Monitoring Terahertz Technology

(Under contract with Armasuisse #8003404787)

ARAMIS-Nr. R-3210/040-22

Report No. 3 (Q4 / 2008)

30.11.2008

Summary

This third report covers aspects related to electronic warfare (EW), understood as the use of the electromagnetic spectrum to effectively deny the use of this medium by an adversary, while optimizing its use by friendly forces. We discuss the three main aspects of electronic warfare: electronic support, electronic attack, and electronic protection and the possible implementation/potential of terahertz waves. We also give an overview of the main groups active in the field of communication with terahertz both in research and industry

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0. Introduction

The past decade has seen an enormous increase in the use and importance of the "electronic battlefield". The detection and evasion through the use of the electromagnetic radiation has become a dominant feature of modern air warfare. The knowledge of test methods and processes as well as definition-clarification of the bandwidth of operation is of great importance.

The term electronic warfare (EW) describes the use of electromagnetic radiation to effectively disturb or block the use of certain communication channels by an adversary, while optimizing its use by friendly forces. Electronic warfare has three main components: electronic support, electronic attack, and electronic protection that will be described in the following sections.

1. Electronic support

In military telecommunication, Electronic Support (ES) or Electronic Support Measures (ESM) is that division of electronic warfare concerned with the ability to search for, intercept, identify, locate, record, and/or analyze sources of radiated electromagnetic energy. Electronic Support provides a source of information required for decisions involving Electronic Protection (EP), Electronic Attack (EA), avoidance, targeting, and other tactical employment of forces. Electronic Support data can be used to produce signal intelligence (SIGINT), communications intelligence (COMINT) and electronics intelligence (ELINT). Radar warning and missile warning receivers, as well as many off-board surveillance systems, are considered elements of ES.

Electronic support measures (ESM) gather intelligence through passive "listening" to electromagnetic radiations of military interest [1]. They can provide: (1) initial detection or knowledge of foreign systems, (2) a library of technical and operational data on foreign systems, and (3) tactical combat information utilizing that library. ESM collection platforms can remain electronically silent and detect and analyze RADAR transmissions beyond the RADAR detection range because of the greater power of the transmitted electromagnetic pulse with respect to a reflected echo of that pulse.

Desirable characteristics for electromagnetic surveillance and collection equipment include:

(1) Wide-spectrum or bandwidth capability because the frequencies used by the enemy are initially unknown.

(2) Wide dynamic range because signal strength is initially unknown.

(3) Narrow bandpass to discriminate the signal of interest from other electromagnetic radiation on nearby frequencies.

(4) Good angle-of arrival measurement for bearings to locate the transmitter. The main frequency spectrum of interest up to now ranges from 30 MHz to 50 GHz, and up. Only the lack of adequate equipment represents a limit to this range. Multiple receivers are typically required for surveillance of the entire spectrum, but tactical receivers may be functional within a specific signal strength threshold of a smaller frequency range. We will discuss two examples where the implementation of terahertz technology will represent an advantage: the radar warning receivers (RWRs) and warning systems.

1.1 Radar Warning Receivers

Radar warning receivers have three basic components: some type of sensor (usually a set of antennas to capture the RF signals of interest), a receiver/processor to measure and analyze the RF signals of interest, and a display to make the information available. The combinations of these components are numerous depending on the mission and configuration of the platform in which they are installed. A typical system is shown symbolically in figure 1. It consists of an antenna array, an RF signal processor, a control panel and display.

