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Through-The-Wall Surveillance

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Defence R&D Canada - Ottawa
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THROUGH-THE-WALL SURVEILLANCE

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TECHNICAL MEMORANDUM

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Abstract

This report describes the DRDC Ottawa research activities and major findings on through-the-wall surveillance, using ultra-wideband (UWB) short-pulse (SP) radars. These activities include both experiments and simulations. Off-the-shelf UWB radio frequency (RF) equipment was purchased to support experimental investigations. For simulations, a 3D computer model of a single room with a cubic, conducting target was developed. UWB radar located outside the room transmits short UWB pulses while the target is moved around the room in discrete steps. At the beginning of the section, we first show that motion detection is easy, since the radar echoes continuously change in time. However, simple motion detection does not provide enough information for most applications of interest. There is a clear requirement to measure the range and direction of the moving targets. Clutter from fixed objects interferes with the detection of moving targets. One way to suppress these fixed clutter is to use difference waveforms, obtained by subtracting echo waveforms from each other. The results of this report clearly show the detection of a moving target and suppression of fixed clutter. The next step is to determine the direction of the moving target. An antenna array combined with back-projection processing is used for that purpose. The simulated results clearly demonstrate that hidden targets can be tracked in both range and direction. These results have been confirmed experimentally.

Résumé

Ce rapport décrit les activités et les résultats de recherches du RDDC Ottawa sur la surveillance radar à travers les murs en utilisant les radars à courte pulse et à très large bande. Ces activités inclus du travail expérimental et des expériences simulées. Des équipements radio fréquence à très large bande ont été achetés pour l'étude expérimentale. En simulation, un model d'ordinateur en 3D d'une chambre avec un cube métallique ont été dessinée pour cela. Un radar à très large bande située à l'extérieur de la chambre transmet de courte pulses tandis que le cube métallique bouge en pas discret a l'intérieur de la chambre. Dans la première section, on montre que la détection de mouvement est très facile. Cependant, la détection de mouvement comme tel ne fournit assez d'information pour la plupart des applications d'intérêt. Il y a un besoin clair pour mesurée la distance ainsi que la direction des cibles mouvantes. Le fouillis des objets fixes interfère avec la localisation du mouvement. Une façon de supprimer ce fouillis fixes est la différence de forme d'onde, obtenue en prenant la différence entre les échos de formes d'ondes subséquents. Les résultats de ce rapport montrent clairement la détection de cible mouvant et la suppression de fixe fouillis. La direction de la cible est mesurée avec un réseau d'antennes combinée avec la technique de projection arrière Les résultas simulée démontre que les cibles cachées peuvent être traquer en distance et direction. Ces résultats ont été confirmés expérimentalement.

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Executive summary

This report describes a DRDC Ottawa study on through-the-wall surveillance, using ultra-wideband (UWB) short-pulse (SP) radar systems. Commanders who know the exact location of adversaries hiding within a building have a significant advantage over them; soldiers would know in advance if an enemy were located around a corner. Similarly, counter-terrorism forces would be able to track the terrorists within rooms and plan strikes with precision.

In the first section, we show that most walls are fairly transparent to radar frequencies, thus making through-the-wall surveillance possible. The second section describes our research activities and major findings on through-the-wall surveillance, using UWB SP radars. These activities include both lab experiments and simulations. Off-the-shelf UWB radio frequency (RF) equipment was purchased for experimental investigation. In simulations, a 3D computer model of a room with a cubic, conducting, target was developed for this investigation. UWB radar outside the room transmits short UWB pulses into the room while a cubic metallic object is moved around the room in discrete steps. We first show that motion detection is easy, because the radar receiver output waveforms change in time. However, simple motion detection does not provide enough information for most applications of interest. There is a clear requirement to measure the range and direction of the moving targets. Clutter from fixed objects interferes with the detection of moving targets. One way to suppress fixed clutter and see only the moving target is to use difference waveforms, i.e., waveforms obtained by subtracting echo waveforms from each other. The results in this report clearly show a moving target during the suppression of fixed clutter. The next step is to determine the direction of the moving target using an antenna array combined with back-projection processing. The simulated results clearly demonstrate that moving targets hidden behind walls can be tracked in both range and direction. These results have been confirmed experimentally.

The last section describes plans for future research on through-the-wall surveillance radars, including radar-imaging enhancements, stand off surveillance, and evaluation of wideband radars with center frequency up to 95GHz.

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Sommaire

Ce rapport décrit les activités et les résultats de recherches du RDDC Ottawa sur la surveillance radar à travers les murs en utilisant les radars à courte pulse et à très large bande. Dans la première section on montre que la plupart des murs sont relativement transparents aux fréquences radar ce qui rend la surveillance a travers les murs possibles. Les commandants qui savent la position de leurs adversaires qui se cachent a l'intérieur d'édifice auront un avantage important sur eux. Les soldats sauront a l'avance si uj ennemi sont situe a l'arrière d'un coin d'édifice. De même, les forces contre terrorisme seront capables de traquer les terrorismes a l'intérieur des édifices et de préparée des frappes avec un précision chirurgicales.

RDDC Ottawa activités sur la surveillance a travers les murs inclus du travail expérimental et des expériences simulées lesquelles sont décrit dans la deuxième section. Des équipements radio fréquence à très large bande ont été achetés pour l'étude expérimentale. En simulation, un model d'ordinateur en 3D d'une chambre avec un cube métallique ont été dessinée pour cela. Un radar à très large bande située à l'extérieur de la chambre transmet de courte pulses tandis que le cube métallique bouge en pas discret a l'intérieur de la chambre. Dans cette section, on montre que la détection de mouvement est très facile. Cependant, la détection de mouvement comme tel ne fournit assez d'information pour la plupart des applications d'intérêt. Il y a un besoin clair pour mesurée la distance ainsi que la direction des cibles mouvantes. Le fouillis des objets fixes interfère avec la localisation du mouvement. Une façon de supprimer ce fouillis fixes est la différence de forme d'onde, obtenue en prenant la différence entre les échos de formes d'ondes subséquents. Les résultats de ce rapport montrent clairement la détection de cible mouvant et la suppression de fixe fouillis. La direction de la cible est mesurée avec un réseau d'antennes combinée avec la technique de projection arrière Les résultas simulée démontre que les cibles cachées peuvent être traquer en distance et direction. Ces résultats ont été confirmés expérimentalement.

Dans la dernière section, on discute les directions futures pour les recherches sur la surveillance radars. Ces plans inclus : l'amélioration des images radars, la surveillance à distance, et l'évaluation de radar à large bande opérant à des fréquences plus élevées.

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1. Introduction

This report describes a DRDC Ottawa study on through-the-wall surveillance, using ultra-wideband (UWB) short-pulse (SP) radar systems. Radar systems used in through wall sensing include UWB radar, X-band and millimeter wave radars [1 to 11]. Low-frequency radars have higher penetration capability but poorer angular resolution and vice versa. This report examines the capability of UWB SP radars to provide through-the-wall surveillance. UWB SP radars are first defined and then some of the controversies associated with these short transient signals are discussed.

In the first section, we show that most walls are fairly transparent to radar frequencies, thus making through-the-wall surveillance possible. The second section describes our research activities and major findings on through-the-wall surveillance, using UWB SP radars. These activities include both lab experiments and simulations. Off-the-shelf UWB radio frequency (RF) equipment was purchased for experimental investigation. In simulations, a 3D computer model of a room with a cubic, conducting, target was developed for this investigation. A UWB radar outside the room transmits short UWB pulses into the room while a cubic metallic object is moved around the room in discrete steps. We first show that motion detection is easy, because the radar receiver output waveforms change in time. However, simple motion detection does not provide enough information for most applications of interest. There is a clear requirement to measure the range and direction of the moving targets. Clutter from fixed objects interferes with the detection of moving targets. One way to suppress fixed clutter and see only the moving target is to use difference waveforms, i.e., waveforms obtained by subtracting echo waveforms from each other. The results in this report clearly show a moving target during the suppression of fixed clutter. The next step is to determine the direction of the moving target using an antenna array combined with back-projection processing. The simulated results clearly demonstrate that moving targets hidden behind walls can be tracked in both range and direction. These results have been confirmed experimentally.

The last section describes plans for future research on through-the-wall surveillance radars, including radar-imaging enhancements, stand off surveillance, and evaluation of wideband radars with center frequency up to 95GHz.

2. Through-The-Wall Surveillance

2.1 Through-the-wall

The capability of seeing through walls is of high interest to many organizations including military and law enforcement. The reality however, is that human vision cannot penetrate solid walls. One option is to use x-ray systems, although the feasibility of building compact systems that can be carried by a person is undetermined. Further, health hazards due to x-ray radiation are a serious constraint.

In our case, we are interested in radar systems that can detect the activities of persons behind walls. The main requirement for detecting a person behind walls using a radar is that the radar signals can propagate through the walls. Our day-to-day experience shows that this condition is indeed met. For example, a portable radio within a building can still receive the broadcasted signal in most parts of the building if not all. Similarly, a walkie-talkie unit within a building can still communicate with an outside unit.

Figure 1 shows the RF attenuation in different types of walls as measured by Currie, et al [1]. The red line shows that the RF attenuation for drywall is less than 3dB at frequencies up to 100GHz. The RF attenuation for plywood and brick walls is much higher. Even in the worst case, for concrete walls, the attenuation is still less than 14dB for frequencies below 10GHz. However, these attenuations are still less than 7dB for frequencies up to 50GHz. The worst case in this figure is concrete wall. Here the attenuation is still rather low and is less than 14dB for frequencies below 10GHz. In short, most non-metallic walls are fairly transparent to radar signals.

Solid metallic walls are completely opaque to the radar frequencies of interest. The radar signals are completely blocked by a thin aluminum foil such as that used in insulating houses. One-way to verify that is to calculate the skin depth for a conductor. This is given by Eq.(1),

$$\delta = \left(\frac{2}{\omega \sigma \mu} \right)^{1/2} \qquad (1)$$

where δ is the skin depth in meters, ω is the angular frequency in rad/sec, σ is the conductivity in mho/meter, and μ is the permeability [12].

The skin depth represents the depth of penetration of electromagnetic waves within a conductor where most of the energy is dissipated. Table 1 shows examples of skin depth for aluminum and copper conductors at different frequencies. The values of conductivity and permeability for copper and aluminum are extracted from reference [12]. The skin depth for aluminum and copper, at a frequency of *3 GHz*, are *1.6* and *1.2 microns* respectively. At *100 MHz*, the skin depths are *8.5* and *6.4microns* respectively. Solid metallic walls are much thicker than a few microns. Hence, they are opaque to radar signals. Even a thin aluminum foil, which is about *200 microns* thick, is opaque to the radar frequency of interest since most energy is attenuated within the first 8 microns. Although solid walls are completely opaque to radar signals, metallic walls with non-metallic spaces are not opaque.

Electromagnetic waves can propagate through the areas that are non-metallic and still reaches a target on the other side of the wall and produce echo returns at the radar. Time Domain Corp claims that this property has been demonstrated in an experiment with metallic chicken wires inside a wall. In these experiments, they were able to detect a person moving behind the wall. Hence, if there are non-metallic spaces in a metallic wall, it is possible to detect targets moving behind walls.

