Automatic RADAR Target Recognition System at THz Frequency Band. A Review

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Abstract: ***The development of technology for communication in the THz frequency band has seen rapid progress recently. Due to the wider bandwidth a THz frequency RADAR provides the possibility of higher precision imaging compared to conventional RADARs. A high resolution RADAR operating at THz frequency can be used for automatically detecting and segmenting concealed objects. Recent advancements in THz circuit integration have opened up a wide range of possibilities for on chip applications, like of security and surveillance. The development of various sources and detectors for generation and detection of THz frequency has been driven by other techniques such as spectroscopy, imaging and impulse ranging. One of the central vision of this type of security system aims at ambient intelligence: the computation and communication carried out intelligently. The need for higher mobility with limited size and power consumption has led to development of nanotechnology based THz generators. In addition to this some of the soft computing tools are used for detection of radar target automatically based on some algorithms named as ANN, RNN, Neuro-Fuzzy and Genetic algorithms. This review article includes UWB radar for THz signal, its characteristics and application, Nanotechnology for THz generation and issues related to ATR.***

Keywords: Radar, Target, Terahertz, Signal processing, Soft Computing, Recognition, Neural network, Fuzzy Logic.

1. Introduction

The most fundamental objective of radar is the detection of an object or any other physical phenomenon. This requires determining whether the receiver output at a given time represents the echo from a reflecting object or whether it is simply noise. Once an object has been detected, it may be desirable to track its location or velocity. The ability to recognize a target quickly and correctly by its radar return alone, at long distances, and under all weather conditions, is of great importance to automatic target recognition (ATR) systems [1]. Advanced soft computing provides a number of tools which could form the basis for a potentially fruitful approach to the ATR problem [1]. Automatic Target Recognition (ATR) generally refers to the use of computer processing to detect and recognize target signature in sensor data. ATR has become increasingly important in modern defense strategy because it permits precision strikes against certain tactical targets with reduced risk and increased efficiency, while minimizing collateral damage to other objects [2].

A key advantage of using tools such as Artificial Neural Network (ANN) is that since the algorithms automatically remember the available data, the resulting high performance algorithms are tailored to the variable data. As viewed from the time domain, the target waveform can also be regarded as a time sequence such that it can be classified using Recurrent Neural Network (RNN), more commonly referred to as RNN (feedback NN) which is suitable for time sequence processing [3].

Device certain optimization methods can be the other alternatives to adhers the ATR issues. These can be in the form of hybrid estimators, which can be combination of ANNs and adaptive filters. Yet another approach can be a bank of ANNs, and hybrid classifier consisting of ANN and Fuzzy logic.

It can be inferred from the recent works reported in the literature [4] [5] [6] [7] [8] [9] that the signal to be transmitted by the radar plays a very important role in the whole process. Instead of using radio waves if a very high frequency signal (THz) is used, then those types of radar referred to as ultra wideband (UWB) radars, and then the ATR system can outperform for surveillance radar due to the unique characteristics of novel materials[10] used to generate the THz signal. Use of this THz signal has a great potential for the development of a high resolution imaging radar for air defense system, aircraft anti-collision system, detection of person borne concealed weapons, contraband, explosives or other objects [11]. The shorter wavelength of THz signal is favorable toward providing a wider bandwidth, thereby aiding higher precision of imaging [12]. However integrating the components in to a functioning system poses a substantial challenge [11]. The rapid advancements in solid state electronics and optoelectronic devices have made it possible to develop UWB RADARs. Nanotechnology can be used for appreciable enhancements in the performance of the ATR systems by taking advantage of unique properties of nonmaterial's [13].

2. RADAR

Radar is an object detection system which uses radio waves to determine the range, altitude, direction, or speed of objects. It can be used to detect aircrafts, ships, spacecrafts, guided missiles, motor vehicles, weather formations, and terrains [16]. The modern uses of radar are highly diverse; it includes locating and detecting of targets as well as surveillance and security [17]. High tech radar systems are associated with digital signal processing and are capable of extracting useful information from signals with very high noise levels [16].

Radar waves scatter in a variety of ways depending on the size (wavelength) of the radio wave and the shape of the target. If the wavelength is much shorter than the target's size, the wave will bounce o in a way similar to the way light is reflected by a mirror. If the wavelength is comparatively larger than the size of the target, the target may not be visible because of poor reflection. Low-frequency radar technology is dependent on resonances for detection, but cannot identify targets. Early radars used very long wavelengths that were larger than the targets and thus received vague signals, whereas some modern systems use shorter wavelengths (a few centimeters or less) that can image objects as small as a loaf of bread [16]. There are many different radar missions, types of radars, and radar modes [17].

3. UWB RADAR

In UWB radar operation the distance, or range of the target, is presumed at the beginning of the pulse-echo round trip and the only information out of the system will regard the presence or absence of the target at that, given range.

UWB radar emits an electromagnetic signal and pause a given time; then a sample of the antenna voltage is taken for the (possible) echo. As shown in the block diagram of Figure 1, the pulse coming out of the generator is transmitted and at the same time sent to a delay line. In this way the same pulse is used for controlling the sampling of the received echoes. Eventually a low pass filter averages the signal with a suitable time constant. Unfortunately practical UWB radar is far more complicated [18].

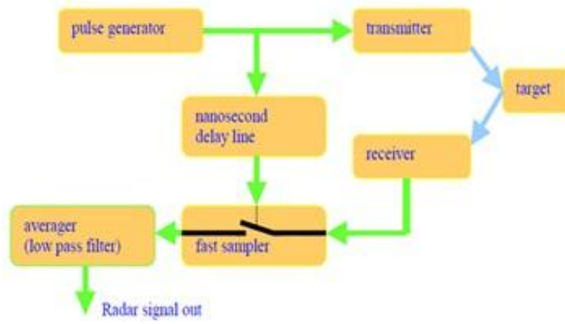

Figure 1: Block diagram of UWB RADAR [18]

UWB radar cannot operate at a range shorter than one half the "pulse length in space" which is the product of pulse duration and the speed of light in the medium. That is because we need to free the antenna of the emitted pulse before we get ready for receiving any echo.

In UWB system, the resolution is enhanced by the use of narrower pulses having higher slew rates. Eventually it will follow a wider spreading of the electromagnetic power in the frequency domain so that delectability of this type of radar and interference probability with other services is even more lowered [18].

4. RADAR SIGNAL PROCESSING

The term radar signal processing encompasses the choice of transmit waveforms for various radars, detection theory, performance evaluation, and the circuitry between the antenna and the displays or data processing computers [19]. Signals recovered by the radar are composite of target echoes and interference. Signal processing role is first to enhance the target echoes and suppress all other signal and secondly to extract information about the targets behavior, including its position, velocity, and signature. The effectiveness of signal processing in separating signals from interference is described by a parameter called process gain. It is defined as the ratio of signal-to-interference ratio out of the process and the signal-to-interference ratio in to the process. The process gain of effective signal processing is less than unity. If not it should not be used. Signal processes must be customized to the type of interference present [20]. The detection of radar targets against ground and sea clutter is a problem of great interest in the radar community. The fusion of signals from different radar to improve detection performance is another relevant topic of research and application [21].

5. THz FREQUENCY FOR RADAR

The term THz is applied to submillimeter wave energy that fills the wavelength range between 1 mm (300 GHz) and 100mm (3 THz). Throughout the last century, the millimeter and submillimeter wave generation started to become a topic of interest for scientists [22], [23], [24], [25], [26], [27], [28], [29]. By 1984, the frequency range from 30 to 100 GHz was in a state of advanced development, but above 100 GHz was still very exploratory. By 2002, the THz frequency range was one of the least explored regions of the electromagnetic spectrum [30]. Due to the difficulty of producing strong and dependable sources and efficient detectors in this exotic band of radiation, the THz regime has for many decades been the last part of the electromagnetic spectrum which has not been intensely used for research and technological applications. It is, therefore, referred to as the THz gap [31].