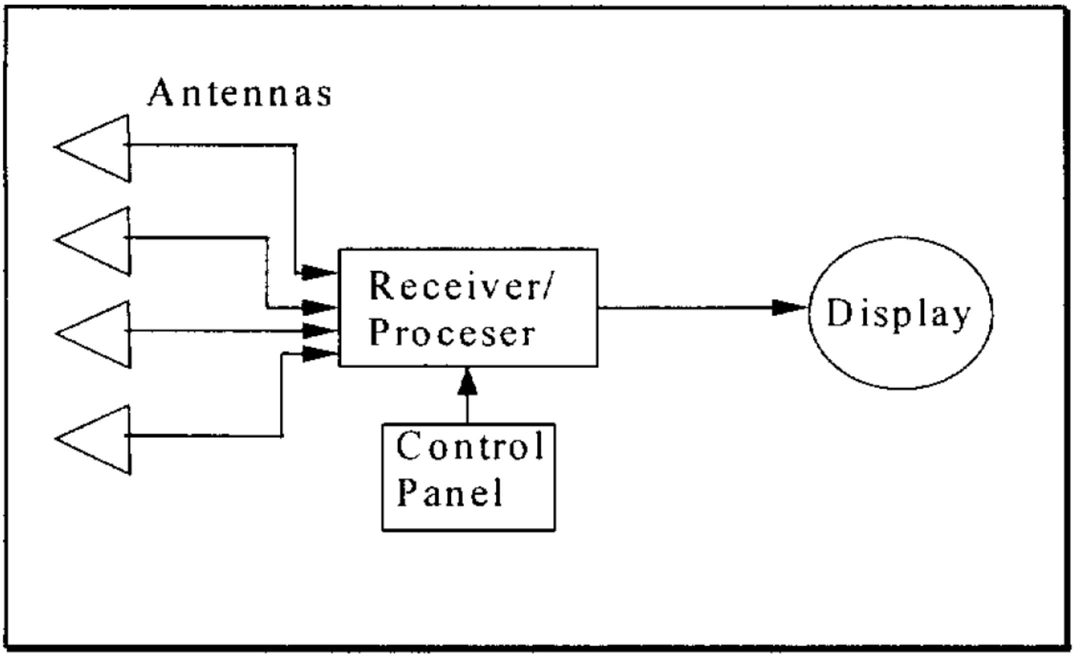

Figure 1. Radar warning receiver simplified block diagram.

The orientation and mounting of the antennas and ultimately of the whole system depend on the object where they are mounted. The receiver/processor measures the magnitude of the RF energy at the four antennas and performs an amplitude comparison to see from which direction the RF energy is being radiated. The time of arrival of each pulse referenced to an internal clock is determined. If the signal is continuous wave, then the band the RF energy is in, or in some cases the actual RF frequency is measured. Pulse widths, amplitude changes over time can also be measured such that radar scan information can be derived. Presently for aircraft surveillance, antennas can mainly cover 2 to 18 GHz.

It is imaginable that this scenario will work in the terahertz range (0.1 – 10 THz) of the spectrum, provided that adequate antennas can be fabricated, and the same can be stated for the receivers. As reported in the second quarter of this monitoring, there are some antennas available below 300 GHz and efforts are ongoing towards 800 GHz [2].

For application in communication nonlinear optical techniques, which allow the generation of 0.2 – 20 THz radiation, have not yet been reported in the literature. This new technique has the following advantages:

- directed (THz laser) radiation with lower divergence angle
- good spatial resolution
- high power
- difficult to detect

However there are not sufficiently precise data available on the THz frequencies that can be used for free space communication through the air (water and gas molecule absorption). Since the communication range most critically depends on the frequencies where molecular vibrations are excited by the THz radiation, it is required that the transmission bands at THz frequencies are identified. From the rough data published we estimate a transmission range of few times ten to few times hundred meters at the earth surface. Therefore from the published air absorption data it is not clear that near earth radar systems at THz frequencies could be used efficiently. More precise absorption data would be required to fin out the best THz transmission channels.

In order to avoid the influence of atmospheric conditions, transmission through clouds, etc… radars operating with radio waves are preferred specially for passive earth observation. In this approach the radio waves are reflected by the earth's surface and are received again by the satellite. An example is the TerraSAR-X [3] radar. This system operates at 9.65 GHz with resolutions of 1m, 3m or 16 m depending on image size. As a particular case the ACROBAT [4] radar normally operates in a mode suited to scanning through the boundary layer, with a minimum range of 1.8 km and maximum range of 48 km. The radar operates with pulse compression techniques to maximize sensitivity whilst maintaining high range resolution. Computer-controlled transmit waveform generation technology, together with a PC-based data acquisition and processing system, provide considerable versatility in terms of custom operating modes. Other systems are using heterodyne radiometers to measure thermal emission at frequencies below 600 GHz and 2.5 THz [5].

1.2 Warning Systems

Passive threat warning systems are designed to detect the electromagnetic radiation from threat missiles for example. Systems operating in the infrared were developed already 30 years ago. So far existing systems operate in the mid-IR band (4-5 micrometers wavelength), they can be scanning or staring sensors. **Scanning systems** provide high resolution direction that is often useful for effective countermeasures deployment. However, they generally give up some capability in the processing area because the time required to scan can prevent the warning system from detecting signature characteristics needed to identify the threat.