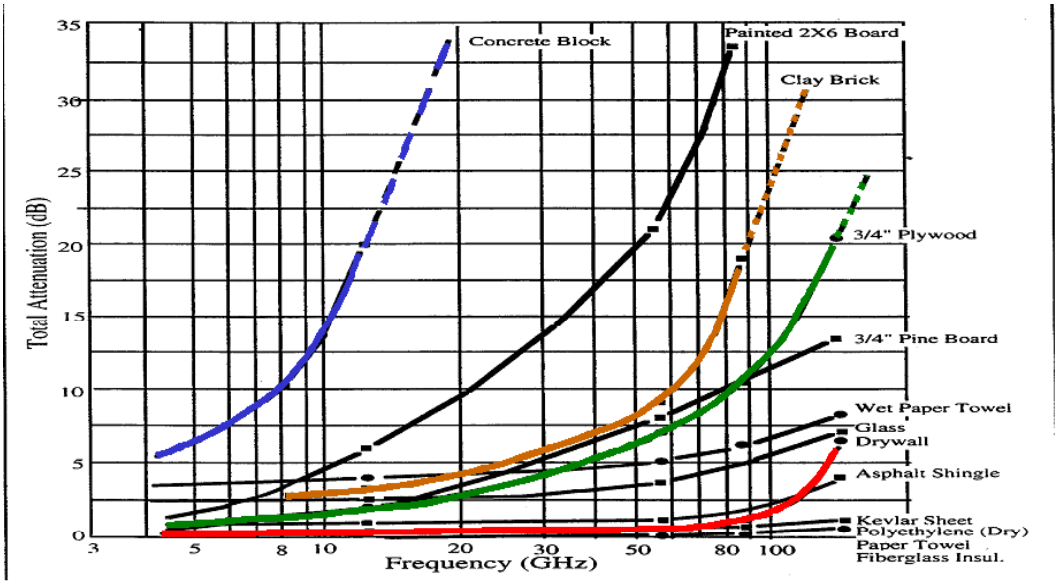


Figure 1. *RF attenuation causes by walls*

Table 1. *Skin depth for conductors*					
CONDUCTOR	**CONDUCTIVITY** (mho / meter)	**RELATIVE PERMEABILITY**	**SKIN DEPTH** (micron)		
			100MHz	***1GHz***	***3GHz***
ALUMINUM	3.54×10^7	1.00	8.5	2.7	1.6
COPPER	5.80×10^7	1.00	6.4	2.0	1.2

2.2 UWB Short-Pulse Radars

2.2.1 UWB radar theory

This report examines the capability of UWB SP radars to provide through-the-wall surveillance. By definition, ultra-wideband (UWB) radars have a bandwidth greater than

or equal to 25% of the central frequency [13]. There are different types of UWB radars, including frequency modulated radars, step frequency radars and short pulse radars (Figure 2). Frequency modulated and step frequency radars compress the radar echo returns to get high range resolution. UWB SP signals provide high range resolution directly without additional processing or compression. UBW SP radars transmit pulses with pulse widths between *0.1* and a few nanoseconds. Pulses with a width of 0.1 *ns* provide a range resolution of *1.5 cm* and make it possible to see moving fingers directly on the radar display. Pulses with a width of few nanoseconds make it possible to see a moving person directly on the radar display.

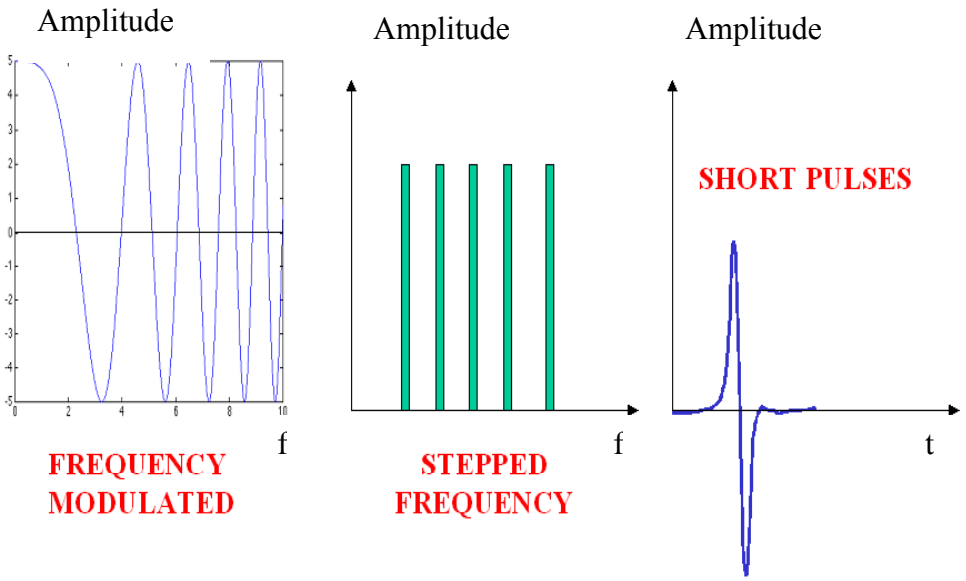


Figure 2. Various types of *UWB signals*

UBW SP signals are transient signals with extremely short pulse widths and contain a wide range of frequency components. They are very different than long-duration sinusoids, which are basically single frequency signals. UBW SP radars systems and associated phenomena, however, are still linear, time-invariant (LTI) systems [14]. A system is LTI if its response is proportional to the magnitude of the input signal, the responses from different inputs are independent of each other, and finally an input signal shifted in time produces the same output but delay in time [16]. Linear time invariance directly implies the superposition principle. For these systems, the best approach to analyze them is to decompose the input signal to simpler components for which the responses are known and then add all the responses together. In other words, the frequency components of UBW SP signals behave the same way either alone or in-group.

The Fourier transform is a mathematical technique to analyze the frequency components of signals. A theorem in Fourier transform states that if a signal *s*(t) and its derivative are continuous and satisfy the finite energy condition Eq.(2),

$$\int_{-\infty}^{+\infty} |s(t)|^2 dt < \infty \qquad (2)$$

then this signal can be represented as a sum of sinusoidal components (Eq. (3)) [15].

$$s(t) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} S(\omega)\, e^{i\omega t}\, d\omega, \qquad S(\omega) = \int_{-\infty}^{+\infty} s(t)\, e^{-i\omega t}\, dt \qquad (3)$$

These conditions are always satisfied in the case of UBW SP signals. Hence, the Fourier transform can be used to decompose sub-nanosecond UWB signals into frequency components and the results are still an exact representation. This is completely independent of the system under study. Figure 3 shows an example of frequency spectrum representation of a temporal signal *s(t)*.

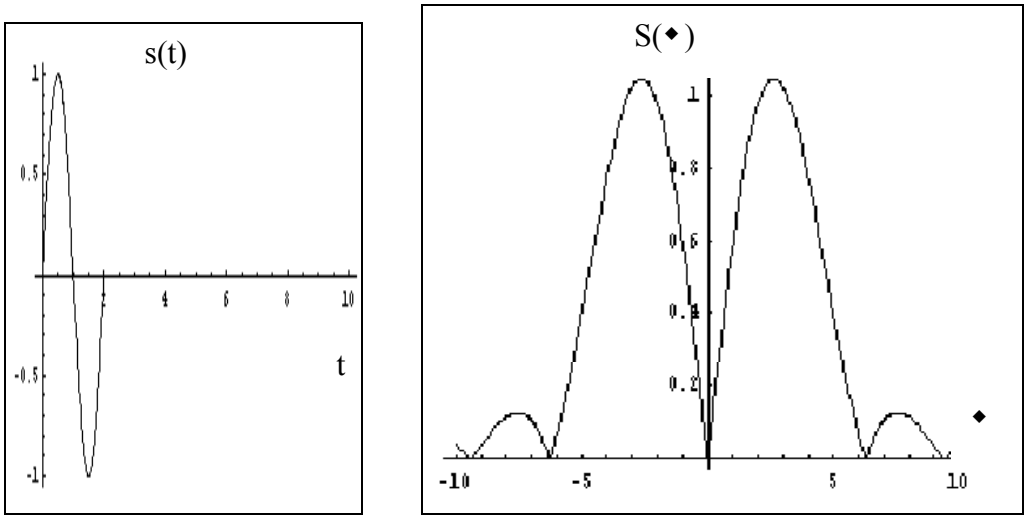


Figure 3. *Fourier transform*

If the frequency spectrum representation *S(ω)* is truncated, then it becomes an approximation of the actual signal, *s(t)*. Discontinuous functions are usually not well represented by truncated spectra. In fact the bandwidth of a signal *s(t)* is inversely proportional to the time duration. Discontinuity means a larger frequency bandwidth. Hence, truncating the frequency spectrum results in a poorer approximation. These approximations usually produce unusual overshoots close to the discontinuity as shown in Figure 4. These approximations are known as the Gibbs phenomenon [16]. Fourier transforms can exactly represent sub-nanosecond signals as long as the Fourier transforms are not truncated.

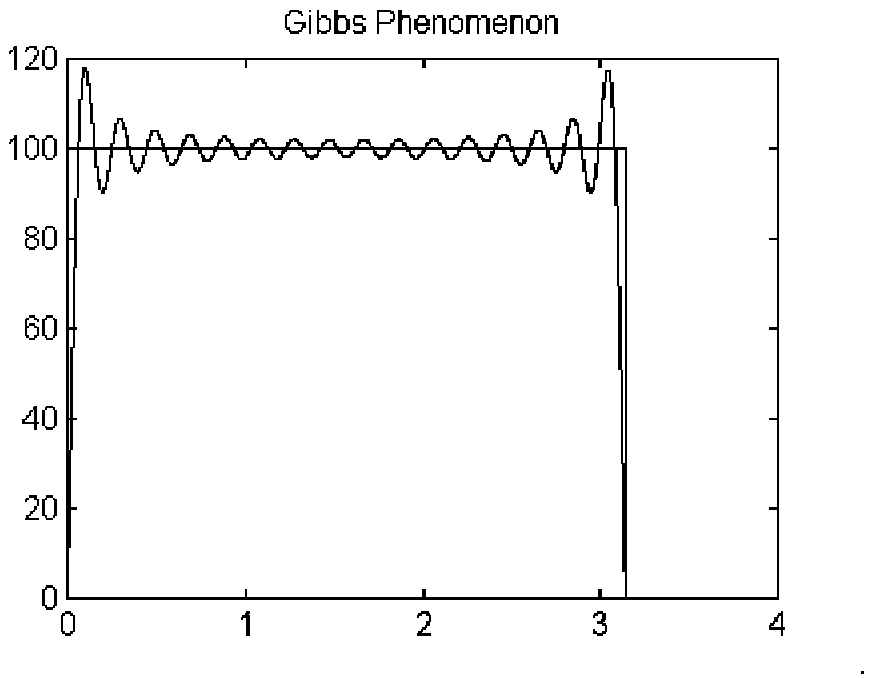


Figure 4. *Gibbs phenomenon.* This is the approximation when 16 terms are included.

