ISTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

# A WIDEBAND LOW-FREQUENCY PULSE RADAR FOR HIDDEN OBJECTS DETECTION

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**İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ**

# GİZLİ CİSİMLERİ ALGILAMAK İÇİN GENİŞ BANDLI DÜŞÜK FREKANSLI DARBE RADARI

**YÜKSEK LİSANS TEZİ**

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## FOREWORD

This thesis is the first serious step I took to microwave engineering field and therefore it is as important as the first step I took in life. First of all I would like to offer my deepest thanks to Prof. Dr.-Ing. Joerg Schoebel who opened the gates of this road. I would like to thank to Assoc. Prof. Dr. Ali Yapar and all microwave group's members of Institute for High Frequency Technology at Technichal University of Braunshweig for their assistance and contributions. Finally, I want to thank to my family always supporting me.

May 2010 Hüseyin Sinan AKŞİMŞEK

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**ABBREVIATIONS**

| | |
|---|---|
| **DDS** | **:** Direct Digital Synthesis |
| **BPF** | **:** Band Pass Filter |
| **HPF** | **:** High Pass Filter |
| **LNA** | **:** Low Noise Amplifier |
| **LPF** | **:** Low Pass Filter |
| **PROM** | **:** Programmable Read Only Memory |
| **RCS** | **:** Radar Cross Section |

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**A WIDE BAND LOW-FREQUENCY PULSE RADAR FOR HIDDEN OBJECTS DETECTION**

**SUMMARY**

In today's world, the research on the detection of objects which is out of sight of the eye has gained speed day by day. Especially, the detection of objects with a restricted field of vision phenomenon has been one of the most common work areas in microwave technology. The best-known practices in this area of the wall and ground penetrating radar imaging consist. On the other hand, the main feature of these systems is to have broadband characteristics. That is the purpose of this study is to design a wide band low-frequency pulse radar for hidden objects detection.

In the study it was focused on the basic idea of radar, the main topics of radar technology was examined and the operating principle of traditional pulse radar was expressed. On the other hand the signal structure of carrier pulses was investigated in time domain and frequency region and the basic advantages of operating with broadband and at low-frequency were revealed. Due to fast frequency hopping chance and digitally programmable feature, direct digital synthesis method was selected for carrier signal generation and for this job Analog Device AD9910 chip was used. This chip was programmed via the digital control circuit by Python programming language and the connection between the controller and PC was provided by IEEE 1284 standard. In this way, by changing the pulse length as it is desired, the response of the system to the carrier signal structure was examined. The required filters, amplifiers and attenuators for the demonstrator circuit were designed in ADS, then fabricated and the corresponding system structure was built up. The demonstrator was controlled by Python, was tested for different target detection scenarios and the system was optimized.

The output of the optimized last demonstrator was examined in time domain and frequency region, the serious potential of the system on hidden object detection was revealed and in last part, a different method was proposed as detection technique.

**GİZLİ CİSİMLERİ ALGILAMAK İÇİN GENİŞ BANDLI DÜŞÜK FREKANSLI DARBE RADARI**


**ÖZET**

Günümüz dünyasında, gözün görme yetisi dışındaki cisimlerin sezilmesi üzerine yapılan araştırmalar gün geçtikçe hız kazanmaktadır. Özellikle bir engelle görüş alanı kısıtlanmış cisimlerin algılanması olayı, mikrodalga teknolojisinin en yaygın çalışma alanlarından biri olmuştur. Bu alanın en bilinen uygulamalarını ise duvar içi görüntüleme ve yeraltı radarı oluşturmaktadır. Öte yandan bu sistemlerin en temel özelliği geniş band karakteristiğine sahip olmalarıdır. İşte bu tez çalışmasının amacı gizli nesneleri algılamak için geniş bandlı düşük frekanslı bir darbe radarı tasarlamaktır.

Çalışmada temel radar fikri üzerinden durulmuş, radar teknolojisinin ana başlıkları incelenmiş ve geleneksel darbe radarının çalışması prensibi dile getirilmiştir. Öte yandan taşıcı darbelerin sinyal yapısı zaman domeninde ve frekans bölgesinde incelenmiş, geniş band ve düşük frekansta çalışmanın temel avantajları ortaya konmuştur. Taşıyıcı sinyal üretimi için hızlı frekans atlama ve sayısal olarak programlanabilme imkanı nedeniyle Doğrudan Sayısal Sentezleme (Direct digital synthesis) yöntemi seçilmiş olup, bu iş için Analog Device AD9910 yongası kullanılmıştır. Bu yonga sayısal kontrol devresi üzerinden Python programlama dili ile programlanmış, kontrol devresi ve bilgisayar arasındaki bağlantı IEEE 1284 standartı ile sağlanmıştır. Bu sayede darbelerin uzunluğu arzulandığı gibi değiştirilerek sistemin sinyal yapısına olan tepkisi de çalışma boyunca incelenmiştir. Gösterici sistem için gerekli filtreler, kuvvetlendiriciler, zayıflatıcılar ADS programında tasarlanmış, ardından üretilmiş ve ilişkin sistem yapısı kurulmuştur. Gösterici devre Python'la kontrol edilerek, farklı hedef sezim senaryoları için test edilmiş ve sistem optimize edilmiştir.

Optimize edilen son gösterici devresi çıkışı zamanda ve frekans domeninde incelenerek sistemin gizli cisimleri algılama konusunda ciddi bir potansiyele sahip olduğu ortaya konmuş, algılama metodu için farklı bir yöntem önerilmiştir.

# 1. INTRODUCTION

The radio systems based on traditional methods possess a narrow frequency range and as carrying waveform utilize sinusoidal signals to communicate. Main reason of this fact is that oscillators, which generate sinusoidal signals using RLC circuits, are the most elementary systems due to the nature of RLC resonance structure which gives us an easy frequency selection chance. The systems which have a narrow frequency range also restrict the quantity of information sent through a channel in a certain time. That’s why it is essential to extend the frequency range in order to obtain more information capacity in radio systems. Otherwise as the only alternative one has to increase the transmission time to overcome this difficulty [1].

The problem mentioned above is especially important for radar systems where the detection time is limited. The recent radars whose fractional bandwidths not exceeding 10% have not give meaningful information opportunities in practice in the sense of resolution and target’s physical features. Therefore, the works on radars which possess wide and ultra wide bandwidth signal characteristics have gained speed inevitably in time [1].

The goal of this study is to investigate theoretically and practically wide band pulse radar operating at sub-GHz frequency range for ranging application such as through wall imaging, ground penetrating radar (GPR) and surveillance. The primary advantages of operating at this frequency region include low propagation loss, good penetration and little group delay. On the other hand, wide band characteristic of the system provides very important possibilities such as simple transceiver architecture, high gain in power consumption because of low transmitter duty cycle, low detection probability, less susceptibility to interference and high accuracy in ranging [2,3].

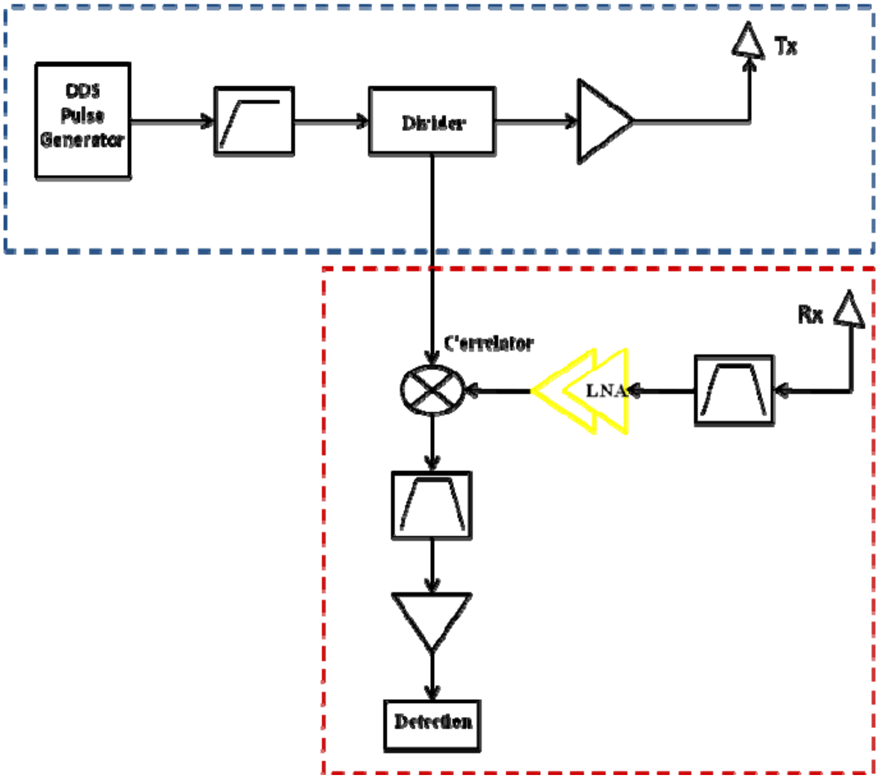



**Figure 1.1** : The transceiver architecture of the pulse radar system.

The whole transceiver circuit is shown in Figure 1.1. The upper side of the system (above the mixer) is the transmitter and the rest part is the receiver. The mixer is the key building block of this coherent structure and correlates the first pulse which returns from the target with the second pulse which comes from DDS pulse generator. While the secondary pulse which drives the mixer is at 250 MHz, the first pulse which carries information about the target and travels through the air is at 350 MHz. The evaluation of the correlation is sum of these frequencies.

One of most important motivation points in this architecture is the opportunity to obtain two pulses from same source with variable difference in time and frequency.

*Direct digital synthesis* (DDS) method is preferred as a pulse generator in the system and Analog Device AD9910 DDS chip is used for this aim. Due to a considerable amount reduction in power consumption, being digitally programmable, fast frequency hopping chance and desired operating frequency, AD9910 direct digital synthesizer matches perfectly as a pulse generator in the system. The corresponding DDS chip is programmed with Python Programming Language via digital controller and the connection between the controller and PC is provided by a PCMCIA parallel card (IEEE 1284).

In the 2nd chapter we will discuss some main topics of radars and the operating principles of general pulse radar. The primary subject of the 3th chapter will be the DDS method and its technology and it will be discussed in details. The rest of this chapter will be all about the fabrication system components and the demonstrator. In the conclusion chapter, system results will be discussed in terms of detection and some outcomes will be given.

## 2. RADAR THEORY

The method for detection and location of objects at distance that cannot be observed visually by using a specific type of waveform is called Radar, or Radio Detection and Ranging. Radar is the one of the most important and widespread applications in microwave engineering area [4-8].

In the operation of basic radar, a transmitter radiates an electromagnetic wave package. A certain amount of this wave package is intercepted by a target and is scattered in all directions. The information regarding the target which is wanted to detect is hidden in the reradiated energy. During the reception, the receiver antenna picks up the reflected signal and sends it as a guided wave to the receiver. This reflected or returned signal is called echo. By evaluating this received signal, it can be reached the direction, height, distance and even image information about the target. The elementary concept figure of this ranging system is given in Figure 2.1[4-8].

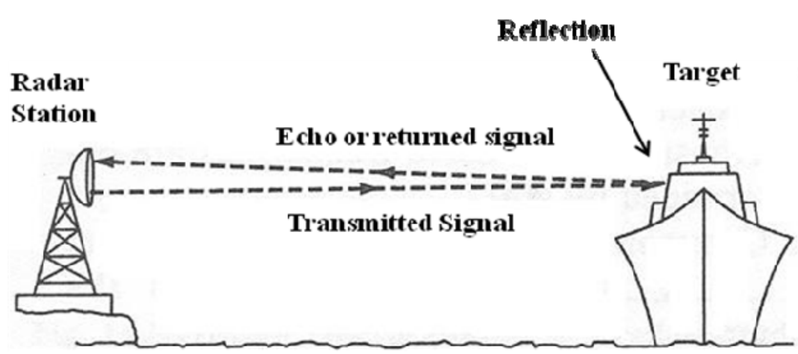



**Figure 2.1 :** The elementary concept of radar [8].

Some of the prevalent applications of radar technology are listed as follows:

Scientific Applications

- Mapping
- Medical imaging
- Through wall imaging

- Sensing of natural resources

Civilian Applications

- Aircraft landing
- Whether radar
- Marine navigation
- Altimetry
- Police speed radar
- Mapping
- Through wall sensing

Military Imaging

- Enemy target tracking
- Reconnaissance
- Air and marine navigation
- Ballistic Missile guidance and defense

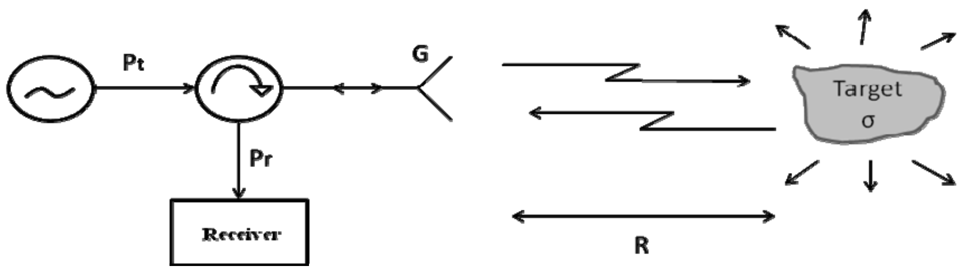
### 2.1. The Radar Equation

The radar equation relates the range of a radar to the characteristics of the transmitter, receiver, antenna, target, and environment. It is useful not just as a means for determining the maximum distance from the radar to the target, but it can serve both as a tool for understanding radar operation and as a basis for radar design [6]. The object of this title is to represent the radar equation.

