Review on Antennas of Through-The-Wall Radar Imaging TTWRI Systems

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Abstract - In this paper, we present a review on the mostly used antennas of Through-The-Wall Radar Imaging TTWRI systems. We focus on the main required properties of the antennas used in these systems, like frequency band, antenna gain, return loss, and side lobe level (SSL). We also focus on other issues like the transmitted signal and the simulated or experimental results of TTWRI systems that used these antennas.

Key Words: TTWRI, GPR, VSWR, UWB, Gain, CST, SSL

1. INTRODUCTION

The main challenge faces through the wall imaging systems is that the reflected signal from the wall is stronger than that reflected from the human behind the wall, so there is a big need to design antennas with the ability to focus the radiating power towards the wall and the target. Thus, there is a need for high gain antennas, there should also be a good impedance matching across the operating bandwidth. Another important consideration while designing TTWRI antennas is the operating frequency range, although lower frequency range provides better penetration through the wall, but in the other hand the antenna becomes larger in size, and in order to distinguish between targets closed to each other, antennas used in TTWRI systems should operate on wide bandwidth, thus obtaining better resolution.

There are many different antenna designs for TTWRI in the literature. The most used antenna types were Vivaldi, horn, Archimedean spiral, and patch antennas.

Vivaldi antennas are used frequently in TTWRI applications because of its high gain with narrow bandwidth, and its UWB property which leads to a better resolution. Vivaldi antennas have been used in many types like antipodal or exponentially tapered Vivaldi antennas, it has been also used as a single antenna or array configuration. Another property of the Vivaldi antenna is that it's very light-weight when compared to other candidates like horn antennas.

Horn antennas have also been used due to its greater directivity, narrow beam width, and small minor lobes. Although horn antennas are larger in size compared to Vivaldi antennas, it's may be used instead of Vivaldi antennas since they have higher gain and greater directivity.

The Archimedean spiral antenna has been also used because of its circular polarization and compact size.

Patch antennas have been used with many different shapes of the patch in order to suppress side lobe or achieving dual polarizations, these antennas have been widely used in literature due to its low cost, lightweight, and ease of installation.

2. REVIEW OF LITERATURE

Li, Y (2018) [1]

In this paper- they implement through-the-wall imaging (TWRI) using dual channel frequency-modulated continuous wave (FMCW) radar, they used one transmitting antenna and two receiving antennas, that achieves low complexity compared with conventional SAR-based FMCW systems which need multiple/several antennas for achieving high-quality imaging. They used three standard horn antennas at carrier frequency 2.9 GHz and 600 MHZ bandwidth with 10 dB gain, the three centers of these antennas were assigned with 12 cm distances (which is approximately equaled to λ) (Fig-1). At 3GHz frequency, the H-plane with 3dB beam width was 43.51 deg, and the E-plane with 3dB beam width was 51.32 deg. Their experimental results demonstrate that their TWRI system achieved high-quality imaging for targets behind concrete walls.

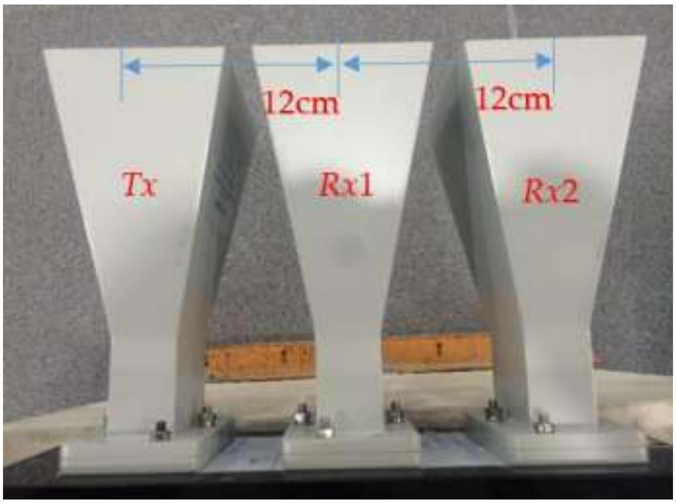

Fig-1: Proposed Horn antenna array [1].

There are also many systems used horn antennas as in [15], [16], [17], [18], [19], [20], [21], [22], [23].

