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EDITORIAL

The journal has been a forum for the new results of Hungarian research and development in the field of communication technology for several years. The present English language issue is devoted to military electronics, thereby emphasizing the close and thought-provoking connection between army and industry. The topics and the papers comprise the most important Hungarian R+D areas and present results that deserve international recognition. Despite the general economic difficulties the country is facing, the existing intellectual capacities allow some specific domains of the industry to interface with the respective industrial domains of the world. The issue has a double objective. First, it wishes to call Hungarian readers' attention to the fact that domestic investment is indispensable to maintain and increase our reputation. Secondly, it provides useful information for the foreign investor wishing to find R+D, manufacturing or business partners in Hungary.

We would like to thank Mr. András Baranyi, editor-in-chief for giving this first opportunity to the experts of military electronics.

The connection between army and electronics goes back to the turn of the century.

It was the appearance of wire and later wireless communication equipment that first made way for electronics in the armed forces. In the early days the Morse telegraph facilitated the control of forces over great distances.

Although electronic tubes appeared already in the period between the two world wars, their endurance remained short. Electro-mechanical tools were manufactured to increase the accuracy of the artillery trajectory.

The first great boost was given to military electronics during World War II, not so much in the field of communication as in the area of radar technology. The invention of the magnetron created a basis for devices of stable frequency and output power. The Allies used them in air and naval reconnaissance and to achieve and preserve air superiority.

Towards the end of the war the upper limit of the multichannel communication devices and systems approached 900 MHz.

The Cold War period gave a decisive impulse to military electronics that did not limit itself to communication and radar technology. The new development tasks aiming at increasing the accuracy of firearms, identifying and marking targets, remote explosion and remote controlled special devices brought success in a relatively short time.

In 1957 the launch of the Sputnik opened up the fifth strategic dimension in the arms race, the space.

The application of solid state technology decreased drastically the size and power consumption of devices while the complexity of the systems and their performance increased. Communication adopted higher frequency ranges and more ingenious modulations.

Integrated circuits and microprocessors, the results of the R+D of the 60s and 70s, introduced the brand new electronic construction principle of systematization. This meant that a general or specific equipment was manufactured of standardised functional electronic units rather than by designing single electronic stages consisting of basic elements.

Besides new technology and electronic components a new signal processing era also heralded itself: the analogue world was replaced by a digitalized one. Faster and more accurate methods were born which opened new opportunities in the field of signal processing in the GHz ranges.

In military application, very large scale integrated circuits increased the life cycle and the meantime between failure of devices and systems, widened their mode of operation and standardised their inputs and outputs.

Digitalized technology started computerisation and the development of automatised systems. With further miniaturization air board equpment became smaller, lighter and more rugged. The decrease in size, weight and power consumption allowed to deploy global satellite communication systems in the space with several thousand channels, thus improving military command and control systems.

New horizons were opened for all-time operating space intelligence systems with high speed picture processing. Owing to its high resolution capability, such method detects relevant changes on Earth.

The unthinkable pace of development of military electronics created the operating conditions for the complex Command Control Communication and Intelligence Systems (C^3I). These systems are basic elements of modern warfare. Nowadays military electronics allow high level commanders to monitor manoeuvres over a vast battlefield in every moment.

A new type of warfare, Electronic Warfare was born through high level integration and complexity of military electronics which means gathering and evaluating information before the start of the battle. The enemy's control system is paralysed as a result of evaluation. Initiation can thus be preserved, military operations successfully controlled and own casualties minimized. Electronic Warfare is therefore a means of increasing the balance of forces.

Today within the area of Electronic Warfare, the increasing importance of peace-keeping activity promotes the concept of Electronic Defence. At the same time, the growing capacity of the global information network has created the Information Warfare.

What has been utilized by the Hungarian Army from the above developments? This has been mainly determined by the relationship between the army and the indsutry.

The role of the army used to be very articulated in the Hungarian electronic industry. Such role was not only manifest in the initiation and support of state-of-the-art research and development but also in shouldering tasks that the industry failed to carry out. Examples of this special mission include:

Instrument and Measurement Techniques (Ionosphere Observing Instrument, 1952)
The first ionosphere observing instrument served as the

basic device for the worldwide measuring network and was awarded the Grand Prix at the World Exhibition.

Computing technique (Scintillation tachometer, 1953)

Although computing technology did not exist in Hungary in the modern sense of the word, this equipment was developed from the first generation elements of computing technique.

Communication (application of higher frequency ranges – starting from 1952)

This initiative has resulted in a long-term programme that adopted ever increasing frequency ranges and reached the extra high range by today. At the beginning of the 50s the importance of this initiative could not be estimated after the first implemented steps; nowadays we are already aware of its industrial significance and its role in creating a tradition.

The application of higher frequency bands proved to be vital to the development of electronic reconnaissance systems. The army acted as a catalyzer for the Hungarian electronic industry, especially as far as those radio reconnaissance systems are concerned which integrate automatized working posts.

Photonization (Photoelectronic effect in communication, 1980)

The army, having recongized the future importance of light transmission, proposed the research of atmospherical information transmission in the medium of light.

The value of the development projects in the field of light transmission systems was further increased by the additional requirement of digitalized signal processing. The army initiated this development in a time when light transmission was a novelty in the most advanced countries.

As we have seen, the above presented instruments could not have been born without the encouragement and active participation of the army. Similarly, generations of industrial experts were also motivated by the scientific programmes of the army.

The importance of military electronics is likely to continue in the near future. Nowadays no army can claim to be modern without advanced electronic systems. Such systems, however, necessitate high-level co-operation with the industry.

Some of the domestic economic capacities have recently been privatized and as a part of this transformation the bases of research and development and manufacturing have decreased to a minimum level. But even this small number of capacities and specialists is capable of adapting the production of military devices to European standards. Moreover, the diversity of the services provided by these devices is unique on the world market.

The present publication reviews the wide structure of Electronic Warfare with special emphasis on the segments with a domestic industrial base. Defining the correct direction of development and the structure of various electronic warfare systems will be tasks of the near future. These issues are described in greater detail in the paper of G. Zakor.

The development and methods of military communication are outlined in the paper of Á. Gubis and J. Szabó, stressing the necessity of stabile anti-jam and secured communication systems.

The development of radio-electronic reconnaissance is considerable even in the VHF and UHF bands owing to the latest domestic development results. L. Takács discusses the main theoretical considerations in the arrangement of workposts and stations.

The relevance of the microwave band for high level command and control is well-known. The reconnaissance and monitoring of both land-based and satellite high-speed multichannel digitalized communications systems represent a challenge. Some sensitive areas thereof are dealt with by V. Torma and J. Elekes. The microwave receivers developed for radar reconnaissance are discussed in the paper of A. Dobrovits.

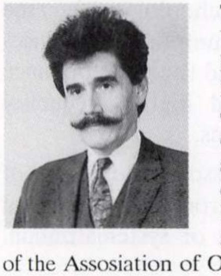
Standards have increasing significance with respect to compatibility in methods of information transmission in communication systems. It follows that the techniques of standard signal processing can be effectively adopted in some cases. A concise report is given by K. Elek and his coauthors.

Optical real-time analyzers can be used for the reconnaissance of high-speed anti-jam communication and radar systems in a relatively wide frequency range. High-speed direction finders capable of indicating and measuring frequency hoppers are based on a similar principle. A. Barócsi and his coauthors have written on these devices.

A wide survey of microwave development in the past few decades is provided by B. Szabó emphasising the importance of domestic experience and the renewal of home industrial capacities.

Some new modulation methods are used in modern military communication systems. One of them is frequency hopper of which the reconnaissance and direction measurement poses a few questions. A home made operating equipment is characterized by Gy. Rothman.

T. RÁTH



Tamás Ráth received an MSc from the University of Technology in 1973. He has played a key role in the realization of long-term programs covering several fields of radio reconnaissance systems, later he dealt with the problem of automatized EW stations. In 1993 he received an MA degree from the Budapest University of Economics in internation relations. He is a founding member of the Paprika Chapter of the Assosiation of Old Crows.

ELECTRONIC WARFARE (EW)

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Introduction. Terms and Definitions. The Electromagnetic Threat. Communications and Non-communications Systems. Special Transmission Methods and Present-Time Development Trends. EW Equipment Made in Hungary.

1. INTRODUCTION

Improvements of speed and effectiveness of forces are greatly due to the use of electronics for command, control, communication and reconnaissance. This has led to a large number and variety of military communications and electronics radiating electromagnetic energy into free space. But such improvements have also created new capabilities and vulnerabilities. The free propagation of the electromagnetic waves offer to anyone, including the enemy, their free exploitation for his own purposes, and to the degree that communications and electronics are indispensable for the one side they are important sources of information and targets of disruption and destruction for the other.

Today, the implications of electronic warfare are widely understood and electronic warfare capabilities are considered to be an important factor of survivability and mission success of the forces.

To know more about your enemy than he knows about you, to control your communications while being able to disorganize and destroy your opponent's systems, such is the vital challenge of electronic warfare.

In *peacetime*, continuous surveillance allows to reconstruct and visualize the operations of a potential enemy and to follow his moves in real time. Synthesizing all the data retrieved by electronic warfare means from the enemy's electromagnetic sources provides the information required to make a correct evaluation of the threat and to define the operational targets.

In case of *conflict*, this information enables to anticipate the situation and to make appropriate strategic and tactical decisions. EW systems then become active and efficient weapons, capable of disrupting hostile C3I (Command-Control-Communication and Intelligence) systems, while protecting one's own transmissions, and providing the knowledge that will lead to take appropriate electronic and conventional measures for defence and attack.

In order to maintain national security and be able to defend the country, political and military authorities must be currently informed about the situation and have a suitable organization at their disposal which provides as necessary

- permanent information on the overall situation in support of basic intelligence, political decision-making and defence planning;
- current and detailed information on a particular limited situation in support of crisis management and mobilization of forces;
- real-time battlefield information and combat EW support.

The division of responsibility between military and security forces providing such support is a matter of the constitution of the country.

2. TERMS AND DEFINITIONS

2.1. Electronic Warfare

EW is that division of military use of electronics involving actions taken to prevent or reduce an enemy's effective use of radiated electromagnetic energy and actions taken to ensure one's own effective use of radiated electromagnetic energy. There are three divisions within electronic warfare (Fig. 1).

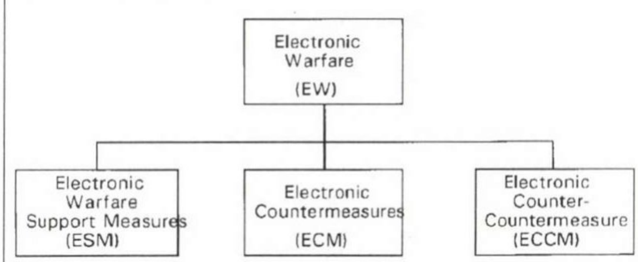

Fig. 1. Electronic Warfare (EW)

2.2. Electronic Warfare Support Measures (ESM)

ESM are that division of electronic warfare involving actions taken to search for, intercept, locate, record and analyze radiated electromagnetic energy for the purpose of exploiting such radiations in support of military operations. Electronic warfare support measures provide a source of information required to conduct electronic countermeasures, electronic counter-countermeasures, threat detection, warning, avoidance, target acquisition and homing.

2.3. Electronic Countermeasures (ECM)

ECM are that division of electronic warfare involving actions taken to prevent or reduce an enemy's effective use of the electromagnetic spectrum. Electronic countermeasures include electronic jamming and electronic deception.

- *Electronic Jamming*
  Electronic Jamming is the deliberate radiation or reflection of electromagnetic energy with the object of impairing the use of electronic devices, equipment or systems being used by an enemy.

- *Electronic Deception*
  Electronic Deception is the deliberate radiation, reradiation, alteration, absorption, or reflection of electromagnetic energy in a manner intended to mislead an enemy in the interpretation of use of information received by his electronic systems.

2.4. Electronic Counter-Countermeasures (ECCM)

ECCM are that division of electronic warfare involving actions taken to ensure friendly effective use of the electromagnetic spectrum despite the enemy's use of electronic warfare.

There are further terms frequently used in connection with EW.

2.5. Signals Intelligence (SIGINT)

SIGINT is the generic terms used to describe COMINT and ELINT when there is no requirement to differentiate between these two types of intelligence, or to represent fusion of the two (Fig. 2).

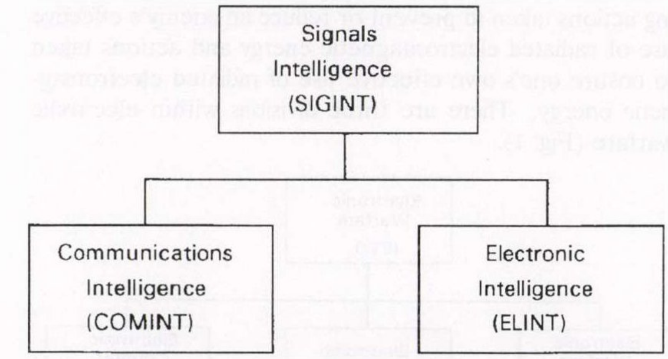

Fig. 2. Signals Intelligence (SIGINT)

2.6. Communications Intelligence (COMINT)

COMINT is technical material and enemy information derived from electromagnetic communications and communications systems (e.g. morse, voice, teletype, facsimile) by other than intended recipients.

2.7. Electronic Intelligence (ELINT)

ELINT is technical material and enemy information derived from electromagnetic non-communications transmissions (e.g. radar, navigational aids, jamming transmissions, electro-optical devices) by other than intended recipients.

2.8. Relationship between SIGINT and EW

It is common practice to use the terms SIGINT (COMINT/ELINT) in connection with different system characteristics. But this method can only describe differences related to aims, organization and procedures:

- SIGINT is *information* about the enemy gained from his communications and electronics. The aim of SIGINT collection is the preparation of basic material about the enemy in support of intelligence and operations, for example the enemy electronic order of battle. SIGINT collection is coordinated at the supreme level of command and, because of its basic nature, requires high security protection resulting in special organization and handling procedures. There is generally more time allowed for in-depth analysis and evaluation.
- EW is military *action* supporting the forces in the field. The aim of EW is the exploitation of the enemy's communications and electronics for the purpose of situation information, threat detection, warning, protection and disruption by ECM.
  EW operations are limited in time and space. The security protection is generally not higher than that of the tactical operation which it is part of, and EW units are organic to the tactical commands.

As regards the relations between SIGINT and EW, both work on the same principles, have the same information sources and functions and use the same basic equipment. For many countries SIGINT collection and EW is "part of the same game". The line between SIGINT and EW is arbitrary and changes if the use of the result changes (Fig. 3).

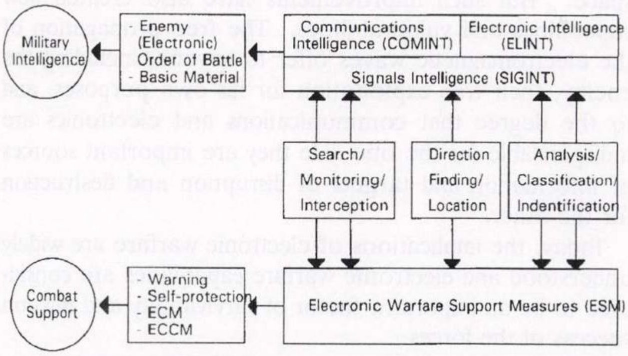

Fig. 3. SIGINT and ESM Relationship

Note: Some countries have introduced the term "Electronic Combat". Electronic Combat is the overall effort made by the integrated use of EW, reconnaissance and fire support to neutralize, disrupt and destroy the enemy's command, control, communications and reconnaissance and by defending friendly systems against the enemy's efforts of the same kind.

3. THE ELECTROMAGNETIC THREAT

The so-called "electronic" or "electromagnetic threat" is the total of all electronics used by the enemy to support his command, control, communications and reconnaissance. Physics have an important influence on employment and effectiveness of communications and electronics and, consequently, on the use of EW. The electromagnetic waves travel at the speed of light and propagate in accordance with the properties of their radio frequency and other factors. Depending upon the particular propagation properties the different frequency bands are used for different purposes. As a result, certain frequency bands are typical of certain military communications and electronics. By definition EW is concerned with the complete electromagnetic frequency spectrum (Fig. 4).

		main frequency range
communications	radio and radio relay	10 kHz to 18 (40) GHz
electronics	radar	(0,1) 1 GHz to 18 (40) GHz
optronics	infrared, ultra violet, laser, TV	300 GHz to 10^{16} GHz

Fig. 4. Main Groups of Threats

There are three main traditional groups of electromagnetic threats and, respectively, EW targets.

The principal differences and historical development of these groups have led to different equipment, employment procedures and organization. However, with the advent of modern technology the situation is changing. Communications and electronics are expanding into higher frequency bands and use digital modulation and frequency agility (frequency hopping). Optronics are taking over tasks which used to be performed by radar, e.g. infra-red for threat detection/location and laser for range-finding and targeting. In many cases all three groups operate in mutual support. This development must also lead to the closer cooperation of EW in the communications and non-communications fields.

For some years intensive research and development has been going on for expanding the traditional radio frequency bands up to 300 GHz.

3.1. HF Radio Communications

HF communications are used practically at all levels of command to cover medium to large distances. They are often used as a back-up if VHF and UHF communications are insufficient (Fig. 5).

Electromagnetic waves of High Frequency (HF: 1,5 MHz to 30 MHz) propagate in two ways.

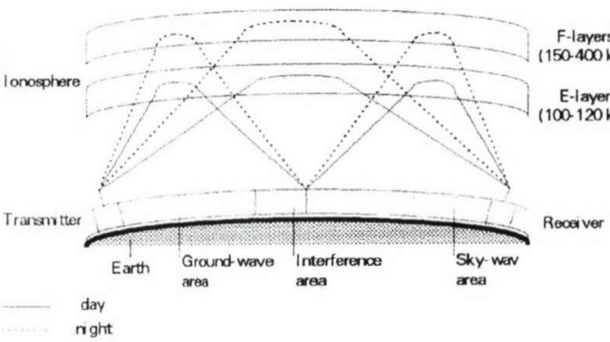

Fig. 5. HF Wave Propagation

One part travels on the ground (ground wave), the other is reflected by the different layers of the ionosphere (sky wave). Ground and sky waves meet and interfere at a certain distance from the emitter. Changes of the ionospheric conditions result in multi-path propagation, interference and fading.

HF communications use the frequency range of 1,5 MHz to 30 MHz mainly for the following transmissions:

- radio telegraphy:
  A1A morse;
  F1B teletype, single-channel;
  F7B teletype, multi-channel;
  F1C facsimile;
- radio data transmission:
  F1D data;
- radio telephony:
  A3E, single-sideband; J3E, single-sideband, suppressed carrier.

Tactical HF communications use power outputs between 10 watts and 100 watts and normally operate on the ground wave. The effective range of the HF ground wave depends upon radio frequency, power output, antenna and, to a large degree, on the conductivity of the ground. HF ground wave travels much further over water than over land where the range generally does not exceed 80 km and is further limited by terrain obstacles. This means that ground-based EW systems must deploy within 80 km of the target emitter and use high points if necessary, similar to the operation in the upper ranges.

Where the circumstances do not permit operating on the HF ground wave or in the VHF-UHF ranges tactical communications will turn to HF sky wave. Special antennas may be used to operate at steep elevation angles and short "tactical" distances (below 50 km).

A tactical EW unit is normally not equipped to work against the sky wave of HF communications and to cope with the difficulties of direction finding under conditions of interference, fading and steep-angle incident waves. A regular HF sky wave EW organization exceeds the capacity of a normal tactical EW unit and belongs to the responsibility of higher commands. However, in some countries the geography requires the use of the sky wave for tactical HF communications. Also in certain cases the ground wave of such communications can only be jammed effectively via the sky wave. It is, therefore, necessary for tactical EW units of some countries to have a limited capability against HF sky wave.

3.2. VHF and UHF Radio Communications

VHF and UHF radio communications are the main means of command, control and communication of combat and combat support forces. The electromagnetic waves of Very High Frequency (VHF) and Ultra High Frequency (UHF) travel (more or less) along the optical line of sight (Fig. 6).

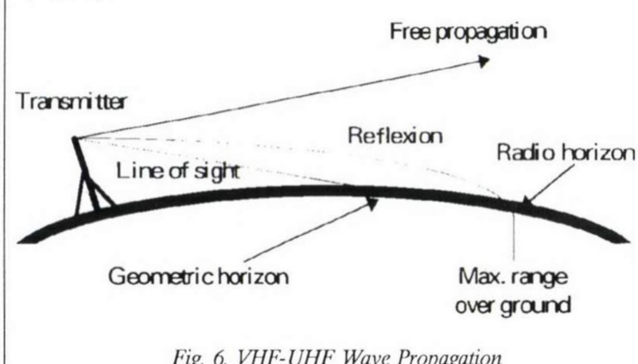

Fig. 6. VHF-UHF Wave Propagation

Their effective range depends upon radio frequency, power output, height of antenna and a few other factors. It is limited by the curvature of the earth and large obstacles like mountains. Due to a certain flexion of the wave propagation in the lower part of the VHF band the "radio horizon" goes somewhat beyond the optical horizon.

Without these limitations VHF-UHF communications can cover 1000 km and more.

VHF radio equipment is generally portable or installed in vehicles or aircraft. It uses the main frequency range from 20 MHz to 80 MHz at 25 kHz or 50 kHz channel spacing. VHF communications use mainly FM voice with power outputs between 1 watt and 100 watts. Their effective range on the ground is between a few hundred meters and 30 km. The range may be increased to about 50 km by using antenna masts and high points in the terrain. Airborne systems frequently permit operating ranges of 100 km and more, depending on their height above ground.

UHF radio equipment is primarily used by combat aircraft and helicopters for their ground-to-air and air-to-air communications. Besides the usual tactical VHF band, aircraft use the upper VHF band for international traffic control (118 MHz to 136 MHz) and the lower part of the UHF band (up to 500 MHz) for their tactical control on the battlefield. UHF radio equipment is installed in vehicles and aircraft and its features are similar to those of the VHF equipment. The power outputs are between 15 watts and 30 watts permitting ranges of up to 70 km between an aircraft flying at 300 m height and its ground control as an example. Where necessary, modern equipment combines the VHF and UHF bands in one system.

The interception, location and jamming of VHF and UHF radio communications is, first of all, a matter of their effective ranges. To obtain optical line-of-sight conditions EW systems must be deployed close enough to their targets or on high points in the terrain or use antenna masts or elevated platforms. The fixed channel spacing of the VHF and UHF bands and lack of adverse effects as in the HF band favour the automation of EW operations against VHF and UHF radio communications.

3.3. Radio Relay Communications

The radio relay communications use the VHF-UHF and microwave ranges and employ highly directional antennas which focus the energy in the form of lobes. The main lobe is directed towards the receiving station and requires quasi-optical line of sight. Most radio relay antennas also produce (weaker) side and back lobes. Depending upon the circumstances (radio frequency, terrain etc.) a single radio relay link covers distances between 30 km and 80 km. The operating range may be increased by interspersed relay stations and, thus, be extended to chains covering several hundred kilometers. By interconnecting several radio relay chains a grid-type communications network may be formed to which access is given via each node. In many armies, such a radio relay network is the backbone of a mobile tactical communications system in the combat zone.

Modern radio relay use a variety of modulations, e.g. FDM (frequency division multiplex) and TDM (time division multiplex). The transmissions include voice, teletype and data. The channels are generally "bulk" encrypted.

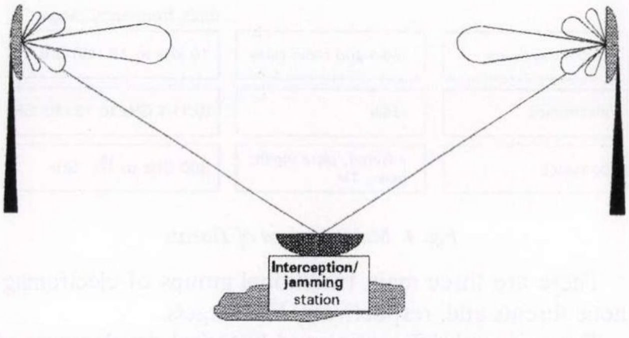

Fig. 7. Radio-relay Interception and Jamming

Radio relay communications may be intercepted if the EW systems has the right location and demodulation equipment and can read the message content (Fig. 7). However, highly directional antennas, shading effects of the terrain (masking), the large variety of modulation types and bulk encryption require high and selective effort in terms of equipment and personnel.

3.4. Satellite Communications

Military satellites provide mainly high capacity strategic communications links, but there are also tactical mission satellite systems with extremely small size (mobile) antennas. The NATO and many other countries have their own military satellites, certain countries hire commercial or national channels to transmit less sensitive military communications.

Most of the frequencies allocated for satellite communications overlap the frequency bands of ground radio relay links (4, 6, 7, 8, 11, 14 GHz), and in order to keep interference at an acceptable level special measures and international standards are in force.

In satellite communications the same digitalization trend can be observed as in terrestrial communication technology. By the turn of the millenium the channel capacity of satellites will be around 200–300 thousand against the 60 thousand in 1990.

Military satellites provide, in addition to communications, important functions on the fields of surveillance, navigation and weapons control.

3.5. Non-communications (radar)

The second main group of electromagnetic threats in terms of EW targets is radar. Radar emits electromagnetic energy. If this energy meets an obstacle a part of it is reflected like an echo. The "echo" is received and analyzed by the receiving part of the radar. The distance between the radar and the object may be determined from the travel time of the signal to return to the receiver. Azimuth and elevation of the return signal together with its return time permit the location of the object. Speed and direction of moving objects may be displayed, acoustically indicated, used directly in weapons employment or ECM.

The radar principle can be used in different applications (Table 1).

Table 1. Different radar applications

threat (units or systems)
• early warning
• air defence
• reconnaissance
• artillery (gun and rocket)
• mortar
• missile launchers (SAM)
• anti-aircraft artillery (AAA)
• missiles and projectiles
• aircraft and helicopters
• remotely piloted vehicles (RPV)
role of associated radar
• surface and air surveillance
• target detection/acquisition/tracking
• fire control
• ballistic tracking
• wind, weather, meteorology
• height finding
• missile control and guidance
• homing
• airborne intercept
• navigation identification friend-or-foe (IFF)
• terrain-following
• bombing

Depending upon the role of the radar, different transmitting and receiving techniques are used, which has led to a great variety of individual radar types and combinations.