THz radar has a very narrow radar beam and huge bandwidth of signal which can be used to precise target imaging. THz signal can penetrate certain material, clothes and be reflected back by the skin [30] [32]. Energy of THz band locates between electronic and photonic region. Many materials are opaque in this range and optical radiation is strongly scattered by dust, fog or grains in heterogeneous materials which added the advantages of using THz signals.

Daniel Mittleman, a professor of Rice University stated that, the THz band is an unlicensed frequency band and is unique in the spectrum because few have figured out how to bend them to their purposes [33]. Konos successful efforts to detect and manipulate THz using graphene and carpets of nanotubes have inspired visions of many potential applications [33]. The THz channel is characterized by molecular absorption, i.e., the conversion of the wave energy in to kinetic energy in several gas molecules, which determines path loss and molecular noise [34]. Due to molecular absorption, the THz channel is highly frequency selective. The channel information capacity depends on the molecular composition of the channel, the total system noise, and the power spectral density (p.s.d.) of the transmitted signal. The THz channel supports very large transmission bandwidths, up to tens of Terabits/second, for very short transmission distances, i.e., below 1 meter. Femtosecond-long pulses have their main frequency components in the THz band [35]. Due to technological constraints, these very short pulses cannot be transmitted in very long bursts, but rather spread out in time.

As a result, the individual transmission rate that a nano-device can achieve is far below the theoretical channel capacity [36]. However, the time between pulses can be used to interleave users, thereby maximizing the total network capacity. If the time between pulses is known in advance, a user can track the input pulse stream of the transmitter while ignoring the other pulses or even carry out multiple receptions.

Some of the important characteristics of THz signals are:

- **Wave particle duality:** THz wave has both particle and wave nature such as interference and diffraction [37].

- **Penetrability:** THz radiation has good penetrability in a lot of dielectric material and non-polar liquids [25]. THz wave can be used to perspective imaging for a lot of non transparent objects. The penetrability of THz wave makes it a possible supplement of X-ray imaging and ultrasound imaging for security checks or quality control in non-destructive testing [37].

- **Security:** Compared to X-ray with KeV photon energy, the energy of THz radiation is only meV. Its energy is lower than the energy of different types of chemical bond, so it will not cause harmful ionizing reaction [26] [38]. Many non-metallic materials are transparent to THz signals. This unique feature opens the door for many interesting applications, such as detecting chemicals and hidden explosives [39]. In THz region it may be possible to detect molecular network through weak intermolecular coupling, which will allow the use of THz waves for protein analysis and drug discovery [37]. The waves stimulate molecular and electronic motions in many materials-reflecting o some, propagating through others, and being absorbed by the rest [26],

[27]. This property can be used to identify explosives, reveal hidden weapons, check for defects in tiles on the space shuttle and screen for skin cancer and tooth decay [38]. Depending on the material property, the signals might get serious attenuation and therefore THz wireless networks would require at least a direct line of sight between the source and the receiver [40].

- **The resolving power of spectrum:** Although in the THz radiation photon energy is relatively low, the band still contains a wealth of spectral information. Many organic molecules has strong absorption and dispersion characteristics in the THz band. The THz spectroscopy of material contains a wealth of physical and chemical information, which making them the unique characteristics, like fingerprints [38]. Therefore, THz spectral imaging technology can not only differentiate objects morphology, but can also identify composition of objects [37].

Disadvantages of THz signals:

- Terrestrial signals sent at THz frequencies can experience extreme atmospheric absorption, due primarily to water vapor and oxygen. For horizontal transmission at sea level and normal humidity the signal attenuation is maximum between 1 and 10 THz [41].

- The power needed to send data at THz frequencies would be impractically high in many cases. However, orbiting THz instruments have a big advantage over their terrestrial counterparts: they are in space! Specifically, they operate in near-vacuum condition and do not have to compete with a dense atmosphere, which absorbs, refracts, and scatters THz signals, nor do they have to operate in inclement weather. But many of the envisioned THz applications are for use on the ground. The signal strength can be boosted anticipating that the radiation will get through to the receiving end. However, at some point, it might just not be practical [42].

- When attempting to identify unknown objects at a distance, nearly all of the THz signal will be lost or get distorted due to atmospheric effects. At distances of 10 meters and 100 meters the samples distinct spectral features are washed away (Illustrated by George Retseck) [41].

6. THz GENERATION

It is difficult to generate THz signals, because for many applications, the source has to be powerful enough to overcome extreme signal attenuation. Certain applications require spectral purity, tenability or bandwidth of the source and can compromise on, so a low power is acceptable [41]. As frequency increases, it becomes increasingly difficult to generate radiation at usable power levels. This limitation is due to the decreasing size of the frequency-sensitive elements in most sources of radiation. At higher frequencies, it becomes even more difficult to fabricate these small structures with accuracy to ensure good performance. This problem occurs with both solid-state and tube-type sources of radiation [43]. Some of the recent techniques for the generation of THz signals are reported in [43]. In general THz sources fall into three broad categories: (i) vacuum (including backward-wave oscillators, klystrons, grating-vacuum devices, travelling-wave tubes, and gyrotrons) which exhibit the highest average power at the lower and upper frequencies, respectively (ii) solid state (including harmonic frequency multipliers, transistors, and monolithic microwave integrated circuits). (iii) Laser and photonic (including quantum cascade lasers, optically pumped molecular lasers, and a variety of optoelectronic RF generators) which also exhibit the highest average power at the lower and upper frequencies, respectively. Low efficiency combined with the devices' small size leads to a problem: extremely high power densities (the amount of power the devices must handle per unit area) and current densities (the amount of current they must handle per unit area). For the vacuum and solid-state devices, the power densities reported are in the range of several megawatts per square centimeter. A THz transistor, with its nanometer features, operates at similarly high power density levels. In typical radio-frequency devices, such as transistors, solid-state diodes, and microwave vacuum tubes, the power tends to fall as the inverse of the frequency squared. In other words, if the frequency is doubled, the output power drops by a factor of four [44][45][46][47].

Researchers have investigated various materials for the generation of THz wave [48], [49] [50] [51] [52]. The most widely used material is zinc telluride (ZnTe) at (100) orientation which has excellent phase matching properties [49]. Different methods for THz generation are, synchrotron radiation from a storage ring [53], free-electron lasers [54], light sources used in FIR Fourier transform spectroscopy [55], gas lasers (the most prominent being the CO_2 laser [56]), quantum cascade lasers [57] and ultrafast mode locked optical lasers used either with second order non-linear optical materials [58] or with photoconductive switches made of semiconductors [59]. Two main THz generation methods viz solid-state generation and by optical generation are discussed in the following section.

6.1 Solid-State Generation

For years, solid-state electronics have generated infrared light by using a layered semi-conductor structure, such as in diodes that emit infrared light or lasers that operate in the infrared range [48]. This principle however, is not easily extended down to the THz band. Inter-band diode lasers, which operate at a wavelength of 3 m, are based on the principle that conduction band electrons recombine with valence band holes across a gap of active material. In doing so light or electromagnetic waves are emitted. However, this type of laser cannot be used to emit THz wave simply because suitable semiconductors for this type of excitation are not available [60]. A new kind of laser, called the quantum cascade concept has been used in research. Here, the transition between semiconductor layers is used to emit light [61]. The advantage is that the thickness of these layers can be changed to manipulate the electrons' paths.

6.2 Optical Generation

The optical generation method does away with the need for a solid-state emitter in the THz band. Instead, optical generation uses a laser that pulses at 10 to 200fs, which is in the visible or infrared spectrum. With an exception of free electron lasers that use relativistic electrons and are capable of reaching kilowatt level terahertz power [62], other THz sources generate milliwatt or microwatt power levels. The photon energy at a frequency of 1 THz is approximately 4 meV, compared to the thermal energy of 26 meV at room temperature. This clearly shows the difficulty of designing THz lasers relying on optical transitions to operate at room temperature [38].