2.2.2 UWB Radar Precedents

UWB radar is not a new technology. It has been used for more than two decades in ground penetrating radar [17]. However, the performance of these radars has always been severely limited by their capability to efficiently transmit and receive pulses of extremely short duration. This has changed recently. Figure 5 shows a picture of an UWB radar on a chip that has been developed by Lawrence Livermore Laboratory in the U.S. [18, 19]. This small radar can transmit millions of UWB pulses per second with a high temporal flexibility. In fact the temporal position of each pulse can be changed with picosecond accuracy. This small radar can also receive reflected pulses in real time and sample at a speed exceeding 33GS/s. Several U.S. scientists believe that this technology will revolutionize several areas of military operations [20]. These areas include secure communications, through-the-wall surveillance, missile seeker, and precision location tracking.

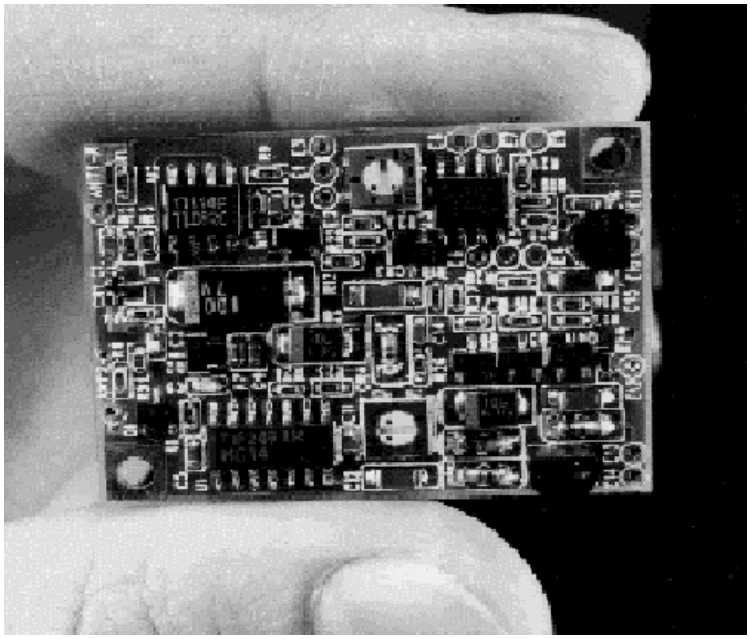


Figure 5. *UWB radar on a chip*

Figure 6 shows an illustration of the Time modulated UWB technique patented by Time Domain Corp in the U.S [21]. The Time Domain Corp radar transmits pulses with *0.5ns* widths that provide range resolution of *15 cm* and bandwidths of *2 GHz* centered at *2 GHz*. The pulses are sent in sequence and the position of each pulse is selected according to a given code. As a result, these signals look like white noise to an outsider. The time modulated UWB signals can also carry binary information just by delaying or advancing slightly the transmitted pulses.

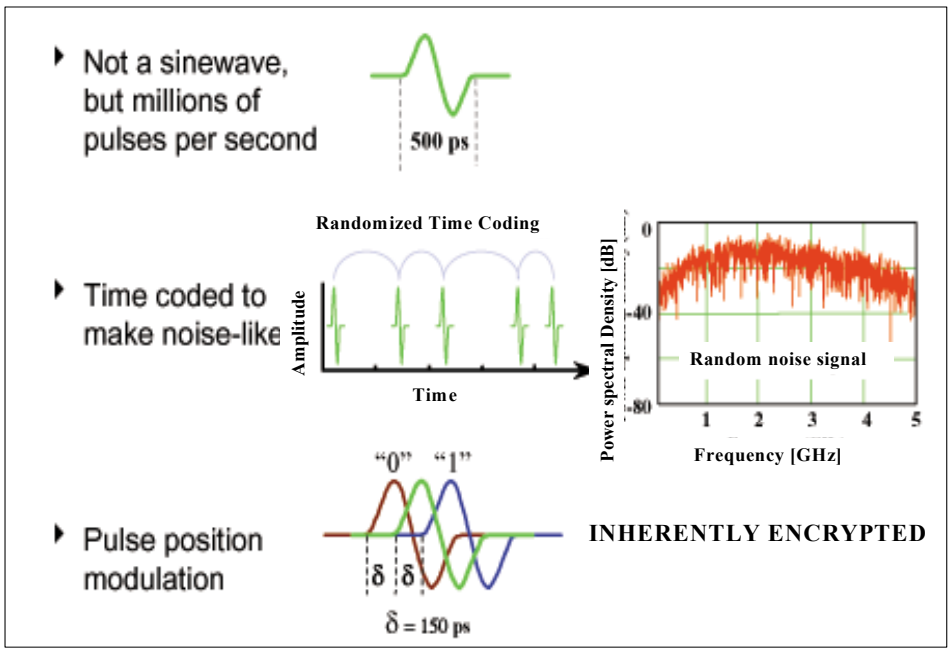


Figure 6. *UWB time modulation concept*

3. Motion Detection and Tracking

3.1 Motion Detection

In order to start our investigation of through-the-wall surveillance using UWB SP radar, we bought off-the-shelf advanced UWB RF equipment. The set includes a high-speed oscilloscope, four UWB RF pulse generators and UWB antennas (Figure 7). The high-speed digital phosphor oscilloscope is made by Tektronix (model TDS-7404) and is used as the radar receiver. This oscilloscope is capable of sampling at *20 GS/s*, has an analog bandwidth of *4 GHz* and a record memory of *64 MB*. The UWB RF pulse generators are described in Table 2 and generate voltage pulses that excite the transmitting antenna directly. The purchased UWB antennas are shown in Figure 7 and are manufactured by FARR research [22, 23, 24]. The Impulse Radiating Antenna has a relatively flat frequency response between *100 MHz* and *18 GHz*.



Tektronix Scope (Model TDS-7404)



Picosecond Pulse Labs (Model 10,000A)



FARR UWB Antenna (Model FRI-IRA-2



FARR UWB Antenna (Model FRI-TEM-02-50)

Figure 7. *UWB RF equipments*

Table 2. *UWB voltage pulse generators*

PULSERS COMPANY	PULSES SHAPE	PEAK VOLTAGE (V)	RISE TIME	FALL TIME	PRF	PULSEWIDTH
AVTECH Model AVP-AV-HV3-C	Square	0 to 40V	Less than150ps	Less than 250ps	0 to 1MHz	0.4 to 2.0ns
AVTECH Model AVG-3B-C-P	Impulse	0 to 450 V	Less than 0.8ns	Less than 0.8ns	0 to 2KHz	Less than 2ns
Picosecond Labs Model 1000	Square	0-40V	400ps	900ps	1 to 100KHz	0.1 to 10ns
KENTECH Model PBG1/S	Square	3.5KV	Less than 150ps		≥ 100Hz	Less than 500ps FWHM

Peak Voltage are for 50 Ohms load

In the first series of through-the-wall experiments, the transmitting and receiving antennas were put on one side of a section of wall. A person then walked on the other side of the wall. As the person walked, the shape of the received waveform changed continuously from frame to frame. As a result, the detection of motion was relatively easy. The real problem is to determine where the motion is coming from and what its cause is. For example, a ventilator on the ceiling could cause motion, which could be mistaken for a potential threat.

The wall sections used in the experiments were either drywall or wood. We observed that these walls have practically no impact on the performance of the UWB radar. This is an indication that these wall sections are transparent to UWB signals, a result that agrees with measurements in Figure 1.

3.2 Range Measurement

In order to measure the range of the moving targets we subtracted the active waveform from reference signal. The previous pulses could be used as a reference, but our high-speed oscilloscope did not have the flexibility. Hence, we took as a reference the recorded waveform when a person is standing in front of the radar. Then the person movement (reflected waveform) is subtracted from the reference. Once again the motion detection is relatively easy since the waveform changes continuously in shape from frame to frame. However, the range of the moving target cannot be determined automatically. Figure 8 shows an example of a difference waveform obtained by subtracting a reference waveform from a new waveform. The resulting waveform is zero up to the range of the initial target position when the reference was recorded. Subtraction worked well up to that point. The electromagnetic wave propagation conditions are exactly the same up to the point where the person was standing for the reference recording. The interference pattern after that range is different since the propagation conditions are different from that point. This is shown in Figure 8. This technique shows where the person was standing when the reference was recorded. However, it does not provide automatically the true range to the person.

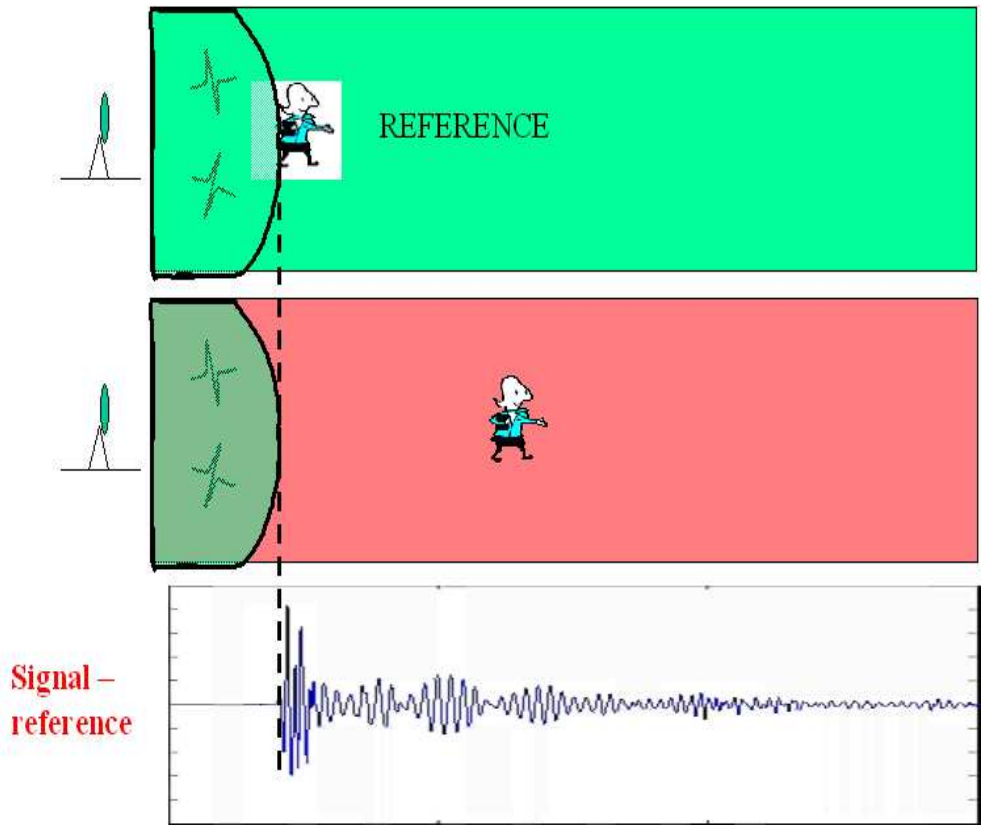


Figure 8. *Active waveform subtract from initial reference*

The ECM section at DRDC-Ottawa developed a 3D model of a room [25]. This model is given in Figure 9. The ground floor is concrete and the wall layout consists of two sheets of wood. The radar is located outside the room and a cubic conductor was placed inside the room. Both the radar antennas and the cubic conductor are located one-meter above ground. The modelled UWB radar has one transmit antenna and several receive antennas. Figure 10 shows the voltage pulse that is sent to the UWB dipole antenna and also the electromagnetic signal that is radiated in the air [25]. The voltage pulse is a monocycle pulse with a pulse width of 0.5ns.