The signal parameters provide the key to the identification of a radar. These may be divided into two main groups, the primary and the secondary parameters, as given in Table 2.

Table 2. Primary and secondary radar parameters

Primary radar parameters
• Radio Frequency (RF)
• Pulse Width (PW)
• Time of Arrival (TAO)
• Angle of Arrival (AOA)
• Amplitude
Secondary radar parameters
• Pulse Repetition Time (PRT)
• Polarization (POL)
• Variation of PRT (PRT agility) (jitter, stagger)
• Variation of RF (RF agility)
• Scan Type (ST)
• Scan Period (SP)

The radar signal parameters identify the radar type, role, platform and user. The jamming and deception of the radar can lead to the disruption or malfunction of the related reconnaissance or weapons system.

For a number of ECM tasks only airborne systems promise the necessary flexibility and effectiveness.

The majority of radars operate in the frequency range between 1 GHz and 18 GHz, about 80 % of them below 10 GHz. The use of modern technology makes higher frequencies available (up to 40 GHz and beyond).

4. SPECIAL TRANSMISSION METHODS AND PRESENT-DAY DEVELOPMENT TRENDS

4.1. Spread-spectrum Techniques

The requirement for reliable, secure and EW resistant communications is increasing the number and variety of communications using spread-spectrum techniques. Spread-spectrum is a method by which the bandwidth of the modulated signal is made much wider than necessary for the transmission of the information. There are two types of spread-spectrum transmission:

- frequency hopping,
- direct-sequence spread-spectrum transmission (DSS).

4.1.1. Frequency Hopping

Frequency hopping changes the carrier frequency of narrow-band transmissions in hops. In this case the original information is radiated on a certain carrier frequency, but the carrier is changed after a short period. The time of transmission on a certain carrier does not exceed 2 – 10 msecs. The method first employed in the VHF range used bands of approximately 6 MHz and 100 hops per second. The tendency goes to faster hoppers which use the whole frequency band at rates of 500 – 600 hops per second and to even faster ones in the UFH range.

Also in the HF (ground wave) range frequency hoppers have been implemented employing 150 hops per second. Coming generations are expected to be faster.

4.1.2. Direct-sequence Spread-spectrum Transmission

In this case the original spectrum is spread by a special spreading code. The bandwidth of the converted signal is several times higher, but its level is several times lower than that of the original signal (Fig. 8).

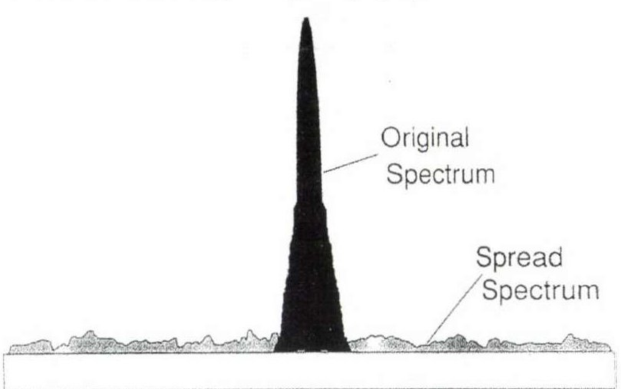

Fig. 8. Spread-spectrum Transmission

Using the same code at the receiver side, the wide spectrum is compressed to the original width. The spread spectrum transmission cannot be received by normal narrowband receivers, sometimes even cannot be detected as the power density may be below the noise level.

The exploitation of communications using spread-spectrum techniques requires increased effort in terms of automated, computer-supported interception and location.

Where encryption makes the reading of message content impossible EW systems must concentrate on the monitoring and location and possibly jamming of such communications.

Modern EW units need therefore a capability to search, monitor, locate and jam sources of spread-spectrum transmissions.

4.2. Airborne EW Systems

The mission of a tactical EW unit is related to targets within the area of operations/interest of the tactical command. Due to the propagation of the electromagnetic waves in the upper (VHF-UHF-SHF) frequency bands the effective range of ground-based EW systems is limited to optical line of sight. Their effectiveness must therefore be improved by using antenna masts and deploying to high points in the terrain. Where the target coverage is still insufficient in terms of intercept range and jamming effectiveness airborne EW systems must be used in support of the ground-based organization. The increased ranges by elevated platforms are shown in Fig. 9.

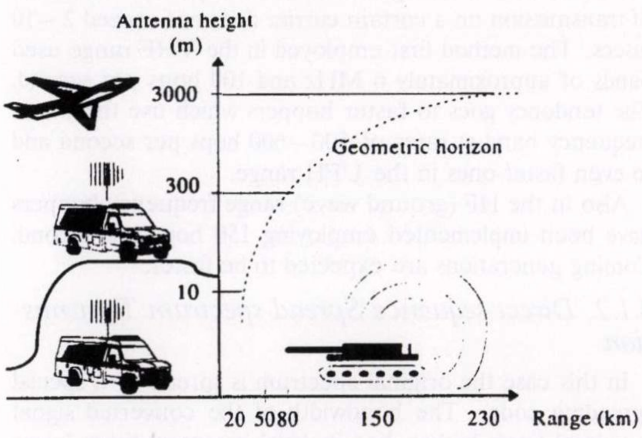

Fig. 9. Approximate Intercept Ranges of ground-based Communications and Radar over Flat Terrain

Airborne EW systems offer the following advantages over ground-based systems:

- increased intercept distance, jamming effectiveness and area coverage;
- better access to critical information, it may be passed on-line to the tactical command post;
- high mobility and flexibility by rapid deployment and redeployment, better survivability.

4.3. Expansion of Frequency Band to mm-wave

Besides the traditional radio-frequency bands intensive developments are carried on to exploit the mm-wave (30–300 GHz) frequency band. Majority of R&D in the mm-wave frequency band serve military purpose. The upper limit of microwave hybrid technology exceeds 200 GHz. This fact, as well as the decrease of noise of active elements allow solving special tasks and producing equipment for military purpose.

4.4. Communications Development Trends

The development of new communication methods have the following features:

- Expanding the use of frequency spectrum to higher ranges up to the millimeter wavelengths.
- Extensive use of digital technology and satellite communications.
- Employing transmissions with high immunity against interception and jamming:
  - frequency hopping transmission with medium and high hopping rates (200–1000 hops/sec);
  - spread-spectrum transmission up to 30 dB system gain;
  - burst transmission mode where the burst time is a few msecs.
- Developing narrow-beamwidth antennas with low level sidelobes to provide minimal radiation towards the sources of EW threats.
- Extensive use of sophisticated modulation and encryption methods.
- Adaptive adjustment of the radiated power.

4.5. Radar Technology Upgrades

- "Stealth" technology
- CW
- Pulse compression
- LPI (Low Probability of Intercept):
  - different or staggered pulses
  - chirp
  - long, irregular AM
  - Modulation within pulse
- 3D radars
- Bistatic, multistatic radars
- Beam steering

4.6. SIGINT Improvement Trends

- Improving the sensitivity of applied receivers.
- Increasing the probability of intercept:
  - parallel processing (overview the band of interest by 20 GHz/sec rate or more);
  - WB superheterodyne;
  - acusto-optics (Bragg-cells);
  - microscan;
  - digital IFM.
- Increasing the dynamic range of receivers to make them applicable in very busy environment.
- Improving the A,τ characteristics of COMINT receiver systems to make them applicable to receive digital transmissions.
- Extensively using computer control and data processing.
- Extending the effective range of recce by applying airborne/heliborne equipment.

4.7. ECM trends

- Increasing effective radiated power by using high gain antennas.

- Employing multichannel jamming with power-sharing and time-sharing techniques.
- Applying airborne/heliborne jammers to reduce losses over the signal's traveling path, the use of UAV (unmanned air vehicle).
- Automatically selecting the most effective modulation mode against targets to be jammed.

5. EW EQUIPMENT MADE IN HUNGARY

- Omnidirectional active and passive Rx-antennas from 10 kHz to 1 MHz, directional linear, cross and circular polarized Rx-antennas from 30 MHz to 40 GHz.
- Tx-antennas for HF and VHF/UHF frequency ranges with 1–50 kW power both for narrow and wideband applications.
- Stationary and mobile antenna masts and positioners.
- Panoramic receivers and receivers with processor or computer control, high tuning speed for search, scan and monitoring in the 10 kHz–18 GHz frequency range.
- Channelized and acousto-optic receivers to detect and analyse transmissions with short periods (e.g. FH) Demodulators and demultiplexers:
  - AM, FM, PSK,
  - FDM, TDM (PCM, DM),
  - TTY,
  - data
- Signal analyzers: RF, IF, video, audio.
- DF systems (1.5–1000 MHz).
- UAV with SIGINT and ECM payloads.
- Communications equipment (spread-spectrum, intercom).
- Jamming equipment:
  - wideband power amplifiers covering multioctave frequency bands;
  - sophisticated modulators.
- Ciphering equipment (voice, data).
- Recorders (voice, data).
- Computer support (control, analysis, data processing).
- Auxiliary devices (power supplies, power generators, etc.)

6. ACKNOWLEDGEMENT

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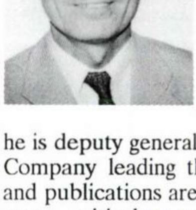

Géza Zakor graduated from Faculty of Electrical Engineering of the Technical University of Budapest in 1966. From 1966 to 1972 he was working at the ORION Radio and Electronic Factory on microwave radio relay systems. As an employee of the Ministry of Defence he held various positions from 1972 as R&D engineer, researching and developing radio reconnaissance equipment and systems. From 1994 he is deputy general manager at the MOD Electronic Directorate Company leading the technical section. His fields of research and publications are EW, V/UHF and microwave radio reconnaissance, critical parameters of receives systems for digital modulation.

MILITARY COMMUNICATIONS

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The paper deals with the system and equipment aspects of military communications. Information is given about ECCM methods and other features providing survivability in jammed electromagnetic environment. The paper gives an overview of the military communications systems abroad and in Hungary.

1. INTRODUCTION

Military communications is for the information transmission with guaranteed security.

In any battle theatre the commander must be able to command and control his forces. In a modern battle, movement of weapon systems is fast which means that reactions must be equally fast. Such speed can be obtained if commands are passed swiftly to the elements under the commander's control. This depends on good (radio)communications.

This paper concentrates on communications systems, which must provide the backbone of a successful coordinated command, control and communications (C3) policy.

2. COMMUNICATIONS EW

Military information being very sensitive, the security aspects play a fundamental role in the system characteristics.

Therefore the Electronic Warfare (EW) is a subject of vital concern to all users of electromagnetic equipment on the battlefield. The final goal of EW is to reach the superiority power over electromagnetic field, i.e. provide optimal operational environment for own/friendly communications equipment while making the use of the enemy's communications impossible.

Limited to communications EW the three quite distinct components of EW and the relationships between them are shown in Fig. 1.

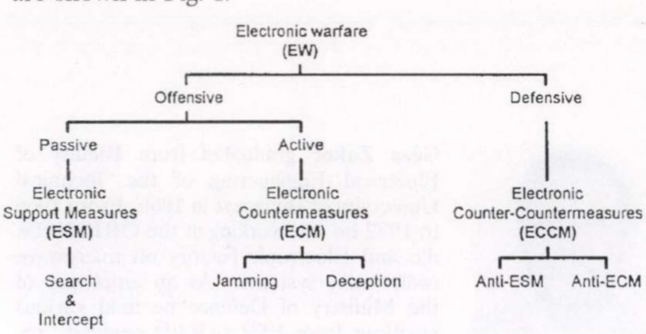

Fig. 1. EW components and their relations

3. PRESENT DAY MILITARY COMMUNICATIONS

The classification of communications levels of the total defence communications system vary from country to country, but usually they can be grouped as:

- nation-wide level:
  may be based on military and/or civil PTT transmission systems;
- tactical level:
  highly flexible, extremely mobile;
- combat level:
  rapid, reliable and secure communication in the combat area.

Another (most usual) classification is the following one:

- Strategic Network:
  interconnects large, major sites, usually in fixed locations remote from the combat zone;
  devices usually are located in facilities protected against attacks and extreme climatic effects;
  transmission links may, nevertheless, be exposed to ECM attacks.
- Tactical Network:
  combination of tactical area trunk network and combat net radio close to or not far off the combat zone;
  survivability is dependent upon mobility, concealment and dispersion, both physically and electronically.

3.1. Stationary and tactical military systems

All the above requirements have been taken into account by the major manufacturers and have found response in the EUROCOM general specification which fix the main characteristics for the military communication systems, e.g. the digital coding and transmission methods, the protocols, the mandatory system facilities and so on.

The two networks share the same general architecture (the classical structure of a grid-type area network), can have the same directory system, can be directly interconnected (on any level) with no need of transcoders or interface boxes. The two networks differ in the following elements: mobility and transportability.

The elements of the tactical system are installed in vehicles or shelters. The system is fully transportable and redeployable, if necessary, several times every 24 hours.

The stationary system is normally installed in fixed locations and is redeployable only in emergency situations.

The common requirement for them is: all of these various networks must be able to interface with each other.

Although it is relatively simple to set up a purpose built communications system for every requirement, it can lead to large number of independent systems which may be impractical to interconnect, expensive and inflexible in reacting to change. Interoperability is not a state which exists or does not exist, there are rather various levels which depend on the technical interface possibilities, and equally importantly, on the management and control philosophies applicable to the systems concerned.

3.2. The systems in general

The continuous connection of the command posts with the fighting units can be maintained using a system of communication centres and links flexibly changing by terrainian-, time- and task conditions. From the technical point of view this means an organization of trunk switching, transmission, user/mobile access and terminal units, the connection of which is shown in Fig. 2.

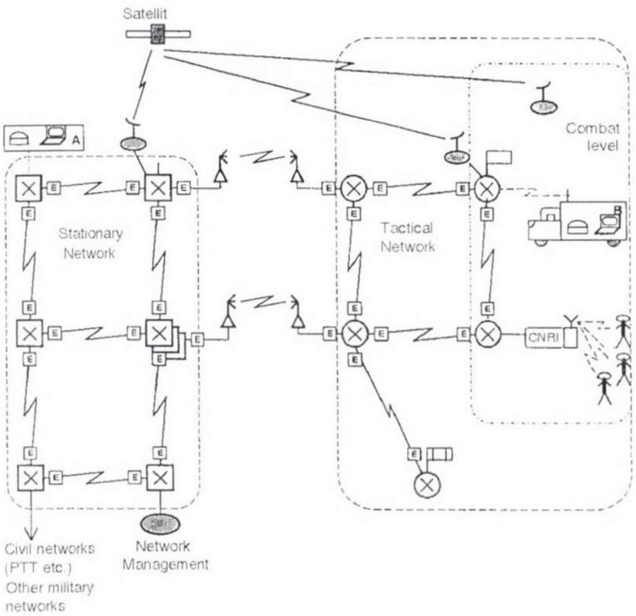

Fig. 2. General communication system sructure

4. NETWORK ELEMENTS AND PROCEDURES

Trunk network is the backbone of the system and comprises a network of nodes deployed to cover the area of operation. The nodes contain stored program controlled digital electronic circuit switches which are interconnected by different transmission lines.

4.1. Switches

The switching subsystem includes microprocessor controlled digital circuit switching and packet (and message) switching.

The routing principle is a combination of saturation routing and adaptive routing to cater for the following requirements:

- free numbering, i.e. a subscribers number is not determined by its connection point;
- mobility, i.e. a subscriber can keep his number when moving in the network;
- topology changes without autonomy, i.e. when switches or lines are out or down, or new switches or lines are added, it is not necessary to set up new routing tables;
- the subscriber shall always be found if there exists a free path from A to B.

4.2. Transmission

The transmission subsystem can use different media: multichannel radio relay (line of sight or tropo-scatter), radios, satellite terminals, fiber optic and metallic cables (short or long range).

4.2.1. Radio relay

Strategic systems use a mix of high capacity multichannel radio relay and fiber optic long distance bearers according to specific local situations and to economic evaluations.

Due to the required high mobility the tactical networks use almost exclusively multichannel radio links. The cables (fiber optic or metallic) are only used for local areas or Command Post internal communication subsystems. It is important, that radio links can operate in harsh electromagnetic condition due to noise, fading phenomena, jamming sources. They have to be able to use all the band spectrum it has been conceived to operate in, be resilient to Bit Error Rates normally not tolerated by civilian systems.

These radio relays have state-of-the-art ECCM methods (adaptive frequency hopping, adaptive output power, etc.) to ensure high TRANSEC (transmission security) level.

4.2.2. Mobile access / Combat net radio

Combat net radio (CNR) is the primary means of command in the forward battle area.

As tactical communications becomes a more integrated part of C3I systems emphasis on data communications has grown. In the latest systems we can meet the so-called Multi Role Radios (MRR) which integrate different services required in combat applications in one radio.

The reliable and secure voice and data communications and enemy's counter-measures dictate the use of different anti-jamming and ECCM solutions. Some of them are listed below:

- Frequency hopping
- Direct Sequence Spread Spectrum (VHF)
- In some newest MRR combined Frequency hopping and Narrow Band Spread Spectrum
- Built-in COMSEC function
- Burst transmission (for coded) messages
- Real time frequency management / Automatic Link Establishment
- Adaptive RF power level regulation
- Selective calling
- etc.

Mobile users are served either by

- Combat Net Radio Interface (CNRI) equipment which enables CNR users to access the trunk network, or by
- single Channel Radio Access (SCRA). In SCRA subsystems special user terminals and complex radio centrals interfacing to the trunk network provide the user with full trunk network subscriber facilities.

4.2.3. Satellites

SATCOM offers high/low capacity links between tactical and strategical networks, and between the trunk system and mobile users. As an example, transportable SATCOM terminals can communicate with similar terminals where radiolinks are impractical due to distance or terrain.

4.3. Terminals

A large variety of subscriber terminals can be connected to the network via standardized interfaces. In principle, all types of commercial and military terminals can be used.

4.4. Protection of information (Encryption)

Measures ensuring the protection of information are of special importance in electronic warfare.

Information protection can be done:

- Passive ... Operating practives ...
- Active

ECCM/TRANSEC ... Frequency hopping, spread spectrum, etc.

COMSEC ... Encryption

Encryption can be divided as:

bulk / trunk;

end-to-end / individual.

Individual crypto devices ensure protection usually in terminal devices requiring special management systems.

Bulk crypto devices ensure general protection on the high speed multichannel trunks . They are installed in the strategic or tactical nodes of the transmission in/outputs.

4.5. Network planning and management

4.5.1. Radio network planning systems

The modern military communications has a need in tools which make easy planning of the radio communications. These software/hardware thanks to their powerful map-handling and network management functions make possible planning point-to-point transmission networks and analysing radio coverage for cellular systems, radio relay links, landmobile radio systems and tactical military systems. Some of them are also suitable for jamming analysis.

Radio equipment parameters, channel tables, antenna diagrams etc., are defined and stored in the central database.

Maps that indicate altitude, land usage and other background informations are stored in the geographical database.

The signal quality of the path is calculated from the generated path profile. This calculation includes atmospheric attenuation, obstacle attenuation and various fading mechanisms.

These radio communications planning software include sub-routines to analyse different interferences.

4.5.2. Telecommunications Network Management (TNM)

The network management subsystem is a computer based information system capable of performing all the tasks related to the management of the network. Network management is able to collect status, traffic and failure data, provides network control supervision facilities.

The computing platforms, the operating system and the basic software tools are the same for the tactical and strategical network management. Application programs are partly common and partly different due to the different specific requirements of the two systems.

5. MILITARY AND CIVILIAN COMMUNICATIONS

In comparison with the nationally owned military transmission system, PTT networks offer:

- A vast capacity, geographical coverage, diversity of routes, flexibility and redundancy. The re-routing capability thus aids the continuous availability of circuits to military/civil users.
- A means of improving connectivity, restoration and network survivability features of the military communications.

The civilian and military communications systems are similar in the extent of their structures in the used methods and technical resolutions. The most significant differences are in ECM resistance, mobility and environmental protection capabilities.

Military equipment are fully rugged and capable to withstand the environmental stresses associated to military field applications.

6. MILITARY COMMUNICATIONS IN HUNGARY

Basic principles of technical development of the Hungarian military communication system consist of the following requirements:

- digital,
- integrated services,
- automatical/intelligent,
- jamming proof, reliable,
- secure.

Digital system should be provided with connection surfaces, which ensure interconnection of the traditional system and equipment to the new network. Data transmission has to be provided by means of direct digital connection, without MODEMs. In the digital system it is possible to realise the independent data transmission network of the HHDF, the present lack of which is an obstacle to meet the informatic modernization demands, arising in different fields.

Automation of services is considered as' a basic requirement (automatic telephone, data communication, etc.). Moreover network control and management, routing should take place automatically. The system has to be capable for automatic replacing of failed, damaged links by finding alternative routes.

In the system it is necessary to deploy highly reliable units. Network structure, technical elements and the philosophy of network control should be in accordance with *reliability* and *survivability* requirements (meshed network, quasi-grid system, non collapsing network). *ECCM* requirements can be met by using meshed network structure, microwave and leased optical trunks, and radio-relay links (with spread spectrum or hopping features) in the especially endangered or relevant directions.

Information protection in the system should be provided by the use of crypto devices. A *bulk* encryption equipment is connected to the trunk lines. It in itself does not authorise users to transmit classified information. Security of classified information has to be ensured by individual encryption equipment. *Individual* encryption equipment may be connected between data sources and the channel. It is advisable to develop (independently or by licence) and employ individual voice and data encryption devices, having digital interfaces.

The new NATO military telecommunication *standards* expected to be introduced in about 2000 are based on the modern civilian standards. Considering, that our own communication system is connected to the domestic (civilian) networks in several points, and we lease channels from them, therefore international recommendations, standards should be taken into consideration as basic requirements during further development of HHDF communication system. Differences from these requirements are allowed only in the field of special military services (priorities, forced interruption, hot lines, etc.).

Satellite communications

When the need arives for the immediate connection of a site (as it happened nowadays for the Hungarian IFOR contingent in Bosnia) subscribers may be connected with the use of voice and/or data transmission services via civilian (VSAT, EUTELSAT, INMARSAT) lines.

One of the most interesting communication and information system development in the near future in Hungary is the Air Sovereignity Operation Centre (ASOC) and its Communication System. Hungary, the Czech Republic, Poland, Slovakia and Romania are involved in this air traffic control modernization program.

The main objectives of the ASOC program are:

- effective integration of the civilian and military systems including the common use of the same equipment;
- regional co-operation between the ASOC systems of neighbouring countries, and
- promotion of the integration toward the NATO.

Basically ASOC is an automated data processing and control system working on a powerful computer workstation network which collects the direct civilian and military radar data, the pre-processed IFF radar data, the newly aquisitioning 3D three-dimensional L-band radar data and after a sophisticated information processing of the plot and track data provides an exact real-time air situation displaying (image). This image is also available for the decentralized control system through data transmission lines of the communication system.

The national ASOC system will be provided:

- with some direct radar data from radar sites of the neighbouring countries, and also
- with real-time air situation information in standard NATO form from the neighbouring ASOC and from NATO data processing centres.

The information will be available through international communication lines connecting the systems by suitable interfaces. In the fully installed state this C3I system will be capable for fighter aircraft and rocket fire control.

7. THE FUTURE

The digital Asynchronous Transfer Mode is a subject of discussions about its role in military communications. According to the latest informations, ATM is a major area of interest to NATO nations for the post-2000 tactical communications network. The three potential ATM application areas:

- Headquarters LAN;
- Backbone WAN;
- Battlefield and Tactical Communications.

Dispite indications that some military requirements could be supported by civilian ATM protocols, in their current forms they do not fully satisfy military requirements particularly in the areas of security, interworking and network management. Proposals for enhancing civilian protocols to support such military requirements, and their inclusion in civilian standards are studied and discussed.

The speed and flexibility of the ATM, the rich set of communications services of the ISDN and the wide area coverage of SATCOM complement each other, particularly with regard to military communications.. Such an ATM-SATCOM-ISDN research and demonstration programme has been initiated within NATO being primarily interested in low-data-rate ATM operation in the tactical environment. From military perspective, it is an attractive means of providing modern services to tactical users at remote locations linked by SATCOM as well as the PTT and other networks.

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József Szabó received his B.Sc. and M.Sc. degrees in electrical engineering from the Technical University of Budapest, Hungary in 1975 and 1983, respectively. In 1976 he joined the Hungarian Army, and was assigned to the Institute of Military Technology as a research assistant and later as an engineer officer. He supervised the development of several military communication equipment for Hungarian Army. He is interested in advanced digital communications and networking technologies and their applicability for military purposes.

RADIO RECONNAISSANCE IN THE VHF/UHF FREQUENCY RANGE

L. TAKÁCS
HUNGARIAN ARMED FORCES

The start of radio communication was followed by the demand to intercept the information forwarded by the radio. This demand originated the radio reconnaissance so called COMINT, that developed along with the telecommunications to reach its present level.

1. INTRODUCTION

Today telecommunications (including the special military requests) use a very wide frequency range: from a few 10 Hz to some 100 GHz. As it is known the propagation properties are very different within this wide range. The radio wave having several thousands km wavelength travels inside the ground (water), then increasing the wavelength it leaves the ground and propagates following the curvature of the earth. From the several ten meters range the line of sight propagation is increasingly characteristic. From this wide frequency range we will examine the radio reconnaissance in the VHF/UHF range. The process can be seen on Fig. 1. Some terms should be defined:

- *Radio reconnaissance:* one type of military reconnaissance, which uses passive (only reception) devices for intercepting, monitoring and direction finding the operating radio devices of the opposite party in order to get and process technical, content and direction information.
- *Data acquisition:* part of the radio reconnaissance, when we get technical, contents and taking direction data by reconnaissance, monitoring and direction finding measurement of the operating radio devices of the opposite party.
  - *Interception:* this is the initial phase of radio reconnaissance, an organized activity to reconnoiter the radio devices — sensing their operation — used within the control and command system of the opposite party, to determine its parameters and their reconnaissance value.
  - *Monitoring:* it is one type of radio reconnaissance, an organized activity to monitor the operating radios consciously, intentionally, continuously or periodically. During the monitoring, radio messages are recorded and the radio traffic and technical data are determined.
  - *Direction finding:* means the determination of bearing of the operating radio transmitters relating to the direction finder station. To determine the location of the deployed radio transmitter is made by calculation from the bearings measured simultaneously by two or more radio direction finder stations.
- *Data processing:* radio reconnaissance data processing means the collection and evaluation of technical, content and direction finding data from the data reconnaissance sources and preparing reports and logs.

