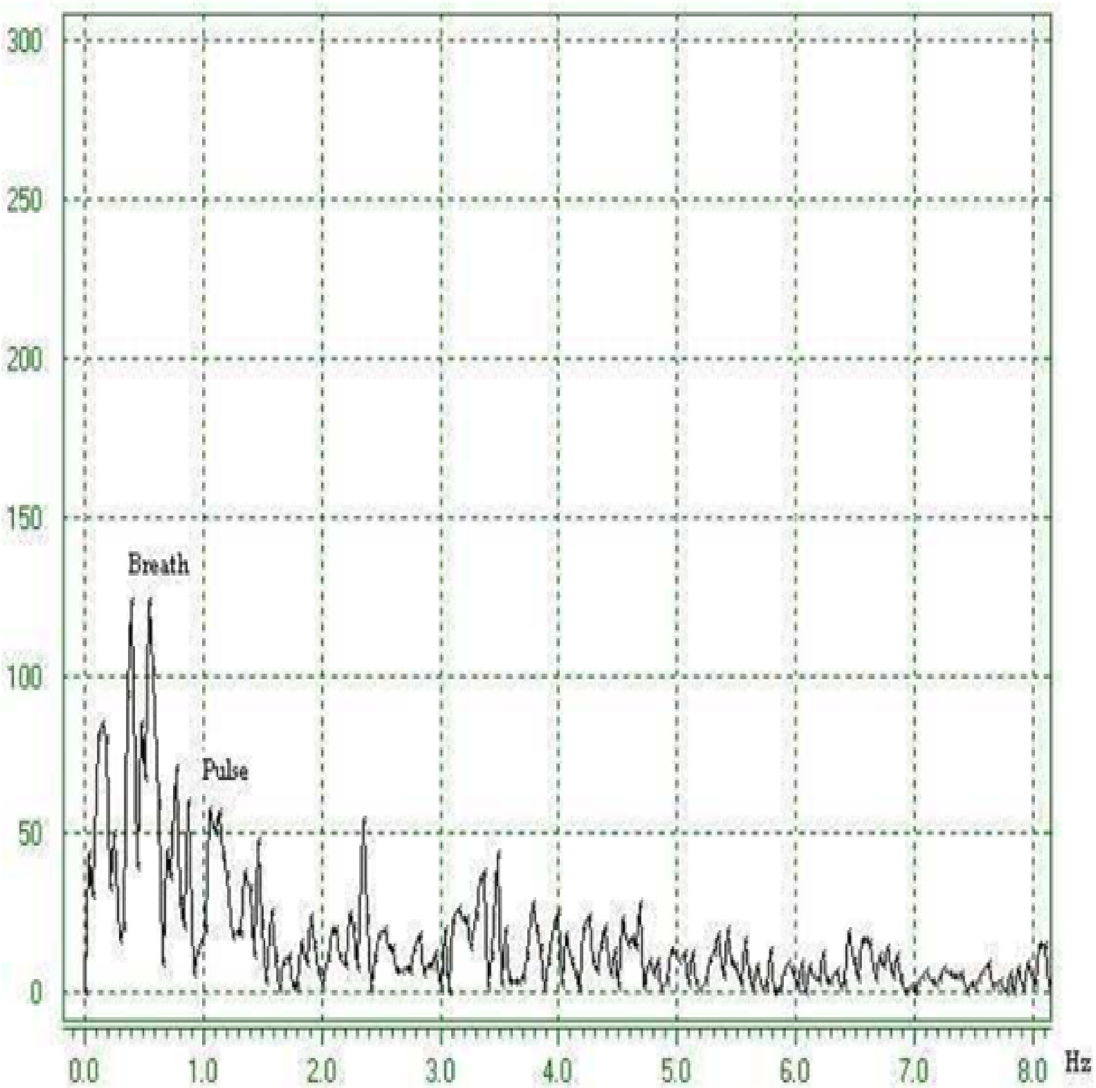

Figure 4.9: Frequency spectrum of breathing and heartbeat, D=12m, W=24cm

4.2 Discussion

This section includes the advantages and disadvantages of the life detection system.

Advantages

- Remote life sensing could be a powerful tool in applications where it is not desirable to disturb a subject's physiological and/or emotional state during detection or in other situations where access to the subject is limited.
- The frequency 2.45 GHz i.e. L-band frequency and this is free for use by commercial applications, so we expect a minimum interference with other devices during our tests.
- No need to use heart beat and the breathing sensor. Our interest is just to observe the minute movement of the victim.

Disadvantages

- Project is expensive but once it is implemented the expenses can be reduce lower extend.
- The L- band frequency is unable to penetrate more metal like structure but it can penetrate over 10 layers of bricks.
- The involvement of clutter signal may destroy the vital information of life signs. But if the proper demodulation is used one can receive the vital signs efficiently.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

A life-detection system with a microprocessor-based automatic clutter cancellation subsystem can be invented for special rescuing robots. This system can operates at 2-G Hz and it will be used remotely to detect the breathing and heartbeat signals of alive subjects through rubble or some other barriers about 3ft in thickness. The microprocessor-based automatic clutter- canceling increases the efficiency of system. The clutter canceller uses an adjustable attenuator and phase shifter to cancel the transmitting power leakage from the circulator and background reflection clutter to enhance the detecting sensitivity of the weak vital signals. We believe that through the development of similar and related techniques for life detection system, it will be possible to overcome the current fundamental problems in detecting buried victims and save many precious lives.

The strategy for detecting trapped alive victim under earthquake rubble was implemented in which a microwave beam was illuminated into rubble to receive essential information about life under rubble. Thus, the system operating at 10-GHz with 190-230V repelled voltage may be used to detect the breathing and heartbeat signals of living subjects through rubble having width of about four layers of bricks. From the result it is observed that phase shift between transmitted and received signals are increases from forehead to heart and then decreases. It is believe that through the development of similar and related techniques for life detection system, it may be possible to overcome the current fundamental problems in detecting buried victims and save many precious lives.

The effect of deteriorating environmental factors was eliminated since the new antenna design has very low leakage due to side lobes. At the same time weaker signals could be detected and processed, due to the optimized design and construction of the electronic parts of the radar.

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