Projection: in the previously discussed types of warning systems there is a need to go to frequencies above 300 GHz and into the terahertz region. There is also a need to reduce the scanning time of a signal. This is a parameter that is closely related with the frequency selected, and the method to generate or detect terahertz radiation. Although the realization of such a system implies a large road map, improvements in the scanning time are inherent to pulsed systems whose operation principle is based on nonlinear optics.

2. Electronic Attack

Electronic attack (EA) is the active or passive use of the electromagnetic spectrum to attack personnel, facilities, or equipment. We can distinguish four basic subdivisions: jamming, deception, antiradiation missiles and directed energy weapons. Jamming is generally defined as deliberate radiation, re-radiation, or reflection of energy for the purpose of preventing or reducing the use of radiation in the electromagnetic spectrum by a second party. This definition can be extended to cover similar actions against similar action against infrared (IR) ultraviolet (UV), and electro-optical systems. We will briefly discuss jamming with radar frequencies RF and infrared radiation.

2.1 RF Countermeasures

Figure 2 shows a simplified Jammer block diagram. An RF system has four basic components: some type of sensor to capture the environment, in this case an antenna, a receiver/processor to analyze the data, and a pilot interface. In addition to these components, the system has a modulator/transmitter module used to modulate and amplify the jamming waveform. The system also includes a transmit antenna or antenna array to radiate the appropriate jamming.

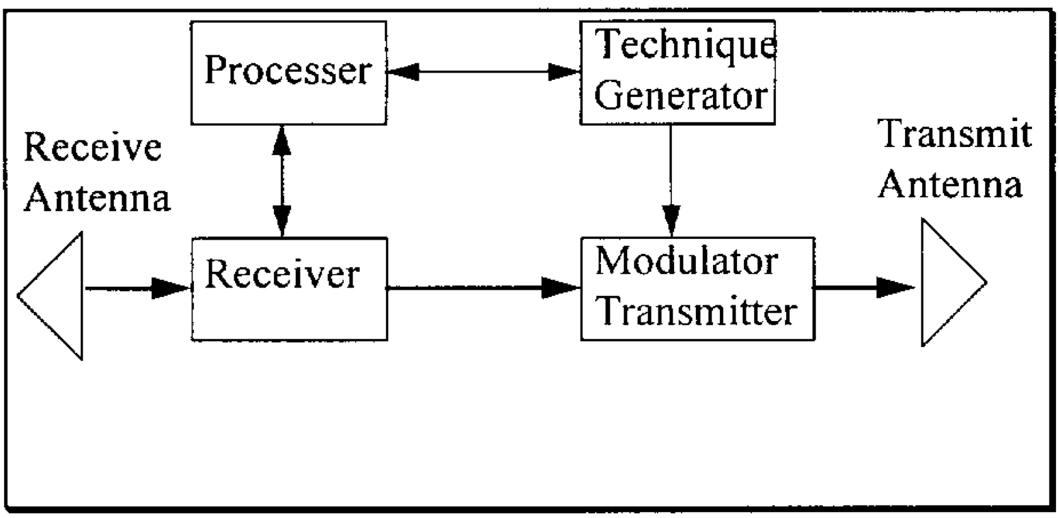

Figure 2. Simplified Jammer block diagram.

Typical existing antennas used in similar systems operate at frequencies between 15 and 110 MHz [6]. Some commercial systems are advancing quickly and offering systems in the GHz frequency range [7]. However many modern EA techniques are considered to be highly classified, but with larger research military groups it is to be expected to see in a near future systems operating close to the terahertz region.

2.2 IR Radiation

Conventional infrared jammers (IR) are electrically powered sets designed to provide protection against heat-seeking misiles. They are the electro-optic analogue of the RF jammers. These jammers have the following characteristics:
a wide IR spectrum (1 to 5 micrometers) in which pulsed infrared radiation is emitted and a wide field of view. A complete IR jammer system consists of one or several transmitters, a modulated power supply, and pilot control indicator. The system radiates a modulated IR signal designed to disturb the detection and/or tracking functions of an incoming IR guided missile and cause it to miss the intended target aircraft.