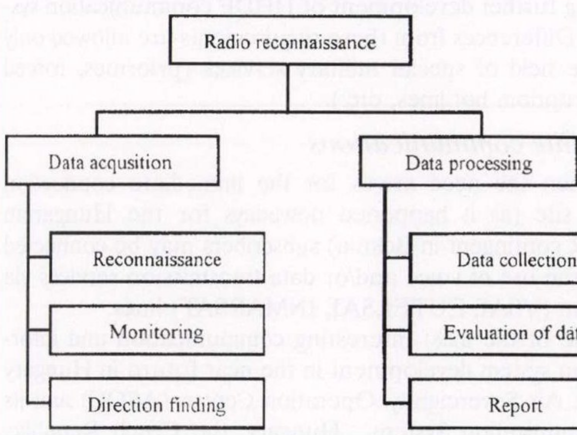


Fig. 1. Process of radio station reconnaissance

Data acquisition is made at a separate station. This workpost includes equipment that can receive the required signal and can derive the necessary information from this signal. Its structure can be seen in Fig. 2.

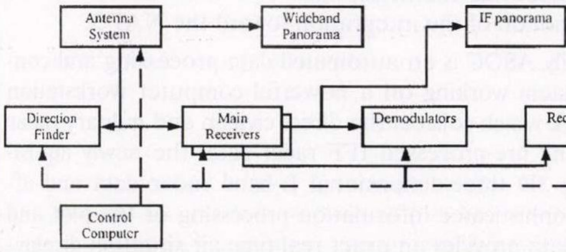


Fig. 2. General structure of radio reconnaissance station

2. REQUIREMENTS OF THE DEVICES OF THE RADIO RECONNAISSANCE STATION

2.1. Antenna system

It is one of the most important element of the radio reconnaissance station. In the VHF/UHF range the aperture angle is becoming smaller as the frequency is increased. Antennas of the point-to-point communicating stations are facing toward each other, and the antennas of the reconnaissance stations are generally out of the main transmission direction. This means, that they can receive signals with very low field strength. This low level signal should be intercepted by the receiver. To produce proper signal-to-noise ratio the antenna should have high gain. The other requirement is contradictory: antenna frequency range should be as wide as possible. Other problem is that the antennas with high gain are directional ones, they can not be used for omnidirectional reception, they should be fixed onto a rotating device. In case of mobile stations the number of antennas can not be optionally chosen, only a few antenna can be fixed to a mast. In case of fixed station the number of antennas can be higher as more antenna can be fixed onto a mast having higher loadability. So the total frequency range can be covered by antennas having narrow frequency range but high gain.

The problem is different in the different sections of the radio reconnaissance procedure.

During radio reconnaissance we have to examine the whole area around. For this, omnidirectional antenna, or rotating directional antennas should be used. During monitoring — as the direction of the transmitters to be monitored is known — directional antenna with high gain set into the proper direction can be used, naturally separate antennas into the different directions. Taking into consideration the above contradictions, antennas should be selected in a way to give the possibly best optimal solution.

The next part of the antenna system is the antenna amplifier. Its task is to amplify the signal produced by the antenna, and to compensate the attenuation of the cable and antenna divider. For installation the amplifier care should be taken to avoid the generation of intermodulation products because of the high gain and the transmitters producing high field strength nearby and so producing false (disturbing) signals at the input of receivers. The antenna cable should have low attenuation, in case of mobile stations it should be flexible and easy to reel.

2.2. Wide band panorama

This is a special receiver, which displays a wide frequency spectrum within its reception range on its display unit graphically. This solution makes reconnaissance easier and quicker. On the display the appearance of a transmitter can immediately be observed. Up-to-date panoramas give additional features for reconnaissance. Some of them are: marking prohibited frequencies, displaying frequencies operated before, displaying the measured highest value (MAX HOLD), markering the frequency of the parallel receiver and by moving their markers, the connected monitoring receiver can be tuned.

2.3. Main receiver

Its task is to receive the signals provided by the antenna, to process the received signals, to demodulate, and to produce special outputs for the purpose of radio reconnaissance. Such outputs are: wideband IF signal for IF panorama receivers with video baseband output. Because of its special utilization, the receiver should fulfill special requirements. Parts of these are because of the military utilization: shock and vibration proofness, wide operation and storage temperature range, high MTBF, short repair time. Beside these the reconnaissance and monitoring tasks produce strict technical requirements. These are: low noise figure, high stability and low phase noise, synthesizer tuning, changeable IF filters with high slope, high blocking range, AGC with high dynamic range and speed. EMC compatibility is also a very important requirement. The receivers should contain built-in test equipment for checking their correct operation.

2.4. IF panorama

Its task is to monitor the operating frequency range and its surroundings on IF level and to display the frequency spectra for analysis. It makes possible to recognize the modulation modes, bandwidth, sidebands. Other possibility is the examination of the IF signal as a function of time. Proper evaluation is helped by moveable markers, comparison of stored pictures, MAX-HOLD operation mode.

2.5. Demodulators

The main receiver generally demodulates only a few "basic operation mode" (A0, A1, A3, A3J, F1, F3, F6). Transmissions using complex modulation modes can be demodulated by special purpose equipment. Such operation modes are frequency and time division multichannel transmissions (FDM, TDM) or multichannel telegraph within one telephone channel, modem connections, fax or other special transmissions. Such transmissions are demodulated by the main receiver first, and then its line or video baseband signals are forwarded to the special demodulator. The demodulator can be a special device for one or more adequate modulation modes. In this case the transmission can be directly demodulated. If the transmission is more complex or not known yet, then a special demodulator is needed, where the demodulating hardware elements can be changed by software.

2.6. Recorders

Previously tape recorders or telegraphs were used for recording information, or the information was put down in hand. Nowadays these recording modes are succeeded by digital technique, independently from the type of information whether it is speech or data.

2.7. Control computer

The equipment of the station are mainly remote controllable. The operation of an up-to-date station essentially differs from a traditional one. Concerning the structure a few device can be operated independently or using a proper program by remote control. Programs ensure that parts of the traditional radio reconnaissance (during reconnaissance the tuning of receivers) are made by computer automatically. This reduces the load of the operators who can pay higher attention to tasks, that can not made by computer e.g. making proper conclusions on the basis of the radio traffic.

2.8. Radio direction finder

Radio direction finder ensures the measurement of the bearing of the transmitter related to the deployment site of the DF station. Using more direction finders, the sections of the bearings determine the probable deployment site of the given transmitter. For this at least two direction finder is needed. For achieving higher accuracy more stations have to be used. More than five stations do not improve the accuracy, so in practice 3 to 5 stations are used.

Requirements for the currently used radio direction finders are more strict than ever. By the development of telecommunication modern transmission modes appear (frequency hopping, packet radio, burst transmission etc.). Common characteristic of these transmissions is the very short transmission time. Depending on the transmission mode it can be from a few msec to a several sec. Measurement should be accomplished during this short time with proper accuracy. This cannot be ensured by one measurement, but depending on the signal-to-noise ratio several measurements should be averaged to get better result. This means, that an up-to-date direction finder should produce bearing data within a few msec. The old fashioned analog direction finders cannot be used for this, thus new instruments using the traditional measurement methods (e.g. Watson-Watt or interferometric) with digital signal processing and evaluation have to be used.

Such solution can be a system, where the control system immediately forwards the measurement demand to the direction finder as the radio transmission detected. Another solution is the use of a high accuracy system-clock, where the direction finding measurements are made in an autonomous way at each DF station and data of the measuring stations are later collected and evaluated based on the measurement time data.

2.9. Selection of deployment site

In the VHF/UHF range the optical visibility should be ensured because of the line of sight propagation characteristics. So the selection of deployment site is very important. This can be calculated by a simple formula:

$$d = 4.12\left(\sqrt{h_1}+\sqrt{h_2}\right),$$

where

d : distance between the two points (reconnaissance station and the enemy's transmitter)

h_1 : height of the antenna of the reconnaissance station

h_2 : height of the antenna of the transmitter

4.12 : a constant given by the curvature of the Earth, taking into consideration that radio wave deviation can yet be calculated in this frequency range

It can be calculate from the above formula that on plane surface what distance can be expected for the reconnaissance station e.g. if our antenna height is 30 m and that of the transmitter antenna is 15 m:

$$d = 4.12\left(\sqrt{30}+\sqrt{15}\right) = 38.5\ \text{km}\,.$$

This means that the deployment site must be selected as high as possible.

For taking into consideration the whole direction finder system is the other important fact. This influences the accuracy of the measurement. The most accurate location determination can be made if the bearings are crossing each other in 90° (Thales circle). Acceptable accuracy can be achieved between 30° and 120°.

The limit 30° can be achieved at 1.86D, where D is the direction finding base, i.e. the distance between the two direction finders. This means that in the above example, where $d = 38.5$ km:

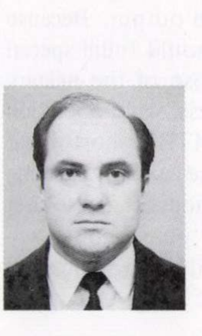
$$D = \frac{38.5}{1.86} = 20.7\ \text{km}\,,$$

So in the above example the two side radio direction finders can be deployed in max. 20.7 km distance from each other.

2.10. Structure of the complex radio reconnaissance station

It is determined by the requirements of the application. In peace mainly fixed stations are used. If data acquisition is made for conducting fighting troops, then mobile stations are needed.

At such a the station the equipment of all the three types of activity (interception, monitoring and DF) can be found in one station in spite of the traditional construction. Antenna height is 30 m, which ensures to have a view in proper depth and minimize the disturbance of the metal parts below the antenna. The built-in hydraulic system ensures quick deployment. Internal construction (ergonomically designed operator posts, air-conditioner, etc.) makes even the long term work convenient. Built-in equipment are the most up-to-date ones ensuring high level reconnaissance operation.



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MICROWAVE COMMUNICATION RECONNAISSANCE

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The detection of radio signals from potential adversaries in the 0.5...40 GHz frequency band and the analysis of electrical parameters, the acquiring of information, storing and reporting the demodulated data are the main tasks for a microwave radio surveillance and reconnaissance station. These problems are discussed in the paper.

1. INTRODUCTION

A microwave radio-surveillance station is shown in Fig. 1.

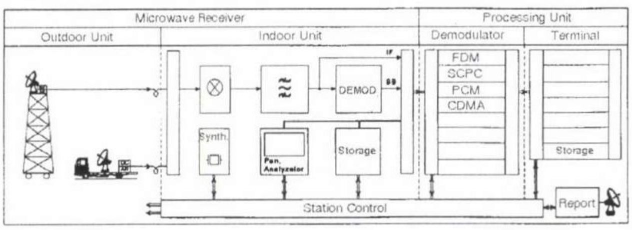

Fig. 1. Microwave radio surveillance station

The station has two basic parts:

- *Microwave receiver*, comprising in- and outdoor units converting the received microwave signal into a suitable frequency range for recovering the information.
- *Processing unit* comprising demodulators and terminals recovering, storing and reporting the information.

2. MICROWAVE RECEIVER

2.1. Requirements

The microwave receiver has to find the hostile transmitter with its important parameters: position, timing, frequency, polarization and modulation, etc. In the microwave band usually several channels with different modulations (FDM, TDM, CDMA, etc.) are superimposed on one carrier frequency. In the reconnaissance function not only the carrier frequency but also the specific channel and its modulation have to be determined.

In the microwave reconnaissance operation the following parameters are to be determined:

Time of transmission

Interesting frequencies should be monitored periodically. A signal with short switch-on time (e.g. FH) can be detected if the receiver scans the entire microwave frequency band during the transmission time.

Receiving frequency

It is necessary to sweep the whole 0.5...40 GHz frequency band periodically. Sweep speed is limited by the bandwidth (the wider the bandwidth the faster the sweep, but lower the SNR of the receiver).

Direction of the received signal

Azimuth (Az): $-180\ldots+180°$.
Elevation (El): $-5\ldots+90°$.
To find the direction it is necessary to use a remotely (and manually) controlled antenna system with the above positioning range. For moving signal sources automatic tracking is needed, producing an important time-function for reconnaissance.

Polarization of the received signal

The antenna system has to be suitable for receiving four (horizontal, vertical, left-hand and right-hand circular) polarizations.

Choosing the suitable one must be done remotely. (If the linear polarization is set slant (45°) all the other polarizations are receiveable with 3 dB loss. In the case of searching spread spectrum transmissions we have to use the right polarization.)

Modulation of microwave carrier frequency
(AM, FM, FSK, MPSK, MQAM, CDMA, FH, TH...)

The modulation scenario is very wide: there might be analog or digital, amplitude, frequency or phase modulation. Modulating signals are usually complex multiplex ones. In the recent practice, digital modulations are getting more dominant. To receive and demodulate different types of modulations needs SNR to be in the range of $-22\ldots+45$ dB. (The signal of spread spectrum modulated transmission (e.g. CDMA) may be under noise level.) We can get channel information only after demodulating and demultiplexing.

2.2. Antenna System – Outdoor Unit

Antenna collects the radiated energy from the transmission media and converts it into guided microwave signal. Antenna must make a difference in both direction and polarization of received signals. In practice, the antenna is integrated with the low noise down-converter to minimize loss and phase shifts introduced by cable. (The distance between the antenna and the indoor unit is usually 10 to 60 m.)

In radiomonitoring and radio-reconnaissance tasks, it is not possible to influence the power of hostile transmitting station; so the only way to increase the level of the received signal is to choose the deployment place of the receiver antenna optimal and/or to increase it's effective surface.

The antenna picks up noise from the medium too. This and the receiver internal noise have to be kept at the possible lowest level, otherwise the quality of reception will decrease.

The SNR determines whether the detection of the signal will be successful or not and what will be the quality of the recovered information.

Satellite reception

The power radiated by the satellite antenna ($P_T G_T$) disperses in the free-space on a surface of sphere ($4\pi d^2$) with the distance as radius (d) between the satellite and earth receiver antennas ($P_T G_T/(4\pi d^2)$). This power density is further decreased by atmospheric, precipitation and polarization attenuations ($P_T G_T/(4\pi d^2)/L$). The effective aperture area ($A_R \eta_R$) defines the collected receiving power ($\eta_R A_R P_T G_T/(4\pi d^2)$) at the antenna output.

Terrestrial reception

The reception distance is limited by tropospheric refraction (h_R^N) and reflection on the earth surface (h_R^R).

To increase the reception distance have to deploy the antenna on tower (mast) or natural peak with the necessary height ($h_R = h_R^N + h_R^R$).

The reflection depends on the frequency. At the low end of the frequency band (0.5 GHz) we need a 50 m high tower for 20 km receiving distance. At the upper end (40 GHz) we can use this tower up to 50 km (at this frequency the refraction is already dominant).

Internal noise of a microwave receiver

The receiver internal noise (FkTB) is related to the receiving bandwidth (B) and the internal operating temperature (T). It can be improved by decreasing the receiver noise figure (F). Due to recent developments the noise figure of wideband microwave amplifiers has been greatly improved (Table 1)

Table 1. Noise figure of antenna amplifiers

f [GHz]		0.5...2	2...18	18...26	26...40
F [dB]	Wideband	0.6	2	1.6	2.5
(23°C)	Narrowband	0.5	0.4...1	1.6	2.5

From the table, it can be seen that a wideband searching system is efficient for monitoring tasks too. (The wideband noise is only 1.6 dB higher than the narrowband one. This means only 20 % difference in antenna diameter.)

Antenna type

Parabolic reflector antennas are still most commonly used for both searching and monitoring tasks.

Wideband antenna feeds

The most commonly used types are:

- crossed log-periodic ones;
- dual polarized horns.

The four polarization modes: H, V, LHC and RHC are realized in one feed. The reception by horizontal (H) and vertical (V) polarizations are direct. The two others are possible with the help of a phase shifter and microwave switches after the two identical (H and V) low noise amplifiers (because of simultaneous reception of horizontally and vertically polarized signals).

For the best result of receiving we have to use narrowband antenna feeds (with one polarization).

Above 5 GHz, the new dielectric lens horn antennas yield better electrical and mechanical parameters compared with others.

The antenna diameter (D) and the focal length (F) give the half-power beam-width (φ_R) and with the antenna efficiency (η_R) the effective aperture area (A_R) of the antenna.

The larger the antenna the better will be the receiving SNR, but the antenna diameter is limited by the permissible maximal size in application, the wind load, the expenses and the smaller beam-width. The requirement of tracking accuracy for satellite orbit is $\pm 0.1°$, the necessary setability of the receiver antenna $\pm 0.1°$ and the antenna pointing error have to be within $\pm 0.1°$. These parameters define the minimum beam-width ($\varphi_{Rm} = 0.6$) of the receiver antenna.

In the band of 2...18 GHz, the calculated maximum diameter is smaller than they are used in practice (6...7 m is needed for higher data rates). Increasing the ratio of focal length to diameter and/or using a distorted parabolic profile the beam-width becomes a bit larger.

Another solution is using some smaller coherently added antennas.

The parameters of the many octave wide parabolic antennas highly depend on the receiving frequency so they aren't able to obtain the optimum reception (Table 2).

Table 2. Maximum diameter and surface gain of the parabolic antenna ($\varphi_{Rm} = 0.6$ [°])

f [GHz]	0.5...2	2...18	18...26	26...40
D_{RM} [m]	18.2	2.03	1.4	0.91
φ_R [°]	2.4...0.6	5.4...0.6	0.87...0.6	0.92...0.6
a_R [dB]	21.6	2.5	−0.7	−4.4

The real solution will be using active phased array antennas. Their characteristics are controllable so those can be optimized at any frequency.

Antenna steering

Receiving of low level signals needs large antenna aperture but thus the beam-width is small. This puts strict restrictions against the antenna rotator and controller system in practice. $\pm 0.1°$ setability and antenna pointing error have to be taken into consideration.

In case of *terrestrial reception* we have to bear the antenna and later correct the effect of wind and refraction changing.

At *satellite* reception usually continuous tracking is needed.

The *geostationary earth orbit satellites* (GEO) try to hold their assigned position in their station keeping box ($\pm 0.1°$) in the equatorial orbit. But in the second part of their lifetimes they begin to drift in the North-South direction, forming an ellipse with a diurnal East-West motion. Viewed from the earth this describes a figure eight type of motion.

The *inclined elliptical* (or circular) Geo.-synchronous (or non-Geo.-synchronous) orbit satellites need continuous tracking. The orbits of satellites are defined by spatial mechanics. So they are known or can be measured and program into the memory of the automatic tracking antenna system.

Direction finding

The microwave receiver antennas can give only the direction of reception. Because the sky above us are covered by many known orbit satellites so the orbit of a new unknown satellite can be extrapolated.

In case of terrestrial reception we can find the main reception bearing.

Antenna system deployment and configuration

Terrestrial receiving antennas have to be deployed on a tower or natural objects or man-made structures with the necessary heights (10...60 m) for surveillance distance (10. . . 50 km).

In case of satellite reception the antenna system is fixed to a massive antenna pedestal. Both terrestrial and satellite antenna systems have stationary and mobile realizations.

Mobile antenna system is mounted on a truck or a trailer. To keep at the lowest level the receiving noise figure, ultra low noise antenna amplifiers have to be connected directly to antenna outputs. This is followed by down-converter, which is connected to the indoor unit usually via a 10. . . 60 m long flexible cable.The microwave surveillance and reconnaissance task requires a complex system, which consists of more antennas and receivers.The continuous searching occupies at least one system. So other(more specialized) systems are needed for the parallel monitoring tasks.

2.3. Receiver Indoor Unit

The most frequently used receiver is the YIG tuned narrowband superhet, because of its good frequency selectivity, high dynamic range and sensitivity. The superheterodyne receiver linearly converts the chosen portion of the microwave frequency range into a suitable intermediate frequency (IF) band using its local oscillators (through two or three frequency conversions).

First of all, the down-converter is tuned to any point of the 0.5. . . 40 GHz band and the chosen subband is transformed into the 300. . . 2000 MHz (e.g. 450, 700, 1000, 1300 MHz. . .). This is the first intermediate frequency band (IF1) of maximum 120 MHz bandwidth. The filter is YIG tuned or passive switched. The YIG and the IF1 filter block determine the largest receivable bandwidth (generally 72, 90 or 112 MHz) and in partly the microwave selectivity.

The second converter puts the IF1 band to a lower intermediate frequency (usually 70 or 160 MHz), where the medium-wide bandwidth IF filters (from 100 kHz to 36 or 44 MHz) are available (IF2).

Finally, the third mixing converts the IF2 band to IF3 band (e.g. 450 kHz, 10.7 or 21.4 MHz), where we can do the narrowband (from 3 kHz to 38 kHz) reception.

Reception frequency tuning

The microwave receiver can be tuned to any frequency in the 0.5. . . 40 GHz band with 1kHz step size. (This yields $\pm 1.25 \cdot 10^{-8}$ frequency accuracy, and stability requirement at 40 GHz for half step.)

The 1 kHz frequency resolution (the finest step-size) is feasible with the help of direct digital synthesizer (DDS) controlled local oscillators.

The frequency accuracy and stability is guaranteed by application of a high quality frequency reference. Because the absolute deviations of the three local oscillators are added, so the most critical requirements are against the first (highest frequency) local oscillator. The DDS based local oscillators have fine frequency resolution, fast switching speed, excellent phase noise and the simplest realization but they have spurious output signals. (Because the digital analog converter of the DDS is not enough good yet. Recently, 65. . . 72 dB spurious signal level maximum can be reached at the low part of the DDS output frequency spectrum for relative small bands. Factories make great efforts to continuously improve DAC parameters, so we can hope for DDS of 80 dB spurious level with wider and wider relative tuning band.) The phase noise and the spurious signal level of the local oscillators can only negligibly increase the microwave receiver system noise.

The frequency accuracy and the short time stability of some received signals may not be enough for good quality reception, so we have to insure automatic frequency tracking (AFC or APC) at the second local oscillator.

Amplifier chain

Task of the amplifiers is, that by gaining the level of gathered signal by the antenna, without introducing much additional noise, to insure the SNR maximum for signal processing. This optimum level must be kept independently of the attenuation changing in the transmission media (ALC, AGC and MGC).

The system dynamic range, at the IF output or at the demodulator input, is limited by upwards the 1 dB compression or the intermodulation and downwards the total system noise or the detector sensitivity. As the noise increases with the transmission bandwidth, as the wider the band the smaller the dynamic range.

Frequency selectivity (channel separation)

Standard IF bandwidth series belongs to the microwave satellite and terrestrial communications transmissions depending on the different modulations. The bandwidth range can be divided into narrow (3. . . 38 kHz), medium (0.1. . . 36 MHz) and wide (36. . . 112 MHz) IF filter subbands.

The task of microwave searching and monitoring station decides which of the filters are needed. In case of reception of MPSK or MQAM signals, have to insure not only the low amplitude but low group delay time ripples too, in the IF band.

In any case, we have to use the right bandwidth. (Using narrower bandwidth, the noise gets smaller and the adjacent channel separation is better but it cuts a part of the modulating spectrum so the demodulated signal is poorer. Using wider bandwidth, the ripples are smaller, but the larger noise and the intermodulation of the adjacent channels make the demodulated signal poorer.)

Demodulation

The more and more complex modulation techniques, channel multiplexing and different multiple access modes require sophisticated processing of received signals.

The microwave receiver may contain analog demodulators (AM, FM, FMTV) and/or some simpler digital demodulators (e.g. FSK, BPSK, QPSK) and/or SCPC receiving option. The sensitivity threshold of all types of demodulators must be low for efficient radio reconnaissance.

Panoramic visualization

A suitable panoramic display (a special spectrum analyzer) is a great help for the operator of microwave surveillance receiver in visual signal detecting and analyzing.

The panoramic analyzer must be selectable to sweep:

- the entire microwave band (0.5. . . 40 GHz);
- continuously variable microwave subband (50 MHz. . . 5 GHz);
- the different IF frequency bands (100 kHz. . . 120 MHz);
- the demodulated baseband (100 kHz. . . 40 MHz).

The panoramic display must be suitable for measuring amplitude and frequency of received signals. For good interception probability, the speed of panorama must be high (during the switch-on of the hostile transmission it has to sweep over the full interested frequency range). The panoramic speed depends on the tuning speed of the local oscillators and the panoramic resolution bandwidth. The panoramic bandwidths have to be automatically matched to the requirements of the task.

Checking the frequency band occupancy needs continuous recording by plotter.

Storage

The reconnaissance data received by the microwave receiver have to instantaneously visualized and stored for further processing and reporting. The analog and digital information, in analog or mainly in digital form, are stored in high capacity analog or digital storage media.

Control

The microwave surveillance and reconnaissance tasks usually are so complex that they need a centralized control of station sub-units.

The self-control of the functional sub-units are coordinated by a central unit.

3. PROCESSING SYSTEM

The target is to retrieve the information carried by the radio-channel of the intercepted communication link. To achieve this goal the IF signal should be demodulated, the multiplex signal should be restored, the multiplex signal should be decomposed to its tributaries (demultiplexing, selection of the base-channels), the information content of the base-channels should be recovered (real-time processing) or the signal should be recorded for off-line analysis.

In most cases, because of the great variety of digital modulation methods and their implementation, the monitoring radio receiver contains analog (AM, FM) demodulators only while the digital demodulator(s) and the demultiplexer constitute a common equipment. If a digital telecom system is to be reconnoitered, the interconnection of the radio receiver and the digital demultiplexer will take place on IF band.