Tahar, Z et al (2018) [2]

In this paper, they design a UWB directional Vivaldi antenna on the frequency range [1.17-4.75] GHz. The proposed antenna was with narrow beam, they simulate it using CST Microwave Studio, they also rescue the mutual coupling effect. They use SFCW as transmitting signal and apply back projection algorithm as imaging algorithm.

They modify on the opening rate of the slot taper and also add linear and circular slots (Fig-2). As a result, their proposed antenna achieves a return loss less than -10 dB, with 8.39 dB gain with a narrow beam. They also study mutual coupling effect between the antennas in order to minimize it as much as possible, they put the TX and RX antennas in parallel or with 90 between them, they also study the case of adding a metallic plane between the antennas when they were in the same plane. They find that the minimum couplings accrue in the case where the two antennas form a perpendicular angle between them (HV or VH) and were lower than -42 dB on the entire frequency range. They were able to detect targets experimentally in both TTWRI and Ground Penetrating Radar (GPR) scenarios.

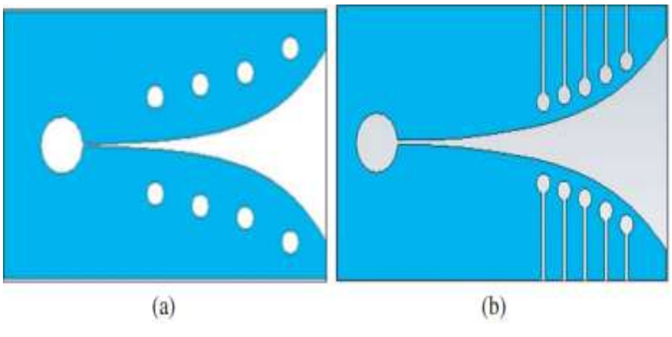

Fig-2: Proposed Vivaldi antenna by adding slot circles to the metal in (a) and Vivaldi antenna by adding slot circles and lines in (b) [2].

Nijhawan et al (2018) [3]

In this paper-they design a Tapered Slot Flexible Corrugated Vivaldi (FCV) antenna using flexible polyimide substrate, they optimize the antenna parameters on the frequency range [2-8] GHz using CST Microwave Studio. They slice uniform corrugations on the top and bottom sides of the slot in order to improve the overall performance of the antenna, they also employ a silver metal strip in the end-fire direction and circular silver metal portions are also applied in the spacing between metallic strips (figure-3). The return loss of the proposed antenna was below -16.767 dB at 3.5856 GHz while the maximum antenna gain was 9.7637 dB at 7.6 GHz, which is suitable for different UWB applications.

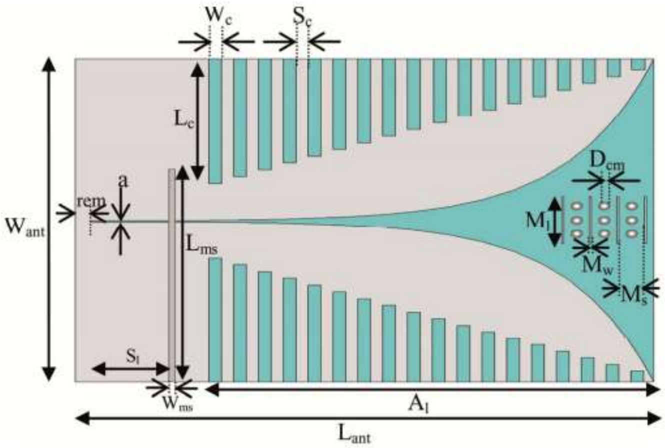

Fig-3: Schematic layout of proposed Vivaldi antenna (dark Silver colored part indicates microstrip line, at the back side of the antenna of width Wms) [3].

Ali, Engr Jawad et al (2017) [4]

In this paper- they design a UWB shifted arc antenna using Rogers RT-5880 Duriod substrate. Their antenna operates on the frequency range [2.8-15.6] GHz with gain approximately 6.05 dB. They achieve this high gain by using defected ground structure (DGS) method and adding slots. They also add a modified half grounded method in order to achieve matching on the entire bandwidth. They use a simulation-based experiment in CST in order to validate the detection capability of their proposed antenna, they model the human skin, the concrete wall, place the antenna at a specified distance from the wall, and observe the different reflection (Fig-4). The obtained analyzed time domain reflections showed that the proposed monostatic UWB antenna has the potential to detect targets behind walls.