The realization of such systems using terahertz sources is on the way. For example Northrop Grumman Corporation (www.northropgrumman.com) [8] is pushing towards the next generation jammer capable of operation at frequencies above 1 THz. They have set a new transistor high-frequency mark with an indium-phosphide (InP) high-electron-mobility-transistor (HEMT) discrete device capable of operating past 1 THz. Equally important is to have a modulated terahertz signal. Voltage and phase modulators are an important topic in various research groups. Recently 100 KHz modulation of a terahertz signal generated by photomixing has been demonstrated [9]. This modulation is about 3 orders of magnitude faster than what can be achieved by mechanical scanning.

3. Electronic Protection

Electronic protection (EP) includes all activities related to making enemy EA activities less successful by means of protecting friendly personnel, facilities, equipment or objectives. EP can also be implemented to prevent friendly forces from being affected by their own EA. In general the major component of electronic protection are airborne radars. For example an airborne intercept radar in an aircraft is frequently victim of jamming attempts, the radar designer can predict the types of jamming that will be applied to the radar, then it may be possible to design a “fix” to negate the jamming effects.

Basic RADAR EP or Electronic-Counter Measures (ECM) strategies are (1) RADAR interference, (2) target modifications, and (3) changing the electrical properties of air [1]. Interference techniques include jamming and deception. Jamming is accomplished by a friendly platform transmitting signals on the RADAR frequency to produce a noise level sufficient to hide echos [1]. The jammer's continuous transmissions will provide a clear direction to the enemy RADAR, but no range information [1]. Deception may use a transponder to mimic the RADAR echo with a delay to indicate incorrect range [1]. Transponders may alternatively increase return echo strength to make a small decoy appear to be a larger target [1]. Target modifications include RADAR absorbing coatings and modifications of the surface shape to either "stealth" a high-value target or enhance reflections from a decoy [1]. Dispersal of small aluminum strips called chaff is a common method of changing the electromagnetic properties of air to provide confusing RADAR echos [1].

ECM is practiced by nearly all military units—land, sea or air. Aircraft, however, are the primary weapons in the ECM battle because they can "see" a larger patch of earth than a sea or land-based unit. When employed effectively, ECM can keep aircraft from being tracked by search radars, surface-to-air missiles or air-to-air missiles. On aircraft ECM can take the form of an attachable underwing pod or could be embedded in the airframe. Active arrays radars like those mounted on the F-22, Eurofighter, MiG-35 (Fulcrum-F) or the F-35 can also act as an ECM device to track, locate and eventually jam enemy radar. Future radar types will be capable to perform these activities more effectively because of:

* the ability of the antenna to use “better” frequencies like THz frequencies
* the processing power needed
* the possibility to practically intermix or segment antenna usages

Presently there are no systems of this sort based on terahertz technology. As mentioned in the previous sections the development of antennas at terahertz frequencies will open the potential possibilities of using terahertz technology in this area. Terahertz radiation offers bandwidth possibilities that can be used more efficiently over fixed frequency transmissions. For example spectrum transmissions offers advantages over a fixed frequency transmission like:

1. Spread-spectrum signals are highly resistant to narrowband interference. The process of re-collecting a spread signal spreads out the interfering signal, causing it to recede into the background.

2. Spread-spectrum signals are difficult to intercept. An FHSS signal simply appears as an increase in the background noise to a narrowband receiver. An eavesdropper would only be able to intercept the transmission if they knew the pseudorandom sequence.

3. Spread-spectrum transmissions can share a frequency band with many types of conventional transmissions with minimal interference. The spread-spectrum signals add minimal noise to the narrow-frequency communications, and vice versa. However, a definition of the frequency channel to be used is important due to the properties of terahertz radiation and the attenuation caused by the atmosphere.

4. Who is active in Terahertz Communication Technology

The list of companies offering products based in terahertz technology is not yet very extense. Several of these companies claim to offer terahertz technology but their products operate at frequencies in the GHz range, the most representatives are listed in the appendix. To our knowledge there are no companies offering products for communication in the terahertz range. We are also certain that military research groups are active in this area but we were not able to find reliable information.

When it comes to universities, the list is quite extensive, however we can distinguish groups that are active in the communication field although their systems still work in the GHz frequency range. These groups are:

1. ETH-Zürich, Nonlinear Optics Group (www.nlo.ch). Research activities in novel materials for terahertz applications, terahertz sources, detection and systems (0.5 – 20 THz).
2. Terahertz Communications Lab, located in Germany (www.tcl.tu-bs-de). Research in terahertz communication systems (<300 GHz).
3. Fraunhoffer Institute (www.ipm-fraunhofer.de). Investigate terahertz emitters based in photoconductive switches.