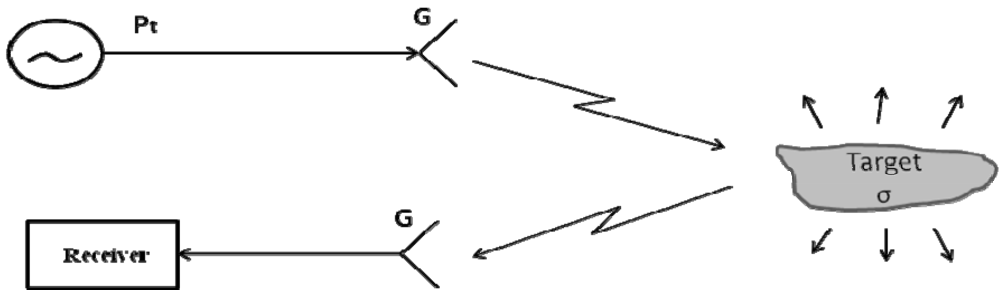
If the output power radiated by the radar transmitter is $P_t$ , and if an isotropic antenna is used (one which radiates uniformly), $S_t$ power density (watts/ unit area) at a distance R from this isotropic antenna

$$S_t = \frac{P_t}{4\pi R^2} \qquad \textbf{(2.1)}$$

Radars use the same antenna for transmitting and receiving is called the monostatic, while the bistatic radars operate with two separate antennas during the whole detection period. The Figure 2.2 given below represents two basic radar systems.




**(a)**




**(b)**

**Figure 2.2 :** Basic monostatic and bistatic radar systems. **(a)** Monostatic radar system. **(b)**Bistatic radar system [4].

Let's consider the monostatic case. According to this model, the power density incident on the target is

$$S_t = \frac{P_T G}{4\pi R^2} \quad \textbf{(2.2)}$$

where G is the gain of the directive antenna. It is assumed that the target to be wanted to detect is in the main beam direction of the transmitting antenna. The target intercepts a certain amount of incident power and scatters it in various directions. The ratio of scattered power in the direction of radar to the incident power intercepted by the target represents the *radar cross section* (RCS) and is symbolized by σ [4-8].

$$\sigma = \frac{P_T}{S_t} \quad \textbf{(2.3)}$$

$P_s$ represents the total scattered power density. The radar cross section has the dimensions of area and is a measure of the size of the target as seen by the radar. In this regard the radar cross section is a unique feature of a target itself. The RCS value of an object not only depends on the polarization of the coming wave, but also on the incident and reflections angels [4-8].

Since the finite sized source behavior of the target according to scattering theory, the power density of the scattered field should be decreased on the order of $1/4\pi R^2$ away from the target. The power density of echo signal at the receiver antenna must be

$$P_r = \frac{P_T G \sigma}{(4\pi R^2)^2} \qquad \textbf{(2.4)}$$

Then using the effective area of the receiver antenna symbolized by $A_e$ gives the power $P_r$ received by the radar is

$$P_r = \frac{P_T G A_e \sigma}{(4\pi R^2)^2} \qquad \textbf{(2.5)}$$

Antenna theory gives the relationship between the maximum effective aperture area of an antenna and the transmitting gain as

$$P_r = \frac{4\pi A_e}{\lambda^2} \qquad \textbf{(2.6)}$$

Substituting (2.6) into equation (2.5) gives us

$$P_r = \frac{P_T G^2 \lambda^2 \sigma}{(4\pi)^3 R^4} \qquad \textbf{(2.7)}$$

This is the radar equation. Note that received power decreases with the $1/R^4$, which means that for detecting target at long distance it is needed a sensitive-low-noise receiver architecture. On the other hand there is a limit of this distance which is called Maximum Radar Range, symbolized by *Rmax,* and it is the distance beyond which the target cannot be detected. Maximum operating distance Rmax is

$$R_{\max} = \left[ \frac{P_T G^2 \lambda^2 \sigma}{(4\pi)^3 P_{r\min}} \right]^{1/4} \qquad \textbf{(2.8)}$$

where $P_{r,min}$ is the minimum received power. This equation states that if long ranges are desired, transmitted power must be large, high-gain antenna must be used (narrow beam width) in transmitter part, large antenna aperture must be preferred to pick up echo signal in receiver front-end part (also synonymous with high gain), and the receiver must be sensitive to weak signals. On the other hand this equation has many idealizations. The atmospheric attenuation along the propagation path negatively affects the maximum radar range, especially at high frequency. In addition, the statistical natures of the target radar cross section, noise and other interfering signals do not allow the maximum operating range for radar to be described by an exact number, but just probabilities can be estimated for it [4-8].

## 2.2. Radar Cross Section

An object exposed to an electromagnetic wave disperses incident energy in all directions. This spatial distribution of energy is called *scattering,* and object itself is often called a *scatterer* [7].

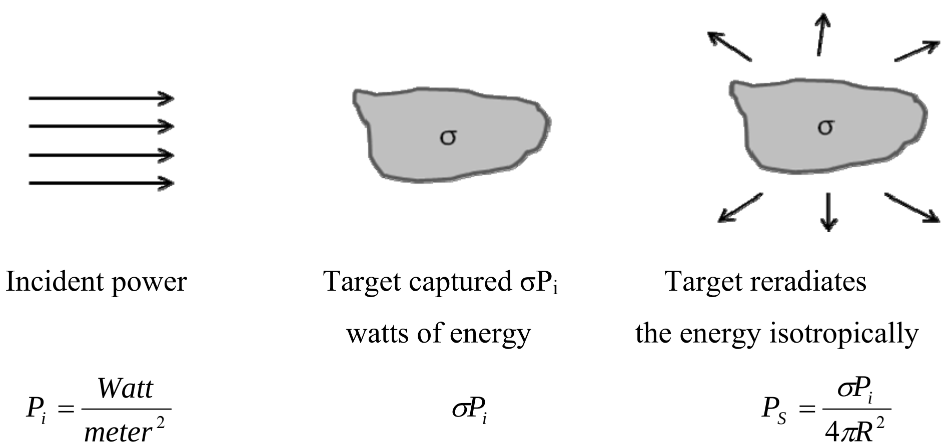



**Figure 2.3 :** Intuitive definition of radar cross section.

The radar cross section of a target is a measure of the ratio of scattered power to incident power density in the radar direction. RCS has been defined to characterize the target features and depends on the frequency and the polarization of the coming wave, and on the incident and reflections angels. Radar cross section is also known as echo area or effective area and therefore has the unit of area [8,9].

The formal definition of radar cross section is

$$\sigma = \lim_{R\to\infty} 4\pi R^2 \frac{|E_S|^2}{|E_i|^2} \qquad \textbf{(2.9)}$$

where $E_i$ is incident field strength at target and $E_s$ scattered field strength at radar.

The derivation of expression given in **(2.9)** assume that a target intercepts power from an incident wave and then reradiates that power isotropically, which means uniformly in all direction. Though the majority of objects do disperse energy uniformly in all direction, the definition just assumes that they do. For the idealization mentioned above, the radar cross section of a target is represented as

$$\sigma = 4\pi R^2 \frac{P_S}{P_i} \qquad \textbf{(2.10)}$$

Note that the distance R should be far from the target to prevent the near-fields effects.

For the most simple of shapes, the scattered field, and hence the radar cross section, can be calculated as an electromagnetic boundary problem by solving Maxwell's equations. The exact radar cross section solution of a perfectly conducting sphere can be determined is shown in Figure 2.4, normalized to optics value $\pi a^2$, the physical cross-sectional area of the sphere [4-9].

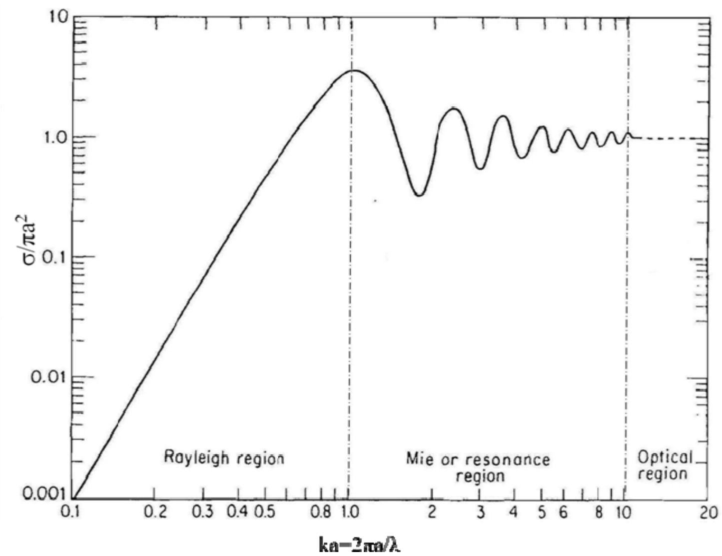



**Figure 2.4 :** Radar cross section of a perfectly conducting sphere.

Note that in the Rayleigh region, radar cross section increases rapidly with size for electrically small sphere ($a<<\lambda$) as $(a/\lambda)^4$. "This strong dependence on frequency explains why the sky is blue, as the blue component of sunlight scatters more strongly from atmospheric particles then do the lower frequency red components" [5]. The optical region, where $a >>\lambda$, represents electrically large bodies and the radar cross section of the conducting sphere is equal to its cross-sectional area, $\pi a^2$. On the other hand, in the resonance region, the electrical size of the sphere is approximately equal to a wavelength. Here the cross section changes with frequency and may reach pretty high values. [4-9].

### 2.3. Radar Frequencies

Radars have been operated at frequencies at frequencies at low as 2 MHz (just above the AM broad-cast band) as high as several hundred GHz (millimeter wave region). More usually, radar frequencies might be from about 5 MHz to over 95 GHz. This is a very large extent frequencies, so it should be expected that radar technology, capabilities, and applications will vary considerably depending on the frequency range at which a radar operates. Radars at a particularly frequency band usually have different capabilities characteristics than radars in other frequency bands [7].

The place of radar frequencies in the electromagnetic spectrum is shown in Figure 2.5. Some of the nomenclature employed to designate the various frequency regions is also shown [6].

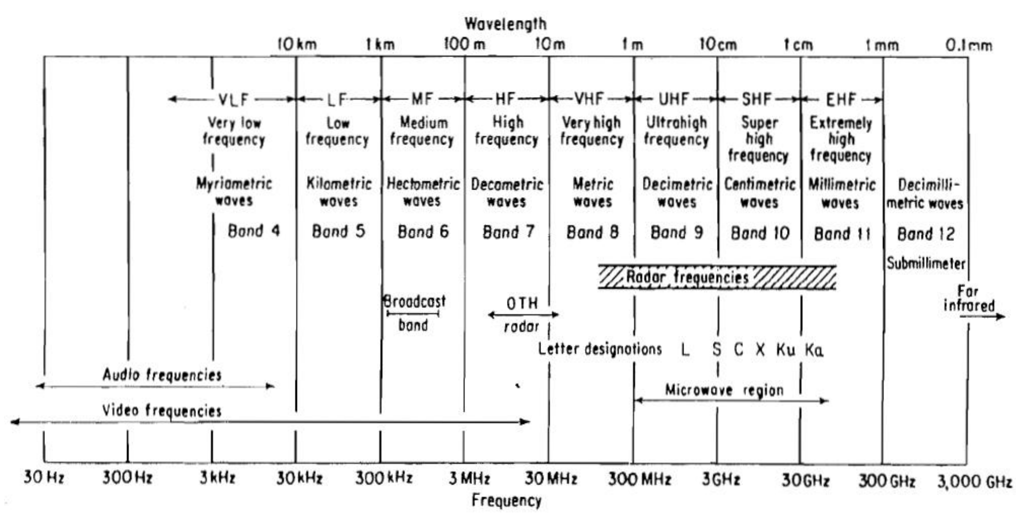



**Figure 2.5 :** Radar frequency and electromagnetic spectrum [5].

Early in the development of radar, a letter code such as S, X, L, etc., was employed to designate radar frequency bands. Although its original purpose was to guard military secrecy, the designations were maintained, probably out of habit as well as the need for some convenient short nomenclature. This usage has continued and is now an accepted practice of radar engineers. Table 2.1 lists the radar-frequency letter-band nomenclature adopted by the IEEE. These are related to the specific bands assigned by the International Telecommunications Union for radar. For example, although the nominal frequency range for L band is 1000 to 2000 MHz, an L-band radar is thought of as being confined within the region from 1215 to 1400 MHz since that is the extent of the assigned band. Letter-band nomenclature is not a substitute for the actual numerical frequency limits of radars. The specific numerical frequency limits should be used whenever appropriate, but the letter designations of Table 2.1 may be used whenever a short notation is desired [6].