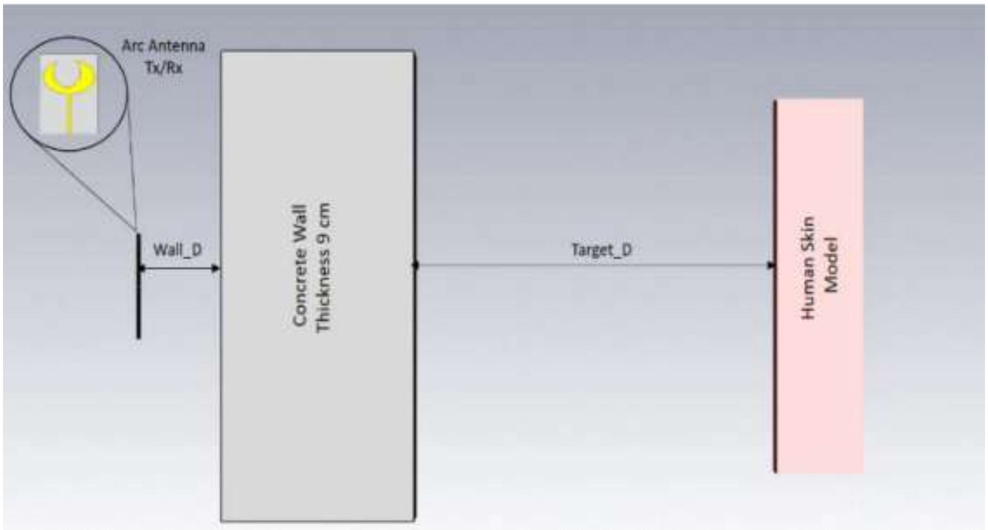

Fig-4: Simulation-based of experimental model [4].

Yilmaz, B. et al (2016) [5]

In this paper, they used a linear array of Vivaldi antennas (Fig-5) consists of 8 elements operate on [4-8] GHz with SFCW as a transmitted signal. These elements were used as sensors of synthetic aperture radar (SAR) configuration in order to improve the resolution in the cross range axis. They simulate their proposed antenna using CST Microwave office and found that the antenna assures an HPBW of 46.1 deg along the E-plane directions, and a maximum side lobe level SSL of -8.9 dB, and the gain of the antenna element was 9.32 dB, wherein the H-plane direction the antenna provides an HPBW of 52.4 deg, a maximum side lobe level SSL of -7.1 dB, and back-lobe level is −12 dB. In order to reduce the back-lobe radiation level and increase the gain of the antenna elements, they use an antenna array of eight elements and encased by a metal box that was made of aluminium material, they can achieve coupling less than -20 dB on the entire frequency band using CST optimization which gives that the minimum spacing between antenna elements was 11cm.

They tested their system and it was able to detect both stationary and moving targets behind the wall.

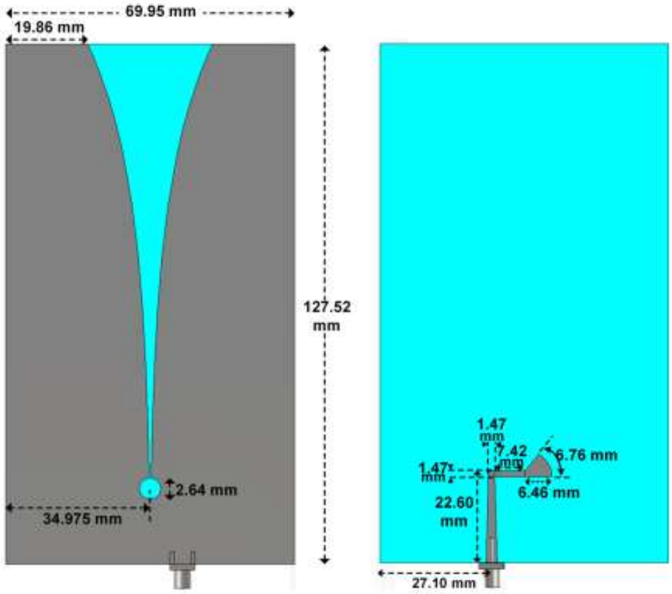

Fig-5: Proposed Designed Vivaldi antenna element: (a) front side and (b) back side [5].