To simulate motion, the cubic conductor is first placed at a given position and then the radar transmits a pulse. The pulse propagates to the target and produces an echo return at the receiving antennas. After that, the box is moved *10 cm* and the radar transmits another pulse, and so on. The box is moved from position "a" to position "uk" as shown in Figure 11.

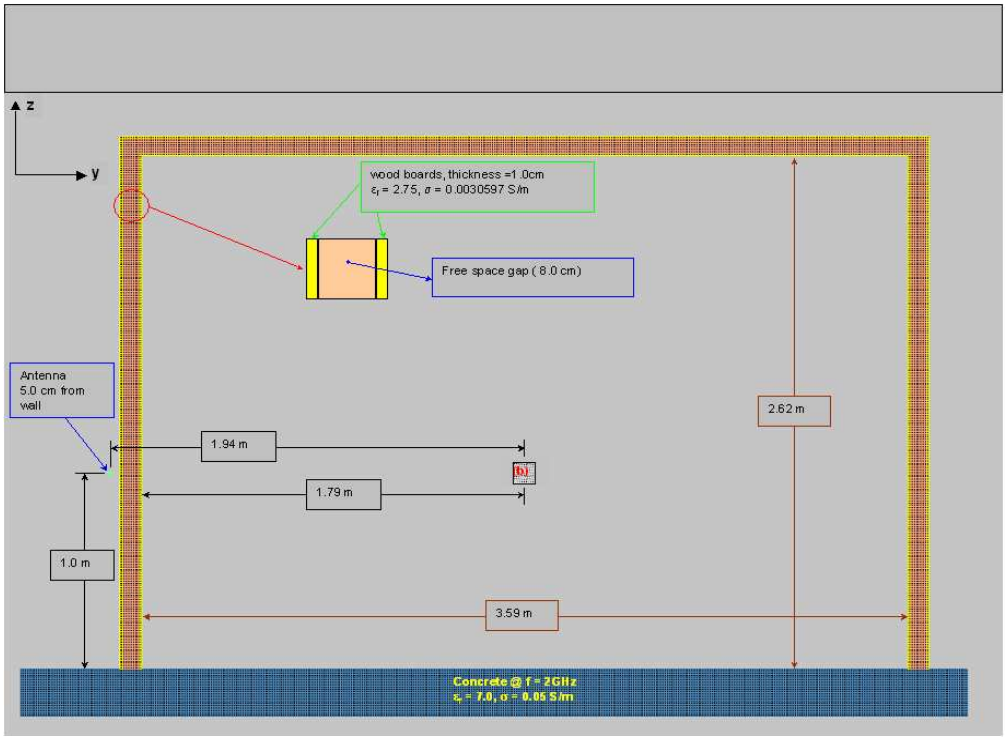


Figure 9. *3D room model*

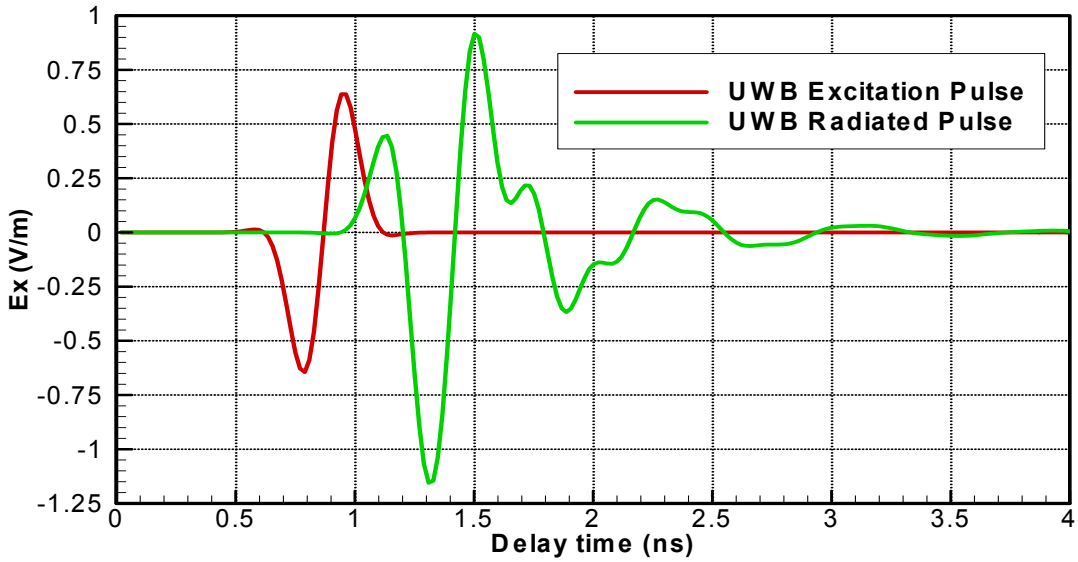


Figure 10. *UWB voltage pulse applies to the dipole antenna and the UWB radiated signal*

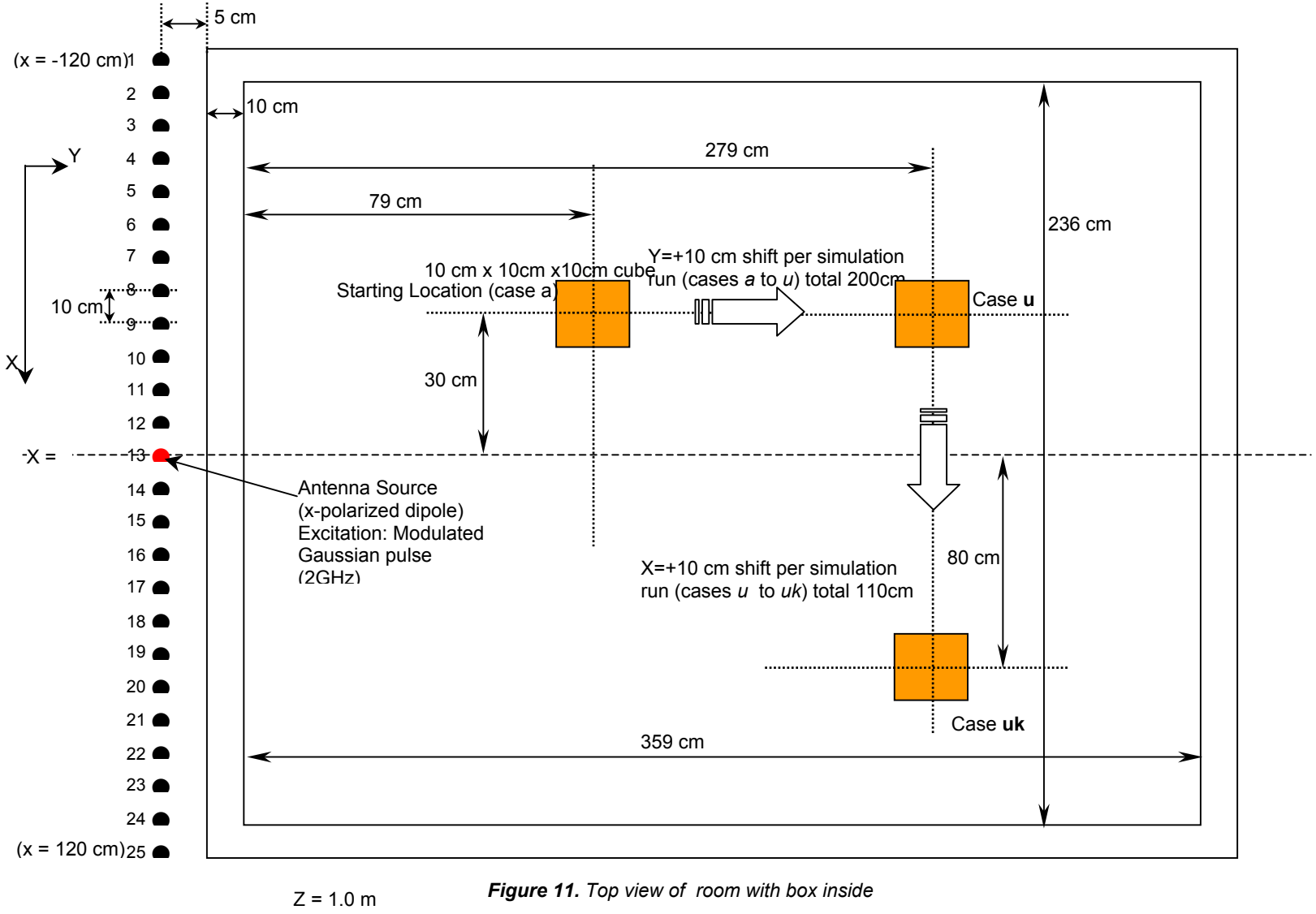


Figure 11. *Top view of room with box inside*

Figure 12 shows a time series of the recorded waveforms, as the box is moved from one position to the next. Once again motion detection is easy since the shape of the waveform changes continuously. Although we have some idea of where the moving target is located, it cannot be measured accurately. One way to suppress returns from fixed clutter and keep only moving targets is to subtract the waveform from pulse to pulse as is done in MTI techniques. Figure 13 shows what happens when this is applied to the simulated data. Now the position of the moving target is clearly visible as the beginning of the waveform perturbation. We notice that there is a trail after the target initial perturbation. This trail is always present and its intensity depends on the environment inside the room. As seen in Figure 8, everything is zero up to the target reference position, which is the previous pulse time in this case. Everything after that position is different since the propagation conditions change beyond that point. Other variants of MTI techniques such as subtraction with the empty room reference can also be be used to measure the range of the moving target [25]. The next stage is to determine the direction of the moving target.