4. Rice University, located in U.S. (http://wwwece.rice.edu/~daniel/research.html). Waveguiding with terahertz is one of their research topics.

5. Conclusion

Communication technology is an advanced and dynamically developing branch where high-end technologies and trends appear. Today radio electronics are the brains, eyes and ears of communication, weapon systems and defense technology. Electronic warfare and radio communications are vital for all types of tactical and counter-terrorism operations. Jamming systems, signal intelligence and radio communications equipment is being engineered and manufactured by many companies around the world. Systems operating in the range from 1MHz to 150 MHz are commercially available. Most of these systems operate with highly developed electronics and radar techniques. From the design of such systems is easy to imagine that some antennas will be replaced by terahertz emitting sources. Yet, in spite of the various advantages of terahertz technology, so far, it has not made a breakthrough, as it is expensive and time-consuming to build the required transmitters and receivers operating at this frequency of the spectrum. Some electronic examples of small and portable sources and detectors are becoming now available at frequencies below 300 GHz, and results on fast modulation of terahertz frequencies at 100 KHz have been recently published.

Some parameters that are important for the definition of an antenna or system for use in electronic warfare are:

- Modelling of antennas, electromagnetic interference sources, BER performance, C/N, antenna noise temperature, and interference values

- Power, frequency, codes, waveform, filtering, gain, channels, tracking loops, polarization, and modulations, S/N ratio
- Model phased-array, flexible power, and spot mean capability
- Calculate and visualize the effect of dynamic platforms and sensors in a 3D environment
- Identify time windows and available ground antennas for uplink to satellite assets directly or via crosslink
- Conduct multi-hop link analyses between assets and threats

Research in this direction is developing rapidly, as can be seen by the number of research groups (that are known) active in this area. Definition of a frequency channel and its corresponding attenuation is important to specify and develop a solution.

6. References

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7. Abbreviations

COMNIT	Communications Intelligence
EA	Electronic Attack
EC	Electronic Countermeasures
ELINT	Electronics Intelligence
ES	Electronic Support
ESM	Electronic Support Measures
EP	Electronic Protection
EW	Electronic Warfare
SIGNIT	Signals Intelligence
DAST	4'-dimethylamino-N-methyl-4-stilbazolium tosylate
$LiNbO_3$	Lithium Niobate
GHz	Gigahertz
HEMT	High-Electron-Mobility-Transistor
InP	Indium Phosphide
MeV	Mega electron Volts
OPO	Optical Parametric Oscillation
OR	Optical Rectification
pW	picoWatt
QCL	Quantum Cascade Laser
RF	Radio Frequency
THz	Terahertz
THz-TDS	Terahertz Time Domain Spectroscopy
TUNNET	Tunnel Injection Transit Time
UCT-PD	Unique Travelling Carrier Photo Diode
ZnTe	Zinc Telluride

8. Appendix

1. Teraview Ltd, located in the U.K. (www.teraview.com). They develop and manufacture 3-D imaging and spectroscopic systems which exploit the properties of terahertz. Their systems are bulky, expensive and operate in the lower terahertz range <3 THz and their technology is based on low temperature semiconductors.
2. Loeffler Technology, located in Germany (www.synview.com). They develop and manufacture 3D imaging systems all electronic in the sub THz frequency range (0.23-0.32 THz).
3. Microtech Instruments, inc, located in U.S. (www.mtinstruments.com). Develop and manufacture terahertz components and prototype-systems in the subterahertz frequency range (100 GHz-1 THz).
4. Thruvision, located in U.K . (www.thruvision.com). Develop and manufacture passive standoff terahertz imaging. Their products detect naturally produced terahertz waves. No information on the frequency range.
5. Zomega Corportion, located in U.S. (www.zomega-terahertz.com). Develop terahertz-based solutions in the frequency range 0.1 to 3 THz. Their technology is based in semiconductors.
6. Rainbow Photonics AG, located in Switzerland (www.rainbowphotonics.com). Develops terahertz systems operating in the frequency range 0.5 to 20 THz. The innovative nonlinear optics technology is based in organic materials and telecom lasers.