Table 2.1 IEEE standard letter dDesignations forrRadar frequency bands [5].

| Band Designation | Nominal FrequencyRange | Specific Frequency Ranges for Radar Based on ITU Frequency Assignments for Region 2 |
|---|---|---|
| HF | 3 MHz – 30 MHZ | |
| VHF | 30 – 300 MHZ | 138 – 144 MHZ<br>216 – 225 MHZ |
| UHF | 300 – 100 MHZ | 420 – 450 MHZ<br>890 – 942 MHZ |
| L | 1.0 – 2.0 GHz | 1215 – 1400 MHz |
| S | 2.0 – 4.0 GHz | 2.3 – 2.5 GHz<br>2.7 – 3.7 GHz |
| C | 4.0 – 8.0 GHz | 4.2 – 4.4 GHz<br>5.25 – 5. 925 GHz |
| X | 8.0 – 12.0 GHz | 8.5 – 10.68 GHz |
| $K_u$ | 12.0 – 18.0 GHz | 13.4 – 14.0 GHz<br>15.7-17.7 GHz |
| K | 18.0 – 27.0 GHz | 24.05 – 24.25 GHz<br>24.65 – 24.75 GHz |
| $K_a$ | 27.0-40.0 GHz | 33.4 – 36.0 GHz |
| V | 40.0 – 75.0 GHz | 59.0 – 64.0 GHz<br>76.0 – 81.0 GHz<br>92.0 – 100 GHz |

## 2.4. Information Available From A Radar

Range: Most probably, the primary characteristic of a conventional radar is its ability to measure the range to a target. There is not any other system which can determine the range to a remote object at long distance, especially with the accuracy of radar.

The accuracy of a distance measurement relies on the bandwidth of carrier signal. The wider bandwidth, the greater the measurement accuracy. Therefore this effect makes the system bandwidth the main measure of range accuracy [9].

Radial Velocity: The target radial velocity can be determined from the rate of change of range in a period of time or the measurement of the doppler frequency shift. Thus the quality of a radial velocity measurement is basically depends on *time* term [9].

Angular Direction: It can be reached by determining the angle where echo signal's magnitude is in maximum level. This mostly needs a narrow beamwidth antenna (also synonymous with high gain). Thus the electrical size of the antenna is the basic parameter describing the quality of an angular measurement [9].

Size and Shape: If the radar has sufficient resolution capability in range or angle, it can provide a measurement of the target extent in the dimension of high resolution [9].

### 2.5. Pulse Radar

The operation principle of a typical pulse radar may be described with the aid of the block diagram shown in Figure 2.6. The signal generator of the transmitter may be an magnetron, a PLL circuit or a direct digital synthesizer (DDS) to generate a repetitive train of short-duration pulses. It might have an average power level as small as miliwatts or as large as megawatts [7].

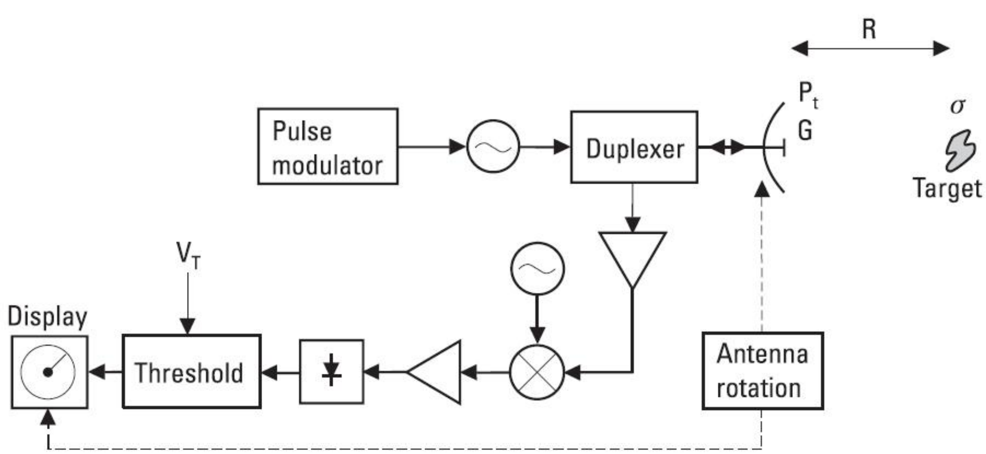



**Figure 2.6 :** Block diagram of pulse radar [7]

The generated pulses travel via a transmission line to the transmitter antenna to radiate into space. For both transmitting and receiving operations, generally just a single antenna is used. The device is called duplexer is used to isolate the receiver from transmitter part while allowing them to share a common antenna. The duplexer protects the sensitive receiver from damage caused by the high power while transmitter is on. The other task of the duplexer is to direct the received echo signal to the receiver rather than the transmitter [4-8].

The receiver is usually of the superheterodyne type. The first stage might be a low-noise RF amplifier, such as a parametric amplifier or a low-noise transistor. The task of this stage amplifies the weak signal to a certain level where its presence can be detected. At the microwave frequencies, noise negatively affects radar performance usually from the first stage of the receiver. Therefore using a low-noise amplifier (LNA) at the front-end of the receiver will make it more sensitive. The other advantages of using LNA are greater receiver dynamic range, less susceptibility to overload, and less sensitivity to interfere [4-8].

Another stage of this superheterodyne structure is mixer. The target of the mixer is to transform the received signal to far more convenient frequency region and make it more readable to obtain information about the target [4-8].

The target range is calculated by

$$R = \frac{c\Delta_t}{2} \qquad \textbf{(2.11)}$$

where $\Delta t$ is the traveling time to the target and back and $c$ is the speed of the wave which in most cases is with a good approximation of the speed of light. Thus, the radar is a timing device.

The target angular direction is reached from the direction of the narrow main beam of the antenna. The radar antenna might be a reflector antenna rotating mechanically, or a phased array which it's the direction of main beam is scanned electronically. On the other hand, the receiver output voltage level is compared to a tunable threshold voltage, $V_T$. Any output voltage bigger than this $V_T$ value is evaluated as a target. The value of this term also represents the sensitivity of the receiver in a sense. In case of too low $V_T$ the receiver can detect the noise as a target while a too high $V_T$ reduces the probability of obtaining the weak returned signal from a target [4-8].

Pulse radar's performance might be improved by integration and compression of pulses, and moving target indication. Even if the beam of the antenna is scanning rapidly, several pulses are received by a target during every single scan. The radar sensitivity can be improved by summing (or integration) these pulses. This operation is performed either coherently at IF or noncoherently after detection. $N$ pulses which have equal amplitudes improve the $S/N$ by a factor of $n$ when an ideal coherent integration of them occurs. On the other hand, A noncoherent summing is not as effective as the coherent integration but it is far more simple for realizing. In pulse compression method, the transmitted pulse is long and its frequency or phase is modulated. In the receiver part, the pulse is then compressed to a shorter impulse, by using a filter whose delay depends on frequency, for instance. Consequently pulse compression combines the advantages of high energy pulses with those of short pulses, that is, a large operating range and a good resolution [7].

### 2.6. Doppler Radar

If the target which is to be detected has a velocity components in the radar range, the frequency of returned signal will be different or shifted in frequency relative to the transmitted signal. This phenomenon is known as the Doppler Effect. The radar transmits a continuous and unmodulated wave at a frequency of $f_0$. If the radial velocity of the target is $v_r$, the frequency of the reflected signal is $f_0 + f_D$ where the

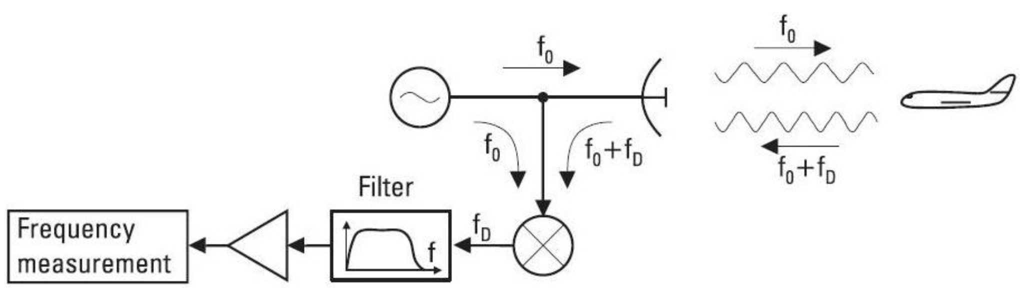



**Figure 2.7 :** Basic doppler radar [7].

Doppler frequency is

$$f_d = \frac{2v_r f_o}{c} \quad \textbf{(2.12)}$$

where c is the velocity of light [4,7]. A simple Doppler radar block diagram, called *continuous wave* (CW) radar, is shown in Figure 2.7.

In short, doppler frequency is positive for an approaching target and negative for a receding target. According to classical mixer theory, mixing the transmitted and received signals produces an output frequency of $|f_D|$. Thus, the sign of $f_D$ is lost in mixing.

The filter following the mixer should have a convenient passband to stop the dc component due to fixed targets. For a good resolution in velocity measurement, the carrier should be generated by an oscillator which has low phase noise.

Figure 2.8 shows a much more sophisticated Doppler radar.

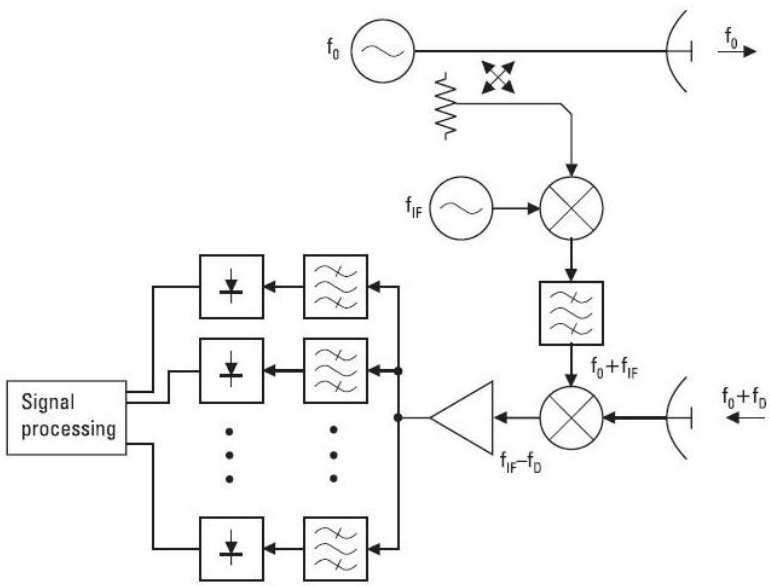



**Figure 2.8 :** Doppler radar having separate antennas for detection [7].

It has two separate antennas, one of them is to transmit and the other is for reception, which reduces the leakage of power from the transmitter to the receiver. The local oscillator frequency is shifted from $f_0$ to $f_0 + f_{IF.}$ Now the output frequency $f_{IF}$ - $f_D$ displays the sign of Doppler frequency.

The higher output frequency value also reduces low-frequency noise effect. The use of a filter bank consisting of narrow-band filters improves the SNR compared to the simple radar of Figure 2.7. Doppler radar is utilized in many kinds of velocity measurements: in traffic control, to measure ascent speeds of aircrafts, and so on. They are also used to detect intruders. Doppler radar cannot calculate the distance to a target. But, pulsed Doppler radar might measure both the distance and the radial velocity [7].

# 3. SYSTEM DESIGN AND VERIFICATION

This part of the thesis is regarding the experimental design stage of the system at all. The topic is mainly divided to three different parts for much more meaningful investigation: The transmitter subsystem, receiver subsystem and the demonstrator. The first two sections are purely about designing microwave components and optimize them to build a demonstrator which we will talk about at the end of this chapter.

## 3.1. Transmitter Subsystem

### 3.1.1. Radar signal generator: AD9910

With the widespread use of digital techniques in instrumentation and communications systems, a digitally-controlled method of generating multiple frequencies from a reference frequency source has evolved called *Direct Digital Synthesis* (DDS) [10-11].

In this simplified model, a stable clock drives a programmable-read-only-memory (PROM) which stores one or more integral number of cycles of a sinewave (or other arbitrary waveform, for that matter). As the address counter steps through each memory location, the corresponding digital amplitude of the signal at each location drives a DAC which in turn generates the analog output signal. The spectral purity of the final analog output signal is determined primarily by the DAC. Because a DDS system is a sampled data system, all the issues involved in sampling must be considered: quantization noise, aliasing, filtering, etc [10-11].

For instance, the higher order harmonics of the DAC output frequencies fold back into the Nyquist bandwidth, making them unfilterable, whereas, the higher order harmonics of the output of PLL-based synthesizers can be filtered.

A fundamental problem with this simple DDS system is that the final output frequency can be changed only by changing the reference clock frequency or by reprogramming the PROM, making it rather inflexible [10-11].

### 3.1.2. Working principles

In its simplest form, a direct digital synthesizer can be implemented from a precision reference clock, an address counter, a programmable read only memory (PROM), and a D/A converter (see Figure 3.1).