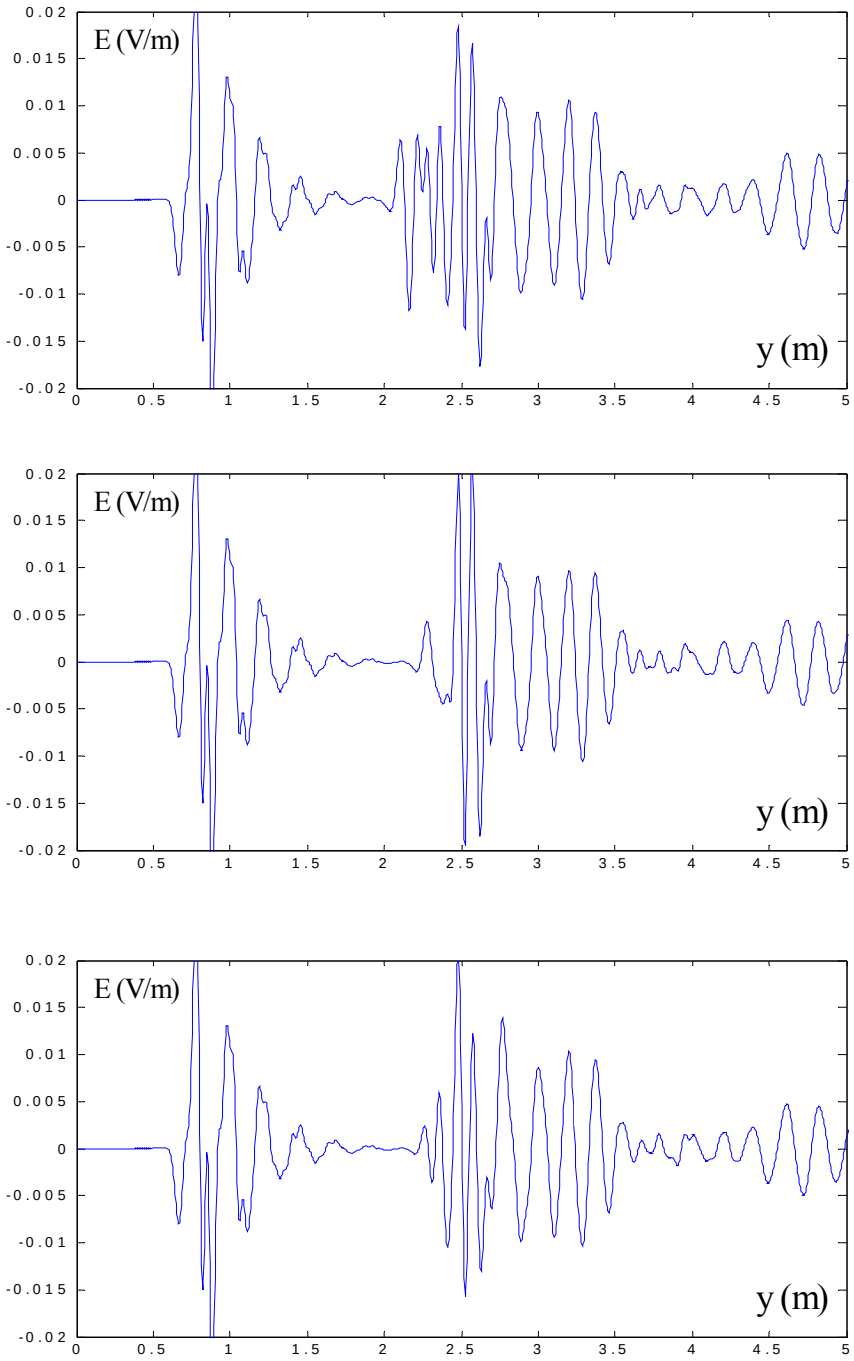


Figure 12. *Time series of raw data as box changes position in discrete step*

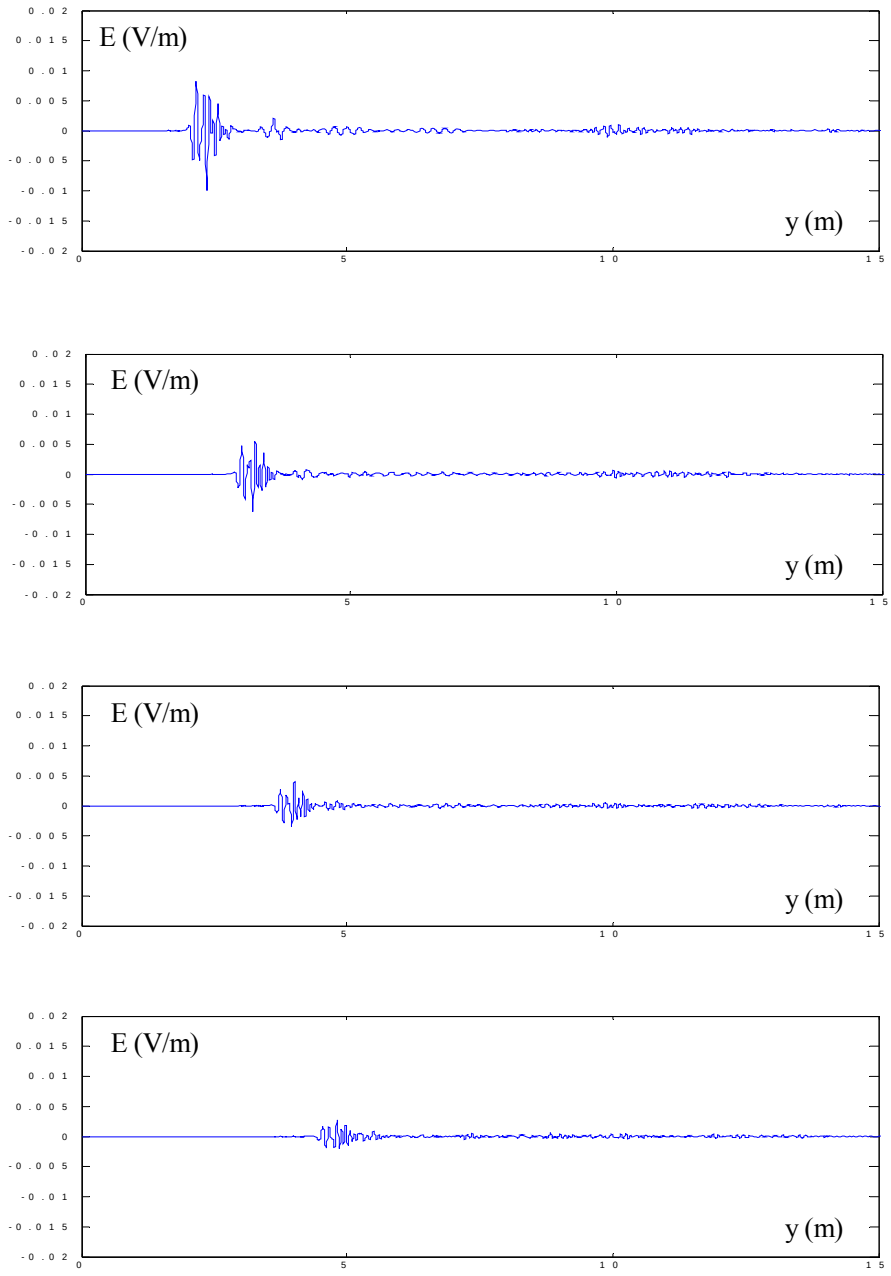


Figure 13. *Echo waveform obtained with pulse-to-pulse subtraction*

3.3 Target Direction

The direction of moving targets can be determined by using an antenna array in combination with the back projection technique [25, 26]. For each antenna element, we can measure the range of the moving targets using these methods. The direction of the moving target, however, can be from any directions on the antenna beam of each antenna element (Figure 14). The back projection technique sums the amplitude of each antenna echo where the semi circle of each antenna beam intersects. Mathematically, the back projected signal at pixel (x_i, y_i) in the room image plane is given by:

$$I(x_i, y_i) = \sum_n E[t_i(n), n] \tag{4}$$

where

$$t_i = (T_i + R_i(n))/c$$

$$T_i = \sqrt{(x_i - x_T)^2 + (y_i - y_T)^2} \tag{5}$$

$$R_i(n) = \sqrt{(x_i - x_R(n))^2 + (y_i - y_R(n))^2}$$

c is the speed of light in the propagation media and $t_i(n)$ is the total time for the transmitted signal to travel to pixel (x_i, y_i), which is T_i, and then travel back to receiver n, which is $R_i(n)$. The set $\{x_T, y_T\}$ are the coordinates of the transmitter and the set $\{x_R(n), y_R(n)\}$ are the coordinates of the n^{th} receiver. The whole result is a 2D radar image, which provides both range and direction of the target moving behind the walls. Figure 15 and Figure 16 show examples of radar images obtained, using the back projection technique with pulse-to-pulse subtraction to remove fixed clutter. In these particular cases, the radar transmits at antenna 13 and receives at antennas 1 to 25 (see Figure 11). These figures clearly demonstrate that UWB radars can be used to measure both the range and direction of targets moving behind walls. These results have also been confirmed experimentally.

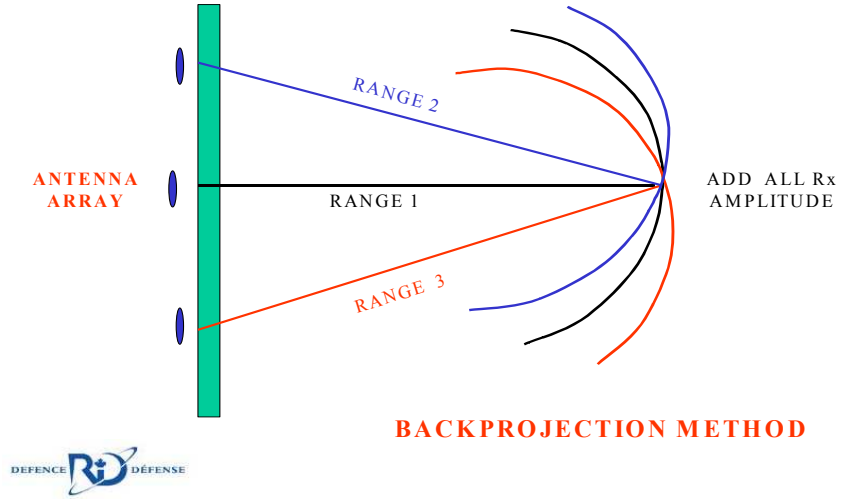


Figure 14. *Antenna array and back projection technique*

Figure 17 and Figure 18 show the radar images obtained with the back projection technique and subtraction of empty room reference waveform to remove fixed clutter. By comparing Figure 16 and Figure 18, we see that the subtraction with the empty room works better when targets move perpendicular to the radar. Subtraction with the empty room provides directly the target response, which is independent of previous box position. In some cases, however, this technique might be less attractive from an operational point of view. For example, the operators might not have the possibility to record the echo for the empty room before an operation.