Because of the more and more increasing number of the digital modulation, channel access, multiplexing and data processing methods the construction of a "universal" digital demodulator/demultiplexer equipment is unreasonable. In this article we deal only with the reception of line-of-sight or satellite radio channels, bearing low/medium-speed plesiochronous TDM signals.

3.1. Special operating conditions and requirements

It is a typical case on a reconnaissance station that

- the technical parameters of the telecom system to be monitored are partially unknown by the operator;
- within a given time period only some channels of the intercepted system are carrying traffic and only a few contains important information;
- the space for the equipment is limited (especially in a mobile station);
- and there is no maintenance staff and instrumentation.

From these conditions follows that

- the circuitry of the reconnaissance equipment should be very flexible: software controlled and field-programmable;
- the implementation of the traffic panorama (displaying the loaded channels of the received system) is essential for the operator;
- the number of the channels to be recorded simultaneously is much less than that of the received system, however any of the channels should be accessible (listenable, recordable) quickly; and
- built-in test and trouble-shooting circuitry is necessary.

In complex reconnaissance systems the remote control of the demodulators/demultiplexers from a central computer is also required.

3.2. Digital demodulators

In small/medium-capacity digital line-of-sight radios the most commonly used modulation technics are the two-state or four-state frequency-shift-keying (2FSK, 4FSK).

Nowadays, because of the severe requirements regarding the efficient use of the microwave frequency spectrum, more sophisticated methods, like the combined phase/amplitude modulation, QAM, are also spreading. In digital satellite telecommunications systems the phase-shift-keying methods, 2PSK and 4PSK, are used exclusively. Some terrestrial radio manufacturers also prefer PSK.

The reconnaissance station has to be equipped with all the three types (FSK, PSK and QAM) of demodulators. They are of coherent types to minimize the BER degradation. One of the most problematic task of the circuit designer is to implement the exact carrier recovery from the poor SNR IF signal.

What makes the task of the digital multiplex baseband restoration even more complicated it is the great variety of baseband signal processing methods used in conjunction with digital radio-transmission.

The processing stages from the multiplex baseband interface to the IF modulator input are the followings:

- the radio frame generation, multiplexing the radio service channel(s) and the payload;
- the differential and forward error correction coding blocks;
- the scrambler;
- the mapping stage.

In the reconnaissance equipment the inverse processing, in reversed order, have to be executed. The problem, from the reconnaissance point of view, is that most of the procedures are non-standard, each of them have more variants while some of them are absent.

Only one example:

The bits of the payload and those of the service, maintenance and signaling channels of the radio network are multiplexed and framed at the input of the transmitter. The multiplexing is often plesiochronous, when the justification control and the justification bits are also inserted into the radio frame.

The usual framelength spans from some hundred to some thousand bits and about 10 % of them belongs to the radio system. As the frame structures are not standardized, the selection of the payload by the reconnaissance equipment is nearly impossible without knowing the multiplexing rule, applied by the manufacturer of the intercepted radio network, exactly. Consequently, the operator of the demodulators needs special analyzers for the system identification.

3.3. Demultiplexer equipment

There are two possible methods of the reconnaissance demultiplexer design. The first one is to follow the architecture of a telecom equipment, keeping the procedure of successive demultiplexing. That means a signal of high multiplex hierarchy level will be decomposed to its lower level standard tributaries, step-by-step, until the base channels are reached. As an example the block schematics of a 300-channel FDM demultiplexer is sketched in Fig. 2.

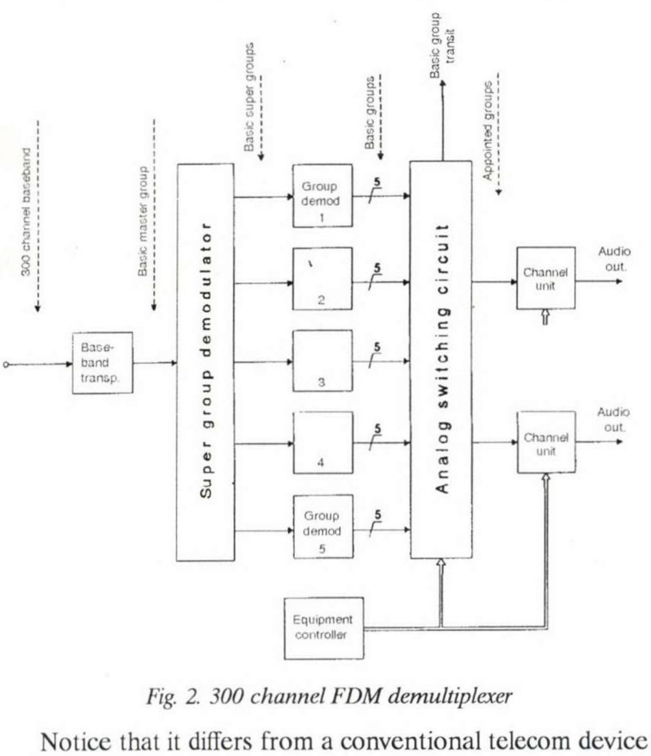

Fig. 2. 300 channel FDM demultiplexer

Notice that it differs from a conventional telecom device only in two points:

- it contains a controlled analogue switching matrix circuitry (because the number of the channel units is less than the number of the basic groups);
- the channel units are controlled too, and are able to demodulate any of the 12 channels within the FDM basic group.

In systems processing more supergroups another switching matrix can be inserted between the supergroup and group demodulators. In a large system (with several tens of audio outputs) digital implementation of a channel demodulator bank is feasible.

It is the advantage of this method that

- the circuitry designed, optimized, for professional telecom equipment can be used; and
- broadband channels (FDM groups, supergroups) carrying non-speech signals (high-speed modem e.g.) are also accessible.

However the access to the channels may be constrained by the multiple-stage matrix network and the control of the switches makes the system complicated.

Principally, similar method can be applied for TDM demultiplexers. In a tertiary (480-channel demultiplexer e.g. the first stage splits the 34 Mbit/s bit-stream to 4 secondary (8 Mbit/s) streams while the second stage generates 4x4 primary level multiplex signals, each carrying 30 telephone channels of 64 Kbit/s. (European PCM system.) The channel units are connected to the primary multiplex signal sources through a controlled digital multiplexer network. Any of the channel units can be synchronized to any of the 30 channel timeslots. The primary level multiplex signal (carrying 2 Mbit/s data signal e.g.) can also be accessed through the multiplexer network.

Another way of the equipment design is the direct single channel demultiplexer approach. In this case an appointed telephone channel is selected by a single channel unit, directly from the incoming frequency spectrum (FDM recon.) or from the incoming bit-stream (TDM recon.)

An FDM channel unit is basically a heterodyne radio receiver tunable over the whole input frequency range.

A TDM channel unit successively selects only those tributaries of the TDM bit-stream which carry the bits of the appointed channel, while the remainder bits are dropped as "dont cares". To achieve this goal the frame synchronization, justification control and bit selector stages for all of the hierarchy levels have to be implemented in one unit.

The advantage of the direct selection approach is that

- the equipment is built from identical units;
- the additional multiplexer stages are omitted and, consequently, the control system is relatively simple;

however

- this approach needs more high-frequency/high-speed circuits; and
- the selection of larger group of channels is unsolved.

The latter drawback can be eliminated by building up the reconnaissance demultiplexer from channel units having different bandwidth, output speed, resp.

An example, for TDM case, is given in Fig. 3.

3.4. System architecture

Fig. 4. shows the block diagram of a modern signal processing subsystem.

For restoration and storing of the information content carried by the monitored telecom channels different terminal equipment are needed besides the demodulator/demultiplexer sets. Some of them are necessary when a telephone channel carries non-speech type information, like telegraph, data or fax. A telephone channel may also be used for the transmission of more, compressed, speeches or speech plus data signals. The procedure is known as submultiplexing. The "subdem" block executes the reversed operation: separates and expands the information channels. For speech recording tape-recorders or multichannel digital audio recorders can be used.

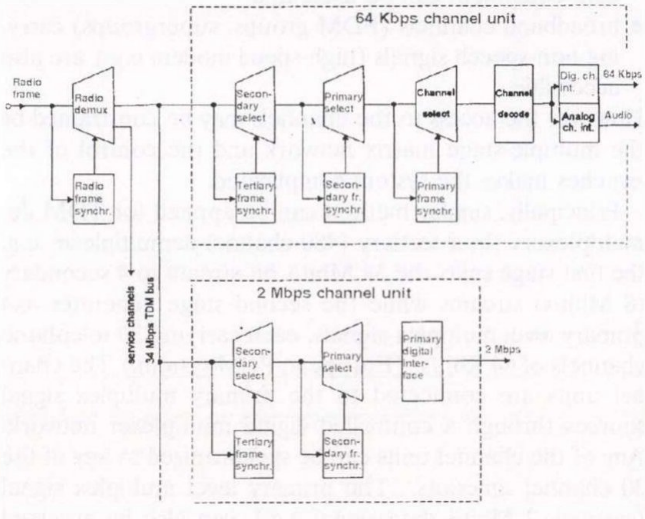

Fig. 3. 34 Mb/s TDM demultiplexer

If there are two microwave receivers in the reconnaissance station, one for digital and one for analog reception, then two operators work with the signal processing equipment.

The devices supporting the operator's work are highlighted in Fig. 4.

Displaying the traffic conditions of the monitored telecom channels is essential both for FDM and TDM demultiplexing.

The traffic panoramas can appear on the monitors of the TDM, FDM control computers, respectively. In the latter case the audio signals have to be transformed to digital form.

The digital scope is useful for modulation analysis, displaying the constellation diagram of the phase-modulated IF signal, and for the analysis of the baseband eye-patterns.

A computer, with a special frame analyzer software, makes possible for the operator to analyze the framing structure of an unknown TDM system. The input for this off-line analysis is a stored data-file. The file contains samples from the TDM multiplex signal recorded at the input of the demultiplexer. The frame-alignment analysis is based on algorithms examining the recorded bit-stream, searching for periodic components and for simultaneously varying bits.

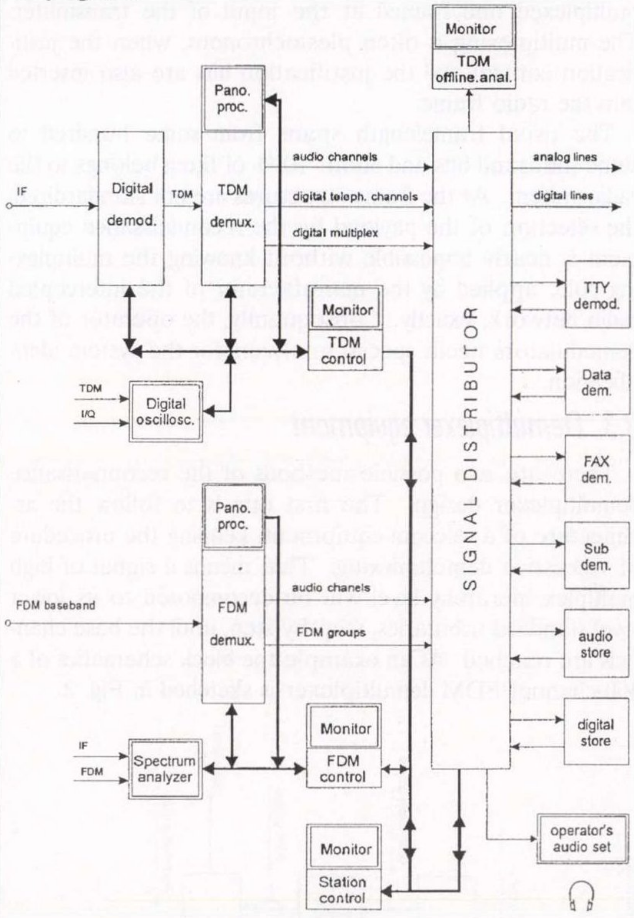

Fig. 4. Signal processing subsystem

The software examines the structures repeatedly, supposing different scrambler circuits. Finding the periodicity the frame synchron code and the frame length can be identified, while the knowledge of the bit-groups moving at the same time helps in the recognition of the justification system.

4. ACKNOWLEDGMENT

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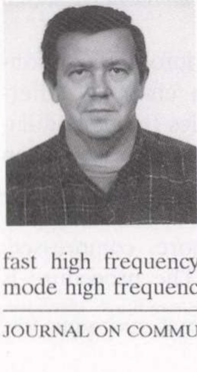

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József Elekes graduated from the Electrical Engineering Faculty at the Technical University of Budapest in 1961. He got his second degree in transmission engineering in 1967 and the technical doctor degree in 1987, also from the TUB. In 1962 he worked as operating engineer in the microwave center of the PTT then he joined the Research Institute for Telecommunications (TKI). In the TKI he was working on the development of different FDM equipment, both for civil and for military applicaitons, and in the system design of reconnaissance stations. From 1980 to 1995 he headed different departments of TKI, from 1992 of TKI Rt. resp. Presently he is senior system eingineer of the TKI. Rt.

RADAR RECONNAISSANCE

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The paper gives a survey of radar reconnaissance receivers in the frequency band of 1 to 18 GHz. Detailed information is given on the IFM, and the microscan type radar reconnaissance receivers.

1. THE EW RADAR THREAT SCENARIO

The function of an EW equipment is to search for, intercept and locate the electromagnetic field of an emitter, analyze the detected spectrum, identify the type of the emitter and try to suppress or neutralize the enemy's electronic capabilities which generally include radars, communications and electro-optical systems.

Radar waveform is the main feature of any radar system. Ambiguity function is the commonly used tool to characterize and visualize the properties of the radar waveforms. In a three-dimensional plane the function displays the response of a matched filter (network whose frequency-response function maximizes the output peak-signal to mean-noise ratio) to the radar waveform. In the design of radar systems the ambiguity function has special importance.

Radar waveforms meeting the necessary requirements such as detection, measurement accuracy, resolution, ambiguity and clutter rejection are belonging to one of the five different classes listed below:

1.) Single short pulse (order of μsec) modulated in amplitude. It has poor Doppler processing capability and is used only for detection of targets in low clutter situations.
2.) Single long pulse (order of msec) modulated only in amplitude. The duration is long enough to resolve the Doppler scatterers but not in delay. This class corresponds to the so-called CW-type radars suitable for detecting moving targets immersed in clutter.
3.) Linear FM waveform used in pulse compression radars, providing a long pulse for large radiated energy (long range), having simultaneously a range resolution corresponding to a short pulse. It has a ridge-like ambiguity function.
4.) Coherent pulse train performing a "bad-of nails" type ambiguity function. Typically used for MTI (Moving Target Indication) or pulsed Doppler radars. It allows the detection of targets in clutter by Doppler processing.
5.) Noise-like waveform which is typically used in low probability of intercept (LPI) radars. It has a "thumbtack" type ambiguity function. It can be generated using a pseudo- random, Barker, or polyphase code.

Most ESM, and radar warning receivers (RWR) are designed to process the first class of radar waveform, the short pulse. Coherence between pulses in a pulse train (class 4) is generally ignored and there is a little capability against pulse compression (class 3) or noise like waveforms (class 5). Recent developments in channelized, compressive and Bragg-cell receivers have the capabilities to process these type of waveforms.

Weapon associated radars are primarily pulsed radars with pulse width of 0.1 to 2 μsec, in case of surveillance radars the width is in the range of 1 to 15 msec.

2. ELECTRONIC SUPPORT MEASURES RECEIVERS

ESM receivers function is to search, intercept, locate, and identify of hostile electromagnetic radiation. The information produced by them is used for the purpose of threat recognition and for tactical employment of military forces. The ESM function means a real-time radar intercept.

There are two main classes of ESM receivers

- Radar warning receivers for self-protection.
- Reconnaissance/surveillance receivers for collecting and analyzing radar signals. These type of receivers are more complicated, having higher direction finding capabilities and measuring additional parameters necessary for retalliation.

The performance of ESM receivers is characterized by the probability of intercept (POI), which gives the probability of matching the receiver parameters to the emitter with in some time period.

In general, high POI is achieved by using wide open (nonscanning) ESM receivers with a multibeam antenna system.

There are four types of commonly used ESM receivers: the wide-open crystal-video (CVR), the YIG tuned Narrowband Superhet, the Wideband Superhet and the Instantaneous Frequency Measurement (IFM) receiver.

2.1. Crystal-video receiver

The basic crystal-video receiver has the most simple structure, it operates in the frequency range of 1 to 18 GHz. The system sensitivity is tipically -60 dBm at 10 MHz bandwidth adequate to detect main beam radiations. The wide-open nature of the receiver provides a high POI value. The receiver is primarily used for detection from main beam radiations of low-duty-cycle signals. It doesn't give frequency and phase information, and a jamming signal can make it blind during surveillance operation.

2.2. Superheterodyne receiver

The selectivity allows the narrowband superhet receiver to find a considerable number of unwanted radiations even in a dense background.

In radar applications the *YIG tuned narrowband superhet* sequentially scans the cells of the frequency band of interest by tuning the preselector and the YIG oscillator.

In case of successfully detected source the sweeping is stopped and the signal processor begins to analyze the received signal for the purpose of identification. The speed of the sweeping process gives the limitation of this type of receiver against emitters with scanning antennas. The criterion for selecting the sweep time is to be able to tune the receiver to the radar frequency within the time less than one pulse repetition interval of one single scan of the emitter. The maximum time to intercept of equal to $t_i = B_T / B_A f_R$, where B_T is the receiver's whole tuning range,B_A is the acceptance band of the receiver and f_R, is the radar's pulse repetition frequency. For a receiver having 1 to 18 GHz sweeping range with 40 MHz acceptance band the maximal time to intercept a radar emitter radiating 1000 pps PRF signal is 430msec. The sweep rate is $v_{sw} = 39.5$ MHz/msec. The typical frame time of a tactical search radar is about 4 to 5 seconds which results 50 to 100 msec dwell time which is shorter than the receiver's scan time. In practice there is no need to search the whole frequency range so one way to improve the response speed is to control the broad and narrowband tuning depending on the necessary resolution. Another way of improving the speed is to search with wideband while fine resolution tasks are performed with narrowband.

Wideband YIG tuned superhet is very efficient for detecting wideband radars such as frequency agile, pulse compression and phase coded pseudo-noise spread-spectrum type emitters. Some applications use switchable filters in place of YIG-tuned filters to improve the scanning speed up to the order of microseconds.

2.3. Instantaneous Frequency Measurement (IFM) Receiver

The primary advantage of IFM receivers is the capability of instantaneous frequency measurement in the range of 2 to 18 GHz. It has the role in active power-managed ECM systems to define the real-time information about the band to be jammed. Further advantages are the capabilities to detect and display the frequency-agile and pulse-compression type radar emitters.

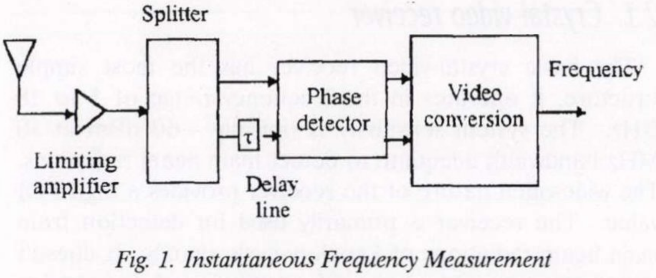

Fig. 1. Instantaneous Frequency Measurement

In principle the IFM receiver depicted on Fig. 1 divides the incoming RF signal into two paths, one of them has a known length delay line and the other has zero delay. The phase shift between the end of the two paths is a function of the incoming frequency.

The modern receivers use digital type (DFD) discriminators (correlators) which are banks of frequency discriminators. It has the feature to give the frequency information in the form of a digital word. The longest delay corresponds to the desired frequency resolution, and the shortest one to the highest frequency to be measured. A set of m correlators with binary outputs can divide the unambiguous frequency range corresponding to the shortest delay correlator (e.g. $df = 1/\tau$) into 2^m frequency cells. For example let the desired frequency range be 4 to 8 GHz, and the number of the correlator element be eight. The minimum delay time is 0.125 nsec, which corresponds to 8 GHz. The frequency resolution is $8000/2^8 = 39.25$ MHz. The processing time needed for the measurement and hence the minimum length pulse which can be processed is in the order of the time delay of the least significant bit correlator. This time delay can be reduced using a quadrature-type correlator (sine and cosine) which divides the frequency range associated with a delay element by a factor of four. It is possible to achieve a typical resolution of 2 MHz configuring one sine and 11 cosine type correlator. The required length of the LSB delay line is $\tau = 125$ nsec [3].

There is a serious limitation of using the basic IFM receiver. It is capable to respond to only one signal at any period of time. If two signals occur simultaneously, the receiver will measure the one which has the stronger power level. This means that it is possible to make the receiver blind with one or more continuous signals. For this reason all practical IFM receivers should have a so-called CW canceller which tunes a YIG notch filter to remove continuous signals.

The IFM can be combined with other type of ESM receivers improving the detection capabilities. Fig. 2 depicts a configuration where the frequency band of the superheterodyne receiver is controlled by the IFM combining the high selectivity and sensitivity of the superhet with the excellent frequency measurement capability of the IFM. The system has 8 PIN diode switched plain spiral antenna evaluating the DF capability by means of amplitude comparison. The central CPU and the multiprocessor controlled signal processing makes the system performance to be more efficient for intercepting, analyzing and identifying the frequency, the spatial and the temporal parameters of the detected signal.

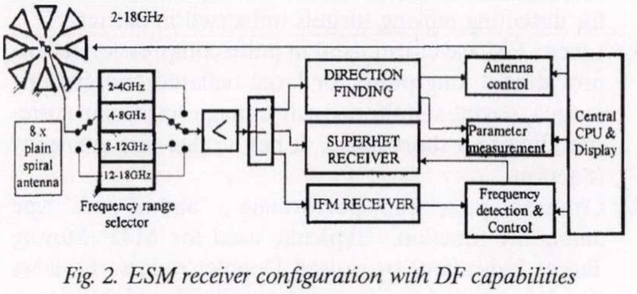

Fig. 2. ESM receiver configuration with DF capabilities

2.4. Advanced ESM receivers

All the receivers previously described have a common limitation in detection. Their performances deteriorates in dense signal environment. The CVR and IFM type have poor capabilities against overlapped signals. The low POI of narrowband superhet comes from its limitation in scanning speed. The wideband superhet is primarily used with other receiver techniques to translate a wide coverage RF range into baseband for analysis.

In the presence of multiple emitters it is a very hard requirement to handle the emitter set in order to classify them according to their frequency (carrier and modulation), pulse and angle of arrival parameters. A very efficient method to do this is the real-time spectrum analysis.

In the following the paper gives a very short summary about three types of receiver based on spectrum analysis. Two of them will be presented briefly and the Microscan Compressive Receiver a little more detailed.

2.5. Channelized receiver

There are three types of channelized receivers which are used in practice. All of them are excellent. The so-called pure channelized receiver divides the frequency range to be covered into contiguous channels equal to the final resolution required. The *band-folded* version folds a number of bands into a common sub-band. The time-shared configuration is the third which switches only those channels which are active into a common sub-band. In the general architecture the RF coverage band is divided into N segments by means of a bank of filters. In the next stage each of the N band is further divided into M sub-bands. The M sub-bands after that are further divided into K channels. The three configurations differ only in handling the M sub-bands. The pure version requires $N * M * K$ while the band-fold and the time-shared version only $M * K$ channels. The SAW filter devices were the technological solution which made the channelized receiver practical because of the high amount of necessary filters.

The channelized receiver is useful for resolving multi-beam and compressive radars too. Its main problem is the necessary large number of filters.

2.6. Bragg-Cell receiver

The acousto-optic spectrum analyzer (AOSA) or Bragg-cell receiver has excellent capabilities of detecting and resolving signals in a high dense emitter environment. The key element of the receiver is the Bragg-cell which deflects the light beam generated by a laser in proportion to the frequency components present in the input signal.

The Bragg-cell receiver can typically handle 30 MHz to 1 GHz bandwidth in a processor of time-bandwidth products up to 1000, which is equivalent to a $100-1000$ point Fourier transform, giving resolutions in the range of 30 KHz to 1 MHz.

One problem with this receiver is the dynamic range limitation which in practical devices is 25 dB. There are great efforts in development to achieve the value of 50 dB.

2.7. Microscan compressive receiver

The relative simplicity of the compressive receiver compared to other receivers applying contiguous filter bank offers a considerable advantage in applications.

The soul of this type of receiver is the high-speed Fourier transform, realized by surface acoustic wave (SAW) linear frequency modulated "chirp" filter. The principle of chirp transform has been well known for a long time but the practical realization came into the focus in the recent years. The main difficulty of application in receivers was the necessarily high speed data processing. The receiver uses a combination of multiplication and convolution of chirp waveforms to produce the Fourier transform of the input signal. The manipulated form of the Fourier transform [4]:

$$F(\Omega) = F(\mu t) = \left[\int_{-\infty}^{+\infty} f(t) \exp(-j\mu t^2) \exp\{j\mu(\tau - t)^2\} dt \right] \exp(-j\mu\tau^2) \tag{1}$$

suggests to multiply the input signal $f(t)$ with a chirp waveform $(\exp(-j\mu t^2))$ followed by convolution in a chirp filter. A second multiplication with another chirp signal gives its M-C-M (multiplication-convolution-multiplication) type Fourier transform where μ is the frequency-time slope for both chirps. The simplified block diagram of the equation above is depicted in Fig. 4.