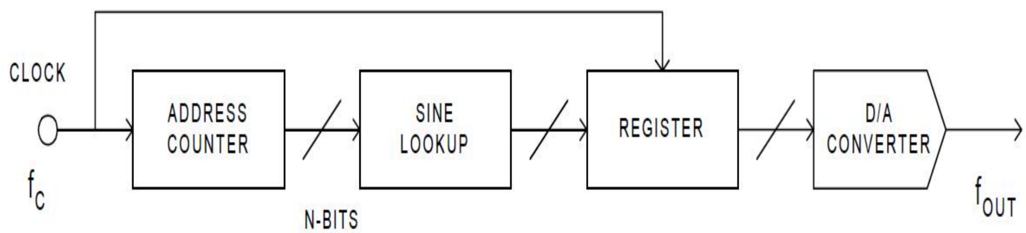



**Figure 3.1 :** Fundamental direct digital synthesis system.

In this case, the digital amplitude information that corresponds to a complete sine wave is accumulated in the PROM. The PROM is therefore functioning as a sine lookup table. The address counter steps through and accesses each of the PROM's memory locations and the contents (the equivalent sine amplitude words) are presented to a high-speed D/A converter. The D/A converter generates an analog sine wave in response to the digital input words from the PROM. The output frequency of this DDS implementation is dependent on the frequency of the reference clock and the sine wave step size that is programmed into the PROM. This sentence could be said like that the output frequency can only be changed by changing the frequency of the reference clock or by reprogramming the PROM. Neither of these options supports high-speed output frequency hopping [10-11]

It can be easily seen that this fundamental characteristic making it rather inflexible in terms of output frequency hopping. A practical DDS system carries out this basic function in a much more flexible and efficient mode using digital hardware called a Numerically Controlled Oscillator (NCO). A block diagram of this new architecture is shown in Figure 3.2 [10-11].

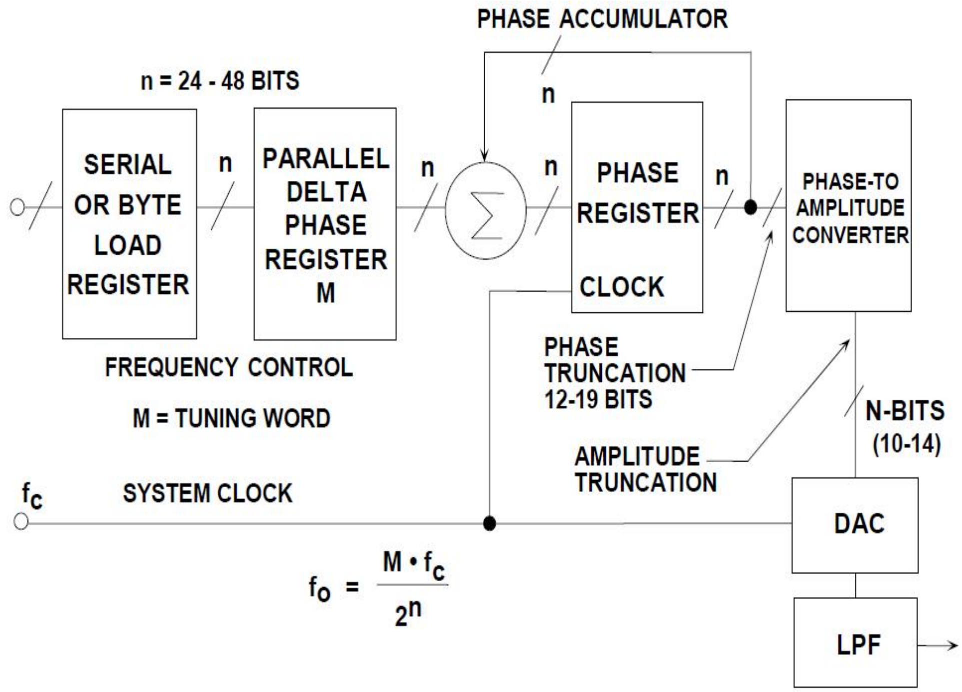
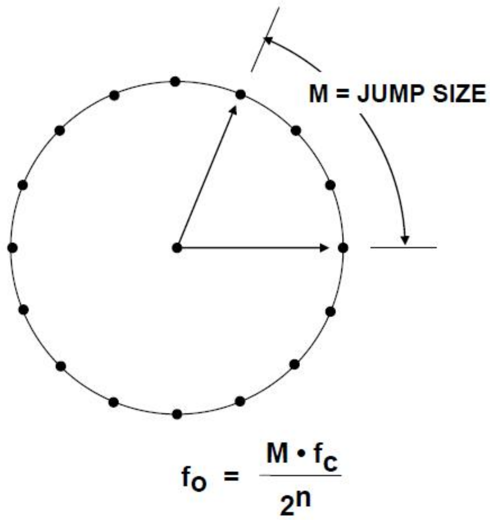



**Figure 3.2 :** A flexible DDS system

The main part of the system is the *phase accumulator* whose content is updated once each clock cycle. Each time the phase accumulator is updated, the digital number, M, stored in the *delta phase register* is added to the number in the phase accumulator register. Assume that the number in the delta phase register is 00...01 and that the initial content of the phase accumulator is 00...00. The phase accumulator is updated by 00...01 on each clock cycle. If the accumulator is 32-bits wide, $2^{32}$ clock cycles (over 4 billion) are required before the phase accumulator returns to 00...00, and the cycle repeats [10-11].

The truncated output of the phase accumulator serves as the address to a sine (or cosine) lookup table. Each address in this table corresponds to an equivalent phase point on the sinewave from 0° to 360°. The lookup table contains the corresponding digital amplitude information for one complete cycle of a sine wave. The lookup table therefore maps the phase information from the phase accumulator into a digital amplitude word, which in turn drives the DAC. To understand this basic function, visualize the sinewave oscillation as a vector rotating around a phase circle (see Figure 3.3) [ 10-11].




| n | Number of Points = $2^n$ |
|---|---|
| 8 | 256 |
| 12 | 4,096 |
| 16 | 65,536 |
| 20 | 1,048,576 |
| 24 | 16,777,216 |
| 28 | 268,435,456 |
| 32 | 4,294,967,296 |
| 48 | 281,474,976,710,656 |

**Figure 3.3 :** Digital phase wheel.

Each designated point on the phase wheel corresponds to the equivalent point on a cycle of a sine waveform. As the vector rotates around the wheel, visualize that a corresponding output sinewave is being generated. One revolution of the vector around the phase wheel, at a constant speed, results in one complete cycle of the output sinewave. The number of discrete phase points contained in the "wheel" is determined by the resolution, N, of the phase accumulator. For an n-bit phase accumulator (n generally ranges from 24 to 32 in most DDS systems), there are $2^n$ possible phase points. The digital word in the delta phase register, M, represents the amount the phase accumulator is incremented each clock cycle. If $f_c$ is the clock frequency, then the frequency of the output sinewave is equal to:

$$f_o = \frac{Mf_c}{2^n} \quad \textbf{(3.1)}$$

This equation is known as the DDS "tuning equation." Note that the frequency resolution of the system is equal to fc/2n. For n = 32, the resolution is greater than one part in four billion [10-11].

### 3.1.3. Analog Device AD9910 chip

The AD9910 is a direct digital synthesizer (DDS) featuring an integrated 14-bit DAC and supporting sample rates up to 1 GSPS. The AD9910 employs an advanced, proprietary DDS technology that provides a significant reduction in power consumption without sacrificing performance. The DDS/DAC combination forms a digitally programmable, high frequency, analog output synthesizer capable of generating a frequency agile sinusoidal waveform at frequencies up to *400 MHz*. The user has access to the three signal control parameters that control the DDS: frequency, phase, and amplitude. The DDS provides fast frequency hopping and frequency tuning resolution with its 32-bit accumulator. With a 1 GSPS sample rate, the tuning resolution is ~0.23 Hz. The DDS also enables fast phase and amplitude switching capability [11-12].

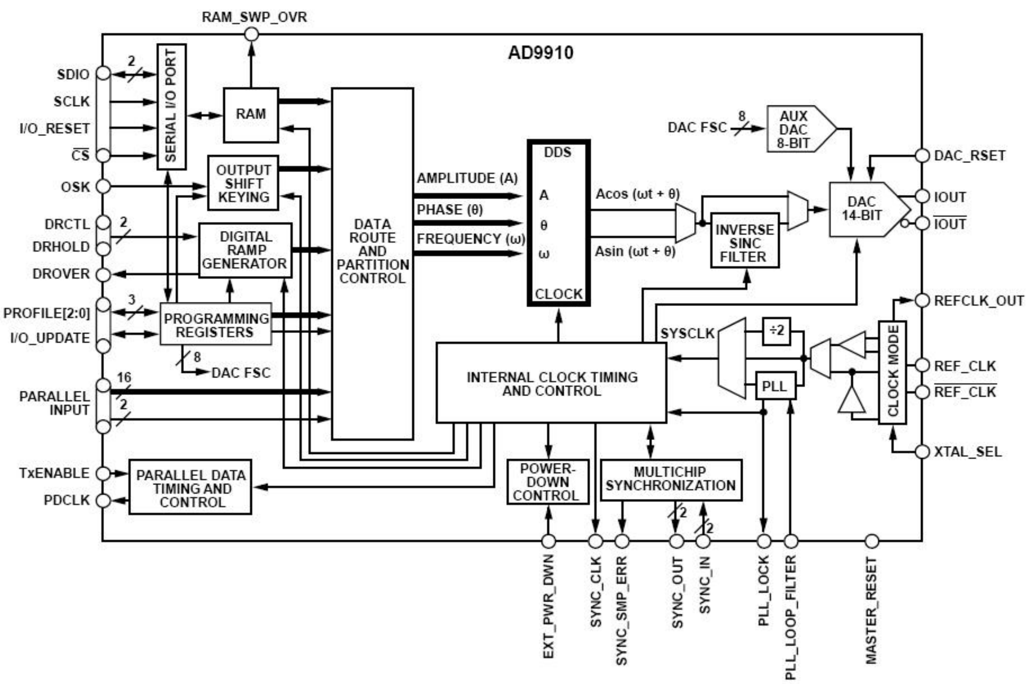



**Figure 3.4 :** Detailed block diagram of AD9910.

The AD9910 is controlled by programming its internal control registers via a serial I/O port. The AD9910 includes an integrated static RAM to support various combinations of frequency, phase, and/or amplitude modulation. The AD9910 also supports a user defined, digitally controlled, digital ramp mode of operation. In this mode, the frequency, phase, or amplitude can be varied linearly over time. For more advanced modulation functions, a high speed parallel data input port is included to enable direct frequency, phase, amplitude, or polar modulation [11-13].

### 3.1.4. Theory of signal generation

The AD9910 chip gives four modes of operation chance.

- Single tone
- RAM modulation
- Digital ramp modulation
- Parallel data port modulation

In the programming the chip via Python, operation mode is selected as RAM modulation. The RAM modulation mode is activated via the RAM enable bit and assertion of the I/O_UPDATE pin (or a profile change). In this mode, the modulated DDS signal control parameters are supplied directly from RAM. The RAM consists of 32-bit words and is 1024 words deep. Coupled with a sophisticated internal state machine, the RAM provides a very flexible method for generating arbitrary, time dependent waveforms. A programmable timer controls the rate at which words are extracted from the RAM for delivery to the DDS. Thus, the programmable timer establishes a sample rate at which 32-bit samples are supplied to the DDS. The selection of the specific DDS signal control parameters that serve as the destination for the RAM samples is also programmable through eight independent RAM profile registers. Select a particular profile using the three external profile pins (PROFILE[2:0]). A change in the state of the profile pins with the next rising edge on SYNC_CLK activates the selected RAM profile. In RAM modulation mode, the ability to generate a time dependent amplitude, phase, or frequency signal enables modulation of any one of the parameters controlling the DDS carrier signal. Furthermore, a polar modulation format is available that partitions each RAM sample into a magnitude and phase component; 16 bits are allocated to phase and 14 bits are allocated to magnitude [11-13].

As mentioned before, the one of the most important motivation points in this study is the proof of concept of successful signal acquisition by programming AD9910 with Python.

By programming the DDS chip with Python it is obtained two pulses with variable difference in time and frequency generated by the same source.


**Figure 3.5 :** AD9910 application board.

The corresponding DDS chip is programmed with Python Programming Language (Appendix 1) via digital controller and the connection between the controller and PC is provided a PCMCIA parallel card (IEEE 1284). On the interface there are 3 Texas Instrument-LC474A d-type flip-flops to control the chip and feeding input with its classical voltage regulator structure of Analog Device ADP3303. The application board given in Figure 3.4 consists of AD9910 chip, ADT1-1WT RF transformer, 50 MHz crystal oscillator, reconstructive filter, feeding points with its regulator structures of ADP3303 and control inputs.

### 3.1.5. AD9910 pulse signal structure

In the previous title, we mentioned the operation of signal generation with DDS. We will discuss in this topic the pulse structure of transmitter both in time domain and frequency region.

In this project we determined two main boundary conditions to investigate. One of them is sub-GHz operating region and the other is wide band signal characteristic. As shown in Figure 3.5 the absolute bandwidth is determined as the difference between the upper and lower -10dB below emission points defined by $f_H$ and $f_L$.

$$B = \Delta f_{-10dB} = f_H - f_L \quad \textbf{(3.2)}$$

which is known as -10dB bandwidth [14].