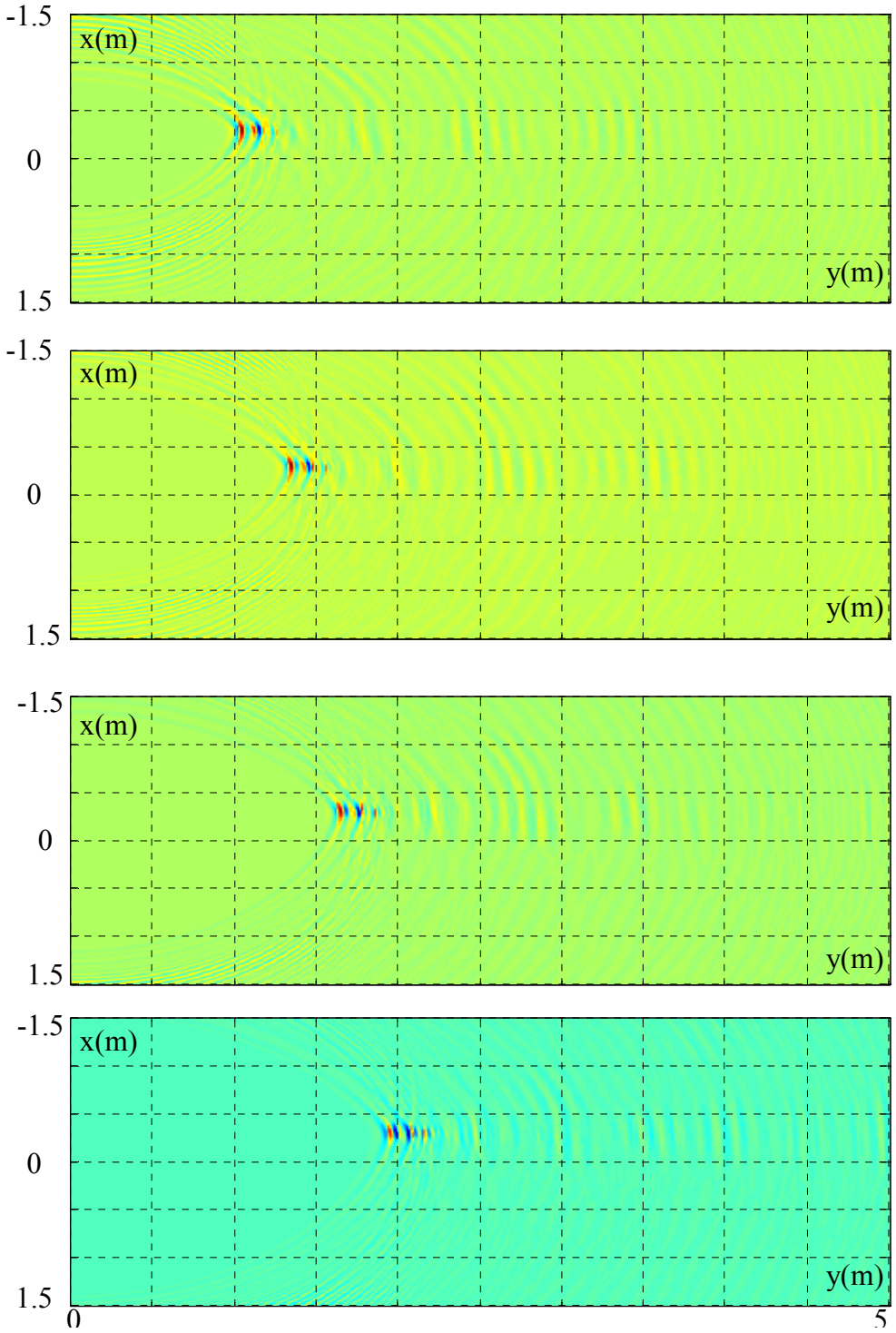


Figure 15. *Radar images of box moving along y axis (pulse-to-pulse difference)*

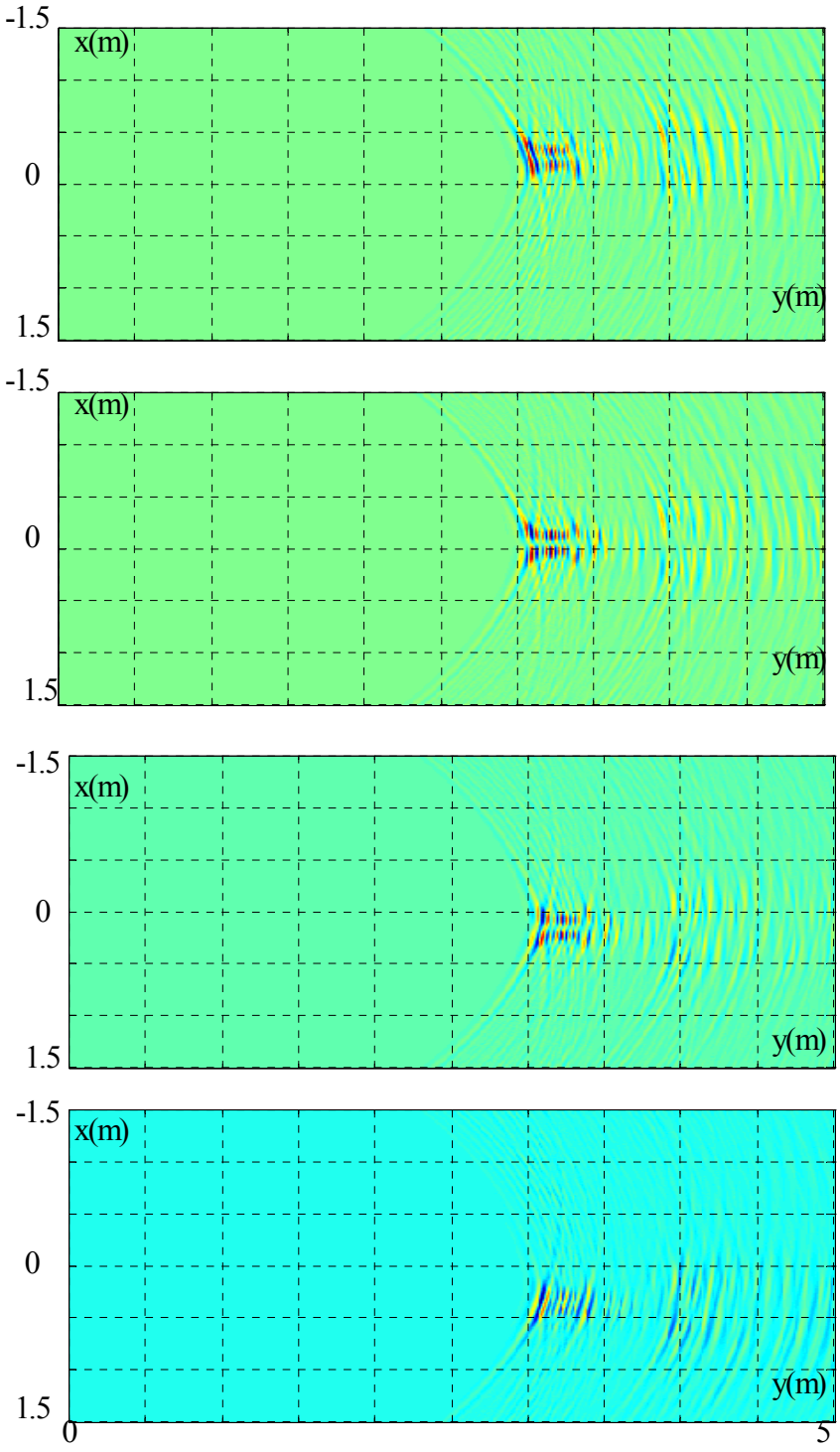


Figure 16. *Radar image of box moving along x axis (pulse-to-pulse difference)*

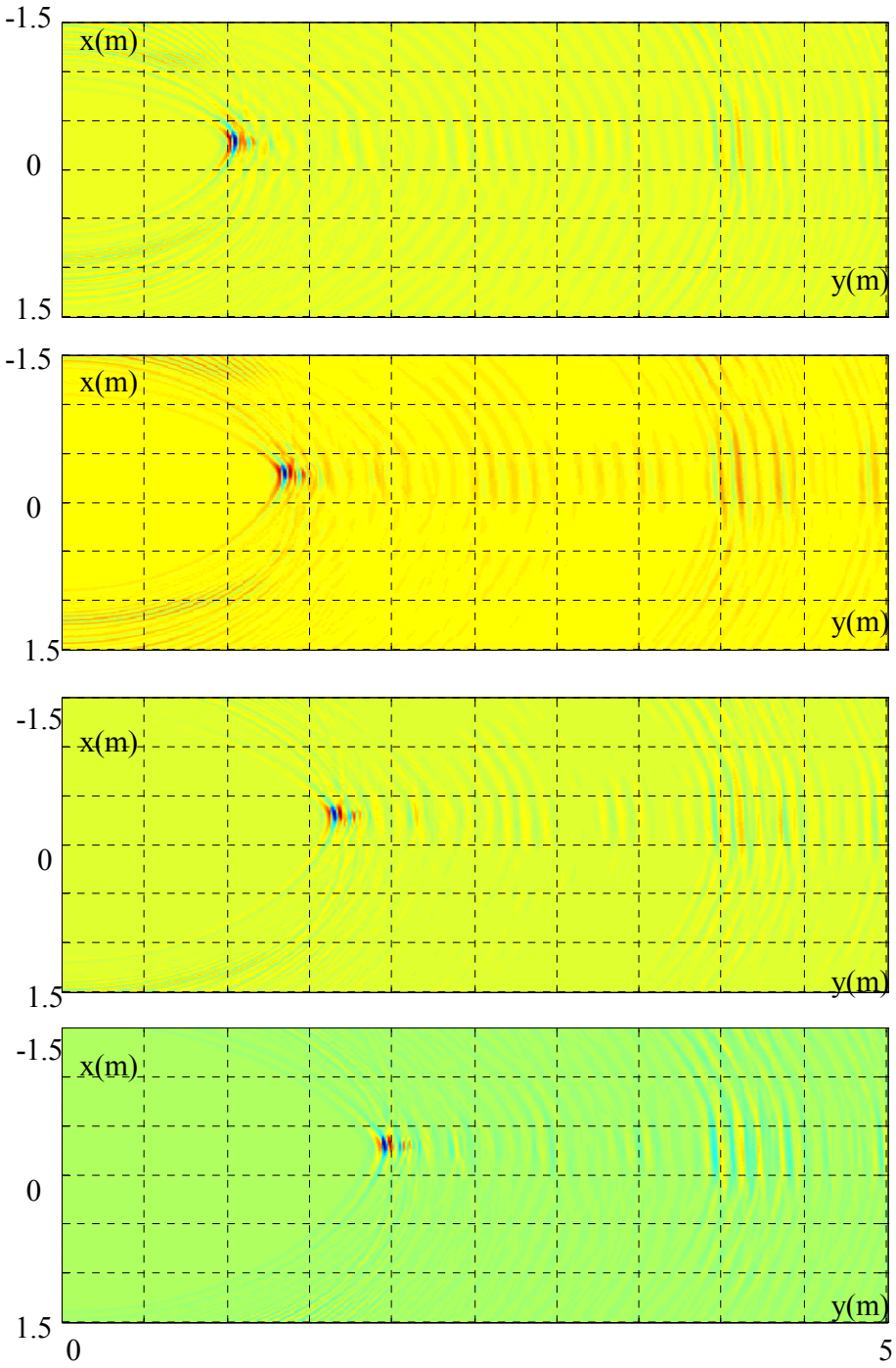


Figure 17. *Radar image of box moving along y axis (empty room difference)*

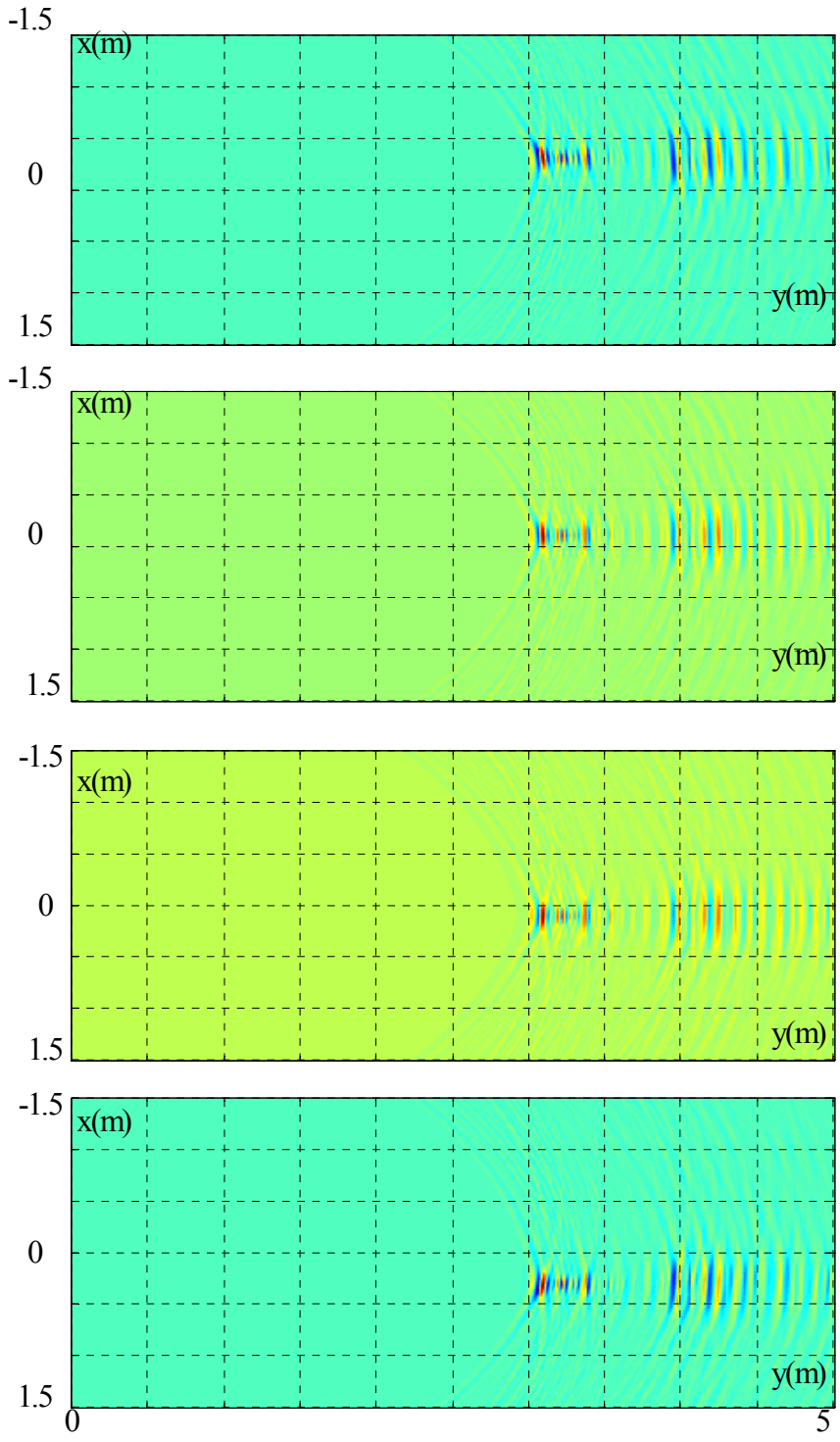


Figure 18. *Radar image of box moving along x axis (empty room difference)*

The radar image of moving targets can be cleaned up by using a threshold which would remove all small ripples.

Because the high-speed oscilloscope provides only the range profile of the echoes and makes it difficult to determine directly the target direction. We gave a contract to London Research Development Corp to develop real time pulse position indicator (PPI) software [27]. The new software also provides more flexibility in terms of processing data in real time [27].

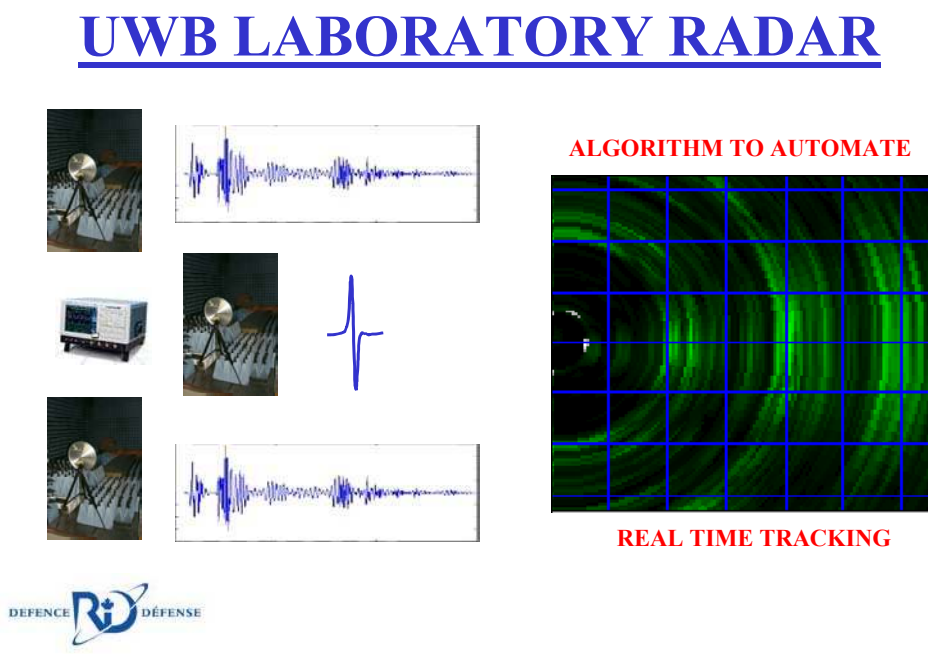


Figure 19. *Real time processing PPI like display*

3.4 Portable UWB Array

The next stage was to study the feasibility of building a compact UWB array that could simultaneously locate targets moving behind walls and provides radar images of fixed objects within a building. For this phase, we intended to use the UWB PulsON Chipset from Time Domain Corp in Alabama, U.S. [29, 30, 31], who was already developing a compact UWB array for through-the-wall surveillance. Their prototype, called RadarVision 2000 was finalized in September 2001 [32, 33].

Time Domain Corp is a world leader in the development of UWB RF technology. Figure 20 shows a picture of their PulsON UBW TM RF chipset. This chipset can transmit millions of

pulses per second with timing accuracy at the picosecond level. Their chipsets have applications in wireless communications, precision location and tracking, radar, and security sensors [33]. For wireless communications, applications include secure handheld radio and indoors wireless computer networks. Examples of precision location and tracking include the tracking of inventory objects within a building or even geolocation of soldiers. Through-the-wall radar and security sensors are also being developed at Time Domain Corp. The interesting fact about all these applications is that they are primarily enabled through software. This means that at some point in the future it would be possible to fuse all these functions into a single system.