Often GaSe, GaP or GaAs semiconductor generator will either reflect the pulses or prop-agate them through itself. This is possible because here the semiconductor is no longer emitting the light. Instead they are simply being used to conduct or refract the light. Photoconduction and rectification are the two different variations of optical generation that result from the propagation or reflection of the incident laser pulses [61].

Photoconduction is the process by which current is generated from a photoconductive semiconductor. When sufficient amount of energy, such as electromagnetic energy from the incident waves is applied to certain semiconductors (like GaSe), small bursts of current result. This process generally provides higher-powered THz waves than optical rectification [61].

The semiconductors that are used as THz generators in conjunction with femto second (fs) laser pulses use one of two methods to generate THz waves. Bulk electro-optic rectification or ultra fast charge transport [60]. In Bulk electro-optic rectification process the large electric field from the laser pulses allows the non-linear receptiveness of a semiconductor to generate the THz waves. A polarization in the THz range occurs which is proportional to the intensity of the laser pulses. Ultra-fast charge transport earns its name from electron-hole pairs that are formed on the surface of the semiconductor. Some of the common semiconductors used in terahertz generation are GaSe, GaAs, GaP, and ZnTe [63]. Using 2 mm GaSe crystals, frequencies from 0.3 to 4.9 THz could be generated that produced at least 3% of the maximum power 15mW (over 2.4 to 3.1 THz). The highest power wave was found at 3 THz. The power dropped back o to 0.48 mW at 4.9 THz, and no signal could be detected at 5.1 THz [50]. Experiments done on GaP, using the same general set up as those conducted with GaSe have shown that they are tunable over a 0.5 to 7 THz range [64]. The experiments in [52] were carried out to compare the response of GaAs and InAs to differing magnetic fields, because of their similarities. The process by which the THz waves were generated was bulk electro-optic rectification and a 140 fs pump laser was used [52].

Figure 2 shows three typical approaches together with representative components for THz transmitters. The rst all-electronics based approach consisted of an RF signal generator, a data modulator and amplifier.

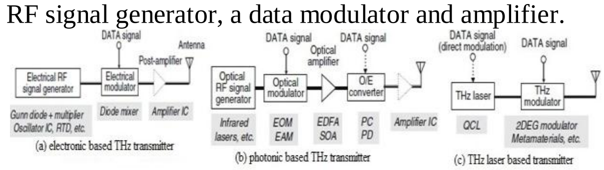

Figure 2: Different THz transmitter [65]

A second approach is the use of photonic techniques for the generation and modulation of THz signals (Figure 2-b). The optical signal whose intensity is modulated at THz frequencies is first generated using infrared lasers, and then it is encoded by an electro-optic (EO) or electro absorption (EA) modulator.

The third approach is based on the use of THz lasers such as quantum cascade lasers (QCLs) (Figure 2-c). The QCLs can operate at around 1 THz even though they require low-temperature and strong magnetic field [65][66] . Another similar kind of generation of tunable millimeter-wave (MMW) and terahertz (THz) signals with an optically injected 1310-nm quantum dot distributed feedback (QD DFB) laser is experimentally demonstrated by Hurtado et.al. [67].

It is obvious that the generation of THz waves is pointless without an effective means for their detection. Figure 3 shows two electronics-based approaches together with representative components for THz receivers. Direct detection (a) is easy to conduct with commercially available Schottky barrier diodes with a cut-o frequency of 1-10 THz. Heterodyne detection (b) with a Schottky barrier diode mixer and a local oscillator (LO) signal source provides higher sensitivity. Preamplifiers with low noise figure (NF) are effective to increase the receiver sensitivity.

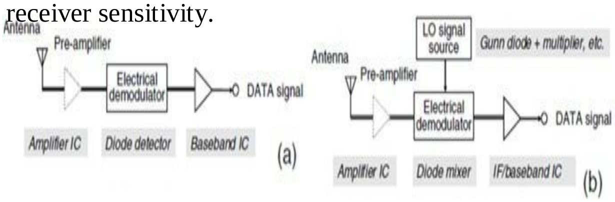

Figure 3: configuration of THz receiver, (a) direct detection, (b) heterodyne detection [65]

7. NANOTECHNOLOGY FOR THZ RADAR SYSTEM

Nanotechnology (NT) is the study of manipulating matter on atomic and molecular scale. NT deals with structures sized between 1to 100 nanometer, and in at least one dimension (Quantum Dots are of zero dimensions). Dominance of electromagnetic force, the presence of quantum mechanical phenomena, the large surface area to volume ratio and the importance of random kinetic motion cause nano-scale sized particles to often have very different properties than their macro-scale (bulk matter) counterparts. NT enable military technologies will ensure high speed and high capacity systems for command, control, communication, surveillance; automation and robotics for minimizing exposure to war fighters, first responders; superior platforms, weapons with miniaturization [68]. The main drivers for using nanotechnology in wireless devices are:

- Increased use of RF spectrum
- Slower performance improvement of RF components compared to digital electronics
- Demand for cheaper, smaller and less power consuming devices.

A four-level quantum dot nanostructure based detection system has been reported for infrared (IR) and THz [68]. Through size control of quantum dots and external voltage, one can design a four level quantum dot system with appropriate energy levels which can be suitable for IR or THz signals detection. In this case, a probe and a control field simultaneously interact with four-level quantum dot system for creation of coherent population trapping. An IR or THz signal can influence the electron population in dark and bright levels, therefore absorption and transmission spectrum of probe field in the medium can be altered. Thus, one can by studying of probe absorption, easily estimate the existence of IR or THz signals in the medium [69].

Currently, the communication options for Nano devices are very limited. Miniaturizing a conventional metallic antenna to meet the size requirements of the Nano devices would require very high operating frequencies (hundreds of THz) [70]. The available transmission bandwidth increases with the antenna resonant frequency, but so does the propagation loss. With the likely very limited power associated with nano devices, this approach would compromise the feasibility of Nano networks.

Intrinsic properties of metals vary at the nanoscale, and common assumptions of antenna theory might no longer be valid. An alternative is to use novel nanomaterials such as graphene (i.e., a layer, one atom thick, of carbon atoms in a honeycomb crystal lattice) to develop nanoantennas. Novel nano material such as graphene and its derivatives, i.e., Carbon Nanotube (CNT) and Graphene nanoribbon (GNR), have been proposed as the building material of novel nano-antennas [71]. The resistivity of a single CNT is lower than that of a strand of gold having the same diameter and this has been a motivating factor for utilizing CNTs in nanoantenna fabrication [72] [73]. A CNT is a type of carbon-based cylindrical-shaped nanomaterial. The CNT's diameter ranges from 0.7 to 10.0 nm and its length can be from a few nanometers up to a few centimeters [73][74]. As a good conductor, CNTs can support current densities as high as 109 A/cm^2, which is about 100 times higher than the current density that can be carried by ordinary metallic conductors [75][76] [77]. A single wall carbon nanotube (SWNT) has a cylindrical geometry with an extremely high aspect ratio. Although a SWNT has a rather high conductivity, its resistance per unit length is fairly high because of its very small radius (on the order of a few nanometers) [78]. These properties limit its direct utilization for RF applications, such as electrical interconnects and radiating elements. To circumvent this problem, bundled CNTs (BCNTs) are proposed to reduce the high intrinsic resistance of a SWNT [79] [80] [81] [82]. P. J. Burke proposed a RF circuit model for the effective electrical (dc to GHz to THz) properties of carbon nanotubes including the effects of kinetic inductance as well as the electrostatic and quantum capacitance [83].

Figure 4 shows a graphene based Nano antenna. The Nano antenna is composed of a Nano ribbon (GNR, the active element), mounted over a metallic at surface (the ground plane), with a dielectric material layer in between (to support the GNR as well as to change its chemical potential by material doping) [84].