Jin, T et al (2015) [6]

In this paper- they use MIMO output array for through the wall radar imaging based on a realistic model. The antenna element was an Archimedean spiral which achieves high resolution in down-range.

The transmitted signal was a stepped-frequency signal at the frequency range [0.5-2.5] GHz. Their MIMO array consists of 2 Transmitting and 11 receiving antennas, with a 25cm distance between centers. They put the two TX antennas at the end the RX array, so there were 22 TX-RX channels in one virtual aperture (Fig-6). The MIMO array was located 8.5 m away from the wall and a trihedral reflector was in the building, they could locate the location of the target with about 0.4m as a locating error in the down-range direction for the target.

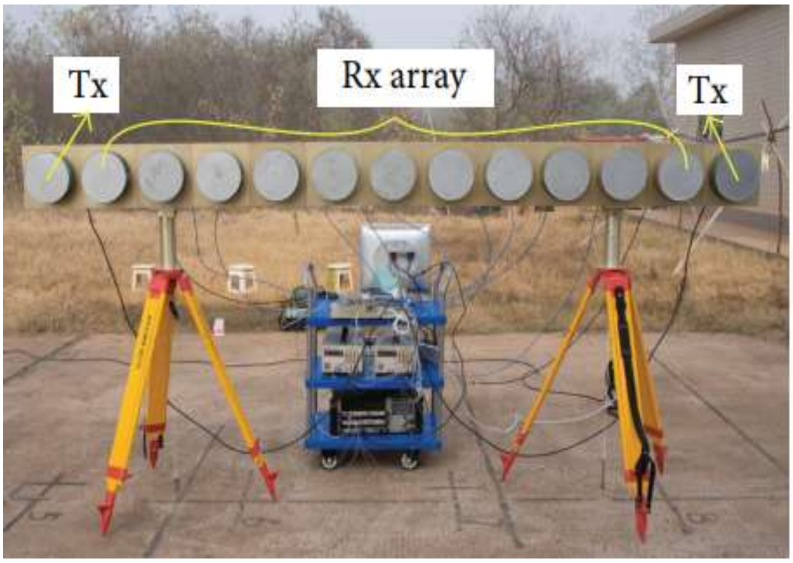

Fig-6: Proposed Photograph of the through-the-wall system [6].

There are also many systems used Archimedean spiral antennas as in [24], [25].

Fioranelli, F et al (2015) [7]

In this paper- they design and optimize a patch-like antenna for TTWI radar. They used e frequency modulated interrupted continuous wave (FMICW) signals at frequency range [0.5-2] GHz. They started by simulating the traditional patch antenna, then they optimize it using CST Microwave Studio in order to reduce the antenna dimensions and improve the radiation characteristics. The proposed antenna is a rectangular patch antenna fed by a microstrip line printed on FR4 dielectric substrate, with ground plane on the other side, with a metal patch which improves the impedance matching (S11<-10 dB) and helps in radiating the power towards wall and target.

The proposed antenna dimensions are 14cm*17cm, that is approximately 57% of the size of the patch-like prototype, they also study the coupling between antennas which was below 15 dB for 20 cm antenna separation.

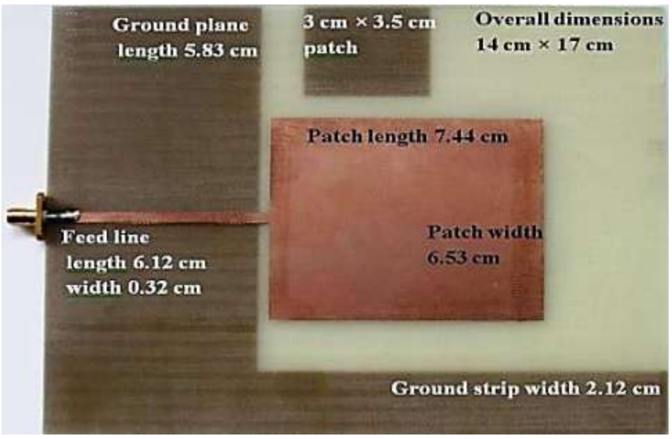

Fig-7: Top view of the optimized patch-like antenna and its dimensions (long side of the antenna aligned with the Y axis and the short size with the X axis) [7].