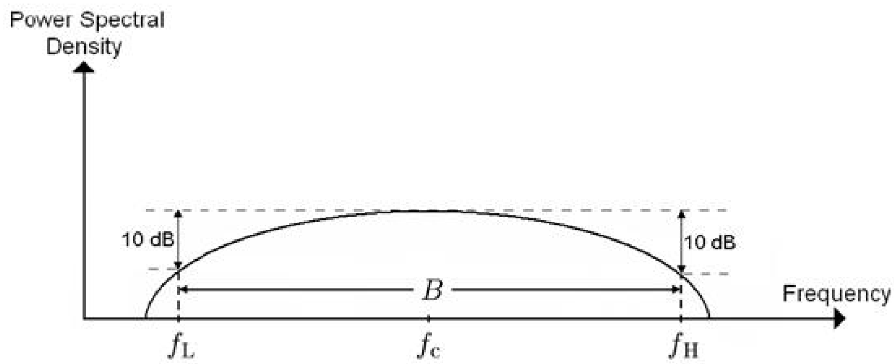



**Figure 3.6 :** Spectral representation of bandwidth [14].

The other term, fractional bandwidth, is determined as

$$B_{frac} = \frac{B}{f_c} \quad \textbf{(3.3)}$$

where $f_c$ is the center frequency [11]. The center frequency $f_c$ is calculated by

$$f_c = \frac{f_H + f_L}{2} \quad \textbf{(3.4)}$$

By substituting **(3.2)** and **(3.4)** into **(3.3)**, the fractional bandwidth is also expressed as

$$B_{frac} = \frac{2(f_H - f_L)}{f_H + f_L} \quad \textbf{(3.5)}$$

The output frequency up to 400 MHz, 1 GSPS sample rate and 0.23 Hz tuning resolution are basic characteristics of AD9910.

The basic concept of the pulse train generated by AD9910 is shown in Figure 3.6. The carrier signal of the system is at 350 MHz, and secondary pulse is at 250 MHz. Width of each pulse is 8ns, between of them is 20ns. "$t_{cycle}$" is our theoretical maximum range is 400ns and finally there is a dead zone to avoid the reflections from targets. The $t_{cycle}$ also is represents the pulse repetition frequency of the system (PRT).

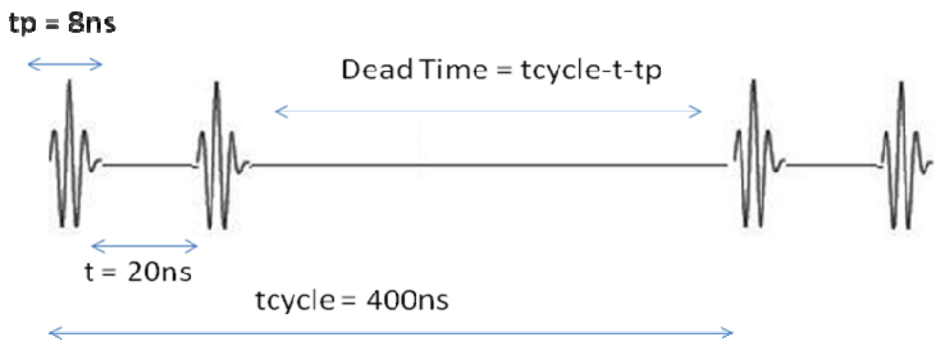



**Figure 3.7 :** The basic concept of the pulse train [14].

The real signal output signal structure is given in Figure 3.7**.** Note that repetitive pulse train actually consists of three signals different in frequency: During a certain amount duration 0 Hz (no signal), after that during 8ns 350 MHz, again 0 Hz is about 20ns, the second pulse at 250 MHz along 8ns, again no signal comes and so on. This fast frequency hopping capacity is unique feature of direct digital synthesis method and forms the signal frame of the system.

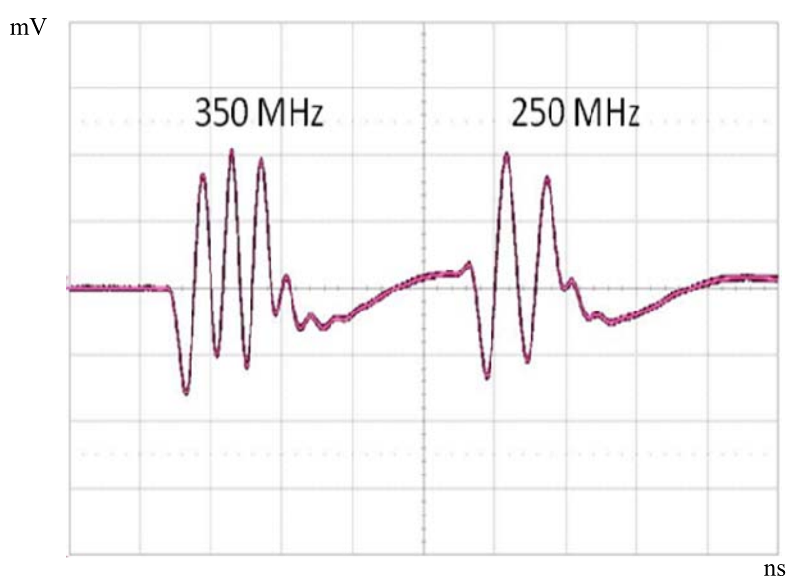



**Figure 3.8 :** The pulse train in time.

As it is known the narrow in time, the wider in frequency and since this inverse relation between the duration and bandwidth form of a signal, short pulse duration makes the system the wide band one.

By using **(3.2)** and **(3.3),** let's determine the bandwidth characteristic of the system.

Absolute Bandwidth $B = f_H - f_L = 425MHz - 275MHz = 150MHz$

Fractional Bandwidth $B_{frac} = \frac{B}{f_c} = \frac{150MHz}{350MHz} = \%43$

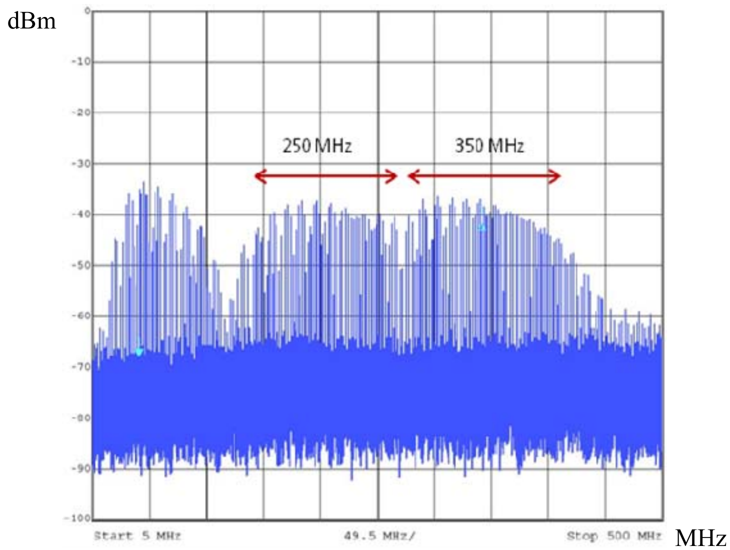



**Figure 3.9 :** The pulse train in frequency region.

The fractional bandwidth of the system is on the order of 50% of the carrier frequency and this is mathematical reason why we define the system as "wide-band" one.

Large bandwidths of wide and ultra-wide band signals bring lots of advantage and let's remember some of them:

- Good penetration through obstacles
- High-speed data transmission
- High accuracy in position estimation
- Low detection and interference probability
- Low power consumption

The penetration capability of a wide band system is based on its large frequency spectrum content. This content includes the high frequency components as well as low frequency ones. The reason of high ranging ability is that this large spectrum results in high time resolution.

As it is known, according to the Shannon channel capacity formula, if you increase the bandwidth of the system, you can sent more information from the transmitter to the receiver [14,15].

$$C = B\log_2(1+SNR) \qquad \textbf{(3.6)}$$

### 3.1.6. 50 MHz high pass filter

In the signal structure topic, it is mentioned $t_{cycle}$ term and said that its value is 400 ns. $t_{cycle}$ term generate a component at 2.5 MHz frequency. In addition, AD9910 chip creates some unwanted harmonics which affect the frequency spectrum content of the output. Consequently, these harmonics cause a certain amount of offset in time (see Figure 3.10).

$$\Delta f = \frac{1}{t_{cycle}} = \frac{1}{400ns} \rightarrow \Delta f = 2.5MHz \qquad \textbf{(3.7)}$$

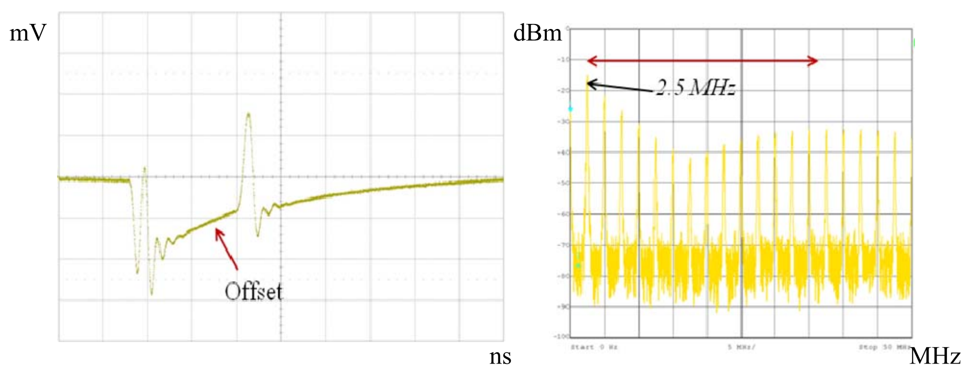



**Figure 3.10 :** DDS Output offset representation in time and frequency region.

For eliminating these spectrum components, a maximally flat high-pass 5th order passive filter with a cutoff frequency of 50 MHz, impedance of 50 ohm was used right after the DDS output. The filter was firstly designed on ADS (Advanced Design System) with the parasitic equivalents and then was implemented on a FR4 type PCB. The FR4's thickness is 0.5 mm and is suitable for low frequencies up to 7GHz. ADS application page and the response of the designed filter are given below in Figure 3.11.

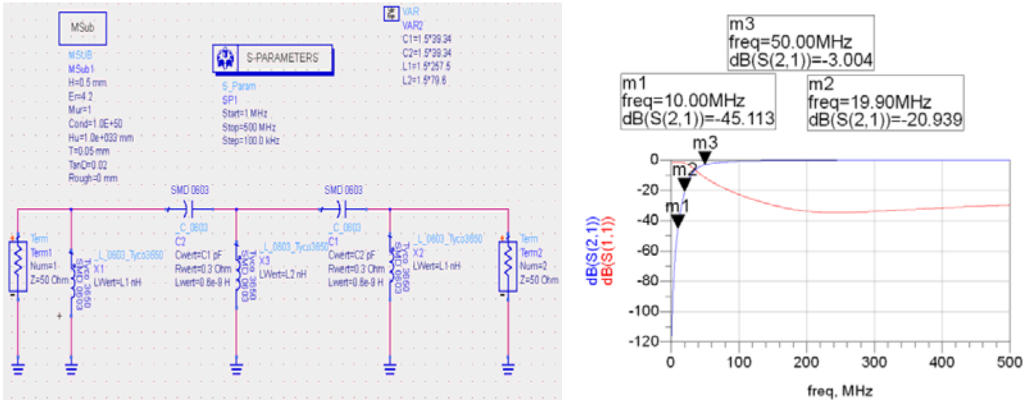



**Figure 3.11 :** ADS application page and frequency response of the filter.

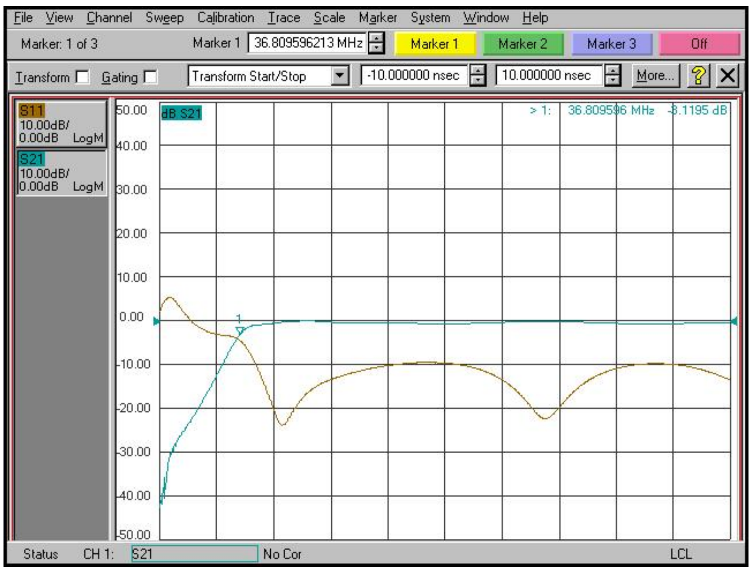



**Figure 3.12 :** The network analyzer response of 50MHz filter.

The network analyzer response of the realized filter is shown above.