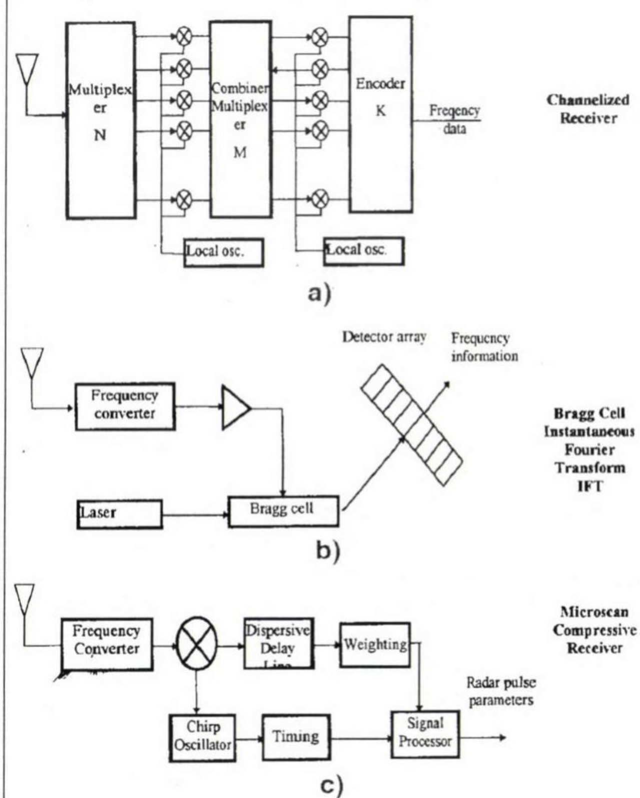

Fig. 3. Advanced ESM receivers
a) channelized receiver; b) Bragg-cell receiver
Microscan compressive receiver

Without making a detailed analysis here about the possible variations of realizations it is important to mention that in practical realizations there is no need to compute all the complete Fourier-transform. Dispense with the phase information the receiver needs only the spectral density from the transform amplitude. This means that the second multiplication implementing the phase of the transform can be neglected. So the chirp algorithm can be simplified to a multiplication followed by a convolution.

The other important thing is that the product of the input signal and the first premultiplying chirp must lie in the bandwidth of the convolving chirp filter.

In contrast to conventional spectrum analyzers the objective of this type of analysis is to perform real-time spectral analysis on a small subset of the temporal domain in order to estimate the carrier frequency and the dynamic pattern of frequency variation with time of an emitter for classification purposes.

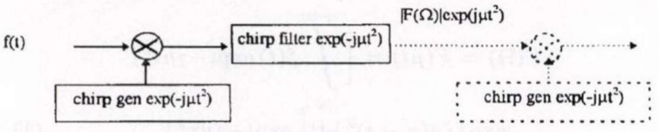

Fig. 4. Circuit realization of Eq. (1)

In the compressive receiver the SAW devices are used as a dispersive delay line having the feature to compress the input chirped signal into a matched chirp filter. The delayed time position of the compressed pulse is seriously belonging to the frequency of the input signal in a linear manner. This means that the position of the compressed pulse on the time axis gives the measure of the input frequency.

3. DEVELOPMENT EXAMPLE

As it was mentioned the primary problem with the wideband compressive receiver is the high rate of data processing needed. The type COMP-EW 01 was developed by TKI Rt. having the input bandwidth of 100 MHz in the range of 650 – 750 MHz. It uses a one-bit serial-to-parallel converter to resolve the processing speed of data problem. The frequency of the detection (sampling rate) is 1 MHz. Within the 1 μsec sampling period the chirp generator sweeps over 100 MHz which is identical to the operating bandwidth of the dispersive delay line. The output data following the serial-to-parallel converter (ECL shift register) are stored in two RAM memories for alternate read/write process.

The receiver has two channels for signal processing and two areas of the display. One of them is provided for the real-time display of the detected signal's frequency-time diagram on a Cartesian coordinate system. The frequency axis is calibrated to the bandwidth being under observation. The simultaneously displayed bandwidth is 100 MHz. The time axis is calibrated to the impulse time parameters. The simultaneously displayed time range is 256 μsec.

The other channel provides for measuring the parameters of the detected samples of the radar signal. The second area serves for displaying the parameters and the time-frequency slope of the signal. It is possible to take the samples automatically or manually from the real-time signal. The coordinate system is the same, but the displayed time interval is 100 μsec for the reason of detailed analysis. All of the measured emitter's parameters can be displayed on a spreadsheet form, too. By means of prestored parameter bank of threat emitters, the receiver is capable to identify the source of the received signal.

The receiver completed with a superhet receiver and with a direction finding unit is capable to intercept and identify the type and location of CW, monopulse, chirp modulated, and hopping type radar sources, too.

- *The main parameters are:*

RF frequency range	1 – 18 GHz
IF frequency range	650. . . 750 MHz
real-time analysis bandwidth	min. 150 MHz
sensitivity to the CW signals	– 90 . . . 100 dBm
frequency resolution	1.0 MHz
time resolution	1.0 μsec
dynamic range	>60.0 dB

- *Automatically measured parameters:*

carrier frequency (Fc);
pulse length (tp);
pulse repetition time (Tr);
frequency in-pulse deviation (dF);
speed of the frequency deviation (dF/dt).

- *Modes of operations:*

real-time panorama of the selected frequency range;
frequency-time analysis with Zoom-in and spreadsheet possibilities;
data storing;
retrieving stored data;
comparison of received and stored data.

4. ACKNOWLEDGMENT

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UNIVERSAL QAM DEMODULATOR WITH AUTOMATIC MODULATION IDENTIFICATION (AMI)

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Digital signal processing implementation of a universal modem with automatic modulation detection is presented in this paper. In these modems multistate QAM modulation (up to 128 states) methods are applied. The architecture of the modem and the modulation type identification algorithm are detailed. Measurements are presented in order to prove the efficiency of the implemented algorithms.

1. INTRODUCTION

In accordance with CCITT recommendations [4], several types of modulation are used on voiceband data signals. For low-transmission-rate signals FSK, whereas for medium-rate signals PSK modulation is used. These types of signals can be received with relatively simple demodulators. Unknown modulation methods can be identified by operating a bank of demodulators in parallel.

Higher-speed modems (2400 baud) employ quadrature amplitude modulation (QAM) or trellis code modulation (TCM). The data constellation diagrams characteristic of the modulation employed in those modems (CCITT V29, V32, V32bis, V33, V17 recommendations) are shown in Fig. 1. As indicated, the corresponding data transmission speeds vary between 7,200 and 14,400 bps. The spectrum of the transmitted signal around the carrier frequency is identical in all the cases discussed here, therefore signal identification on that basis is not possible.

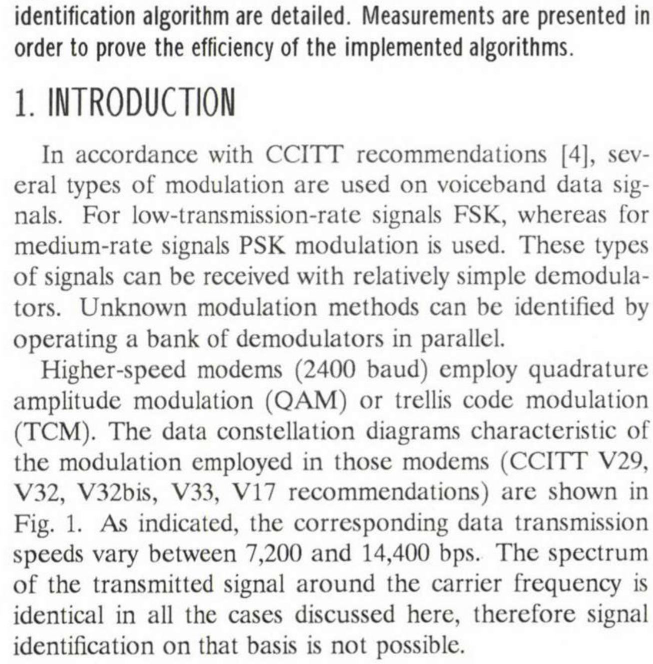

Fig. 1. Constellation diagrams of noisy signals in the case of six different types of QAM modulations with SNR=23 dB

Normally, in accordance with the sign-on protocol recommended by CCITT, the data transmitter informs the receiver which modulation technique it will employ. When no such prior knowledge is available about the transmitting modem, only the data transmission speed can be determined by measuring the bandwidth of the received signal. From that information however, the most likely QAM modulation that is being employed can be determined. Therefore, there is a need for a quick and possibly automated identification process.

In this paper, a demodulator that performs such automatic modulation identification (*AMI*) will be discussed. In this demodulator only the timing recovery of the unknown signal needs to be assured without a need for the correct restoration of the carrier phase, for which the modulation type would have to be known in many cases. The technical details of the demodulator are described in Section 2.

The *AMI* method is based on the recursive computation of the probability distribution of the various modulation types. In accordance with Bayes' theorem, a probability estimate can be improved by processing experiments. In the investigated case, "experiment" means measuring the normalized power of the complex signal in the center of the symbol intervals. Using the characteristic one-dimensional probability density functions of the various modulation types and the above mentioned experiments (series of signal power measurements), the accuracy of the probability estimate is progressively improved. The algorithm employed in this process is discussed in Section 3.

The universal *AMI* voiceband data signal demodulator has been implemented on a PC compatible DSP card. The relevant experience and observations of the developers of the system are discussed in Section 4.

2. THE AMI DEMODULATOR

Fig. 2 shows the block diagram of the demodulator. The input signal is digitalized with a 12-bit, 9.6 kHz analog-to-digital converter. The digitalized data are passed through a complex FIR bandpass filter whose output is the quadrature component of each Hilbert transformed data pair.

The center frequency of the bandpass filter has to be set to the carrier frequency of the received signal. If this frequency is not known, a good estimate of it is obtained by performing an FFT analysis on the received signal upstream of the complex FIR filter. The width of the passband is determined by the data transmission speed, which in the cases discussed here is always 2400 baud.

The characteristic shape of the bandpass filter has to be such that the distortion caused by intersymbol interference in the channel will be minimum. The filter skirt shape that provides this property is a square root, raised cosine form (Nyquist filter). After the determination of the demodulation type, this complex filter in combination with adaptive decision feedback, acting as an adaptive equalizer minimizes channel distortions.

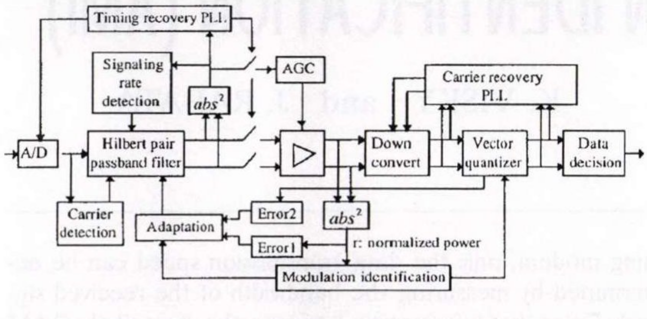

Fig. 2. Block diagram of the universal demodulator

The square of the complex signal (the squared amplitude of the rotating vector) obtained at the output of the Hilbert Transform-Nyquist Filter module is the signal power. There is a discrete component at the frequency corresponding to the data speed in the spectrum of this signal. In the case of an unknown signal, the FFT of the output of a wideband Hilbert transform can be used to estimate the unknown data speed.

The determination of the center of the symbol interval (timing) is performed by a PLL. This module performs the phase-correct tracking of the timing signal which has a spectral line at the baud frequency in the power signal.

At the time intervals corresponding to the symbol centers, both the complex signal (i.e. the quadrature components) and the power signal are re-sampled with the nominal rate of 2400 Hz. Following that, an AGC module adjusts the signal amplitude to a predetermined amplitude and normalizes it to the average power.

From the re-sampled and normalized complex signal the constellation diagrams shown in Fig. 3 are created for each modulation type. Of course, the symbol-center samples of the rotating vectors are shown since the carrier recovery and down-conversion are only performed at later stages when the modulation type has already been determined.

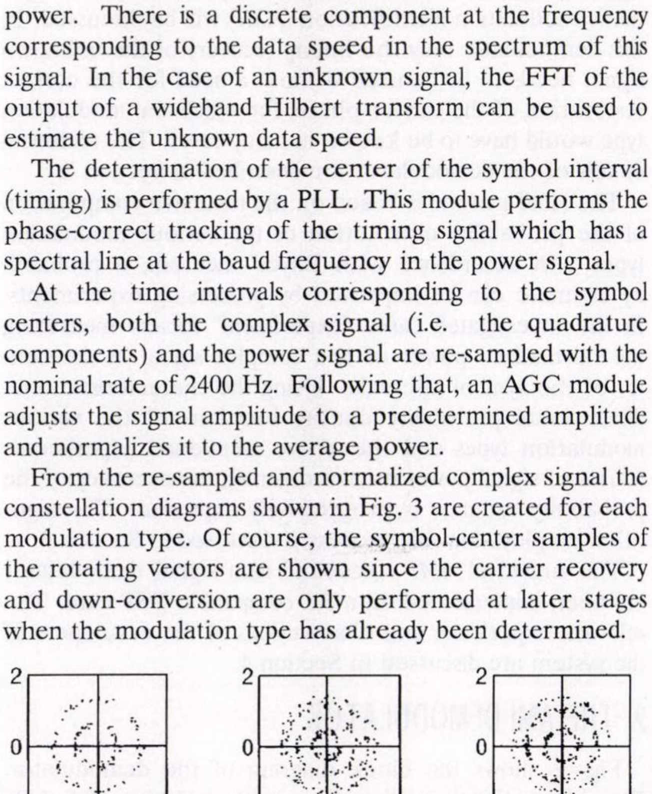

Fig. 3. Constellation diagrams of noisy signals with SNR=23 dB after timing recovery and without carrier recovery

The input to the *AMI* stage is the symbol-center sample sequence of the normalized power signal. The relevant algorithm will be discussed in the next section.

After the modulation type has been identified, a PLL employing a decision feedback phase detector produces the phase-correct complex carrier for the complex demodulation, i.e. transposing the spectrum of the complex signal into the baseband. After this complex mixer stage are the constellation diagrams produced that have been shown in Fig. 1.

The two dimensional, constellation dependent decision of the demodulated baseband complex signal gives the quantized complex samples. The QAM or TCM decoding [3] of these samples produces the received bitstream.

The automatic equalizer adaptation can be done in two ways. In simpler cases or when the modulation type is not yet known and the carrier recovery has not been accomplished, the error signal is obtained from the course quantization of the normalized power signal. In the case of more complex QAM modulation, automatic equalization of considerably better quality can be achieved by using the error signal of the baseband decision-feedback detector for the adaptation.

3. THE AMI ALGORITHM

The basis of the computational procedure to be discussed can be found in [1]. The specific algorithm implemented in the AMI demodulator has been tailored to the architecture of the demodulator hardware, and therefore differs in some details from the one described in reference [1].

3.1. Formulation of the task

Let $A_1, A_2, \ldots, A_N$ be events corresponding to encountering the possible N modulation types. (For example in the case of Fig. 1. $N = 6$.)

Let $P_1, P_2, \ldots P_N$ be the probability of encountering these N modulation types. Assume further that the use of these types is equally likely, i.e.

$$P_j = \frac{1}{N} \quad j = 1, 2, \ldots N \; . \qquad (1)$$

The normalized and resampled power signal will be considered as random variable denoted by r. Its probability density function is a function of the modulation type, the distribution of the source symbol and finally any channel noise and distortion present. By virtue of the scramblers employed in the data transmission, the transmitted symbol distribution is assumed to be uniform. The combined effect of channel noise and distortion is approximated by using a normal distribution with given standard deviation. Fig. 4 shows the conditional probability density functions corresponding to the six QAM types represented in Fig. 1. The functions were computed for two standard deviations corresponding to 17 and 23 dB SNR conditions respectively.

In practical applications of the system, tables of finite size are used in place of probability density functions. That is, the values of r are quantized and the discrete distributions are tabulated. For example, using an 8-bit quantizer the table size is 256.

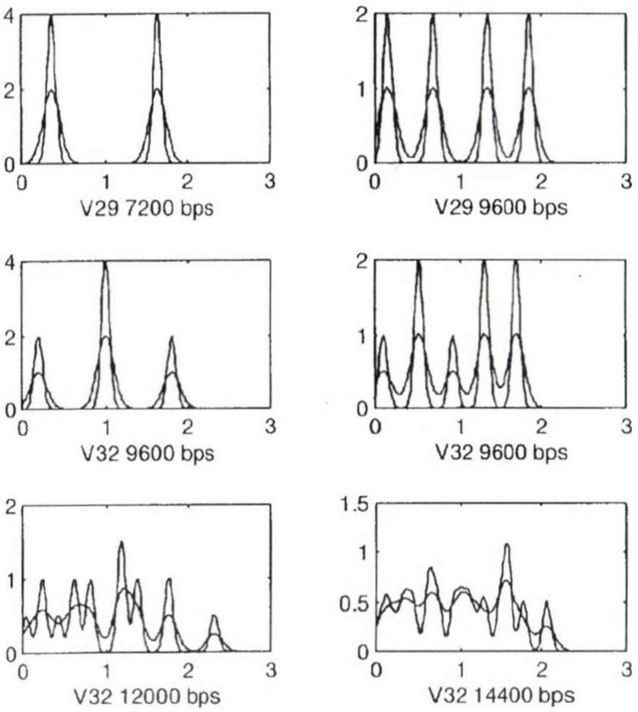

Fig. 4. Probability density functions of signal elements power in the six cases of modulation types illustrated in Fig. 1 (SNR=17 dB, 23 dB)

Let $f_i(r_k)$ be the conditional probability distribution of the quntized value of normalized power samples r with the condition that the current nodulation type is A_1:

$$f_i(r_k) = \text{prob}\{r = r_k | A_1\}\ . \tag{2}$$

In the process of modulation identification, the receiver observes a time sequence of normalized signal powers $\{r^1, r^2, \ldots, r^m, \ldots r^M\}$. r^m These values are considered as independent samples from the distribution of the probability variable r.

The task is to determine the conditional distribution based on the $\{r^1, r^2, \ldots, r^m, \ldots r^M\}$ sequence:

$$C_i^M = \text{prob}\{A_i | \{r^1, r^2, \ldots r^M\}\ , \tag{3}$$

which is used to determine the unknown modulation type based on the largest probability value.

3.2. Derivation of the Algorithm

The starting point is Bayes theorem given in the form of

$$\text{prob}\{A_j | r^1, r^2, \ldots r^m\} =$$

$$= \frac{\text{prob}\{A_j | r^1, r^2, \ldots r^m | A_j\} \cdot \text{prob}\{A_j\}}{\sum\limits_{i=1}^{N} \text{prob}\{A_j | r^1, r^2, \ldots r^m | A_i\} \cdot \text{prob}\{A_i\}}\ . \tag{4}$$

Let F_j^m represent the m-dimensional distribution corresponding to the modulation type A_j represented by

$$F_j^m = \text{prob}\{r^1, r^2, \ldots r^m | A_j\}\ . \tag{5}$$

From equations (3) through (5) Bayes' theorem can be written as follows:

$$C_j^m = \frac{F_j^m P_j}{\sum\limits_{k=1}^{N} F_k^m P_k} = \frac{F_j^m}{\sum\limits_{k=1}^{N} F_k^m}\ , \tag{6}$$

where the assumed initial uniform distribution stated in equation (1) has been incorporated.

Since the r^m probability variables are assumed to be independent, the m-dimensional distribution can be written as the product of m one-dimensional distributions:

$$F_j^m = \text{prob}\{r^1, r^2, \ldots r^m | A_j\} = \prod_{n=1}^{m} \text{prob}\{r^n | A_j\} =$$
$$= \text{prob}\{r^m | A_j\}\text{prob}\{r^1, r^2, \ldots r^{(m-1)} | A_j\}\ . \tag{7}$$

Using equation (2) the above relationship can be rewritten as:

$$F_j^m = f_j(r^m) F_j^{(m-1)} \tag{8}$$

and the sought conditional distribution takes the form of

$$C_j^m = \frac{f_j(r^m) F_j^{(m-1)}}{\sum\limits_{i=1}^{N} f_i(r^m) F_i^{(m-1)}}\ . \tag{9}$$

From (5) it follows that $F_j^0 = P_j$. Starting with that initial value and performing the $m = 1, 2, \ldots, M$ measurements, equations (9) and (8) are evaluated to finally arrive at C_j^M, ($j = 1 \ldots N$), that is the basis of the determination of the modulation type.

During the recursive computations represented by equation (8) a numerical problem can arise. The reason for this problem is that relationship $f_j(r^m) < 1$ applies to the one-dimensional distributions and the series F_j^m is monotonously decreasing, causing an underflow during the numerical computations. To avoid this problem, equation (6) is re-written into

$$F_j^{(m-1)} = C_j^{(m-1)} \sum_{k=1}^{N} F_k^{(m-1)}\ , \tag{10}$$

where substituting into equation (9) and rearranging the denominator C_j^m is written as:

$$C_j^m = \frac{f_j(r^m) C_j^{(m-1)} \sum\limits_{k=1}^{N} F_l^{(m-1)}}{\sum\limits_{i=1}^{N} f_i(r^m) C_i^{(m-1)} \sum\limits_{k=1}^{N} F_k^{(m-1)}} =$$
$$= \frac{f_j(r^m) C_j^{(m-1)} \sum\limits_{k=1}^{N} F_l^{(m-1)}}{\sum\limits_{k=1}^{N} F_k(r^m) \sum\limits_{k=1}^{N} f_i(r^m) C_i^{(m-1)}}\ , \tag{11}$$

which finally leads to the following form that avoids any computational underflow problem:

$$C_j^m = \frac{f_j(r^m) C_j^{(m-1)}}{\sum\limits_{i=1}^{N} f_i(r^m) C_j^{(m-1)}}\ , \quad j = 1, 2, \ldots, N\ . \tag{12}$$

The initial value of the iteration comes from equation (3): $C_j^0 = P_j = \frac{1}{N}$.

Experience indicated that strong impulse type noise inputs during the computations might cause large oscillations in the computed distributions. As a consequence of the functions $f_j(R^m)$, such noise input can increase the probability of certain modulation types (during one iteration) while it reduces the probability of other modulation types. Substantially better results were obtained when the iterations were performed more carefully (slower) as follows.

In every iteration step K number of measurements are taken and the values of $C_j^m(k)$ are computed

$$C_j^m(k) = \frac{f_j(r^s)\overline{C}_j^{(m-1)}}{\sum_{i=1}^{N} f_i(r^s)\overline{C}_i^{(m-1)}}, \quad k = 1, 2, \ldots, K, \qquad (13)$$

where $s = (m-1)K + k$ for the m-th iteration.

Then the new $\overline{C}_j^m$ value is updated in each iteration step by the average value of the values of $C_j^m(k)$, $k = 1, 2, \ldots, K$:

$$\overline{C}_j^m = \frac{1}{K}\sum_{k=1}^{K} C_j^m(k)\,. \qquad (14)$$

Following the M-th iteration, the identification of the so far unknown modulation method is decided on the basis of the location of the conditional distribution maximum:

$$A = A_i \quad \text{if} \quad \overline{C}_j^M = \max_j\{\overline{C}_j^M\}\,. \qquad (15)$$

In this manner, the identification is done in $M * K$ iteration steps. The above described refinement produces substantially more reliable results, particularly in the case of high point-number (64 or 128) modulation types.

4. IMPLEMENTATION OF THE ALGORITHM

The AMI type modem discussed here has been built on a PC-DSP card that can be installed in a personal computer [2]. The card contains two Texas Instruments TMS 320c25 digital signal processors. The earlier version of this modem was described in [3]. Implementation with real-time capability made it possible to evaluate continuously the algorithm under realistic conditions during its development.

One of the most critical operations involved in the DSP implementation of the *AMI* algorithm was the division in equation (13). The operation is performed in floating-point mode using a look-up table for the reciprocal of the mantissa values. This way it is possible to circumvent potential under- or overflow problems. Similarly, tables are used to store the one-dimensional distribution of the various modulation methods. The size of the tables did not have to be curtailed due to memory limitations. The requirements for the real-time performance of the algorithm were well within the available computational capacity.

Many distribution functions, with various standard deviations were tested. In the tests, the quality (noise, linear distortion, frequency offset) of the signal to be identified varied within wide limits using a channel simulator. Due to space limitation, it is not practical to discuss here the results of the many experiments that were performed. Fig. 5 shows the time history of the identification process for six modulation types, with eight experiments for each. Only the "winner" type's probability distribution series is shown.

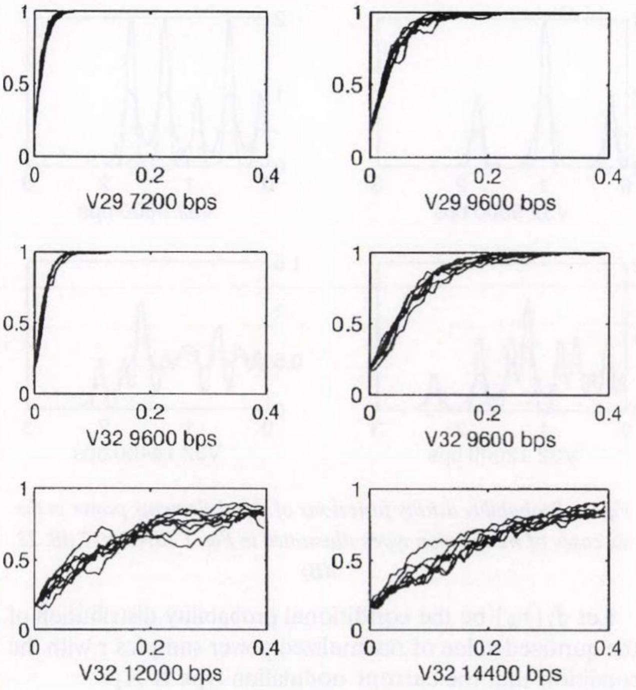

Fig. 5. Eight time histories of the 'winner' probabilities in cases of six different modulation types. Parameters of experiments: SNR=23 dB, M=60 iteration, K=16 avaraging by iterations. The time axis are scaled in seconds.

The constellation diagrams in Fig. 1 indicate the quality of the signals to be identified in the experiments. In each case, the *AMI* system had to select the correct one from six possible modulation types. The tabulated distributions had standard deviations corresponding to signals with 23 dB SNR. The number of averages was $K = 8$ and the number of iterations performed was 60. As can be seen in Fig. 5, the simpler constellations' identification required substantially less time than the more complex ones. During the generation of the diagrams the operation of the adaptive equalizer was disabled.