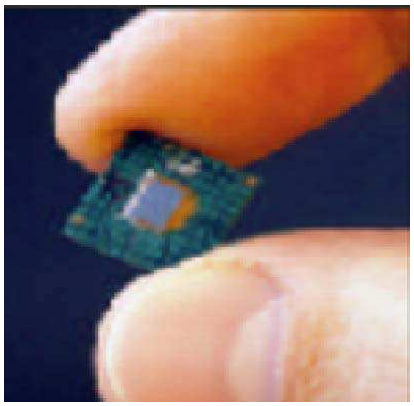


Figure 20. *Time Domain Corp UWB PulsON chipset*

Figure 21 shows a picture of the Radar vision 1000, which is the first version of through-the-wall radar developed by TDC. Their technical specifications are given in Table 3. Figure 22 shows the latest version called RadarVision 2000, which can measure both the range and direction of targets moving behind a wall [34]. At the front of the radar are two rows of antenna elements. At the back of the system we see the radar display, which is a small liquid crystal display. Figure 23 shows examples of what is displayed by the RV2000 as a target moves in front of the radar. In these examples, the walking man looks like a moving blob. The U.S. army has recently signed a contract with Time Domain Corp to ruggedize and lighten the RadarVision 2000 system and turn it into a system called SoldierVision [35]. This radar will be used within the advanced concept technology demonstration for military operation in urban terrain (MOUT).

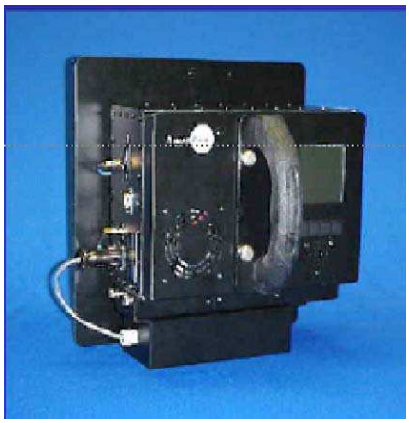


Figure 21. *RadarVision 1000*

Table 3. *RadarVision 1000 technical specifications*

CHARACTERICS	SPECS
Center Frequency	2.0GHz
Bandwidth (3dB)	1.4GHz
Range Resolution	4.5Inches
Transmit Power	0.01mW (Standard)
	1mW (Federal Option)
Antenna Gain	6dBi
Effective Radiated Power	0.04mW (Standard)
	4mW (Federal)
Code Span	25ns
Code length	1001 chips
Nominal Pulse Repetition Rate	5MHz
Field of View	120 degrees (Azimuth)
	100 degrees (Elevation)
Minimum Target Sensitivity	-10dBsm
Detection Velocities	0.5 through 15ft/s

*Company Fact Sheet

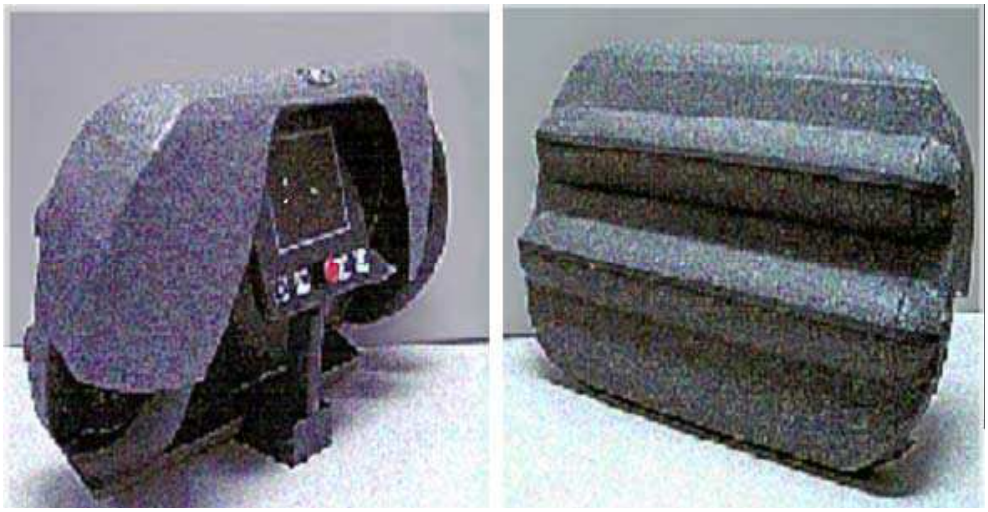


Figure 22. *RadarVision 2000*

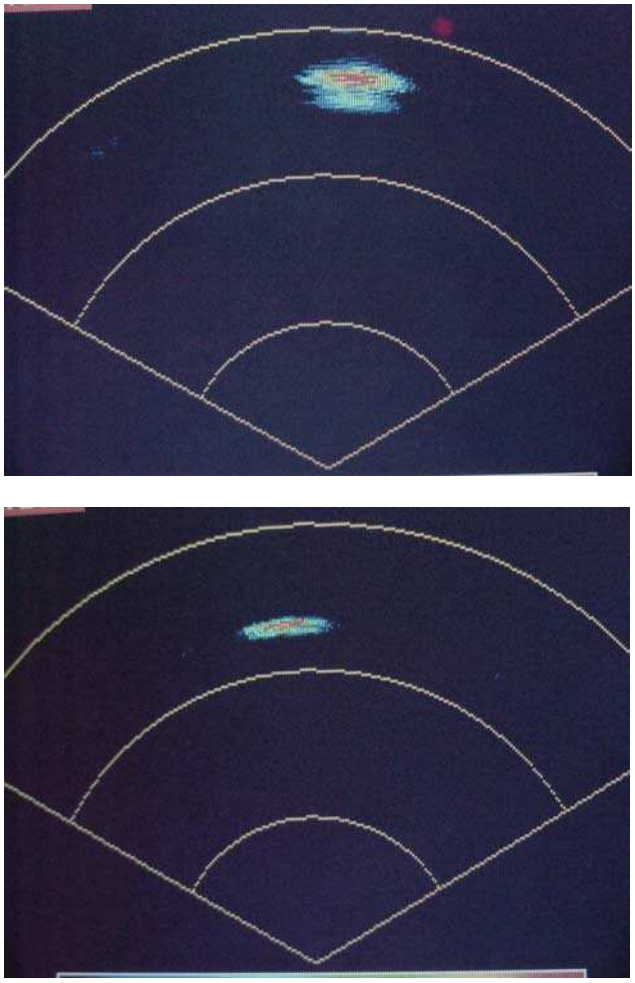


Figure 23.*Screen Image of RV2000 with person walking in front of radar.*

Time Domain Corp provided raw radar data for the person moving in front of the RV2000. We have processed their data using the DRDC software described in [27]. Some resulting frames are shown in Figure 24. There are fewer artifacts in our radar images than in the Time Domain Corp. version. The reduction is due to the use of the Hilbert transform, which has not been used by Time Domain Corp. Hilbert transform has been used to extract the envelope of the reflected signal and process it to obtain the radar images. The green pixels represent the position of the fixed clutter, which are reflections from the ground.