### 3.1.7. Suhner divider

Suhner power divider was used to equally split the DDS output signal into two 6 dB output channels. One of those channels drives the mixer and the other emits the carrier signals to the antenna. Suhner divider operates up to 12.4 GHz and maximum power level is 0.5 watts. The suhner divider used in the demonstrator is shown in Figure 3.13.

**Figure 3.13 :** Suhner divider.

### 3.1.8. HMC816 amplifier

This two stage amplifier also was used in the receiver part. Therefore this topic will be discussed in the next pages in detail.

## 3.2. Receiver Subsystem

The receiver of the demonstrator is a typical superheterodyne receiver. The architecture of the receiver is given in figure.

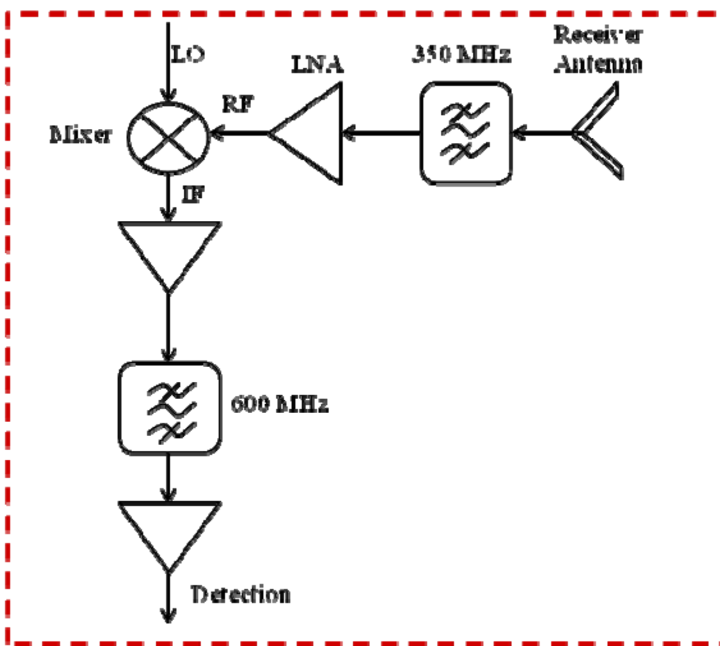



**Figure 3.14 :** The receiver architecture.

### 3.2.1. 350 MHz preselector filter

As it is know that each carrier pulse is at 350 MHz and each pulse has a width of 150 MHz in frequency region. The preselector filter is used to attenuate out-of-band signals such as images and interference stems from other systems or high-powered electrical signals during reception [16]. On the other hand, this filter possesses a band pass characteristic which allows passing the target returned signal. The designed 2nd order band-pass filter frequency response is shown below.

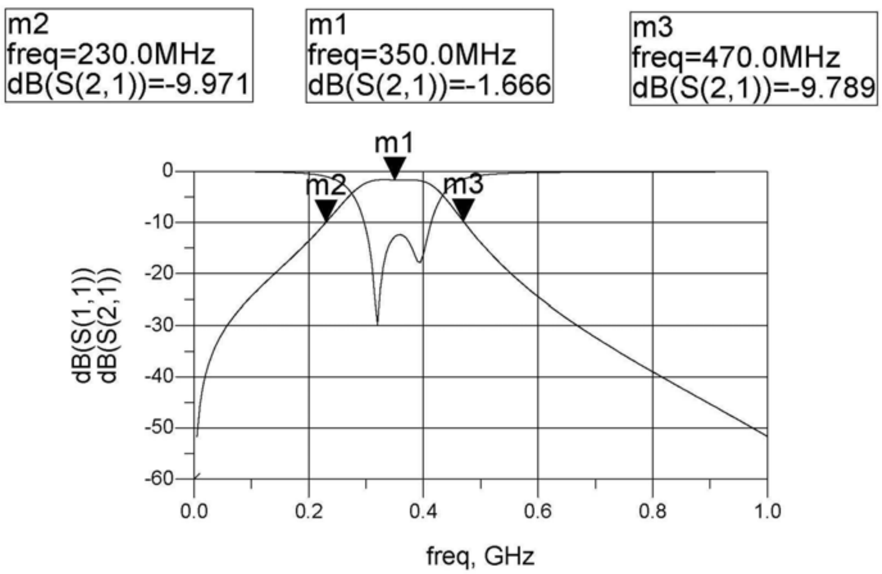



**Figure 3.15 :** Frequency response of the pre-selector filter.

### 3.2.2. LNA

Amplification is one of the most basic and prevalent microwave circuit functions in modern RF and microwave systems. Early microwave amplifiers relied on tubes, such as klystrons and traveling –wave tubes, or solid-state reflection amplifiers based on the negative resistance characteristics of tunnel or varactor diodes. But due to the dramatic improvements innovations in solid-state technology that have occurred since the 1970s, most RF and microwave amplifiers today use transistor devices such as Si or SiGe BJTs, GaAs HBTs, GaAs or InPut due to the dramatic improvements innovations in solid-state technology that have occurred since the 1970s, most RF and microwave amplifiers today use transistor devices such as Si or SiGe BJTs, GaAs HBTs, GaAs or InP FETs, or GaAs HEMT [4].

Our discussion in this topic will be HMC816 low noise amplifier (LNA). The purpose of a low noise amplifier is to increase the signal power in desired band. But the other important motivation point of a LNA is to add as little distortion and noise as possible during the amplification process. Therefore LNA is expressed an amplifier which has low noise characteristic. The noise figure of LNA is determined by the ratio of the input SNR to output SNR and thus has a direct effect on the receiver performance [17].

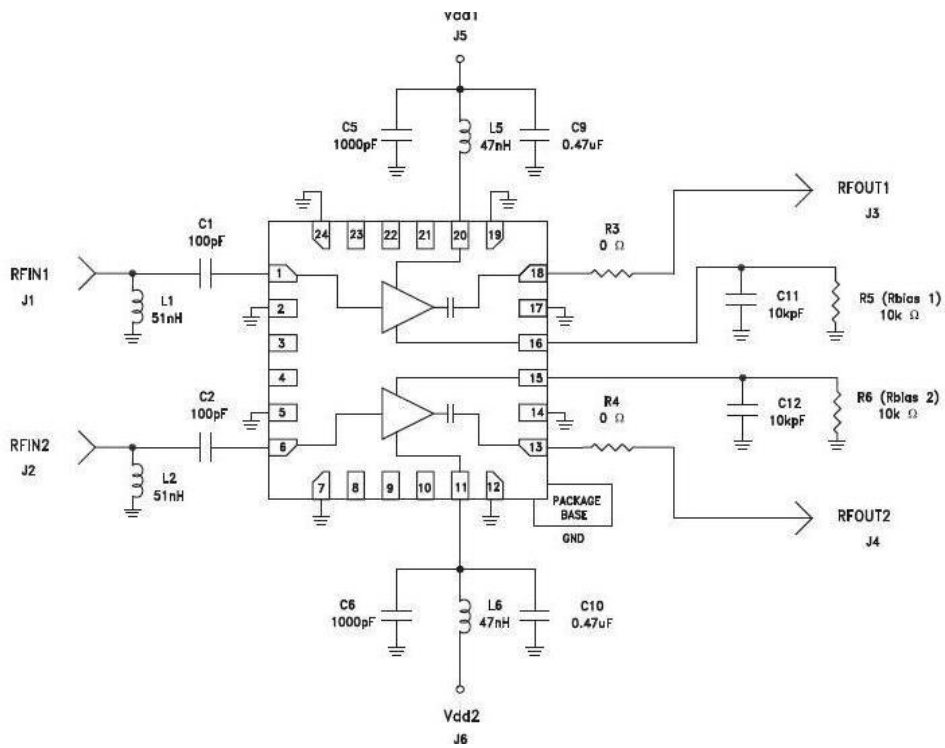



**Figure 3.16 :** Application Board of HMC816.

In the receiver part of the demonstrator, HMC816 amplifier produced by Hittite Microwave Corporation was used as a LNA. HMC816 is GaAs PHEMT dual channel low noise amplifier, operates at 230 – 600 MHz. The amplifier has been to provide 0.5 dB noise figure, 22 dB gain and +37 dBm output IP3 from a single supply of +5V (see Figure 3.16)**.**

The application board was designed in ADS and implemented to a FR4 type PCB. The ADS layout is given in Figure 3.17.

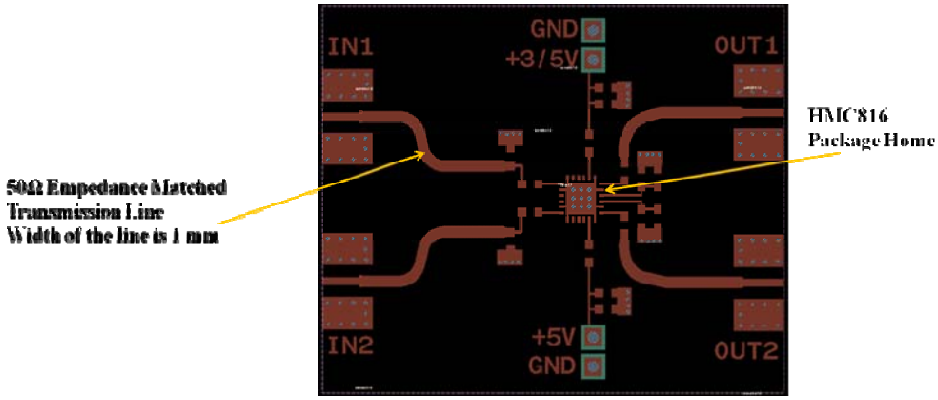



**Figure 3.17 :** ADS Layout of HMC816.

As you see in the layout, the components used on the application board have too small package size and thus it is not possible to build this circuit to a PCB by hand. Therefore HMC816 application board was fabricated with the LPKF ProtoMat S62 circuit board plotter which is shown in Figure 3.18.

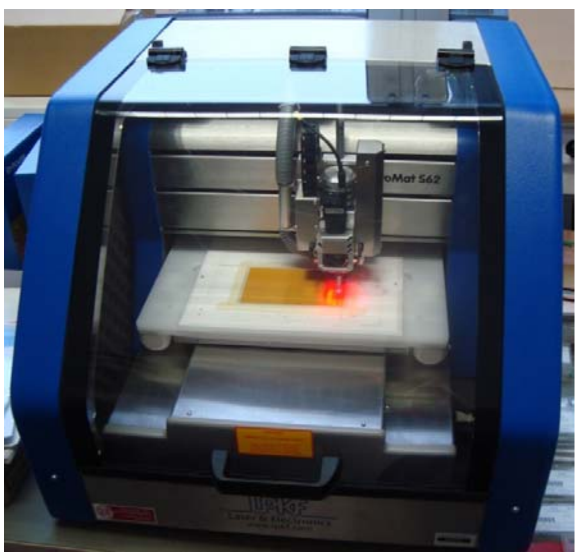


**Figure 3.18 :** LPKF ProtoMat S62 circuit board plotters.

After milling and drilling processes in LPKF ProtoMat, conducting paste was applied to the both sides of the PCB. The reason is to provide a perfect conductivity between bottom and top side of the PCB. After that, the circuit was warmed up about 30 minutes at 120 $^{o}$C and washed with a special cleaner to clean the oxidation. Laststage of the fabrication was that solder the semiconductor parasitic elements, HMC816 chip and the other components to the fabricated board. In addition, this soldering step was occurred under a good quality microscope due to too small size of the components.

The fabricated low noise amplifier and its network analyzer response is shown in Figure 3.19.

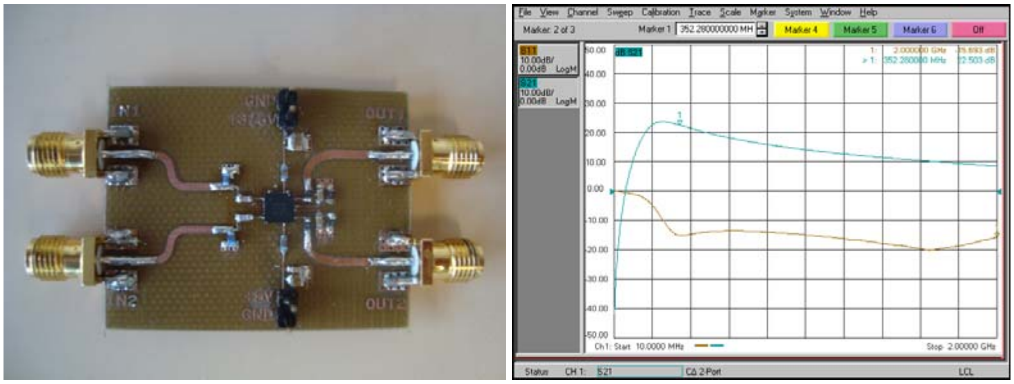



**Figure 3.19 :** HMC816 application board and its network analyzer response.

### 3.2.3. The mixer

A mixer is a three port device that uses a nonlinear or time-varying element to achieve frequency conversion. An ideal mixer produces an output consisting of the sum and difference frequencies of its two input signals. Mixers are used in communication, radar and sensing systems to change the spectrum range in which a signal extend. The reason of this operation is to transform the signal to much more convenient spectrum range to evaluate later. Operation of practical RF and microwave mixers is usually based on the nonlinearity provided by either a diode or transistor. Since a nonlinear component can generate a wide variety of harmonics and other products, in modern microwave systems typically filters are used right after the mixer [4,18,19].