The system allows the parameter K to vary in order to suit the need. With this parameter the running time of the *AMI* algorithm can be influenced within wide limits. Based on experience with the system, this is a very useful feature when the quality of the signal to be identified is poor. The identification process can also be sped up if *a priori* knowledge justifies narrowing the class of the possible signals, and thereby the algorithm is required to work with fewer choices. When operating in accordance with CCITT recommendations, the classification based on carrier frequency is one such possibility. For example, the V.29 recommended carrier is 1700 Hz and the V.32, V.32bis carrier is 1800 Hz. In these cases, it is sufficient to perform the identification from 3 or 4 choices.

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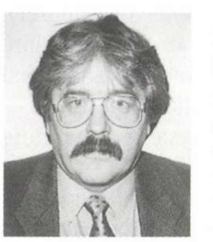

Kálmán Elek received the Electrical Engineer and Dr. Univ. degrees from the Technical University of Budapest in 1971 and 1982 respectively. Since graduation he is a lecturer at the Department of Communication Electronics, giving lectures on Technical Acoustics, Programming, Control Systems, Digital Signal Processing, etc. In the 70's he continued research on the field of electromechanical filters, especially crystal and surface acoustic filters. Since 1983 his iterest turned into the field of digital signal processing applied in audio systems. In the latest years he took part of several research and developing projects such as digital signal processing in inertial navigation, adaptive differntial PCM coding, signal processing implementation of data modems. He is a member of RTD USA – BME Laboratories at the Technical University of Budapest.

József Gaál received the Electrical Engineer and Dr. Univ. degrees from the Technical University of Budapest in 1976 and 1979 respectively. Since graduation he is a lecturer at the Department of Communication Electronics, giving lectures on Liner networks, Computer aided electronic design, Digital signal processing, Quantization and coding, etc. Until 1984 his field of research was the Monte Carlo methods applied in the theory of network tolerances. He is the author of the monograph "Statistical Analysis and Synthesis of Electronic Circuits by Monte Carlo Methods" published by Akadémiai Kiadó Budapest in 1987. Since 1984 his research interest are in the field of digital signal processing. He took parts in several development and research projects such as digital signal processing in PCM codec, digital signal processing in inertial navigation, adaptive differntial PCM coding, signal processing implementation of data modems. He is a member of RTD USA – BME Laboratories at the Technical University of Budapest.

István Koller received the Electrical Engineer and Dr. Univ. degrees from the Technical University of Budapest in 1985 and 1991 respectively. Since graduation he is a lecturer at the Department of Telecommunications giving lectures on Telecommunication Components, Communication Systems, Acoustical Measurement, etc. In the second half of the 80's he continued research on the field of new methods of loudspeaker measurement methods. He took parts in several development and research projects such as digital hardware design of adaptive differential PCM codec, inertial navigation system and DSP based computer boards. He is a member of RTD USA – BME Laboratories at the Technical University of Budapest.

OPTOELECTRONIC SIGNAL PROCESSING

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Several new principles of radiocommunication and navigation systems have been developed for military applications in the last few years. Such new developments are the frequency-hopping-, the burst- and the spread-spectrum-communication and -radar systems. Because the bandwidths and the signal processing rate of the classical equipments for radio reconnaissance are very limited, the probability of interception or direction finding of such types of transmissions are very low or impossible. Change-over the signal processing from the electrical plane to the optical plane made possible the solution of this problem. The optical processing can be realized with acousto-optic (AO) method based on Bragg-effect. This paper discusses the problems of different types of AO signal processing systems designed and realized recently. A real-time RF (VHF) power-spectrum analyzer (RTSA) operating in the 30–90 or 50–100 MHz frequency range with a resolution of 30 kHz is described. Then a microwave (MW) RTSA operating from 1 to 2 GHz with a resolution of 1 MHz is presented. Finally a panoramic direction finding system based on a 5-channel direction of arrival processor (DOAP) operating in the 30–90 MHz range is demonstrated.

1. INTRODUCTION AND PRINCIPLES OF OPERATION

The Department of Atomic Physics (DAP) of the Technical University of Budapest has been active for a long time in designing and manufacturing optical signal processing systems based on acousto-optic processors[1,2,3,6]. Efforts have been concentrated especially on developing fast RTSA and DOA analyzers for RF signal analysis. Such systems require high resolution single or multichannel light deflectors (Bragg-cells)[4,5,7].

The operation of the acousto-optic devices is based on the Bragg-diffraction of an incident light beam from a refraction index grating induced by a traveling acoustic wave in a single crystal medium as shown in Fig. 1.

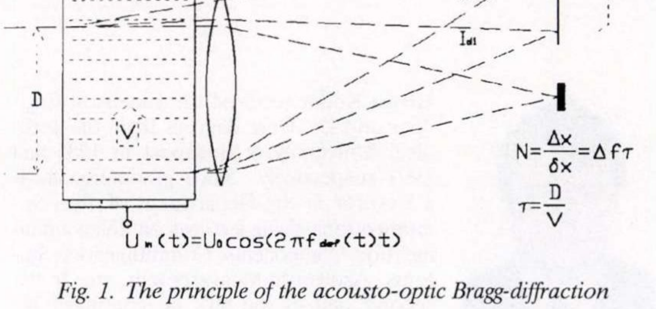

Fig. 1. The principle of the acousto-optic Bragg-diffraction

The intensity of the reflected light is dependent on the power of the acoustic beam which is proportional to the input RF power of the ultrasound transducer. The angle of diffraction θ_d is determined by the ratio of the optical and acoustic wavelengths, λ and Λ, respectively, hence it is proportional to the acoustic frequency f,

$$\theta_d = \lambda/\Lambda = \frac{\lambda_0}{n}\frac{f}{v} , \qquad (1)$$

therefore the light beam can be scanned by changing the input frequency. This is the basis of operation of acoustooptic deflectors. The optical resolution of a Bragg-cell is defined by the time-bandwidth product of the cell,

$$N = \tau \Delta f = \Delta x / \delta x , \qquad (2)$$

where N is the number of resolvable deflection angles, τ is the time aperture D/v, with D being the optical aperture and v is the acoustic velocity, and Δf is the diffraction bandwidth of the Bragg-cell, δx is the optical beam divergence and $\Delta x \cong \theta_d F$ with F being the focal distance.

The received VHF or MW signals are transformed to optical signals due to the acousto-optic effect, then the signals are retransformed into electrical form on a detector line, digitized, transferred with high speed interface to then post-processing unit (stand alone or built-in-computer). The system bus and modular set-up allows the extension, or reconfiguration of the system with various additional units if necessary for a particular application.

DAP has developed three analyzer systems operating in the 30 – 90 or 50 – 100 MHz VHF and 1 – 2 GHz microwave range taking into account the above guidelines and earlier experiences. The RTSA systems offer attractive solutions for applications requiring high-speed and wide bandwidth signal analysis, such as:

- electronic warfare systems,
- frequency-hopping and related communication systems,
- radio-astronomy receivers,
- applications requiring fast Fourier-transform.

2. VHF-BAND RTSA SYSTEM CONFIGURATION

The RTSA systems consist of 4 main parts as shown in Fig. 2. The input signal, coming from an antenna or other VHF source to be analyzed, is received by a chain of amplifiers. Signals outside the operating frequency range are eliminated by input bandpass filters. The amplifiers ensure the required input sensitivity as well as the appropriate driving level of the Bragg-cell. Electronic gain control possibility extends the dynamic range. Optionally a precision internal calibration source can be embedded.

The optical unit contains a gas laser source, a high resolution Bragg-cell, a Fourier-lens, a low-light antiblooming CCD-line and additional optical elements. The entire unit is placed in a rigid cast aluminium housing to ensure mechanical stability of the optics. The configuration of the optical system is shown in Fig. 3. The line filtered beam of a 633 nm He-Ne laser illuminates the Bragg-cell after being expandęd by a prism. The diffracted beam is focused onto the CCD-line by a Fourier-lens. The focal length of the Fourier-optics is determined so that the deflection angle of the diffracted light covers the entire detector length. The operating frequency range determines a large focal length hence bending of the light path is necessary. To keep the size compact the optical system is build up in a double decked moulding.

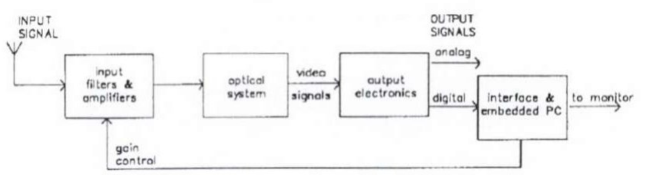

Fig. 2. Block scheme of the RTSA systems

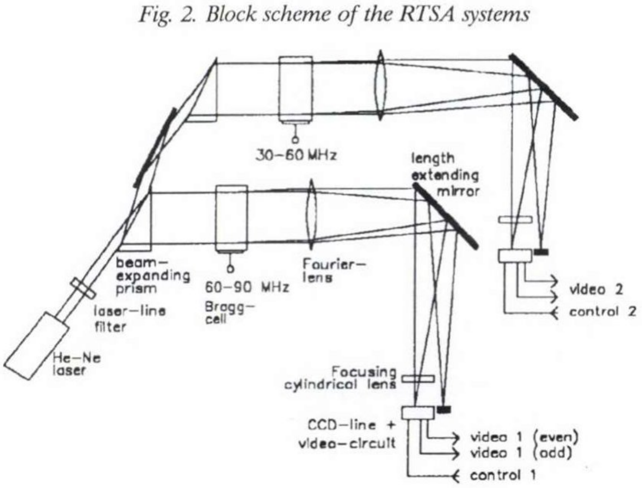

Fig. 3. Optical setup of the double (30 – 60 – 90 MHz) RTSA system (only a single optical path exists in the 50 – 100 MHz RTSA)

The realization of at least 2000 frequency channels has been aimed. To achieve this a 2048 element CCD-line is utilized and a long time aperture Bragg-cell is designed according to Eq. (1). The large bandwidth and long aperture Bragg-cell has been realized using TeO_2 in optically rotated anisotropic slow shear mode AO interaction geometry. The resolution and bandwidth required realization of a 40 mm (64 μs) long aperture. The integration time of the CCD-line, running at 5 MHz, is set to 500 μs.

The signal coming from the CCD-head is received by the output electronics. This circuitry serves the timing signals for the CCD-head, forms the analog video signal that can be monitored and digitized. The CCD-line runs at a 5 MHz clock. A high resolution (12-bit) fast video AD converter digitizes the video signal for the post-processing unit.

The post-processing unit is an embedded 486 machine with PC/104 ISA bus. The data interface between the AD converter and the PC/104 bus is a 32 Kbyte * 16-bit high speed FIFO system with asynchronous data write and read possibility to ensure high data transfer rate towards the computer. The computer is fitted with on-board RAM and flash EPROM, keyboard connector, parallel and RS-232 ports as well as an SVGA monitor interface.

The evaluation program handles the electronic gain control, receives and processes the data. Level/frequency and time waterfall diagrams of a partial or the total frequency range are available quasi real-time. That is several lines of video data, from the CCD-line, is captured consecutively without loss of information. This makes possible the detection and monitoring of quickly changing, such as frequency hopping or similar signals.

The systems are designed so that they fit in a 19" wide rack-mounted housing. All electronic units (amplifier stages, output and interface electronics and embedded computer) are built onto $145 * 145$ mm PCBs with $2 * 32$-pin EURO connectors and HF coaxial (SMB) connectors (where necessary). These racks are properly connected by the internal bus system of the RTSA which is expandable with additional racks.

The optical units are mounted in 19" frames using rubber amortizers to avoid mechanical shock and vibration.

3. MICROWAVE-BAND POWER-SPECTRUM ANALYZER

The setup of the MW-RTSA is similar to that of the VHF-band systems. The input circuitry is somewhat more complicated due to stricter requirements at high frequencies, but the optical system is quite simple since its size can be reduced at these frequencies.

The configuration of the optical system showing the optical path and the main dimensions is illustrated in Fig. 4. In this system a 650 nm diode-laser is used as a light source. The collimated 7 mm wide beam illuminates the Bragg-cell made of $LiNbO_3$. The diffracted beam is focused onto a 1024-element CCD-line, which gives 1 MHz channel separation, with the 1 GHz bandwidth, and an integration time of 250 μs.

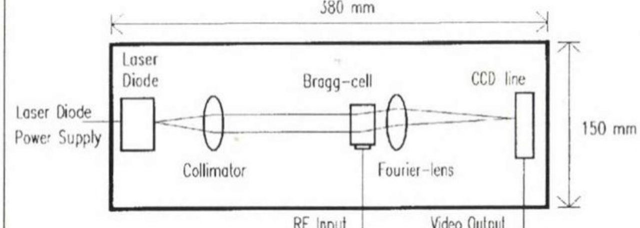

Fig. 4. The optical system of the MW RTSA

The Bragg-cell utilized in the system is connected to a 50-ohm strip line with its electrical matching circuitry. The AO interaction geometry is determined so that fast longitudinal mode is utilized in a 7 mm long aperture, which results in a reaction time of approx. 1 s. To achieve a 1 GHz bandwidth centered around 1.5 GHz the $LiNbO_3$ transducer is thinned down to 2.4 μm and layered with 0.3 mm long electrode. The Bragg-cell efficiency in this case is approx. 4 %/W.

4. DOAP-BASED DIRECTION FINDING SYSTEM

The operation of the direction finder system is shown in Fig. 5. A 5-channel Bragg-cell is illuminated with uniform laser beam from a He-Ne laser and driven with amplified VHF signals arriving from a 5-element antenna array. The Bragg-cell behaves like a 5-slit grating, hence the diffraction pattern contains the phase information of the input VHF signals which is imaged onto a CCDmatrix. As the DOA of the input signal varies the diffraction maximum in the Fourier-plane is shifted. This way both the frequency and the direction of the VHF signal can be idetified. Recently a panoramic direction finding system operating from 30 to 90 MHz is realized. To cover the entire range two parallel optical systems are built in a single casted Al housing based on 30–60 MHz and 60–90 MHz Bragg-cells (similar to the 30–90 MHz RTSA). Signal identification in the full 360 angular range is possible using 2*5 element crossed linear antenna arrays. Post-processing is carried out using a frame-grabber card added in a 486 machine. The evaluation software allows the separation of CW and hopping signals detected with 99.99 % probability for duration greater than 0.5 ms.

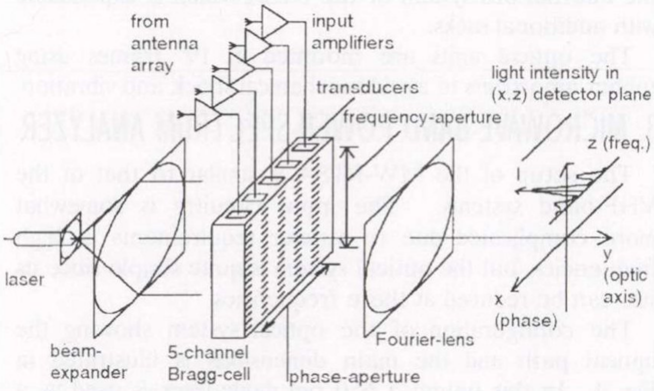

Fig. 5. Direction finding system based on a 5-channel DOAP

5. SYSTEM PERFORMANCES

Measurements has been made by the preliminary versions of the evaluation program of the VHF RTSA systems capturing linear step signals as shown in Fig. 6. The view of the RTSA systems are shown in Fig. 7. The characteristics are listed in Table 1 for all the RTSA systems. The parameters of the DOAP system are listed also in Table 1. Fig. 8 demonstrates the evaluation of DOA signals. Due to the nonlinearities and phase distortions a calibration procedure is required for accurate DOA evaluation.

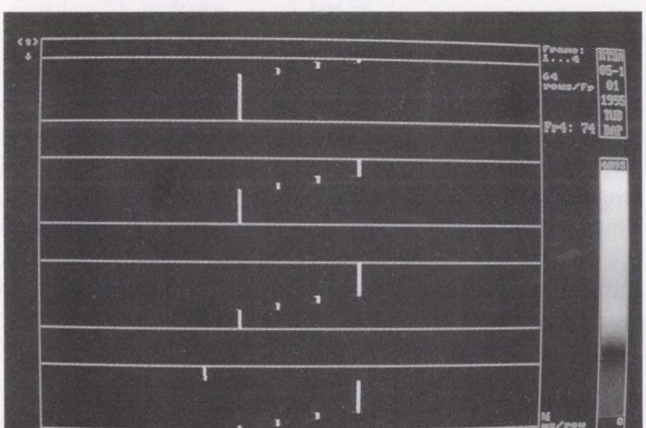

Fig. 6. Waterfall (power-frequency-time color level) diagram of a 8 ms step signal of 92.5–95.5 MHz with 1 MHz steps. Each section contains 64 video lines with 0.5 ms/line duration.

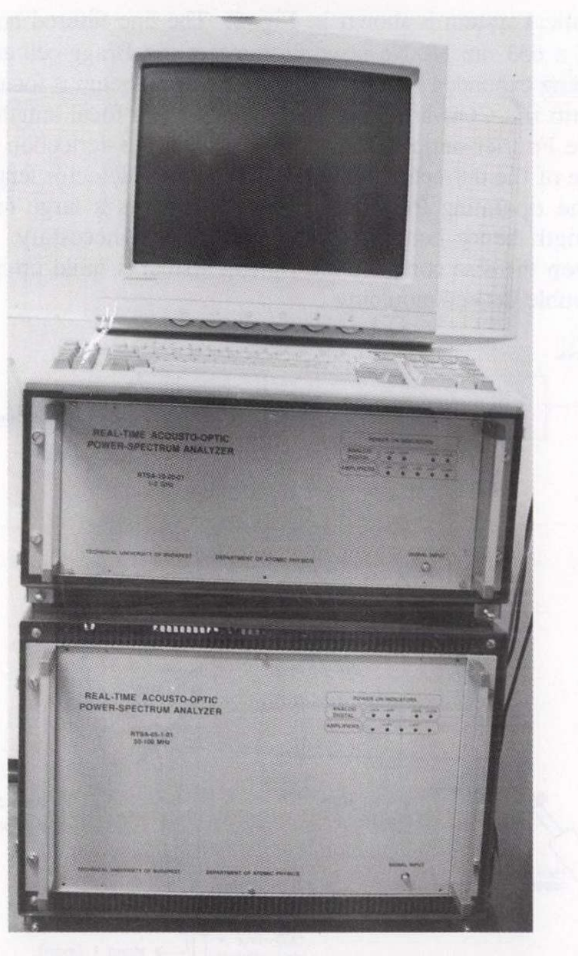

Fig. 7. View of the 50–100 MHz VHF and MW RTSA systems

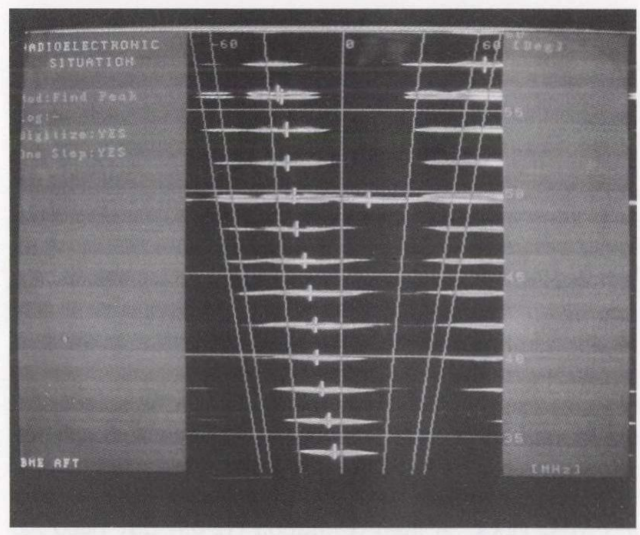

Fig. 8. Evaluation of a 2.5 MHz raster frequency brush DOA signal arriving from −23 direction. Horizontal axis: DOA angle (−90 to +90); vertical axis: frequency range (33–60 MHz).

Table 1. Characteristics of the systems (L, S: longitudinal, and slow shear acoustic mode)

Parameters	RTSA 1	RTSA 2	RTSA 3	DOAP 1	Units
Interact. medium (ac. mode)	TeO_2 (S)	TeO_2 (S)	$LiNbO_3$ (L)	TeO_2 (S)	
Optical wavelength (source)	633 (He-Ne)	633 (He-Ne)	650 (diode)	633 (He-Ne)	nm
Reaction (aperture) time	64	64	1	16	μs
Frequency band	$52-102$	$30-60-90$	$980-2000$	$30-60-90$	MHz
Freq. channels * channel BW	$2048 * 0.025$	$2048 * 0.015$	$1024 * 1$	$480 * 0.07$	MHz
Lin. / saturated resolution	0.030 / 0.2	0.025 / 0.2	1.5	0.2 / 0.4	MHz (FWHM)
Direction range / accuracy				360 / < 3	deg (RMS)
Sensitivity / linear inp. dynamics	-60 dBm / > 33	-100 dBm / > 33	-55 dBm / > 33	$5\ \mu V\ m^{-1}$ / > 23	/ dB
Detector integration time	420 μs/line	420 μs/line	210 μs/line	32 ms/frame	(max)
Detector scale / noise level	2 / 2	2 / 3	2 / 2		V / mV
D/A accuracy	12	8+8	12	8	bits
Post processing unit	embedded 486	external 486	emb./ext. 486	external 486	
Power requirements	$110-220$/120	220/200	$110-220$/100	220/250	V/VA
Dimensions (W*D*H)	$510 * 480 * 340$		$510 * 420 * 240$		mm

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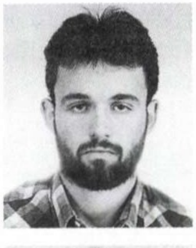
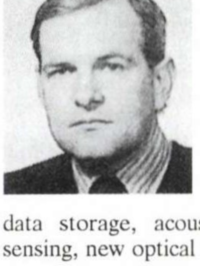
Attila Barócsi graduated in the Faculty of electronic engineering at the Technical University of Budapest in 1985. He started working at the Dept. of Atomic Physics of the TUB. His present status is associate professor. His research is related to the field of applied optics, such as development of acousto-optic, SAW and integrated optical devices and systems. His most important results are: optical spectrometer based on AO tunable filter; AO devices for special applications (mode-lockers, low frequency shifters and 2D multichannel deflectors). He completed his PhD in 1993. He is involved in several international projects. He participated, as an author/exhibitor, in the SPIE Conference and Exhibition for Aerospace Sensing in Orlando, USA in 1992, 1994 and 1996.

István Szőnyi received his B.S. degree in electrical engineering from the Technical University of Budapest in 1949. From 1949 to 1988, he was engaged in the R&D of radiocommunication and navigation systems while employed in military institutes, the Research Institue for Telecommunication and the Mechanical Laboratory. He has beeen twice awarded the State Prize. Since 1988, he is scientific advisor in the Physical Institute of the TUB, engaged in acousto-optical research.

László Jakab received his diploma in electric engineering in 1981 and his PhD in solid state physics in 1985 at the Technical University of Budapest. In 1992 he became the candidate of technical sciences of the Hungarian Academy of Sciences. He joined the Dept. of Atomic Physics of the TUB in 1981, where he is now associate professor and head of the Laboratory of Optics. His research fields are acousto-optics, integrated optics, optical signal processing, and communication.



István Verhás received his diploma in electronic engineering in 1994 from the Technical University of Budapest. He is involved int he researches at the Department of Atomic Physics from the Technical University of Budapest as a postgraduate student in the field of telecommuhnication fiber connectors and acousto-optics. He is to defend his PhD theses in 1997.



Péter Richter received his diploma from the Eotvos L. University of Sciences in Budapest in 1973. He received his MS in physics from Florida State University in 1975 and his PhD in physics from Eötvos L. University in Budapest in 1978. In 1989 he became the doctor of technical sciences at the Hungarian Academy of Sciences. He now heads the Dept. of Atomic Physics at the TUB. His research fields are optical data storage, acousto-optics, signal processing, laser remote sensing, new optical technologies, and applied spectroscopy.

COMBAT RADIO RAVEN 2V

1. SIEMENS PLESSEY SYSTEMS' VHF MANPACK AND VEHICLE COMBAT NET RADIO

Raven 2V is a combat net radio station which provides reliable multi-role battlefield communications from a range of high or low-power vehicle and base-stations with co-siting multiple-radio capabilities. The manpack comprises a transceiver, battery pack, whip antenna, and lightweight carrying frame. In a permanent vehicle installation, the transceiver and associated equipment are mounted on a shock-absorbent tray to form a low or high-powered mobile station. The station can be connected to a variety of vehicle harnesses such as AN-VIC or those of other US and European manufacture.

Voice, data, teleprinter and facsimile communications are protected by an extensive range of advanced electronic-counter-counter-measures (ECCM). These include frequency hopping, digital encryption, remote control, frequency offset and burst-data transmission — ensuring successful prevention of interception, jamming, direction finding and spoofing .

Operating in the 30 MHz to 88 MHz frequency band, the radio provides 25 kHz channel spacing and an additional 12.5 kHz offset facility. A programmable channel facility allows 16 fixed frequencies and hop nets (plus one operator's channel) to be pre-set before beginning a mission. The transmitter offers three power levels (5 W, 0.5 W, and 100 mW) which are selectable via the keypad.

In data mode, the system allows exchange of both synchronous and asynchronous data from a range of rates up to 16 kbit/s, essential for modern weapon command and control and data systems.

Operational flexibility is provided by a comprehensive range of remote control facilities. A remote handset can be connected to the manpack transceiver, using field cable up to 5 km long, providing voice and transmitter key control. By connecting a remote radio control system, full intercom and radio station operation is provided, again at up to 5 km. An extended front panel is also available.

The radio can be powered by primary or re-chargeable secondary batteries and can be readily clipped into a vehicle to benefit from vehicle power supplies and the increased range afforded by vehicle antenna.

2. VEHICLE AND BASE STATION

Co-site Filter Unit

For dual high-power installations, the Co-site Filter Unit provides frequency-agile electronically-switched filters, allowing several VHF installations to operate with frequency separations of typically 10

High power vehicle adaptor

The High Power Vehicle Adaptor is designed for mobile or fixed station operation, working into any 50 ohm wideband antenna system. Powered from a standard 24 V supply, the equipment provides a power output of up to 50 W. The small size of the unit allows considerable flexibility in installation.