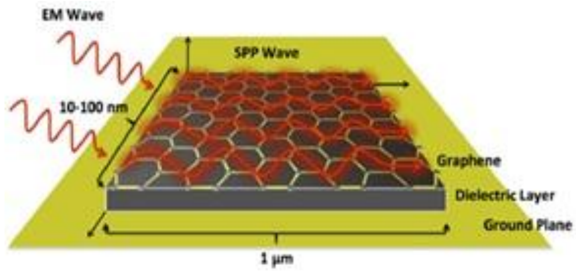

Figure 4: Graphene based nanoantenna [84]

By accounting for the interaction between every single atom in the graphene structure, the transmission line properties of nano antenna can be accurately modeled. Several quantum phenomena determine the propagation speed of EM waves in graphene (kinetic inductance, quantum capacitance, contact resistance). As a result, the EM wave propagation speed can be up to 100 times below that of speed of light in vacuum [84].

Besides the nano antenna, a nano transceiver is needed to generate and process the signals that drive the nano antenna. Keeping this in mind, Ian F. Akyildiz and Josep Miquel Jornet [84] recently proposed a novel plasmonic nano transceiver that is based on high-electron-mobility transistors, built with III-V semiconductor material, and enhanced with graphene [85] [86]. The proposed plasmonic nano transceiver operates efficiently in the THz band, is sufficiently small, and is easily integrated with the nano antenna. The main difference between a metallic antenna and a plasmonic antenna is that the equivalent electrical size of a plasmonic antenna is much larger than its physical dimensions, due to the much lower speed of Surface Plasmon Polarization (SPP) waves in the plasmonic antenna compared to that of free-space EM waves in classical antennas. The main difference between classical plasmonic antennas and graphene based plasmonic antennas is that SPP waves in graphene are observed at frequencies in the Terahertz Band, i.e. two orders of magnitude below SPP waves observed in gold and other noble materials [87]. In addition, graphene SPP waves can be tuned by material doping, which opens the door to tunable nano-antennas.

In recent literature, it has been reported that the THz emission efficiency can be substantially increased if the bulk semiconductor is replaced with a structured surface. For example, emission from porous InP [88], InN nanorods [89] and ZnSe nanograins [90] has been reported as two orders of magnitude larger than their corresponding bulk samples. InAs nanowires have about 15 times greater THz power efficiency than a planar InAs substrate [91]. GaAs NWs were excited by femto second optical pulses, and the duration of the generated THz pulses was measured [92]. If optical rectification is dominant in the emission, then the duration of the generated THz pulses should be comparable to that of the optical excitation pulse. The power of the THz emission was measured in the specular direction as a function of the relative time delay between the pulses. It is found that the n-doped GaAs NWs with gold caps have the strongest THz response, exceeding those of bulk epitaxial GaAs. This confirms that GaAs NWs can be used for the fabrication of efficient THz emitters.

In addition to the challenges of miniaturizing the device, enabling communication among nano devices requires the development of new THz band channel models, novel physical layer solutions (e.g., information coding and modulation techniques), as well as networking protocols tailored to the peculiarities of nano networks [93].

8. AUTOMATIC TARGET RECOGNITION (ATR)

Automatic target recognition (ATR) generally refers to the use of computer processing to detect and recognize target signature in sensor data.

Detection and location of different targets buried in ground or constructional walls depends to a great extent on the knowledge of expected target return response [94]. Interest in ATR is increasing in the defense community as the need for precision strikes in limited warfare situations has become an increasingly important part of defense activity [95]. ATR permits precision strikes against certain tactical targets with reduced risk and increased efficiency while minimizing collateral damage to other objects. ATR technology can also be applied to non military problems as well. We can think of the ATR problem as one part of the general problem of machine vision; namely how computers can be made to do what humans do so easily and naturally.

ATR system design usually consists of four stages. The first stage is to select the sensor or sensors to detect the target parameters. The next stage is the pre-processing of the data and the selection of regions of interest within the data (segmentation). The third design step is feature extraction and selection: the extraction of a set of numbers which characterize regions of the data. The last step is the processing of the features for decision making (classification) [96]. A generic data flow in ATR system is shown in Figure 5

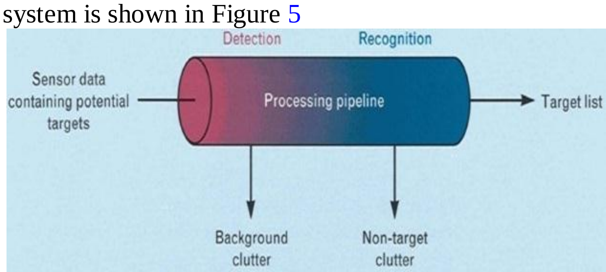

Figure 5: Conceptual data flow in ATR [95]

Many technologies and techniques are utilized in attempting to solve the problem of ATR, as illustrated in Figure 6. Pattern recognition is the most mature approach used for ATR applications. Target-signature representation options range from two dimensional image templates to lower dimensional vectors of feature that are designed to be differentially sensitive target and non target. Pattern recognition, which also relies heavily on statistics, includes more ad hoc approaches (e.g., spectral coefficients, fractal dimensions, and blob aspect ratios), especially in the definition and extraction of the features used to characterize targets [97].

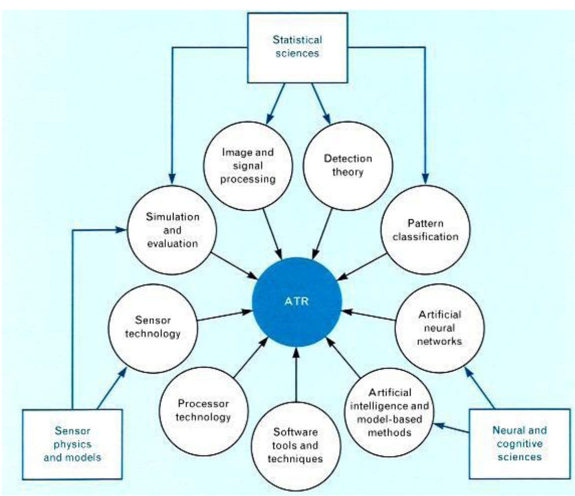

Figure 6: Some Possible technologies and processing method for ATRs [95]

The fundamental problem of ATR is to detect and recognize objects of interest (targets) in an environment of clutter imaged by an imperfect sensor that introduces noise into the resulting signal [98]. Clutter refers to real things that are imaged (buildings, cars, trucks, grass, trees, and other objects) but are not targets of interest. Clutter tends to dominate the imagery simply because targets are generally sparse compared to the environment in they operate. Noise refers to electronic noise in the sensor as well as inaccuracies introduced in the computations by a signal processor. Depending on the ATR application, the problem may be one of a signal from noise or it may be one of separating a target from its surrounding clutter. Such problem can be overcome by using THz frequency signal which can easily penetrate through most of the elements and a very high-frequency compact radar range has been developed to measure scale models of tactical targets. This compact range has demonstrated very good signal-to-noise and is useful in measuring low observable targets. In addition to normal ISAR imaging of targets (range vs. horizontal cross-range), the system can also produce two-dimensional images in azimuth and elevation (vertical cross-range vs. horizontal cross-range) [99].

ATR system development and evaluation requires an enormous quantity of data because of the variability in target signatures and background clutter [95]. The assembly of large, realistic experimental database, however, is time consuming and expensive. As a result, we need to develop techniques that minimize data requirements or, to put it differently, utilize experimental data more effectively. Simulation is one such approach; limited experimental data can be used to develop and validate simulation model that can then be used to generate data for system development and evaluation [95].

The ATR problem may not be solved by a single brilliant idea. The solutions will probably require a combination of improved sensors, faster computers and better algorithms.