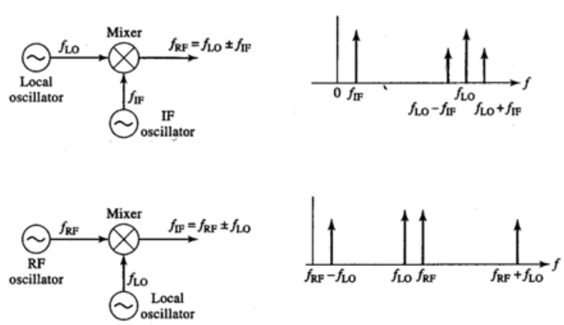



**Figure 3.20 :** Frequency Conversion [4].

We used SYM-11 level-7 type double-balanced frequency mixer produced by Mini-Circuits in the receiver part of the system as a mixer. The main characteristics of the mixer are given below.

- Wideband, 1 to 2500 MHz
- Low conversion loss, 7.0 dB typ.
- Good isolation, 40 dB typ. L-R, 35 dB typ. L-I
- Maximum RF Power 50 mW

The corresponding PCB board of SYM-11 was design on ADS layout page and then fabricated with the LPKF ProtoMat S62 circuit board plotter. After fabrication it was soldered to the PCB.

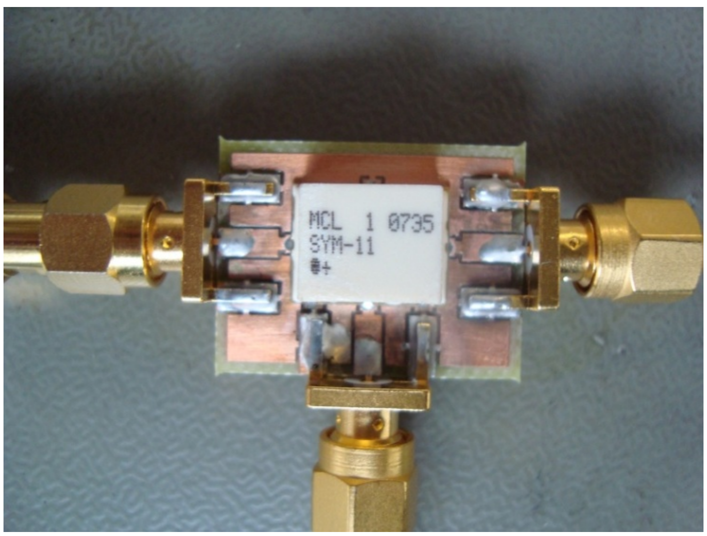



**Figure 3.21 :** SYM-11 double-balanced frequency mixer.

### 3.2.4. 600 MHz BPF

As mentioned in the previous topic, mixers generate a wide variety of harmonics and other products due to its nonlinear characteristic and therefore filters are used right after mixers.

The out of typical mixers consist of the main signals $f_1+f_2$ and $f_1-f_2$ and harmonics $2f_1$, $2f_2$, $3f_1$, $3f_2$, $2f_1-2f_2$, $2f_1+2f_2$ and so on. In the project the desired frequency region is around 600 MHz, $f_1+f_2$, and thus the other products and harmonics are unwanted ones for detection. Here is the using reason of this band pass filter is to clean these unwanted harmonics and obtain meaningful and effective a frequency region. The filter was designed and simulated in ADS and implemented to the convenient PCB board. The corresponding ADS working page, the frequency and the network analyzer response to the filter is given in figure.

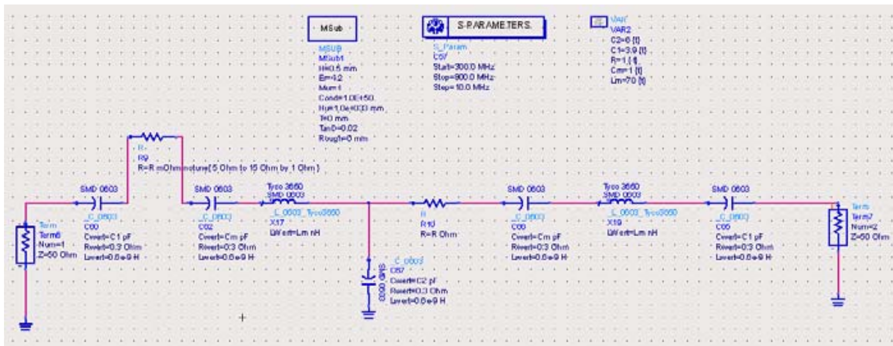


**Figure 3.22 :** ADS application page.

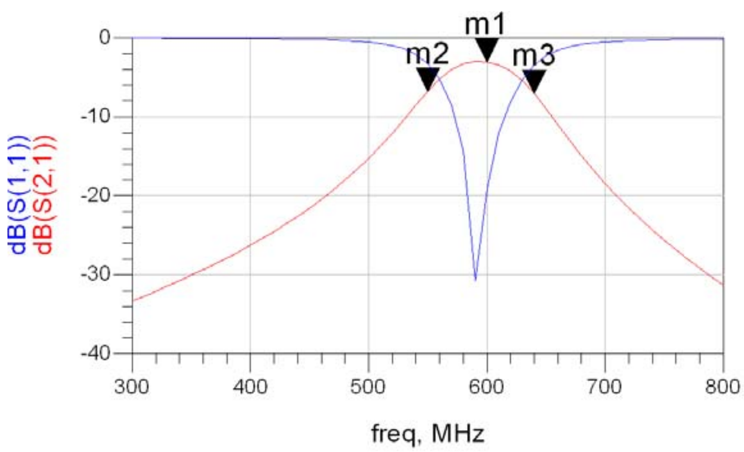



**Figure 3.23 :** Frequency response of the filter.

### 3.3. The Demonstrator

In the previous topics of this chapter we mainly discussed the corresponding microwave components in the demonstrator. The object of those topics is to show the using reasons, the basic operating principles and fabrication procedures of these components. In this topic we combine the all components and build up the demonstrator. The point that we want to reach is to evaluate the last demonstrator and obtain meaningful physical verification regarding realization.

The function of this system is to detect wanted echo signals in the presence of noise, clutter, and interference. It must distinguished desired signals from unwanted ones and amplifies them which carry information about the target for the last detection stage.

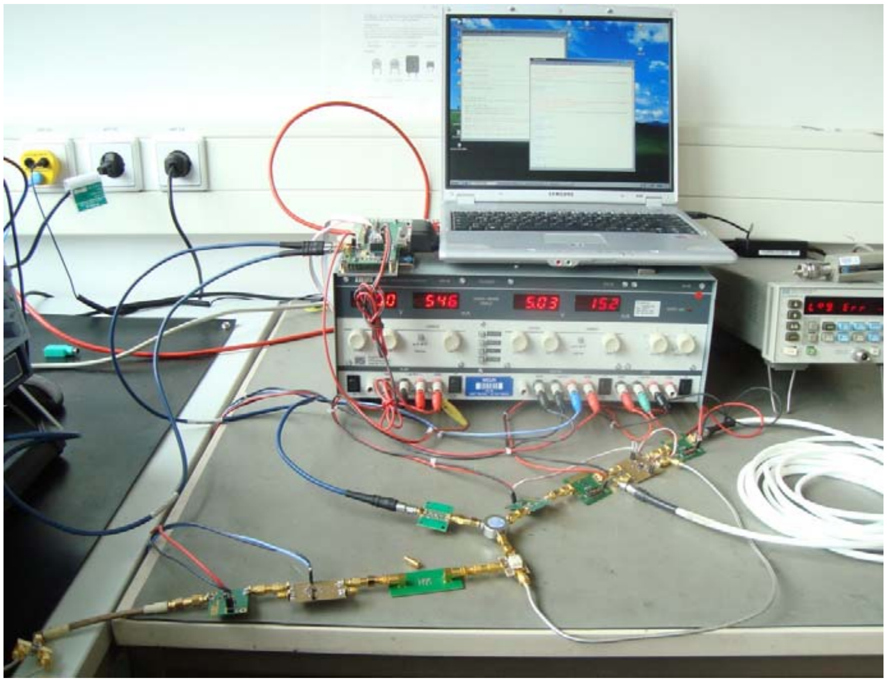


**Figure 3.24 :** The demonstrator setup.

In this demonstrator instead of antennas, it was used a 1.8 meters length cable. This method gave us the really good chance to investigate the receiver sensitivity and SNR level. In this way, we saw the performance of the demonstrator far more clearly in terms of detection.

The statements about the advantages of using a cable instead of antennas are given above actually stems from our main motivation point is that programming the AD9910 chip by Python independently.

- We can change the duration between first and second pulses
- And we know the cable length and thereby the delay between the pulses.

The 1.8 meters in length means 6ns in time. Consequently, we can provide different pulse matches in the mixer such as perfect match, detectable but not perfect match and no match.

The optimized last demonstrator is shown in Figure 3.24**.** This system consists of the corresponding receiver and transmitter parts as well as the cable and the attenuation components. Attenuation is provided by using two The HMC424LP3 digital attenuators right after the cable. The output of the transmitter part is connected to the cable and the other side of the cable is connected to the the front-end of the receiver and amount of the attenuation is 60dB.

With this demonstrator, different attenuation scenarios were implemented. The results of the these different scenarios will be discussed in the next chapter for a completeness evaluation.

### 3.3.1. The perfect match

The attenuation is maximum during the measurements. The detected signal output of the band pass filter is represented both in frequency and time. The power level of the detected signal is -11 dBm. As seen from Figure 3.25 the signal level is clearly definable and this is the typical radar output signal representation in detection situation.

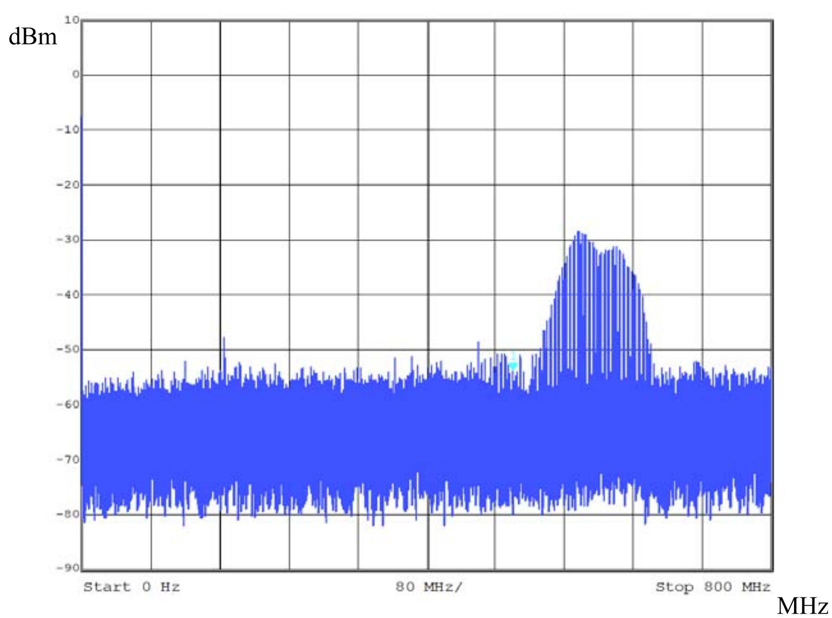



**Figure 3.25 :** The perfect match in frequency region.

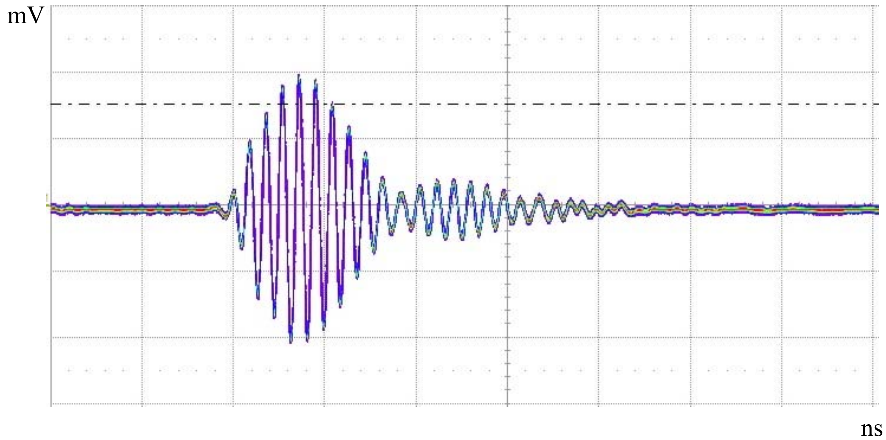



**Figure 3.26 :** The perfect match in time domain.

### 3.3.2. The no match

The attenuation is maximum during the measurements. The detected signal output of the band pass filter is represented both in frequency and time. As you see from Figure 3.27, approximately there is nothing in term of detection.