Low power vehicle adaptor

For vehicle installations, where a 5 W output is sufficient, the Low Power Vehicle Adaptor is available to provide power supply conditioning and a secure mounting for the radio.

System components

PTR 4411 Transceiver
PV 4430 High Power Vehicle Adaptor
PV 4431 Co-site Filter Unit
PV 4432 Low Power Vehicle Adaptor
PV 4433 Slimline Vehicle Amplifier
PV 4293/4294 Mounting Trays

Audio

Handsets Headsets (one or two earphone/boom microphone) Vehicle loudspeaker.

Mounting

A range of mounting adaptors are available to suit all military armoured and soft-skinned vehicles.

3. ANCILLARIES

Antennas

Manpack standard whip, manpack blade,
manpack elevated

Audio

Handset Headsets (one or two earphones/mic)
Manpack loudspeaker

Carrying/mounting

Manpack (harness or frame)
Vehicle clip-in frame

Batteries

Lithium 8 Ah, or Nicad 1.2 Ah and 4 Ah

Chargers

One, five or ten channel

Power ancillaries

Solar panels
Hand generators
12V/24V Vehicle DC converters

Product support

In Hungary comprehensive product support available at Siemens Telefongyár Kft.

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H-1143 Budapest, Gizella út 51-57.

SIEMENS

Proven performance... proven pedigree

Siemens Plessey Systems' expertise in combat net radios and area systems is reflected in expanding world-wide sales of its advanced communications technologies.

Raven 2V provides high performance VHF and HF communications with in-built ECCM, a well-designed MMI and easy maintenance. These benefits have been recognised by customers ranging from the Far East to Africa.

The company's MRS 2000 provides highly effective tactical switching systems to full EUROCOM standards, supplying flexibility, interoperability and enhanced data handling capabilities. World-wide sales have recently been significantly increased by its selection for use in the Swiss Army's new area system and its purchase by the British Army to meet an urgent operational requirement.

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CUSTOMIZED RADIOMONITORING FROM VLF THROUGH SHF

Radiomonitoring System RAMON from Rohde & Schwarz detects and monitors emissions in the frequency range 10 kHz to 18 GHz. Made up of tried and tested standard components, it allows comprehensive radiomonitoring systems to be set up to customer requirements. A graphics user interface ensures easy-to-learn and convenient operation.

1. INTRODUCTION

The purpose of interception and monitoring is to provide information about radiocommunications for the determination of a scenario (systems, positions, movements, distribution, concentrations, intentions). A few *typical activities of radiomonitoring* are:

- searching for known and unknown signals,
- monitoring of radiocommunication activities and alarm frequencies,
- identification, detection or recognition of transmitters,
- direction finding and location of radio stations,
- aural monitoring and recording of radio messages,
- analysis under technical and textual aspects,
- preparation of reports,
- evaluation and comparison of obtained data,
- setting up and updating of a database,
- preparation of statistics.

2. MODULAR DESIGN

To permit the great variety of tasks to be performed, Radiomonitoring System RAMON is of modular design. The number of modules used and their associated tasks vary depending on application. RAMON may be configured as required from a compact system with only one operator position through to a hierarchical system with an appropriate number of operator positions (Fig. 1). Thus each system can be optimally adapted to the desired application and reliability is ensured through the use of tried and tested modules. The following *modules* are available:

- RAMON-supervise — coordinator position
- RAMON-search — search and identification position
- RAMON-monitor — monitoring position
- RAMON-analyze — analyzer position (in development)
- RAMON-locate — radiolocation position (in development)
- RAMON-compact — compact single-position system

Each module is a configurable unit comprising radiomonitoring equipment, a controller and software tailored to the particular application and complement. Operators of the individual modules exchange data within the system via LAN for sending messages, giving orders or storing reports. The variety of systems that can be set up with the aid of these modules ranges from single-position systems (RAMON-compact) through medium-sized systems (Fig. 2) to large, hierarchically organized systems made up of several subsystems.

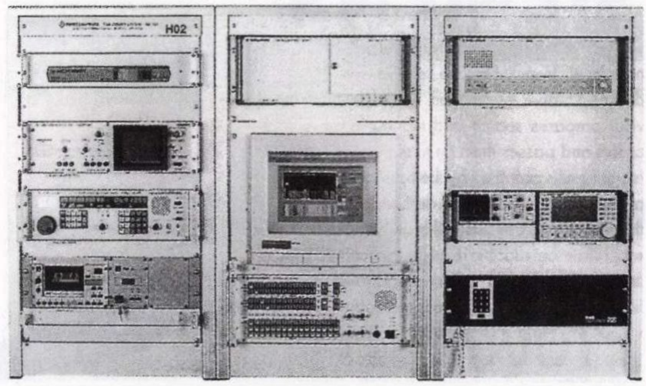

Fig. 1. Radiomonitoring System RAMON-search with application-specific add-ons as desktop

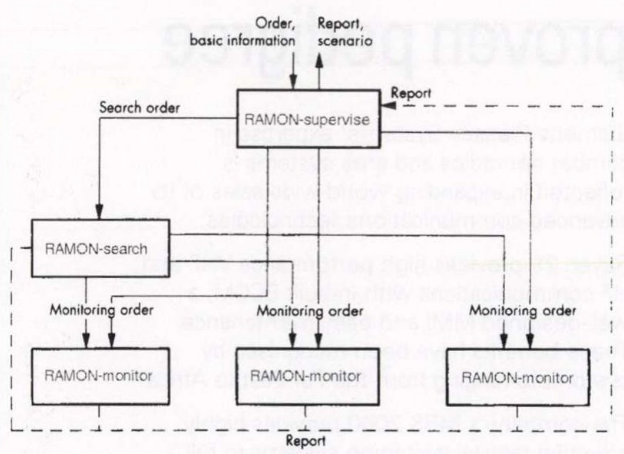

Fig. 2. Block diagram of medium-sized radio-monitoring system

The operator position *RAMON-supervise* offers functions allowing the supervisor to control radiomonitoring and prepare reports. Thus assignments can be issued, their handling checked, reports or results examined and allocated to individual radio stations. The supervisor is the interface with the superordinate level, from where he receives orders and further information. The supervisor prepares search and monitoring orders and passes them on to the operators. Results obtained by the operators are stored as reports in a database. If the results are not post-processed, the supervisor carries out evaluation with the aid of the database and supporting function (Fig. 3). He utilizes the information obtained to control monitoring activities. Based on this information and his specialist knowledge and experience he prepares reports for the superordinate level, which is his contribution to fixing the scenario. All his activities are supported by the graphics user interface of RAMON-supervise, permitting fast acquisition of results.

RAMON-search (Fig. 4) comprises a Search Receiver ESMA [1] and one or more Compact Receivers ESMC [2]. The module permits a fast search through frequency bands and rapid signal identification. The search operator scans specified frequency bands for active transmitters with his receiver in the overview mode.

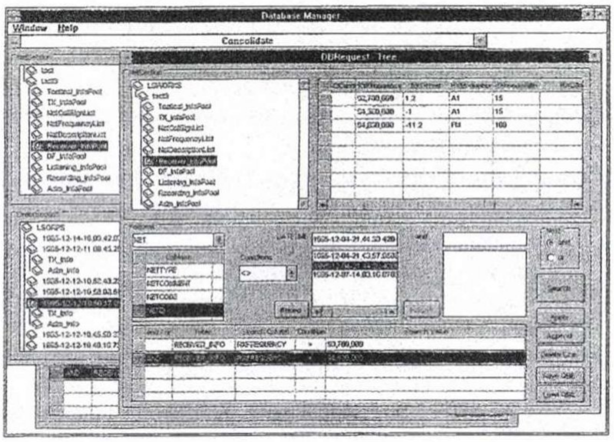

Fig. 3. Evaluation of reports using database

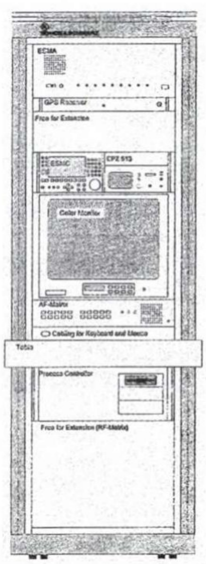

Fig. 4. Single-rack operator position RAMON-search

Fig. 5 shows a snapshot of a search receiver operating in overview mode. Single frequencies and frequency bands are combined to a scan sequence of up to 10,000 channels. Known signals or unwanted bands may be suppressed. The overview provides tools permitting signals to be measured or the display to be zoomed or frozen. Recommended search receivers are ESMA and ESMC.

In this mode the search receiver scans the defined range at maximum speed. Detected signals are shown in a panoramic display. Frequencies of interest are marked in the display and sent at a click to the compact receiver, where they are aurally identified and measured. If a signal is to be further monitored and analyzed, he sends an automatically prepared order to the monitoring operator by a single keystroke. Supported by RAMON-search the operator is able to respond quickly to new signals, identify a multitude of emissions and execute a great number of search orders.

RAMON-monitor (Fig. 6) contains several aural-monitoring receivers and at least one recorder. The software of the position guarantees efficient monitoring performance. The monitoring operator receives an order from the supervisor or search operator and the system immediately tunes a receiver to the frequency to be monitored. He records the detected signal and notes down important information in a report in which receiver settings are automatically included. The operator locates the transmitter with the aid of direction finders and is able to view the position on his map (Fig. 7). Detected emissions are recorded on tape for subsequent evaluation. Depending on the technical facilities of his position, the operator may carry out detailed signal measurements. The results are also noted down in the report. RAMON-monitor allows the operator to monitor several frequencies simultaneously and speedily prepare detailed reports.

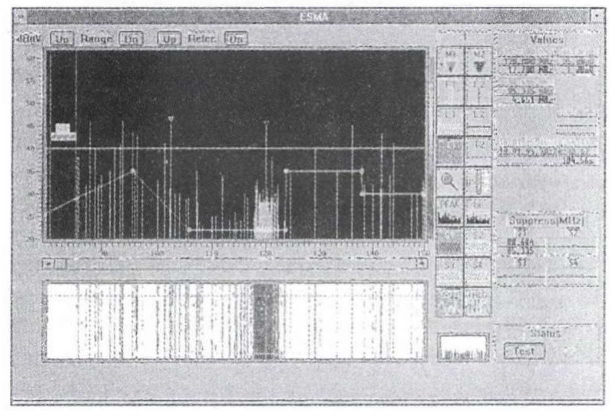

Fig. 5. Overview mode in search operation

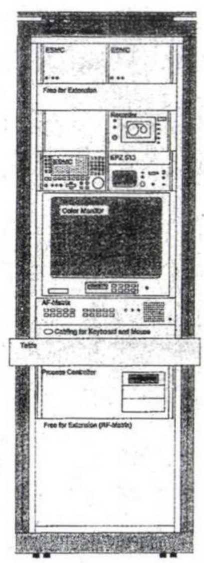

Fig. 6. Rack layout of RAMON-monitor

The single-position system *RAMON-compact* includes a search receiver, an aural-monitoring receiver and a recorder. The software includes all main functions of RAMON-supervise, -search and -monitor. The tasks normally performed at the supervisor, search and monitoring positions are concentrated in one position. Procedures are similar to those performed at the separate positions but the individual tasks are carried out at a less detailed level. This makes system software support so particularly important. With RAMON-compact a single operator is able to obtain all essential information by means of radiomonitoring and to add this information to the scenario.

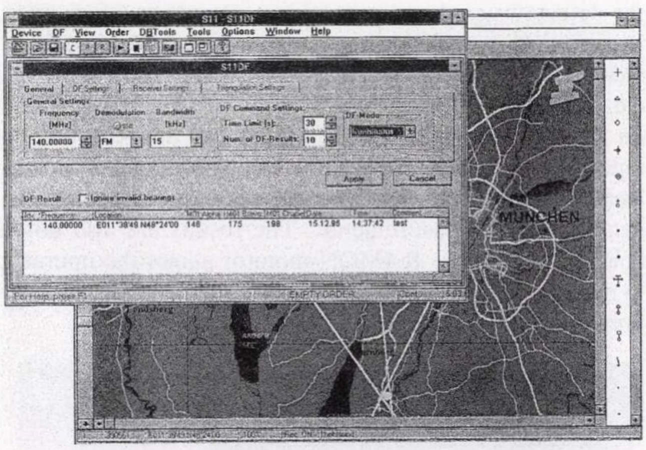

Fig. 7. Direction finding and radiolocation in monitoring mode with map (R & D MapView software)

3. OPTIMIZATION AND UPGRADING

Rohde & Schwarz continuously enhances existing modules and is developing new ones like RAMON-analyze and RAMON-locate. This allows systems in use to be upgraded and improved by updates. Thanks to the modular design, upgrading may be carried out in steps so that even a small installation can be expanded to an increasingly powerful radiomonitoring system.

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[1] Oberbuchner, E.: Search Receiver ESMA – The ideal frontend for VHF-UHF monitoring systems. *News from Rohde & Schwarz* (1995), No. 149, pp. 7-9.

[2] Boguslawski, R. and Egert, H.-J.: VHF-UHF Compact Receiver ESMC – Easy radio detection in VHF-UHF range. *News from Rohde & Schwarz* (1994), No. 143, pp. 11-13.

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RESEARCH & DEVELOPMENT IN THE INSTITUTE OF MILITARY TECHNOLOGY

Military research and development pursued presently in the Institute of Military Technology is realized essentially in two fields between which there is a close relationship. One of them is the area of basic and applied research related to the theory and practice of military sceince, the other is the field of basicly applied research and development of military equipment and systems.

Domestic military technological research and development does not cover the entire scope of military equipment. It comprises merely those military equipment, systems and military material which can be produced on the basis of the domestic industry.

Some equipment produced in Hungary are as follows:

- radio reconnaissance equipment, direction finders, electronic countermeasures equipment;
- equipment of radio communications and elements of communications system;
- equipment of chemical protection and radiation reconnaissance;
- military cargo vehicles;
- infantry weapons and ammunitions;
- demolition equipment and pyrotechnics for eingineer troops;
- training equipment, clothing and supply means.

There is also a significant repair and maintenance capacity in Hungary regarding tanks, aviation-, communications- and radar equipment, and missile.

In practice military technological research and development is generally realized in cooperation with those companies (factories, firms, enterprises) of military industry which can be the possible basis of production.

Following recognitions given at Genius'96 International Exhibition of Inventions and novelties characterize success of the activity of the Institute of Military Technology:

- Grand Prize: Determination of position with electronic firection meter
- Prize of Minister of Defence: Ballistic body armour family
- Prizes:
  - Rasterscan worksation
  - Airborne equipment of the small unmanned aerial vehicle
  - Reactive armour
  - Integrated computerized objective system for recording and evaluating flight data
  - Radioelectronic check and measurement system
  - 12.7 mm sniper rifle
- Certificates:
  - Recording activity of moving object and data-processing
  - Computer sub-system or artillery battalion fire control system
- In-flight measuring and objective evaluation of parameteres characterizing physiological condition of flight personnal

It added to the glory of the results achieved, that at the International Exhibition of Inventions in Geneva a silver and a bronze medals was awarded to the Determination of position with electronic direction meter and to the Ballistic body armour family, respectively.

Numerous projects of the Institute of Military Technology have gained patents.

Some of the most significant patents in the field of electronics:

- unmanned aerial vehicle, in particular airborne search optics, airborne data transmission radio equipment, airborne gamma dosimeter, airborne electronic countermeasures equipment, ground control station and ground data processing station;
- fighter and helicopter flight data recording and evaluating system;
- automatized planning system for non-public civilian and military flights;

- equipment for automatized processing of radar data;
- navigation eqipment with electronic compass.

The technical condition of the military equipment of the Hungarian Home Defence Fources has been impaired year by year, recently due to the collapse of the industrial repair system. So the establishing and adequate and modern fleet of armament and equipment is motivated by military and technical reasons on the one hand. Another motivating factor is the intention to join the NATO, that raises particular questions of compatibility relating to the armament and equipment. These factors require a systematic. The question of what kind of equipment should be modernized on the basis of domestic industry has to be answered too. Accumulated knowledge and experience of many decades emphasizes growing importance of the Institute of Military Technology in domestic R&D, in domestic and international R&D and in expert activity during acquisition.

Comprehensive and detailed information and analysis based on it are indispens-able for establishing the fleet of military equipment required for modernization of Hungarian Home Defence Forces. In the Institute of Military Technology an information background and a computer infrastructure have been established and are developing, in possession of which the Institute can successfully comply with the requirements mentioned above.

MILITARY TECHNOLOGY DATABASES

The purpose of these databases is primarily to provide information for analytical, decisionmaking and scientific research activities related to military technological development, however they can be used in teaching knowledge of military technology as well. By way of example it can be quoted that the information obtained from these databases was useful for experts involved in invitation for the radar tender or for disposal of advanced mines laid at the southern boundary of our contry.

Nowadays one of the most advanced information carrier device applicable on computer is the CD-ROM. Because of its 600 MH capacity it can store texts and pictures of enormous quantity. The Institute of Military Technology has procured CD-ROMs of Jane's Information Group publishing for nearly 100 yeras the most accurate books on the subjects of defence, weapons, aviation and transportation.

The most comprehensive part of the Jane's database is the ELECTRONIC LIBRARY containing information related to military equipment is specialized grouping.

None of the less significant and important part of this database is DEFENCE MAGAZINE LIBRARY containing all the articles of the following Jane's magazines from August 1989 to July 1995:

- Jane's Defence Weekly
- Jane's Defence Weekly – Defence Contracts
- Jane's Intelligence Review
- Jane's Intelligence Review – Pointer
- International Defence Review
- International Defence Review – Dispatches
- Jane's Defence Systems Modernization
- Jane's Navy International

The third bigger area of the database is INTERNATIONAL DEFENCE DIRECTORY from which among others information can be obtained on almost all the world's governmental, military, economical and scientific organizations, defence manufacturers and their organization, key personnel, products, telephone and fax numbers, address as concerning the dfence business world-wide.

Moreover, from the Jane's database information can be obtained on international ground transport, waterage and air transport. In the database there is a dictionary containing more than 20 000 abbreviations and acronyms too.

Since 1994 the Department of Scientific Analysis ha been collecting, systematizing, putting on file and storing prospectuses and publications of domestic and foreign firms manufacturing and distributing weaponry or products suitable for defence application. The colleagues of the Department have developed the program PROSPECTUSTÁR which provides simple search and immediate access to these documents. The database contains the name and type of weapons and equipment, the name and country of manufacturers, and characteristics of the prospectuses. Improvement of this database is continuous, now it contains more than 2000 items. In 1995 and 1996 the Department has published this database in form of publication and has sent it to the proper authorities and directorates of the Ministry of Defence and Hungarian Home Defence Forces, and to the institutions of military education.

In addition to the CD-ROMs there are numerous considerable books in the Department. One of them is directory of public databases produced by the Institutions of the European Communities. It contains information on 46 databases related to tenders, jurisdiction, information market for example.

A catalogue is available in the Department which comprises the monographs published by the institutions of EU during the period 1985 – 1993.

Useful source of information can be 1995 BUYERS' GUIDE and REGISTER OF MEMBERS, PRODUCTS & SERVICES published by the Defence Manufacturers Association of Great Britain containing data on companies supplying products and services for the defence, police and security market.

Considerable database is FRENCH EQUIPMENT FOR FRENCH LAND FORCES comprising information on weapons and ammunition, armoured vehicles, C3I systems, training equipment.

The brief presentation of hungarian companies active in the field of military industry is a useful material too.

POSSIBLE FUTURE

As it appears from the facts mentioned above the databases of the information system of the Institute of Military Technology, that are growing continuously, form the reliable basis for modernization of the Hungarian Home Defence Fources and its technological improvement.

More thatn 400 000 records involved in the databases contain all those absolutely necessary for analyses and decisionmaking.

The role of information available in time is increasing more and more for this reason it is necessary to establish a Military Technological Information Centre that would optimize effectiveness of relationship between the Hungarian Home Defence Forces and the industry, and the military-civilian research and development activity.

One of the important pillars of this system growing continuously is the Internet to which the Institute of Military Technology has already connected.

S. GÖNCZI
Institute of Military Technology

MILITARY ELECTRONICS UNDER THE LOGO

VIDEOTON-MECHLABOR Kft.

The *Videoton-Mechlabor Ltd.* has a design and manufacturing experience in the field of MILITARY ELECTRONICS more than 40 years.

The company is the legal successor with full powers of *Mechanical Laboratory*. It was founded by the Defense Ministry and the Ministry of the Interior in 1951 for design and manufacture special electronic equipment to establish a technical background for obtaining the necessary information both for military and intelligence organizations.

From the beginning *Mechanical Laboratory* worked successfully and became a centre of producing different radio reconassaince equipment in the HF/VHF/UHF range.

The latest product structure of the *Videoton-Mechlabor Ltd.* has the following features:

- electronic control;
- distributed intelligence;
- possibility for user-oriented workpost and system;
- protection against environmental influences; electromagnetic compatibility;
- modular construction;
- continuous modernization.

The different equipment produced by ML can be classified in 6 main groups:

- receivers;
- direction finders;
- panoramic equipments;
- demodulators;
- complementary devices, such as
  - antennas,
  - antenna amplifiers, distributors,
  - intercoms
  - special-purpose field-test instrument;
- equipment for complex purposes;
- new design Parallel Signal Processor (PSP) family.

The individual pieces of equipment are suitable for building up workposts, stations, subsystems and systems in compliance with user demands and the tasks to be fulfilled.

In the followings receivers, direction finders, panoramic equipment, demodulators and the parallel signal processor family will be presented in some detail.

- *Electronic tuning, remote controlled intelligent communication receiver family for the HF, VHF and UHF band, with autonomous SCAN/SEARCH facility*

Typical common parameters:

Sensitivity	< 10 kTo
Frequency accuracy	1×10^{-7}
Bandwidths and modes	appropriate for receiving all the usual modulations in the given frequency range
High linearity and dynamic range	
Tuning speed	20 msec
Frequency resolution	1 Hz for HF, 100 HZ for VHF/UHF
Outputs	for IF panoramas and demodulators
Supply	24 V DC / 220 V AC

The different types are:

REV-400:	0.2–30 MHz
VREV-T:	20–100 MHz
UREV:	100–500 MHz
UREV-G:	100–1000 MHz
VUREV:	20–500 MHz
VUREV-G:	20–1000 MHz

- *Electronically controlled intelligent radio direction finding equipment for ECM systems*

Typical common parameters:

Sensitivity	2–5 μV/m typically
Effective angle error	1.5–2°
Measurement time	0.2–1 s (10 ms for IFR-403)
Measuring method	Interferometric for HF, Single channel adcock-goniometer method for VHF/UHF range

Frequency range:

IFR-301:	0.2–30 MHz
IFR-403:	0.2–30 MHz
IU-60:	20–100 MHz
IU-67:	20–500 MHz
IU-678:	20–1000 MHz
IU-70:	100–500 MHz
IU-78:	100–1000 MHz
IU-80:	500–1000 MHz

- *Electronic tuning, remote controlled, intelligent wide-band panoramic receiver family to display a wide digitally processed frequency spectra for radio surveillance*

Typical common parameters:

Sensitivity	< 10 kTo
Frequency accuracy	1×10^{-7}
Number opf displayed channels	800
High linearity and dynamic range	
Synthesizer controlled sweeping	
Frequency range: REV-P	1,5–30 MHz
VREV-P	20–100 MHz
UREV-P (G)	100–500 (1000) Mhz
VUREV-P (G)	20–500 (1000) Mhz

- *Intelligent IF panoramic equipment family for controlling and identifying received spectra for radio surveillance*

Typical common parameters:

Frequency accuracy	1×10^{-7}
Number of channels	160/320
Sweeping rate	0.1–2.4 s
Spread range	2.5 kHz – 4 MHz

Frequency range:

PR-351	200 kHz $\pm$ 6.4 kHz
PV-351	10.7 MHz $\pm$ 128 kHz
PU-351	21.4 MHz $\pm$ 2 Mhz

- *Demodulators*

FD-1 – Frequency Demultiplex TTY demodulator for demodulating multi-channel TTY transmission

Frequency range	200 $\pm$ 6 kHz

Channel division	120 or 170 Hz
Number of processabele channels	max 16
Modulation rate	50/75/100 Baud
Modes	FSK, FEK

FCM – Frequency multiplex demodulator for intelligent receiver stations of multi-channel microwave systems

Frequency range	0.3 – 14000 kHz (baseband)
Frequency accuracy	1×10^{-7}
Channel bandwidth	4 kHz
Simultaneous panoramic display	for 60 channels
Channel number	2 – 28
Input matrix	up to 8 baseband microwave input

FRIDA-M2 – FSK analyzer for dtecting, analyzing and identifying TTY and data signals

Input frequency	200 kHz ± 2kHz
Measurement range	40-6000 Baud
Frequency swing	20 – 300 Hz
Measurement accuracy	0.1 % – rate 1 % – frequency swing
Display	9" CRT, 256x256 graphic+alphanumeric

MOD-02 – Automatic modulation recognizer equipment for radio reconnaissance systems

Input frequency range	200 kHz, 10.7 or 21.4 MHz
Automatically detected modulations	AM, FM, SSB, FSK, CW, noise, complex, other
Detection time	min. 200 ms
Determination probability	> 80 % at 10 dB S/N

- *Complex Equipment for Complex Purposes*

VHF/UHF automatic radio reconnaissance and jamming system for the use on-board of a helicopter *Heliborn EW subsystem*

Frequncy range	30 – 1000 MHz
Reception sensitivity	10 kTo typically
Jamming power	200 W
Control	by a built-in station control computer
Jamming modes	manual, semi-automatic, preprogrammed automatic
Modulation modes	wobbulated sine-wave, pink noise, imitative
Maximal jamming bandwidth	10 MHz
Supply	27 V DC

Communication subsystem for RPV system *MOHA*

Uplink	3x16 kbit/s data
Downlink	3x16 kbit/s data + B/W PAL real-time

- *High Mobile COMINT/COMJAM Subsystem* for Battlefield Radio Surveillance, high efficiency jam and for distance monitoring as an RPV COMINT/COMJAM payload

Frequency range	30 – 500 MHz
Receiving sensitivity	10 kTo typically
Jamming power	20/40 W
Remote control	from Ground Control Station through MOHA communication subsystem

- *New Design Parallel Signal Processor Family*

Videoton-Mechlabor Ltd. has been continuing R&D activities for developing modern radio reconnaissance devices and complex recce systems for a long time. The new PSP system, based on parallel processing concept provides efficient reaction against FH transmission modes.