8.1 Soft computing tools for ATR

Automatic target recognition is an algorithm that locates or detects potential targets and identifies their types. Detection decisions can be applied to signals present at various stages of the radar signal processing, from raw echoes to heavily pre-processed data such as Doppler spectra or even synthetic aperture radar images [95]. Neural network, fuzzy systems and genetic algorithms are the structural elements (soft computing tools) of computational intelligence (CI) [100]. Artificial Neural Network (ANN) can be used as a non-parametric prediction tool that can have the ability to retain the learning acquired from the surroundings for target recognition. A special kind of dynamic ANN is Recurrent Neural Network which can track the time varying contextual information and use this knowledge subsequently to make discrimination between adjacent patterns [101]. The medium through which the radar signal will pass is not ideal and will distort the signal. So for a conventional system, it is very difficult to recognize the target from the distorted signal. In such a situation, non parametric tools such as ANN can outperform the conventional systems. S. Chakrabarti, N. Bindal, and K. Theagharajan proposed an ANN based radar target classifier, and its performance is compared with that of a conventional classifier. Radar returns from realistic aircraft are synthesized using a thin wire time domain electromagnetic code. The time varying backscattered electric field from each target is processed using both a conventional scheme and best scheme for classification purposes. It is found that a multi layer feed forward ANN, trained with a backpropagation learning algorithm, provides a higher percentage successful than the conventional scheme [102]. The pulses which will actually be transmitted will then be correlated in time. So systems with memory can perform better, and that is why dynamic network can be used in ATR. Automatic classification of the radar target signals is a pattern recognition problem, and for this feature extraction plays a vital role. An ANN could be used for feature extraction followed by adaptive network based fuzzy inference system as a classifier [103]. Another soft-computing tool is the use of fuzzy-neural or neuro-fuzzy systems. As far as Fuzzy logic based systems are concerned, their mathematical foundation was established by Loft Zadeh, who came up with the principle of incompatibility which is, in some sense, the same concept as that developed by Aristotle, more than 2000 years ago. Since then people have been using both neural network and fuzzy logic based systems separately, or in combination to solve many engineering problems [103]. Advantages of using Fuzzy logic are as follows [103]:

- Capacity to represent inherent uncertainties of human knowledge
- Simple interaction of the expert of the domain with designer of the system Easy interpretation of the results
- Easy extension of the base of knowledge robustness in relation to disturbances in the system

8.2 Issues in ATR

The primary objective of ATR for RADAR is to detect and recognize objects, such as tanks in the battle field, different clutters, different obstacles etc. The existing ATR methods are not fully automatic which always rely upon the partnership between computer processing and human analysis. In the existing situation, to detect a battle vehicle (such as tank) it takes about thirty minutes by a group of seven image analysts and one supervisor. To distinguish between different types of radar returns including weather, bird and aircraft, a Neural Network classifier can be used [104] [105]. This classifier can be used for both pre and post processing procedures and multilayer feed forward network in its design. It has an average classification accuracy of 89% on generalization for data collected in a single scan of radar antenna [105]. The difficulties associated with ANNs include dimensionality and generalization related problems. For learning many dimensional data such as radar return, either a huge number of samples are required, or the data must first be reduced by the extraction of a relatively small number of features for the ANN to learn. If the number of data samples available is too less, then the network will over t the training data, resulting in poor generalization on the test data. Hence, designing an ANN requires experimentation to determine the best architecture for a given problem and associated data set [101]. The size of the network is an important consideration from both the performance and computational points of view [106]. When using a neural network to perform pattern classification and pattern recognition, some representative features must be presented to the network for it to learn. In general, good features normally lead to a good performance for the neural network. But determining a set of meaningful and representative features is usually a difficult problem [98]. A better approach would be a bank of ANNs, connected to an ANN intended to perform optimization. The output of each of the networks in the ANN-bank can be used by another ANN trained to optimize and select the best estimation offered by the ANNs forming the ANN-based estimator bank. Further hybrid systems consisting of ANN-Fuzzy or Genetic Algorithm-Fuzzy [107] could be other prospective solutions.

9. CURRENT STATUS

Of late, there has been renewed interest for research in the field of ATR technology. Of late, people have started the hybrid estimator/classifier using ANN and Fuzzy for ATR problem. In addition people have tried to use feedback neural network like RNN for the proper processing of the radar signals [108]. There are some other research groups world-wide, who are working in the development of radar system for the THz frequency band. MIT Linchon Laboratory is one of the prominent laboratories, where advancement in radar technology is growing up. Very few research works have been found recently, where people have started designing nanotechnology based THz signal generator and detector for radar. The phenomenon of using soft computing tools like Neuro-Fuzzy and Fuzzy-Neuro in the field of ATR for radar in THz band is very new.

Terahertz and sub terahertz frequencies have also been investigated for decades as a high-speed data-transfer solution; especially for rural or remote locations where extending the fiber-optic network would be difficult and costly. The problem with the radio spectrum between 3 and 3000 megahertz is that, its crowded. TV, radio, mobile phones, Bluetooth, GPS, two-way communication devices, and Wi-Fi all operate in this high to ultrahigh frequency range. So with nowhere to go but up, researchers have been working for decades to utilize the 3- to 3000-gigahertz span. Scientists in Germany, at the Karlsruhe Institute of Technology (KIT), the Fraunhofer Institute for Applied Solid State Physics and the University of Stuttgart, created a wireless connection between a transmitter and a receiver that were 20 meters apart at a frequency of 237.5 GHz. This frequency is in the millimeter-wave portion of the spectrum and sufficiently close to the THz region [109]. One feature of sub THz transmission that the German group found especially promising is that this type of radiation is less affected by local conditions like fog or rain when compared with free-space optical transmission, which uses lasers to carry data through the air.

THz research has seen the synergistic integration of THz waves, THz photonics, and THz electronics. For instance biometrics combined with the wireless communication can be a potential security sensor network system in the future [110].

DARPAs THz Monolithic Integrated Circuit (TMIC) is the first solid state amplifier demonstrating gain above 1THz (1012 GHz). This achievement recognized by Guinness World Records, could open up new areas of research and unforeseen applications in the sub-milimeter wave spectrum and brings unprecedented performance to circuits operating in more conventional frequency bands [111].

A single component solution capable of room temperature and widely tunable operation is highly desirable to enable next generation THz systems. The Director of North westerns center for Quantum Devices, Dr. Razeghi and her team has been working to develop such a device. In a recent paper in Applied Physics Letters they demonstrated a room temperature, highly tunable, high power THz source. Based on nonlinear mixing in quantum cascade lasers, the source can emit up to 1.9 milliwatts of power and has wide frequency coverage of 1 to 4 THz [112].

UCLA Henry Samueli School of Engineering and Applied Science research team has developed a breakthrough broadband modulator that could eventually lead to more advanced security imaging systems. The new modulator is based on an innovative artificial meta-surface, a type of surface with unique properties that is defined by the geometry of its individual building blocks and their arrangement which diminishes many of the physical constraint in routing and manipulating THz waves especially in THz imaging and spectroscopy systems [113].

A new solution for detecting hidden materials offered by THz scanner developed by researchers at the Fraunhofer Institute for physical Measurement Techniques IPM in Kaiser-slautern in collaboration with Hubner Gmbh and Co. KG in Kassel. Their T-CONGNITION systems are capable of detecting and identifying the hidden content of suspicious packages of envelopes without having to open them [114].

Recent developments in surveillance and security system demands for a very high frequency radar system, which can be operated with high bandwidth and high fidelity. High frequency radar system can be very useful for security and surveillance as signal in THz frequency band can behave differently for different object; also it can locate hidden objects.

Soft computational framework for ATR of radar in THz band has not been reported in the literature. Generation and detection of THz signal is also found to be a big challenge for the developer. This may lead to development of new systems based on nanotechnology. The only solution of fabrication of THz source and detector may lie in the hand of nanotechnologist. Intrinsic properties of metals vary at the nano-scale, and common assumptions of antenna theory might no longer be valid. An alternative is to use novel nanomaterials such as graphene to develop nanoantennas for THz signals. So far no literature has been found where there is a physical realization of ATR for radar in THz frequency using nanotechnology. Therefore in future a complete setup of ATR system based on neuro-fuzzy and/or fuzzy-neuro for radar with nanotechnology based source detector for THz signal could be a solution for security and surveillance. It may develop a new dimension towards the machine intelligence in involvement of nanotechnology in radar engineering.