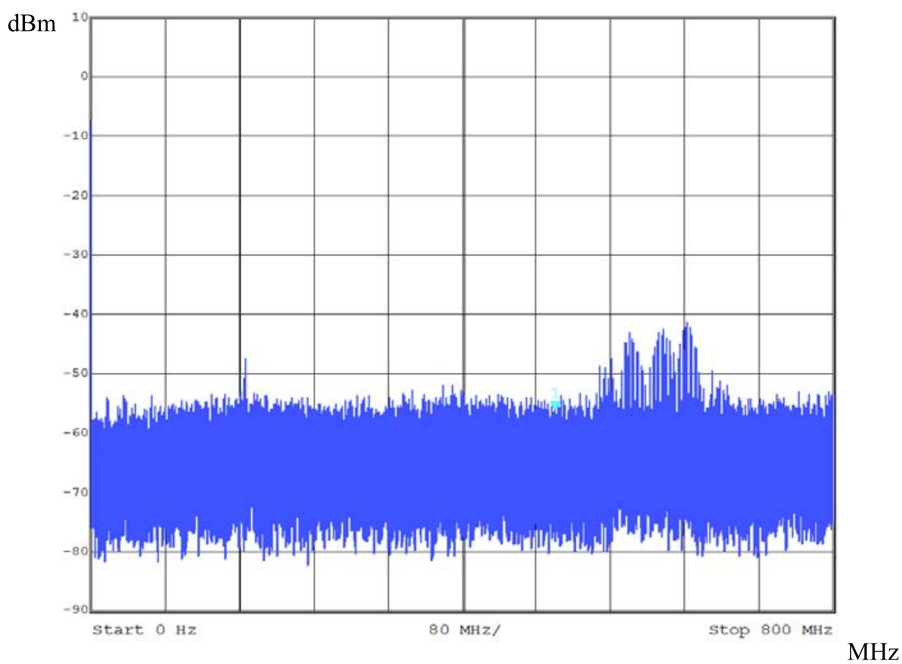



**Figure 3.27 :** No match in frequency region.

As readers remember, the operating frequency is 350 MHz and the bandwidth of the system is 150 MHz. This low frequency and wide band characteristics provide some advantages. The most important two of them are good penetration capability and high resolution [20].

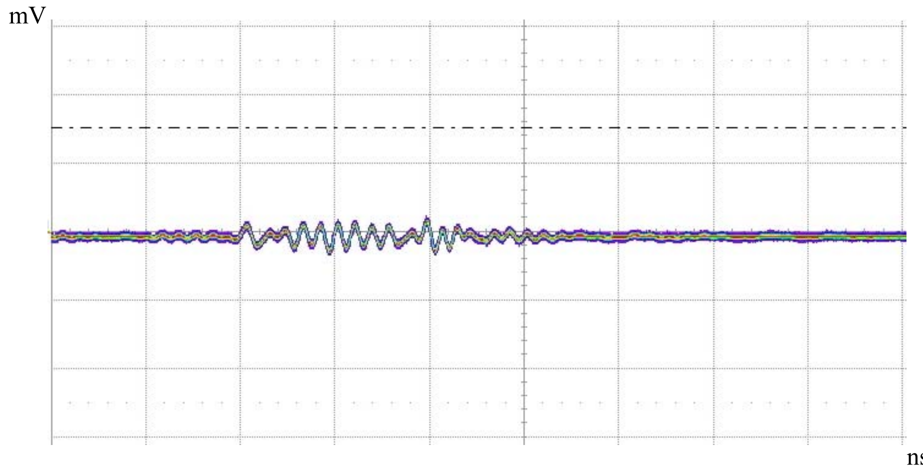



**Figure 3.28 :** The no match in time domain.

In figure 3.27 and 3.28 the no match scenario is shown. The measurements do not have almost any meaningful information about the target in time and frequency domain. Because, there should been the whole frequency components over the bandwidth of 150 MHz. However according to this scenario too many components are missing and it can be evaluated interference at the same band or a clutter. As discussed before, the main purpose of this project is to detect the image of objects and under the ground. In other words, for providing the primary condition of imaging, first of all you need a wide frequency range and all the components regarding the band. This scenario is insufficient for detection is that the demonstrator (the radar) did not detect the target.

On the other hand, according to the other scenario, the perfect match was occurred in the mixer. As it shown in Figure 3.25**,** there are the whole frequency components over the corresponding band. While the peak values extend about the center frequency region (600 MHz), the other components around the center are lined up by increasing and decreasing in power. Therefore, this scenario is a serious indicator of detection ability of the demonstrator as a pulse radar.

## 4. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this project is to investigate and design a wideband pulse radar operating at sub-GHz frequency ranges for sensing applications. The radar is based on a pulse correlation receiver, featuring a simple and precise pulse and delay generation using a DDS (direct digital synthesis) oscillator. In this framework, first, the basic advantages of the wide band approach over conventional radars were given and the main principle of the system was expressed in brief. Then, conventional radar concept was mentioned and the main topics of radar theory were discussed. Finally, the DDS oscillator was explained in detail, the microwave components and their theories in the system were given and the test results of final demonstrator were discussed.

In the test stage, we changed the delay between the pulses and represented two different phenomenons, the perfect detection and the no detection. According to these test results, it is observed that the demonstrator has a serious detection capability. The wide band characteristic of the system provides a pretty important advantage over narrow band radars and a quite increase is appeared in information amount and quality regarding the target. In addition, this feature of the system brings together another important advantage is that high accuracy in target range. As mentioned before, if one increases the bandwidth in a sensing system, it is possible to reach more information about the object which is to be detected. However, there must be a limit of bandwidth, since the wider bandwidth, the higher noise level also. Therefore, it is a necessity to keep the bandwidth of the system in a certain level to protect the receiver sensitivity [21].

Consequently, in the last stage of this thesis it is seen clearly that this unconventional approach with its wide band characteristic for a low-frequency pulse radar has a serious sensing potential as a through wall imaging and a ground penetrating radar.

This thesis is a proof-of-concept study on a wide band low-frequency pulse radar for hidden objects detection.

Although the system performance seems very satisfactory, the real target measurements with antennas should be considered and tested in order to obtain the certain values for fabrication. Therefore, instead of a cable, transmitter and receiver antennas can be used. For example, in 200 MHz bandwidth, operating at 350 MHz, Vivaldi type low-frequency antennas can be designed and mounted to the demonstrator.

The system can be tested in a field surrounded absorption walls with these Vivaldi antennas by using a corner reflector whose exact cross-section area is known. This test setup will give a serious opportunity to improve the demonstrator in terms of fabrication.

On the other hand, other current technologies in the sensing area can be integrated to this system. For instance, it can be evaluate the feasibility of a harmonic radar by adding to the concept an RFID which is another nonlinear element. In this concept target carries an RFID circuit which describes itself. To reach meaningful information about this new concept, some kind of questions can be asked: What would be the detection range? Is there an advantage of having a second continues wave transmitter compared to trying to detect a harmonic of the transmitted radar signal etc. In short, this new concept of the project will open another door which is really worthy of investigation.

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## APPENDICES

APPENDIX A.1: Python Codes

## APPENDIX A.1

```
# -*- coding: cp1252 -*-
#Parallel Port DDS Controller Subroutines
#
#J.Schoebel


#import sys
#import time
from numpy import *

#from ctypes import *
#inpout = windll.LoadLibrary('INPOUT32.DLL')

import PControlLib2

reload(PControlLib2)

#---------------------------------------------------
# Program DDS System
#---------------------------------------------------
Osc = PControlLib2.PDDS()

def programDDS(t):
  #programs the DDS with 2 pulses and delay of t*4ns

  #turn off the RAM
  dat = int(AD9910default[0][1].replace(' ',''),2)
  #print PControlLib2.conv_bin(dat,32)
  Osc.writeAD9910(AD9910default[0][0],dat,0)

  #Mode = int('011',2)  #continous bidirectional ramp (profile 0 only)
  Mode = int('100',2)  #continous recirculate (profile 0 only)

  #program DDS with a range of
  #start freq, stop freq, number of lines

  Rate = 1  #all have the same rate, in units of 4 ns

    #-----------------------------------------------------------------
  #definition of pulses and frequencies


  f1 = 350.0e6  #frequency of first pulse
  f2 = 350.0e6  #frequency of second pulse
  tp = 4       #pulse length in 4ns
  ##  t = 5        #delay between start of pulses in 4ns (cable delay 6)
```

```
tcycle = 8  #cycle time in 4 ns (consists of pulse, dt, pulse, guard interval)

#--------------------------------------------------------------------


#calculate frequency during guard interval, so that phase of each pulse cycle is the
same
#use actual frequencies as represented by ftw
f1f = Osc.FTWAD9910(f1)
f2f = Osc.FTWAD9910(f2)
a = tp*4*f1f + tp*4*f2f
a &= (1<<32)-1
a = (1<<32)-a
ta = tcycle-t-tp-1
da = a/(4*ta)
b = (a-da*4*ta)/4

f3 = Osc.freqAD9910(da)
f4 = Osc.freqAD9910(b)

f = [[ f1, f1,  tp],
     [  0,  0,  t-tp],
     [ f2, f2,  tp],
     [ f3, f3,  ta],
     [ f4, f4,  1]]

istart = 0
for jj in range(len(f)):
  f1 = f[jj][0]
  f2 = f[jj][1]
  nn = f[jj][2]

  if nn > 1.5 :
    df = (f2-f1)/(nn-1)
  else:
    df = 0

  #calculate all frequency tuning words
  ff = [Osc.FTWAD9910(f1)]
  for ii in range(1,nn):
    ff.append(Osc.FTWAD9910(f1+ii*df))

  #program RAM
  Osc.writeRAMAD9910(istart,ff,0)

  #adjust start RAM adress for next cycle
  istart = istart+nn

#istart shold now point to the end address
istart = istart-1
print 'End Address'
```

```
  print istart

  #program control words
  #write the same data to all profiles
  for ii in range(8):
    Osc.writeProfileAD9910(ii,0,istart,Rate,Mode,0)

  #RAM enable can be set from the very beginning, then the DDS will output some
  #not very well defined signal while the RAM is being written; it is also possible to
  #write the RAM while RAM Enable = 0 and activate the RAM profiles after the
RAM
  #has been fully written
  #set RAM Enable = 1
  dat = int(AD9910default[0][1].replace(' ',''),2)
  dat = bitwise_or(dat,2**31)  #set RAM enable bit
  #print PControlLib2.conv_bin(dat,32)
  Osc.writeAD9910(AD9910default[0][0],dat,0)
#------------------------------------
#program AD9910

AD9910default = [ [ 0,'00000000 01011100 00000000 00000010','CFR1'],\
                [ 1,'00000000 00000000 00000000 00000000','CFR2'],\
                [ 2,'00000101 00011000 11000001 00101000','CFR3, PLL on,
Icp=287uA, f_ref=50MHz, N=20'],\
                [ 3,'00000000 00000000 00000000 00111111','CFR4, DAC current'],\
                [ 4,'00000000 00000000 00000000 00000000','IOUpdate Rate, not
used'],\
                [ 7,'00000000 00000000 00000000 00000000','FTW'],\
                [ 8,'00000000 00000000','Phase offset word'],\
                [ 9,'00000000 00000000 11111111 11111100','Amplitude Scale Factor'],\
                [10,'00000000 00000000 00000000 00000000','Multichip Sync, ot used'],\
                [11,'00000000 00000000 00000000 00000000 00000000 00000000
00000000 00000000','Digital Ramp Limits, not used'],\
                [12,'00000000 00000000 00000000 00000000 00000000 00000000
00000000 00000000','Digital Ramp Step, not used'],\
                [13,'00000000 00000000 00000000 00000000','Digital Ramp Rate, not
used'],\
                [14,'00000000 00000000 00000000 00000000 00000000 00000000
00000000 00000000','RAM Profile 0'],\
                [15,'00000000 00000000 00000000 00000000 00000000 00000000
00000000 00000000','RAM Profile 1']]
                #single tone:
                #    xx------ASF------ ------POW-------- ---------------FTW-----------------
                #RAM:
                #    xxxxxxxx ----Step Rate---- --End Addr-xxxxxx -Strt Addr-xxxxxx
xxaxbmmm
                # a : no-dwell high; b: zero crossing; m: Mode control

#RAM enable bit is set after writing the RAM
#profile control CFR1(20:17) ist set to 7 profiles, continuous recirculate
```

```
#program the default register contents
for ii in range(len(AD9910default)):
  #convert the binary string to integer and remove the spaces before
  dat = int(AD9910default[ii][1].replace(' ',''),2)
  #print ii, AD9910default[ii][0], dat
  Osc.writeAD9910(AD9910default[ii][0],dat,0)
  Osc.writeAD9910(AD9910default[ii][0],dat,1)

#program all other addresses (15-21) with zero
for ii in range(16,22):
  Osc.writeAD9910(ii,0,0)
  Osc.writeAD9910(ii,0,1)



delays = [4,5,6,7,8,10,12,15,20,35]

#delays = [5]

for t in delays:
  print 'programming delay :',t
  programDDS(t)
  a = raw_input('continue...')
```

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