Then they use an alternative antenna which is a Vivaldi antenna manufactured on substrate Taconic CER10. The overall dimension of the proposed antenna was 26cm*18.2 cm. Although the proposed Vivaldi antenna is bigger in size compared with the patch-like one, Vivaldi is matched at a higher frequency up to 3 GHz, which means wider bandwidth and better resolution.

The experiments of their system with the proposed antennas demonstrate the validation of their removal of the wall technique, and they can detect stationary and moving targets behind the wall.

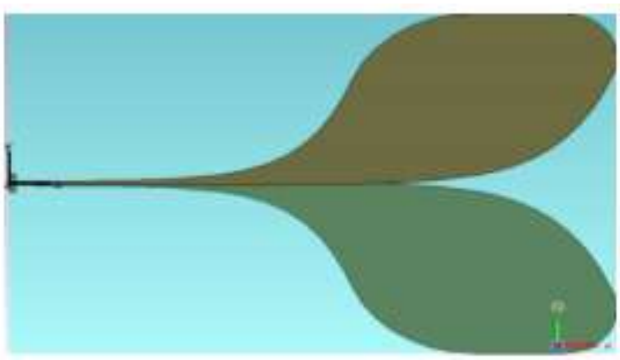

Fig-8: Simulation model of the Vivaldi antenna with coordinate system [7].

Elboushi, Ayman et al (2013) [8]

In this paper, they design a UWB antenna array consists of 4 elements balanced antipodal Vivaldi antenna array (BAVA) fed by modified Wilkinson power divider. They add many modifications on the prototype antenna and test and optimize the performance using CST Microwave Office, some of their modifications are using curved corners instead of the sharp ones in order to reduce the undesired radiation from the feeding network and other modifications in the lengths of the matching stubs.

The proposed antenna operates on the frequency range [3.4-10.2] GHz, with about 10 dB gain, and -20 dB Side Lobe Level SLL

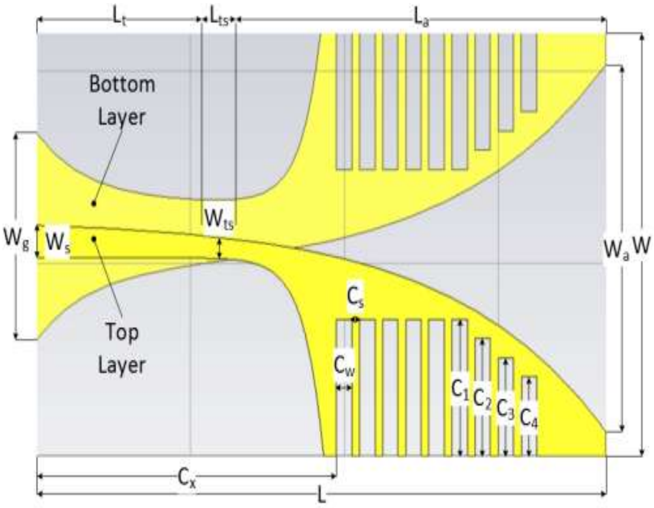

Fig-9: Modified BAVA antenna schematic diagram [8].

There are also many TTWRI systems used horn transmitter antennas and Vivaldi receiver antennas as in [9], [10], [11], [12], [13], [14].

3. CONCLUSION

As we see in our review, there are many different kinds of antennas used in the literature for TTWRI applications, we have seen that Vivaldi and horn antenna are the most widely used because of their wide bandwidth and high directivity. We also notice that the reflection coefficient should be less than -10 dB, which means that less than 10% percent of the power reached to the antenna is reflected because of the change in the impedance of the medium. We also find that all the used antennas were ultra-wideband UWB, in order to achieve a better resolution which means better distinguishing between close objects or targets. There are also some studies that use array antenna configuration in order to have higher directivity and lower side lobe level. However, while designing antennas for TTWRI applications, we should take into account using a UWB antenna with lower frequency band, high gain, low SSL, lightweight and ease of installation.

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