10. CONCLUSION

Based on applications, there is an increasing range of radar systems like police traffic radar, spaceborne (both satellite and space shuttle) radar and airborne radar, to name a few. While this sketch of radar applications is far from exhaustive, it does indicate the breadth of applications of this remarkable technology. This text presents a thorough, straightforward, and consistent description of the automatic target recognition of radar technology, focusing primarily on the high frequency (THz) radar. The reason for this focus is that, high frequency signals have very important advantages towards the application in surveillance and security systems. Over nearly two decades, THz technology have made some progress and development in both basic research and applied research. A comprehensive summary of the current THz technology in the field of basic research, technology research and civilian applications is presented. Since the terahertz frequency band is still in immature fields from production point of view, measurement technology for evaluating characteristics has not yet been developed. Finally, the subject is approached from a nanotechnology viewpoint as much as practicable, both because most new high frequency radar designs rely heavily on nanomaterial and because this approach can unify concepts and results often treated separately.

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References

[1] F. Qiang, Y. Wenxian, Automatic target recognition based on incoherent radar returns, Proceedings of the IEEE Aerospace and Electronics Conference, NAECON 1995 1 (May 1995) 123-128.

[2] D. E. Dudgeon, R. T. Lacoss, An overview of automatic target recognition, The Lincoln Laboratory Journal 6 (1) (1993) 3-10.

[3] S. Haykin, Neural Networks, Pearson Education, New Delhi, 2003.

[4] C. H. Wilcox, The synthesis problem for radar ambiguity functions, Math Res. Center, U.S. Army, Univ. Wisconsin, Madison, WI, MRC Tech. Summary Rep. 157, April 1960; reprinted in R. E. Blahut, W. M. Miller, and C. H. Wilcox, Radar and Sonar, Part 1, New York, Springer-Verlang (1991).

[5] H. Naparst, Dense target signal processing, IEEE Transactions on Information Theory 37 (2) (March 1991) 317-327.

[6] M. R. Bell, Information theory and radar waveform design, IEEE Transactions on Information Theory 39 (5) (September 1993) 1578-1597.

[7] S. U. Pillai, H. S. Oh, D. C. Youla, J. R. Guerci, Optimum transmit-receiver design in the presence of signal-dependent interference and channel noise, IEEE Transactions on Information Theory 46 (2) (March 2000) 577-584.

[8] S. Kay, Optimal signal design for detection of point targets in stationary gaussian clutter/reverberation, IEEE Journal on Selected Topics in Signal Processing 1 (1) (June 2007) 31-41.

[9] K. Bhattacharyya, K. K. Sarma, E cient signal processing for design of ANN based automatic target recognition (ATR) system, proceeding of 57th Annual Technical session and Journal of Assam science Society (February, 2012) .

[10] Goyette, T. M., A. Gatesman, T. M. Horgan, THz compact range radar systems, Pennsylvania (June 13, 2003).

[11] K. B. Cooper, R. J. Dengler, NuriaLlombart, B. Thomas, G. Chattopadhyay, P. H. Siegel, THz imaging radar for stando personnel screening, IEEE Transaction on Terahertz Science and Technology 1 (1) (September 2011).

[12] Y. Wu, ZhengwuXu, J. Li, Terahertz radar signal for heart and breath rate detection based on time-frequency analysis, Communications, Signal Processing and Systems, Lecture Notes in Electrical Engineering 202, Springer science business Media New York (2012) doi:10.1007/978.1.4614.5803.653.

[13] J. M. Jornet, I. F. Akyildiz, Graphene-based plasmonic nano-transceiver for terahertz band communication, 8th European Conference on Antennas and Propagation (Eu-CAP) (April 2014) 492-496.

[14] M. J. Fitch, R. Osiander, Terahertz waves for communications and sensing, JOHNS HOPKINS APL TECHNICAL DIGEST 25 (4).

[15] M. Tonouchi, Cutting-edge terahertz technology, Nature Photonics 1 (2007) 97-105.

[16] M. I. Skolnik, Opportunities in radar, Electronic, Communication and Engineering Journal (ECEJ), IEEE (December 2002) 263-272.

[17] Radar basics, www.radartutorial.eu.

[18] E. M. Staderini, Everything you always wanted to know about UWB radar: a practical introduction to the ultra wideband technology, downloaded from http://67.225.133.110/ gbpprorg/mil/radar/osee.pdf on 05-06-2015.

[19] Nathanson, F. A, Radar Design Principles: Signal Processing and the Environment, McGraw-Hill, 1969.

[20] M. I. Skolnik, Introduction to radar systems, 3rd ed. Mc Graw Hill, 2001.

[21] F. Gini, A. Farina, M. Greco, Selected list of references on radar signal processing, IEEE transaction on Aerospace and Electronic Systems AES-37 (January 2001) 329-359.

[22] Coleman, P. D., R. C. Becker, Present state of the millimeter wave generation and technique, IEEE Transactions on Microwave Theory and Techniques 7 (January 1959) 42-61.

[23] Appleby, R., R. N. Anderton, Millimeter-wave and submilimeter-wave imaging for security surveillance, Proceedings of the IEEE 95 (2) (August. 2007) 1683-1690.

[24] Oka, S. H. Togo, N. Kukutsu, T. Nagatsuma, Latest trends in millimeter-wave imaging technology, Progress In Electromagnetic Research Letters 1 (2008) 197-204.

[25] Kemp, M. C., A. Glauser, C. Baker, Recent developments in people screening using terahertz technology| seeing the world through terahertz eyes, Proc. SPIE 6212 (2006) 27-34.

[26] Appleby, R., H. B. Wallace, Stando detection of weapons and contraband in the 100 GHz to 1 THz region, IEEE Trans. on Ant. and Prop. 55 (11) (November 2007) 2944-2956.

[27] Federici, J. F. B. Schulkin, F. Huang, G. Dale, R. Barat, F. Oliveira, D. Zimdars, THz imaging and sensing for security applications | explosives, weapons and drugs, Semiconductor Sci. Tecnol. 20 (7) (Jully 2005) S266-S280.

[28] Sheen, D. McMakin, T. E. Hall, Three-dimensional millimeter-wave imaging for concealed weapon detection, IEEE Trans. MTT 49 (9) (2001) 1581-1592.

[29] S. W. Harmer, S. E. Cole, N. J. Bowring, N. D. Rezgui, D. Andrews, On body concealed weapon detection using a phased antenna array, Progress In Electromagnetics Research 124 (2012) 187-210.

[30] Siegel, P. H, Terahertz technology, IEEE Transactions on Microwave Theory and Techniques 50 (March 2002) 910-928.

[31] Q.Wu, X.-C.Zhang, Free-space electro-optic sampling of terahertz beams, Applied Physics Letters 67 (1995) 3523-3525.

[32] W. JC, History of millimeter and submillimeter waves, IEEE Trans Microwave Theory Tech (MTT) 32 (1984) 1118-1127.

[33] M. Williams, Terahertz tech gets a major push at rice, Posted In Current News, Fea-tured Stories, Rice University News and Media (June 24, 2014) .

[34] J. Jomet, I. Akyildiz, Channel capacity of electromagnetic nanonetworks in the tera-hertz band, Proc. Of International Conference on Communications, ICC, Cape Town, South Africa (May, 2010).

[35] J. M. Jornet, I. F. Akyildiz, Femtosecond-long pulse-based modulation for terahertz band communication in nanonetworks, IEEE TRANSACTIONS ON COMMUNICA-TIONS 62 (5) (MAY 2014) 1742{1754.

[36] I. F. Akyildiz, J. M. Jornet, C. Hana, Terahertz band: Next frontier for wireless communications, Physical Communication 12 (2014) 1632.

[37] B. Zhu, Y. Chen, K. Deng, W. Hu, Z. S. Yao, Terahertz science and technology and applications, PIERS Proceedings, Beijing, China (March 23-27, 2009) .

[38] A. B. Shah, Terahertz data processing for stando detection of improvised explosive devices, Masters Theses, Curtis Laws Wilson Library, Missouri University of Science and Technology (2007).