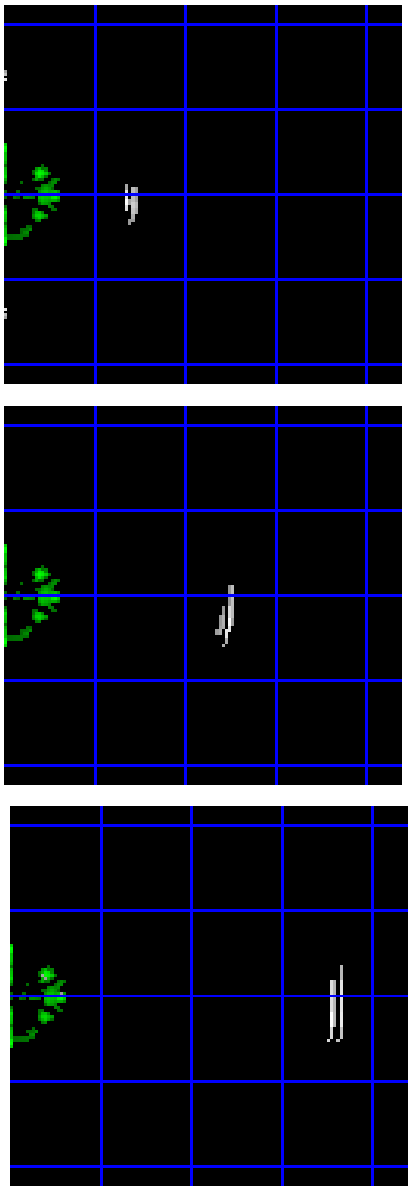


Figure 24. *DRDC radar images of RV2000 moving targets. Person walking away from radar.*

In summary, in this section, we have demonstrated both numerically and experimentally that targets moving behind walls can be tracked in both range and azimuth. We have also found that a prototype of a portable array radar already exists.

4. Future R&D Activities

There are three directions for our future R&D activities: Through-the-wall imaging enhancements, stand off capability, and evaluation of higher frequency radar up to *95 GHz*.

Currently, UWB radar such as the RV2000 can only measure the range and direction of moving targets. It does not provide any classification or identification on the target itself or on the layout of the rooms and the building. This type of information might make a significant difference during a real operation. In the short term, we will develop algorithms to produce radar images of both moving targets and of fixed objects such as the position of walls and furniture. Ideally, images of both moving and fixed objects would be overlaid. This should improve both the surveillance capability and situational awareness. Once this is done, we will extend the imaging capability from 2 to 3 dimensions (range, azimuth and elevation). This phase will also be pursued both numerically and experimentally. A 3D measurement capability should significantly enhance the capability to discriminate the targets (adult, child, pet, ventilator, carry weapons or not). This should also make it possible to track targets on other stories to provide greater situation awareness. 3D radar imaging would also make it possible to get details of the building infrastructure especially of the first wall. This may be useful for the Special Forces to break quickly into a building when necessary.

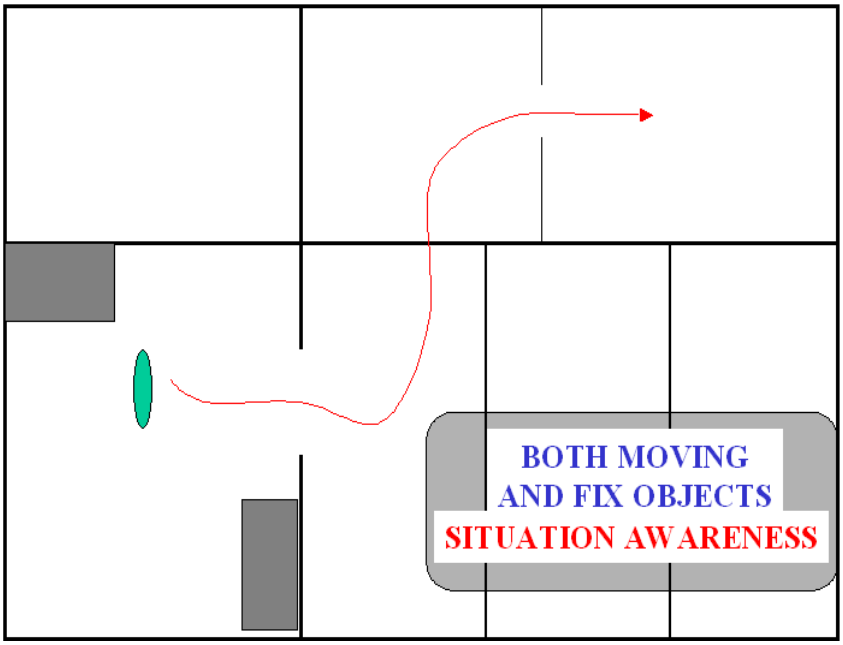


Figure 25. *Radar images of both moving and fixed objects*

Currently, the RV2000 must be kept close to the wall in order to perform surveillance. A stand-off capability, in many cases, would be much more useful to police, military and counter-terrorism organizations. Hence, we have initiated a study on the feasibility of developing a stand off through-the-wall surveillance capability. As a first step, the

capabilities and limitations of an UWB radar and its maximum distance from a building will be studied. We have acquired high voltage UWB pulsers for that purpose and the ECM section has already started electromagnetic modeling of stand-off UWB radars. If that goes as well as expected, we will put the UWB radar on mobile platforms such as robots or unmanned airborne vehicle (UAV). This would provide not only a stand-off capability but also a possibility to enhance the radar image resolution through synthetic aperture processing. Ideally we would like to see both moving targets and fixed objects using UWB radars installed on mobile platforms. We are confident that a through-the-roof surveillance capability could be implemented using UWB radars installed on helicopters or small UAV.

Another way to get a stand-off capabilities would be to use multistatic radar configuration, which would make it possible to do covert surveillance as well (see Figure 26). For example, the transmitter can be on one side of the building, whereas passive receivers located on the other side can conduct through-the-wall covert surveillance. Once again, the through-the-wall capability and limitation of a multistatic radar will be studied both experimentally and numerically. So far, preliminary results using simulated data are very promising.

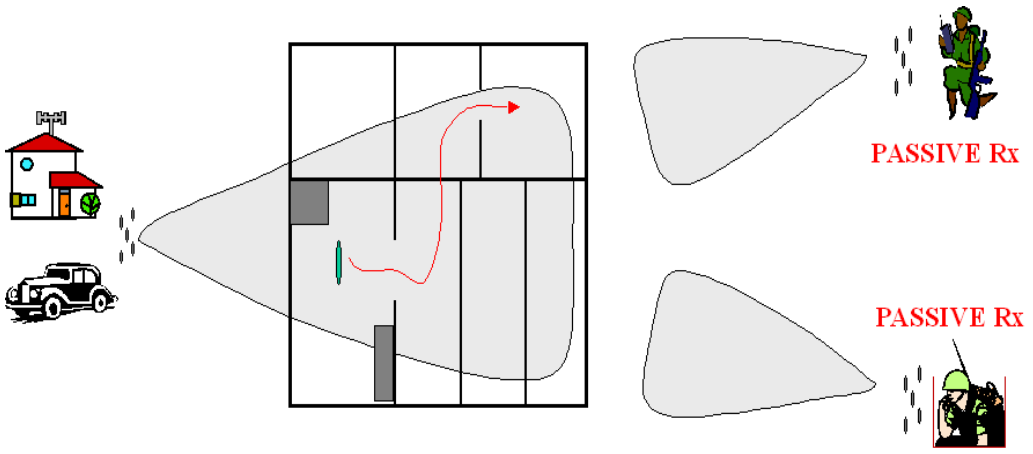


Figure 26. *Stand off capability*

In the second section of this document, we saw that wall construction is fairly transparent to radar signals up to 100GHz for drywall and 10GHz for concrete walls. Each frequency band presents its own advantages: lower frequency means better penetration and higher frequency means better angular resolution and quality. So far, we have studied the capability of UWB radars with the frequency spectrum centered on 2GHz. However, we recently gave a contract to Comlab Inc in Quebec City to test their X-band short-pulse short-range radar for through-the-wall applications. Preliminary results are very promising. Eventually, millimeter wave sensors operating at frequencies up to 95GHz will be evaluated to complete our through-the-wall radar study. Millimeter wave sensors are very attractive for their high resolution imaging capability. Figure 27 shows an example of millimeter wave camera developed by

Millivision a U.S. company. A concealed plastic gun is clearly visible on the millimeter wave camera display. After this research is completed, a thorough comparison on the through-the-wall capabilities and limitations between each radar technology will be done. The results will be reported to clients, allowing them to decide what radar technology is best for their requirements.



Figure 27. *Image of a millimeter wave camera*

5. Conclusion

DRDC-O has extensively used electromagnetic modeling and simulation to investigate through-the-wall surveillance. Finite difference time domain (FDTD) numerical algorithms have been used to generate accurate data of UWB SP radar operating in through-wall mode. The simulated data have clearly demonstrated that targets moving behind walls can be followed in range and direction.

Through-the-wall radar surveillance is a relatively new area of research and more investigation must be performed to understand its capabilities and limitations. Companies abroad have developed prototypes of portable UWB through-the-wall radar. The U.S. army is testing these new through-the-wall radar prototypes for military operation into urban terrain. DRDC Ottawa will continue its study on through-the-wall radar surveillance technology, which is very promising, but nevertheless still in its infancy. All results will be reported to the CF and clients. This should put them in a position to quickly exploit this new capability to its full potential. Commanders knowing the exact location of adversaries hiding within a building would have a significant advantage over them. Similarly, counter-terrorism forces would be able to track the terrorists within rooms and plan strikes with precision.

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List of symbols/abbreviations/acronyms/initialisms

DND	Department of National Defence
RF	Radio Frequency
UWB	Ultra-wideband
UWB SP	Ultra-wideband short pulse
LTI	Linear time-invariant
UAV	Unmanned Airborne Vehicle
CF	Canadian Force

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