[39] B. Fischer, M. Homan, H. Helm, G. Modjesch, P. U. Jepsen, Chemical recognition in terahertz time-domain spectroscopy and imaging, Semicond.Sci.Technol. 20 (2005) S246-S253.

[40] X. Shen, C. R. Dietlein, E. Grossman, Z. Popovic, F. G. Meyer, Detection and segmen-tation of concealed objects in terahertz images, IEEE Transaction on image Processing, 17 (12) (December 2008) 2465-2476.

[41] M. J. Rosker, H. B. Wallace, Imaging through the atmosphere at terahertz frequencies, IEEE MTT-S International Symposium (June 2007).

[42] C. M. Armstrong, The truth about terahertz, IEEE Spectrum (17 August 2012).

[43] R. W. McMillan, Terahertz imaging, millimeter-wave RADAR, U.S. Army Space and Missile Defence Command, Huntsville, Alabama, USA.

[44] H.-J. Song, T. Nagatsuma, Present and future of terahertz communications, IEEE Transactions on Terahertz Science and Technology 1 (1) (September 2011).

[45] M. C. Kemp, Explosives detection by terahertz spectroscopya bridge too far?, IEEE Transactions on Terahertz Science and Technology 1 (1) (September 2011).

[46] Z. D. T. et al, Thz medical imaging: In vivo hydration sensing, IEEE Transactions on Terahertz Science and Technology Special Inaugural Issue 1 (1) (September 2011).

[47] J. Norbury, C. Gibbins, D. Matheson, A study in to the theoretical appraisal of the highest usable frequencies, Radio communications

Agency Contract Reference AY 4329 (May 2003) .

[48] A. G. Davis, E. H. Lin led, M. B. Jonston, The development of terahertz sources and their applications, Physics in Medicine and Biology 47 (October 2002) 3679-3689.

[49] Y. C. Shen, P. C. Upadhya, H. E. Beere, E. H. Lin eld, A. G. Davies, I. S. Gregory, C. Baker, W. R. Tribe, M. J. Evans, Generation and detection of ultrabroadband tera-hertz radiation using photoconductive emitters and receivers, Applied Physics Letters, 85 (2) (July 2004) 164-166.

[50] T. Tanabe, K. Suto, J. ichi Nishizawa, T. Sasaki, Characteristics of terahertz-wave generation from GaSe crystals, Journal of Physics D: Applied Physics 37.

[51] M. K. Saito, Y. Nagai, K. Yamamoto, K. Maeda, T. Tanabe, Y. Oyama, Terahertz wave generation via nonlinear parametric process from GaSe single crystals grown by liquid phase solution method, Optics and Photonics Journal, 4 (2014) 213-218.

[52] J. N. Heyman, P. Neocleous, D. Hebert, P. A. Crowell, T. Muller, K. Unterrainer, Terahertz emission from GaAs and InAs in a magnetic eld, Phys. Rev. B 64, 085202.

[53] F. Wang, D. Cheever, M. Farkhondeh, W. Franklin, E. Ihlo, J. van der Laan, B.McAllister, R. Milner, C. Tschalaer, D. Wang, D. F. Wang, A. Zolfaghari, T. Zwart, G. Carr, B. Podobedov, F. Sannibale, Coherent thz synchrotron radiation from a stor-age ring with high frequency rf system, Phys. Rev. Lett., 96 (2006) 064801.

[54] G. L. Carr, M. C. Martin, W. R. McKinney, K. Jordan, G. R. Neil, G. P. Williams, High-power terahertz radiation from relativistic electrons, Nature 420 (2002) 153-156.

[55] R. J. Bell, Introductory fourier transform spectroscopy, Academic, New York (1972).

[56] K. M. Evenson, D. A. Jennings, K. R. Leopold, L. R., Zink in laser spectroscopy VII., Seventh International Conference on Laser Spectroscopy (T. W. H. andY. R. Shen, ed.), Springer, Berlin (1985).

[57] Q. H. B. Xu, M. R. Melloch, Electrically pumped tunable terahertz emitter based on intersubband transition, Appl. Phys. Lett. 71 (1997) 440-442.

[58] D. Turchinovich, Study of ultrafast polarization and carrier dynamics in semiconductor nanostructures: A THz spectroscopy approach, PhD thesis, University of Freiburg (2004).

[59] D. H. Auston, Subpicosecond electro optic shock waves, Appl. Phys. Lett. 43 (1983) 713-715.

[60] A. G. Davis, E. H. Lin led, M. I. M. B. Jonston, The development of terahertz sources and their applications, Physics in Medicine and Biology 47 3679-3689.

[61] M. R. Boersma, An introduction to terahertz electromagnetic waves generation, detection, properties and applications, downloaded from https://www.calvin.edu/.../boersma-tera%201st%20rough%20draft.doc.

[62] L. Carr, M. Martin, W. McKinney, G. Neil, K. Jordan, G. Williams, High power terahertz radiation from relativistic electrons, Nature (2002) 420-153.

[63] T. Tanabe, K. Suto, J. Nishizawa, T. Sasaki, Characteristics of terahertz-wave gener-ation from GaSe crystals, Journal of Physics D: Applied Physics 37 155-158.

[64] T. Tanabe, K. Suto, J. Nishizawa, K. Saito, T. Kimura, Frequency-tunable terahertz wave generation via excitation of phonon-polaritons in GaP, Jurnal of Physics D: Ap-plied Physics 953-957.

[65] T. K.-O. &. TadaoNagatsuma, A review on terahertz communications research, Journal of Infrared MilliTerahz Waves 32 (2011) 143171. doi:10.1007/s10762-010-9758-1.

[66] F. Grillot, N. A. Naderi, J. B. Wright, R. Raghunathan, M. T. Crowley, L. F. Lester, A dual-mode quantum dot laser operating in the excited state, Appl. Phys. Lett. 99 (23) (December 2011) 231110-1231110-3

[67] A. Hurtado, I. D. Henning, M. J. Adams, L. F. Lester, Generation of tunable millimeter-wave and THz signals with an optically injected quantum dot distributed feedback laser, IEEE Photonics Journal 5 (4) (August 2013) .

[68] I. N. D. Anupam Tiwari, Member (L-209735), Military nanotechnology, International Journal of Engineering Science and Advanced Technology, ISSN: 22503676 2 (4) (July-August 2012) 825 830.

[69] H. R. S. Seyyed Hossein Asadpour, Zahra Golsanamlou, Infrared and terahertz sig-nal detection in a quantum dot nanostructure, Elsevier, Physica E: Low-dimensional Systems and Nanostructures 54 (4552) (December 2013).

[70] S. Choi, E cient antennas for terahertz and optical frequencies, PhD Dissertation, Electrical Engineering, University of Michigan (2014).

[71] J. Jomet, I. Akyildiz, Graphene-based nano-antennas for electromagnetic nanonetworks in

the terahertz band, in Proc. Of 4th European Conference on Antenna and ropagation, Barcelona, Spain (April 2010) .

[72] P. L. McEuen, M. S. Fuhrer, H. K. Park, Single-walled carbon nanotube electronics, IEEE Transactions on Nanotechnology 1 (March 2002) 78-85.

[73] S. D. Li, Z. Yu, C. Rutherglen, P. J. Burke, Electrical properties of 0.4 cm long single-walled carbon nanotubes, Nano Letters 4 (October 2004) 2003-2007.

[74] R. Saito, G. Dresselhaus, M. S. Dresselhaus, Physical properties of carbon nanotubes, World Scienti c 4 (1998).

[75] C. Rutherglen, P. Burke, Nanoelectromagnetics: Circuit and electromagnetic proper-ties of carbon nanotubes, Small 5 (April 2009) 884-906.

[76] B. Q. Wei, R. Vajtai, P. M. Ajayan, Reliability and current carrying capacity of carbon nanotubes, Applied Physics Letters 79 (August 2001) 1172-1174.

[77] S. Choi, K. Sarabandi, Design of e cient terahertz antenna: Carbon nanotube vesus gold, 2010 IEEE Int. Symp. On Antennas and Propag. And USNC/URSI Nat. Radio Science Meeting, Toronto, ON, Canada (July 2010).

[78] S. Salahuddin, M. Lundstrom, S. Datta, Transport e ects on signal propagation in quantum wires, IEEE Transactions on Electron Devices 52 (August 2005) 1734-1742.

[79] J. J. Plombon, K. P. O'Brien, F. Gstrein, V. M. Dubin, Y. Jiao, High-frequency electrical properties of individual and bundled carbon nanotubes, Applied Physics Letters 90 (February 2007) .

[80] C. Rutherglen, D. Jain, P. Burke, Rf resistance and inductance of massively parallel single walled carbon nanotubes: Direct, broadband measurements and near perfect 50 omega impedance matching, Applied Physics Letters 93 (August 2008).

[81] G. W. Hanson, Fundamental transmitting properties of carbon nanotube antennas, IEEE Transactions on Antennas and Propagation 53 (November 2005) 3426-3435.

[82] S. Choi, K. Sarabandi, Performance assessment of bundled carbon nanotube for an-765 tenna applications at terahertz frequencies and higher, IEEE Transactions Antennas Propagation 59 (3) (March 2011) 802-809.

[83] P. J. Burke, An RF circuit model for carbon nanotubes, IEEE Transaction on Nan-otechnology 2 (1) (March 2003).

[84] I. F. Akyildiz, J. M. Jornet, Nanoscale broadband terahertz communication, Spie, 770 Newsroom, 10.1117/2.1201402.005341 (2014).

[85] J. M. Jornet, I. F. Akyildiz, Graphene-based plasmonic nano-transceiver for terahertz band communication, Proc. Eur. Conf. Antenn. Prop. (EuCAP) (2014).

[86] I. F. Akyildiz, J. M. Jornet, Graphene-based plasmonic nano-transceiver for wireless communication in the terahertz band, US Provisional Patent (2013. Filed on 6 December) .

[87] J. M. Jornet, I. F. Akyildiz, Graphene-based plasmonic nano-antenna for terahertz band communication in nanonetworks, IEEE Jornal on Selected research in Commu-nications/Suppliment Part 2 31 (12) (December 2013) 685-694.

[88] M. Reid, I. V. Cravetchi, R. Fedosejevs, I. M. Tiginyanu, L. Sirbu, Enhanced terahertz emission from porous InP (111) membranes, Applied Physics Letters 86 (2005) 021904.

[89] H. Ahn, Y. Ku, Y. Wang, C. Chuang, S. Gwo, C. Pan, Terahertz emission from vertically aligned InN nanorod arrays, Applied Physics Letters 91 (2007) 132108.

[90] S. He, X. Chen, X. Wu, G. Wang, F. Zhao, Enhanced terahertz emission from ZnSe nano-grain surface, Journal of Lightwave Technology, IEEE 26 (11) (2008) 1519-1523.

[91] D. V. Seletskiy, M. P. Hasselbeck, J. G. Cederberg, A. Katzenmeyer, M. Toimil-Molares, F. Leonard, A. A. Talin, M. Sheik-Bahae, E cient terahertz emission from InAs nanowires, Phys. Rev. B 84 (2011) 115421.

[92] V. N. Trukhin, A. S. Buyskikh, N. A. Kaliteevskaya, A. D. Bourauleuv, L. L. Samoilov, Y. B. Samsonenko, G. E. Cirlin, M. A. Kaliteevski, A. J. Gallant, Terahertz generation by GaAs nanowires, Applied Physics Letters 103 (2013) 72108_1-72108_4. doi:10. 1063/1.4818719.

[93] J. M. Jornet, I. F. Akyildiz, Channel modeling and capacity analysis for electromag-netic wireless nano networks in the terahertz band, IEEE Transaction on Wireless Communications 10 (10) (October 2011) 3211-3221.

[94] A. Z. Botros, A. D. Olver, Analysis of target response of FM-CW radar, IEEE Trans-action on Antennas And Propagation AP-34 (April 1986).

[95] A. M. Aull, R. A. Gabel, T. J. Goblick, Real-time radar image understanding: A machine

intelligence approach, The Lincoln Laboratory Journal 5 (2) (1992) 195-222.

[96] S. K. Rogers, J. M. Colombi, C. E. Martin, J. C. Gainey, Kenh, T. Burns, D. W. Ruck, 800 M. Kabrisky, M. Oxley, Automatic target recognition using neural networks, Neural Networks 8 (January1995) 1153-1184.

[97] L. M. Novak, G. J. Owirka, C. M. Netishen, Performance of a high-resolution polari-metric SAR automatic target recognition system, the Lincoln Laboratory Journal 6 (1) (1993) 11-24.

[98] S. Haykin, C. Deng, Classi cation of radar clutter using neural networks, IEEE Trans-actions On Neural Networks 2 (6) 174-188.

[99] Space-time versus frequency domain signal processing for 3d THz imaging, IEEE SEN-SORS Conference (2009) doi:978-1-4244-5335-1/09/.

[100] P. Stavroulakis, Neuro-Fuzzy and Fuzzy-Neural Applications in Telecommunications, Springer Engineering online library, 2004.

[101] K. Bhattacharyya, K. K. Sarma, Automatic target recognition (ATR) system using recurrent neural network (RNN) for pulse radar, International Journal of Computer Applications (0975 8887) 50 (23) (July 2012)

[102] S. Chakrabarti, N. Bindal, K. Theagharajan, Robust radar target classifier using artificial neural networks, IEEE Transactions On Neural Networks 6 (May 1995) .

[103] E. Avci, I. Turkoolu, M. Poyraz, Elazig, An intelligent target recognition system based on periodogram for pulsed radar systems, G.U. Journal of Science 18 (2) (2005) 259- 272.

[104] S. Haykin, C. Deng, Classi cation of radar clutter using neural network, IEEE Transactions on Neural Networks 2 (6) (November 1991) .

[105] D. E. Nelson, J. A. Starzyk, Advanced feature selection methodology for automatic target recognition, Proceedings of the 29th Southeastern Symposium on System Theory (SSST97), IEEE Computer Society Washington, DC, USA (1997) 24.

[106] S. Haykin, Neural Networks, A Comprehensive Foundation, 2nd ed., Pearson Education, New Delhi, 2003.

[107] I. Valova, G. Milano, K. Bowen, NatachaGueorguieva, Bridging the fuzzy, neural and evolutionary paradigms for automatic target recognition, Appl. Intel 35 (2011) 211-225, doi:10.1007/s10489-010-0213-8.

[108] M. U. Shaika, V. Rao, Pulse compression techniques of phase coded waveforms in radar, International Journal of Scienti c & Engineering Research 3 (8) (August 2012).

[109] L. H. Newman, A new record for terahertz transmission engineers achieve amazing data rates in a once-inaccessible band, Posted 28 Nov 2013 j20:30 GMT.

[110] M. Tonouchi, New frontier of terahertz technology, Terahertz Photonics Laboratory, 835 Institute of Laser Engineering, Osaka University (2006).

[111] Darpa circuit achieves speeds of 1 trillion cycles per second, earns guinness world record (2014, October 31, retrieved 25 June 2015 from http://phys.org/news/2014-10-darpa-circuit-trillion-guinnessworld.html).

[112] A. Morris, New terahertz device could strengthen security, McCORMICK News http://www.mccormick.northwestern.edu/new s /articles/2014/11/new-terahertz device-could-strengthen-security.html (November 20, 2014).

[113] M. Chin, Developed by UCLA team, new terahertz modulator could lead to more advanced medical and security imaging, SCIENCE + TECHNOLOGY, UCLA Newsroom (July 16, 2014).

[114] Fraunhofer Gesellschaft, Inspecting letters with terahertz waves, Press Release www.fraunhofer.de/en/press/research-news /2014/may/inspecting-letters-with terahertz-waves.html (May 21, 2014)