The main technical requirements of a complete system are as follows:

- 25 kHz resolution in frequency range;
- 200 μs resolution in time range;
- 60 dB processing dynamic range;
- Built-in evaluating algorithms for selecting the FH transmissions;
- User firendly SW assistance;
- Automatic modes of operation

Features of the complete system:

- Providing information on frequency spectrum oocupancy, and changes of it;
- Direct detection of appearance of FH transmissions;
- Estimating the number of simultaneous FH transmission;
- Analysis of FH transmissions;
- Direction finding of FH transmissions (by the PSPD subsystem);
- Jamming FH transmissions (by the PSPJ subsystem).

Calculations showed, that the criteria of hopper's interception cannot be fulfilled with a single-channel/frequency-sweeping panoramic or serial processing method. Consequently the processing method should be parallel instead of serial.

The base equipment of the system is a 160 channel parallel receiver bank. Each receiver channel has 25 kHz bandwidth, creating a 4 MHz wide frequency subband. The processing time in the channel-receiver is 160 μs. During this time all the 160 channels are processed parallel, i.e. the whole 4 MHz sub-band is processed. The 4 MHz sub-band is the second IF output of the VUREV-HG special front-end receiver. So processing wider than 4 MHz frequency band is possible in the 20 – 1000 MHz range step by step in 160 μs time duration. The 4 Mhz tuning time of the front-end receiver is 40 μsand so the whole processing time is 200 μs.

In this way the processing speed is 4 MHz/200 μs, i.e. 20 GHz/s.

Each channel filter output is connected to a logarithmic detector followed by 8 bit ADC. The data of the ADC is transferred by a special data input card to the high speed computer. The data transmission speed is about 8 Mbit/s.

The processing software measures the frequency, amplitude and time period of the intercepted signal. It can select the signals with determined time duration e.g. 3 – 8 ms. In this way both noise spikes and stationary signals can be locked out from the evaluation and the individual hopping transmissions can be classified with high probability. If the computer fields a branch of transmission with same transmission period after each other on different frequencies, it can generate an alarm signal in automatic hopper interception mode of operation.

From the evaluated signals, the processing computer can display the highly agile frequency spectra in a selectable frequency band. These spectra have zoom facility down to 25 kHz resolution.

A characteristic display can be generated by the computer as a two dimensional water-fall like image, where the third dimension is the amplitude level signed by intensity. By the help of this image, the operator can identify very easily the hoppers, even if they work in a radio net. Moreover, by measuring the individual hopping times and their beginning and finishing time with a few hundred microsec accuracy, it is possible to determine the orthogonal nets, or classifying the different FH radios.

DF-ing or follower jamming mode of operation are also possible by special HW structures and processing SW segments based on this PSP elements.

G. ROTHMAN
Videoton-Mechlabor Ltd.

RECONFIGURABLE HARDWARE ACCELERATOR SYSTEM BASED ON MULTIPROCESSING TECHNICS

BACKGROUND

KFKI RECOWARE Ltd. was established at the end of 1991 by KFKI Computer Systems Co. for image processing and domestic dermathoglyphic research and development purposes based on the experiences piled up in KFKI. This company has created RECOderm, *only one* Automatic Dermathoglypic (*Palm-* and Fingerprint) Identification System (*ADIS*) all over the world.

The palm- and fingerprint identification (image processing, associating) procedures require high level computer technology. The reduction of duration of computation (acceleration) is essential for applications.

Supercomputers offer high performance for general purposes but at high price. Special hard-wired equpment give solution at lower cost but only for special applications.

So Recoware Ltd. has developed his own general purpose *MPR-16 System* which is easy to fit special and different tasks. This computer system completed with special but flexible resources (accelerating units) reserved for users giving *supercomputer performance at cost effetive way.* This effectivness is ensured by the architecture of resources, which:

- makes *high speed hardware implementation of user algorithms* be possible and repeatable at all times;
- supports *parallel operation* of resources.

DESCRIPTION

MPR-16 System comprises three major elements: MPR-CPU Modul System, Program Development System and XILINX XACT Development System (Fig. 1). All of them are needed to realize accelerating process successfully.

MPR-CPU Modul System is a multiprocessor computer system which gives a user a possibility to define a special accelerator implemented in hardware on prupose to complete their tasks more effectively. It contains maximum 16 MPR-CPU Moduls connected to 32 bit VMEbus. MPR-CPU Modul consists of two parts: a base board and a "piggy back" accelerator board. Base board is a MIPS R305E RISC based processor card with fully standard 32 bit VMEbus interface and UNIX microkernel. The accelerator as a piggz back connects to the possibility of increase of performance with change of accelerator, if more integrated and faster circuits are published on market. The accelerator as the hardware implementation of user algorithms and instructions is constructed with two VLSI (10,000 gates) FPGAs (XILINX XC4010). Their content is determined by the user, so these devices are customized by loading configuration data into the FPGA's internal memory cells. Since they can be re-programmed an unlimited number of times, they can be used in innovative designs where hardware is changed dynamically, or where hardware must be adapted to different user applications.

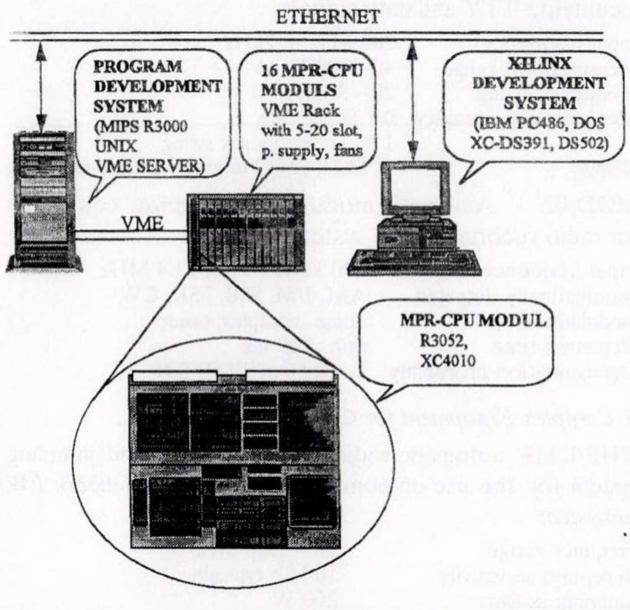


Fig. 1.

Program Development System is a MIPS R3000 and UNIX-based server with at least one 32 bit VMEbus slot. It supports development of user programs running on MPR-CPU moduls. Any appropriate tools of UNIX can be used for program development (i.e. texteditors, compilers, assemblers, subrutin libraries etc.).

XILINX XACT Development System running on 386/486PC, Apollo, Sun-3/4, DECstation 3100 platform is to help you to define the content of FPGA devices. Application programs ranging from schematic capture to partitioning, placement and routing automates the entire process and generates configuration file for FPGA devices. The system supports both simulation and in-circuit debugging technics, too.

ACCELERATING PROCESS

After parallellising the task, making configuration file by XILINX XACT Development System, testing your user program on Program Development System, you can run your program on MPR-CPU moduls and load configuration files into the accelerators.

G. MAYER
Recoware Ltd.

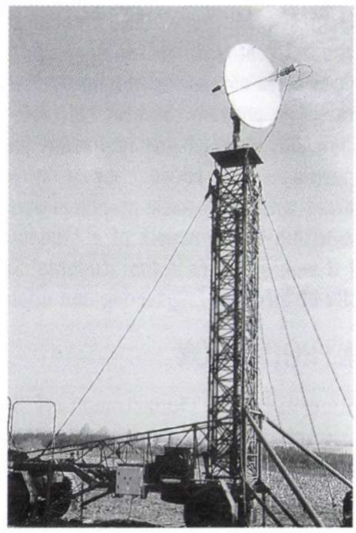
MINISTRY OF DEFENCE

ELECTRONIC DIRECTORATE CO.

The Ministry of Defence established the MOD Electronic Directorate Company on 1 January 1993 from the previously successfully operating Electronic Directorate of the Hungarian Home Defence Forces.

FIELDS OF OPERATIONS

- **ELECTRONIC WARFARE**
- **AIR DEFENCE, AIR TRAFFIC CONTROL**
- **COMMUNICATIONS SYSTEMS**
- **GPS APPLICATIONS**
- **INFORMATION SECURITY**
- **SECURITY SYSTEMS**
- **EMC/EMI PROTECTION**
- **INFORMATION & COMPUTER TECHNIQUE**
- **LOGISTICS**
- **EDUCATION AND TRAINING**
- **QUALITY SYSTEMS & STANDARDIZATION**



The Hungarian electronic industry has realized significant export turnover with the decisive participation of the MOD ED Company.
The above fields of operations mean the following:

SCOPE OF ACTIVITIES

- DESIGN AND DEVELOPMENT
- SYSTEM INTEGRATION
- QUALITY CONTROL & CERTIFICATION
- INSTALLATION & SUPPORT
- EDUCATION & TRAINING
- ADVISORY ACTIVITY
- MARKETING & TRADE

In addition to preparing offers, providing open market operations and sales services – we design and develop systems, special hardware and software, organise and manage production, provide system and equipment quality control and military certification, turn systems over and train the same in Hungary or abroad. System designs are based upon the wide scope of products manufactured by Hungarian industry.
Our systems and their elements may be installed in stationary facilities, mobile shelters, vehicle platforms, on board of aircraft, helicopters and UAVs. Microprocessor or computer controlled system elements are integrated into computer controlled systems. We deliver systems with complex integrated services tailored to individual requirements.
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COMPUTER CONTROLLED ANTENNA PATTERN MEASUREMENTS

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In this paper a report is presented on a novel type of measurement developed in the antenna laboratory of Technical University Budapest, Department of Microwave Telecommunication. It is the first time that a computer controlled measuring setup, made for the students, has displayed three-dimensional antenna patterns from its really measured values. The program can also calculate the directivity of a given antenna and shows all the important parameters used in antenna engineering. It is all done by utilising the Windows' graphical resources with comfortable graphical user interface. The work was made within the framework of a student laboratory project and in 1994 it won first prize in the Students' Scientific Conference of the Faculty of Electrical Engineering and Informatics.

1. INTRODUCTION

Since 1985 the Department of Microwave Telecommunications has a microwave anechoic chamber with fairly good parameters especially in the microwave frequency range. The chamber has a floor area of 4×5 m and its wall is covered with absorbent material operating above 2,5 GHz, which is in accordance with the farfield criteria. The aim of our work was to make the indoor antenna pattern measurements much more impressive. The setup is basically made for teaching purposes but professional measurements also can be made with it. Experiments taking place in the antenna laboratory are connected with the subject of Antennas and Propagation and aims to demonstrate the technique of antenna measurements and the main antenna parameters in practice. The program controls the equipment and interprets the results using the Windows' graphical interface. Data files can be created for an antenna for printing or displaying the results or new measuring points can be added to the file owing to the very flexible data structure.

2. THE MEASURING METHOD

In ideal case the antenna pattern is measured in the following way. A transmitting antenna is placed to a fixed point as origin, and an another antenna measures the power density along of a spherical surface whit large radius. In the direction where the antenna's transmitted power is higher, the receiver can measure higher power density. This gives a function, which shows dependence on direction. Normalising it with its maximum value we can get the normalized power antenna pattern (Eq. 2.1).

$$P(\vartheta, \varphi) = \frac{S(r, \vartheta, \varphi)}{S_{\max}(r)}. \qquad (2.1)$$

The large radius, in practice, means a distance which satisfies the farfield criteria. In case of aperture antennas it is (Eq. 2.2):

$$r_{\min} > 2\frac{D^2}{\lambda}, \qquad (2.2)$$

where D is the largest size of the aperture. Since it is very difficult to move around an antenna on a spherical surface the antennas are measured in a more practical way. According to the reciprocity law the antenna to be tested can be used for reception and transmission interchangeably. Thus the transmitter is fixed while the receiver is directed into all directions to record the measured data. The two-dimensional antenna pattern function, which can be represented in three dimensions as a surface, can be depicted from the recorded data. From a finite number of discrete data the surface is reconstructed by linear interpolation between the points.

To direct an antenna to all directions it needs rotating around its vertical axis, and tilting (Fig. 1/a). Another solution, which we chose, doesn't need tilting of the antenna but it must be rotated around its horizontal axis. When the antenna is rotated once around its vertical axis, a plane pattern is measured, which is a plane section of a three-dimensional antenna pattern. The whole pattern is built up always from plane patterns, which are the longitudinal sections of a three-dimensional pattern function. This measured plane pattern system has a reference direction, it is usually the main direction of the antenna, as can be see in Fig. 1/b.

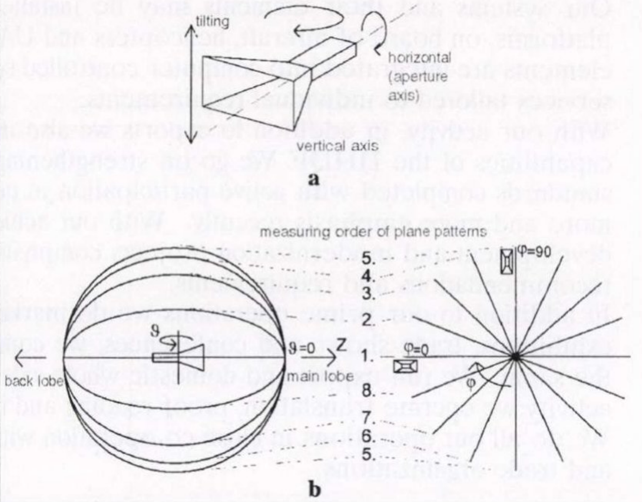


Fig. 1. a) Moving modes necessary for directing an antenna to any direction. b) The method of measuring a three-dimensional antenna pattern.

The recording of a pattern starts with setting the receiver and the transmitter to the same polarization. Then the receiver is rotated once around its vertical axis and the computer records the measured values in several points (for example in 1° steps). This gives the first plane pattern. After it both antennas are rotated around their aperture axes with the same angle in order that the antennas remain at the same polarization. Rotating the antenna under test again the second plane pattern is recorded. This is continued until the antennas rotate once around their aperture axes. In this way all the plane patterns will have two common points like in Fig. 1/b, where eight measured plane patterns are represented. Using a horn antenna these are the main lobe and the back lobe directions, thus all the plane patterns contain the main direction. It should be mentioned, that the spherical co-ordinate system is not used in the usual way. The Z axis was chosen to be the main direction, so a measuring point in the space is given by the angle of its plane pattern φ, and its angle in it ϑ. Thus $0 \leq \varphi < \pi$ and $-\pi \leq \vartheta < \pi$.

3. THE EQUIPMENT

In the test system we used a simple synchronous antenna rotator, a HP scalar network analyser with sweep generator (0.1 – 18 GHz) and a computer with HP-IB card. It has the advantage of measuring a whole frequency range in a short time. This advantage made it possible to observe the changing of the antenna pattern as the frequency varies. In this way the program can demonstrate the frequency dependence of the directivity from the measured data and the bandwidth of an antenna can be seen.

When the measurement is taken in a frequency range the antenna stays in one position while it is measured on the frequency band (one sweep). Then the program adds every value to the appropriate pattern data depending on frequency. The measurement of all the patterns in the frequency range are finished at once in the last position.

The accuracy of the measurement is limited by the dynamic range of the analyser: below -70 dBm the signal is mashed by the noise of the wide band detector. The maximum output power is about 15 dBm from the generator, the attenuation of the power divider, transmission lines and the free space between the antennas is altogether 35 dB, thus we get 50 dB dynamic range as a maximum. This is not enough for getting really detailed patterns, which have deep zeros, it would be much better to use a vector analyser. In that case we would be able to measure the phase error of the antennas and would have larger dynamic range.

It is also a problem that the antenna rotator cannot be stopped in discrete positions because it is driven synchronously. Therefore the antenna is moving while the analyser sweeps and it may cause errors in the result.

4. FUNCTIONS OF THE PROGRAM

Such a program was designed, which can be used efficiently in everyday work and demonstrates the fundamentals in expressive way. It does all these things from really measured data, in this way the theoretical and practical results are comparable. All the curves and diagrams, which appear on the screen, can be printed or transferred to other applications via the Windows' clipboard. The figures of this paper are obtained also in this way while testing an X band horn antenna, and a microstrip antenna, wich has a zero in its main direction.

4.1. Basic methods of representation

Plane patterns are the plane cuts of a three-dimensional antenna pattern, and referred usually as antenna pattern. In practice these are represented in polar (Fig. 2) or in rectangular diagrams. Fig. 2 shows the difference between the E ($\varphi = 90°$) and H ($\varphi = 0°$) plane antenna patterns in case of the horn antenna. The curves can be rolled and rotated separately; the reference level and the scale can be set through the appropriate menu points. The user can choose between linear and decibel scaling for the plane patterns, and the normalization can be switched off or on also. This is needed to determine the cross polarization attenuation.

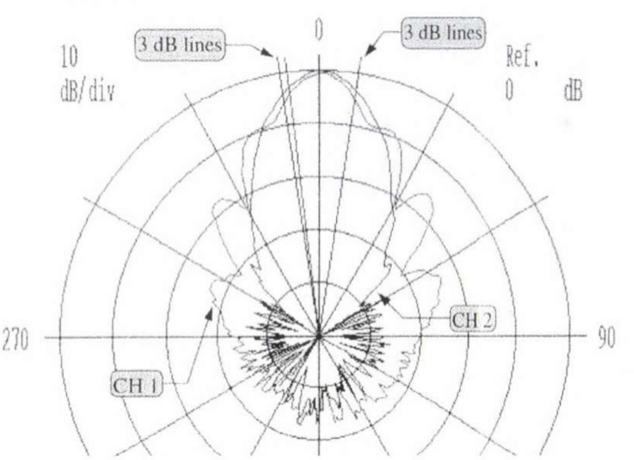


Fig. 2. E (CH2, $\varphi = 90°$) and H (CH1, ($\varphi = 0°$) plane pattern of a horn antenna in polar co-ordinate system

To represent an antenna pattern in three dimensions three methods were chosen. The first method simply works in a spherical system of co-ordinates with the function (4.1),

$$\begin{aligned} r(\vartheta,\varphi) &= k \cdot (P(\vartheta,\varphi) - T) \quad \text{if} \quad P(\vartheta,\varphi) > T \\ r(\vartheta,\varphi) &= 0 \quad \text{if} \quad P(\vartheta,\varphi) \leq T \end{aligned} \tag{4.1}$$

which gives three-dimensional surface (Fig. 3). $r(\vartheta, \varphi)$ is the distance from the origin, which is equal to the difference between the power density function and the T threshold value, k is a scaling factor. T can be chosen freely, its importance is that it could be set over the noise level and in this way the noise disappears from the graphics. This is really important in order to get valuable figures.

The problem of hiding the invisible portion of the surface is also solved in the program resulting in much more plastical effect than the simple line drawing would have. The witty algorithm, that makes the hiding, will be described later in this paper. The program can rotate the figures but the result seems spectacular only on quick computers. The figure is painted in different colours as the function $P(\vartheta, \varphi)$ varies to a certain extent (8 dB on

Figs. 3 – 5). This function can be set off since it slows down rotation very much.

The second method of representation uses cylindrical co-ordinate system which is very similar to the previous method. The only difference is that antenna's angle in the plane pattern (ϑ before) is represented as the radius. The pattern function value, $P(\vartheta, \varphi)$, is represented as height above the base plane (Fig. 4). This kind of figure can also be painted rotated and scaled.

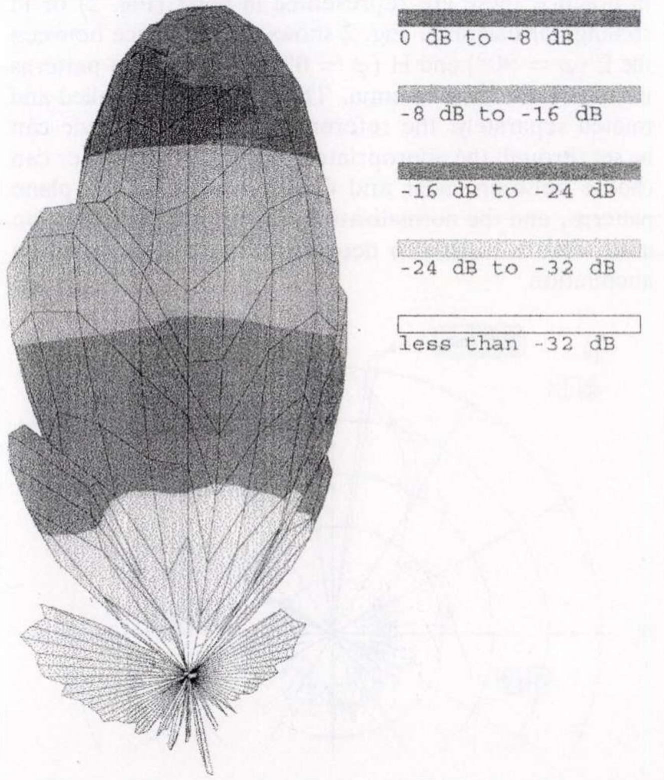


Fig. 3. Three-dimensional pattern of a horn antenna represented in spherical co-ordinate system

The third type of figure represents the antenna pattern with level lines, this is the top-view of the cylindrical co-ordinate case. In this kind of figure the extent and the position of the side lobes can be seen very well (Fig. 5).

The user can switch from one method of representation to other in a window at any time, or several windows can be opened with different representing methods inside.

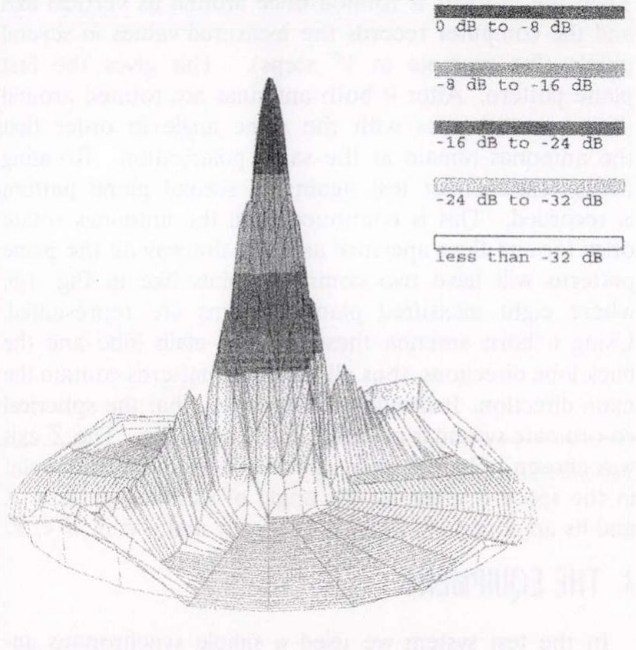


Fig. 4. Three-dimensional pattern of a horn antenna represented in cylindrical co-ordinate system

4.2. Calculation of directivity

It is an extraordinary function of the program that it computes the directivity of an antenna from the measured data. It is done by carrying out the integration of

$$D = \frac{4\pi}{\oint\limits_{4\pi} P(\vartheta, \varphi) d\Omega}, \tag{4.3}$$

where Ω means solid angle. The program calculates this for every measured antenna pattern on every frequency and polarization. This is a very time consuming process, mainly in cases of detailed patterns with a lot of measuring points. The computer has to compute the solid angles of every surface element formed by three adjacent points. Over these triangles the function value is assumed to be constant and it is the average of the values in the nodes.

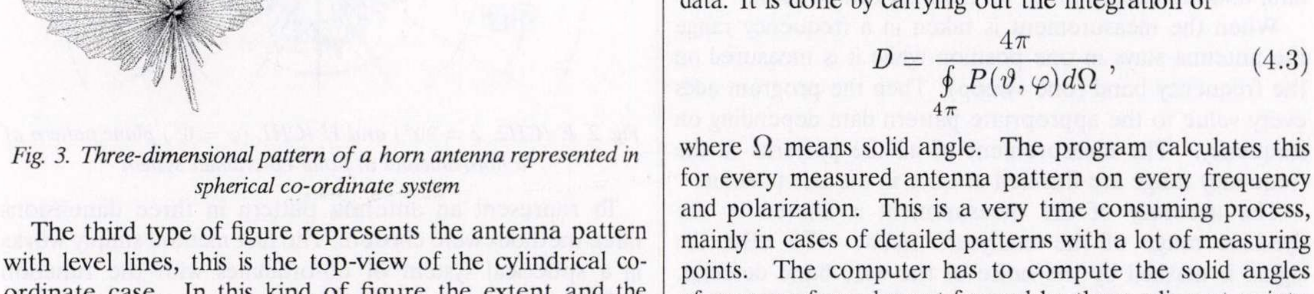


Fig. 5. The pattern function of a horn antenna represented with level lines (vertical projection of the cylindrical representation)

Representing of directivity versus frequency shows the cut off frequency or the bandwidth of an antenna. The cursor, scaling and switching between dB and linear scales are also available in this type of chart.

The measuring setup makes it possible to measure the gain of an antenna with the classical method using two antennas. If the gain is known, one can get the efficiency of the antenna:

$$G = \eta \cdot D . \tag{4.4}$$

4.3. Representing in three dimensions

In case of representing the pattern in a spherical co-ordinate system the algorithm approximates the surface with rectangles and determines, which is the rearmost from our view-point. The drawing must begin with the rearmost one then it continues with the second rearmost one, etc. Since filled rectangle are drawn, the nearer one repaints everything, what it covers from the previous squares. The procedure ends with the square nearest to the observer since it is sure that it can be seen totally. This method does not give good result with any type of surface but antenna patterns have a special property, which guarantees the good result. This property is that its surface has only one intersection with every radial line starting from the origin (where the antenna is). When the drawing order is known (Fig. 6/a), the squares must be transformed to the screen. The algorithm calculates the Descartes co-ordinates of the squares and projects them axonometrically on the display.

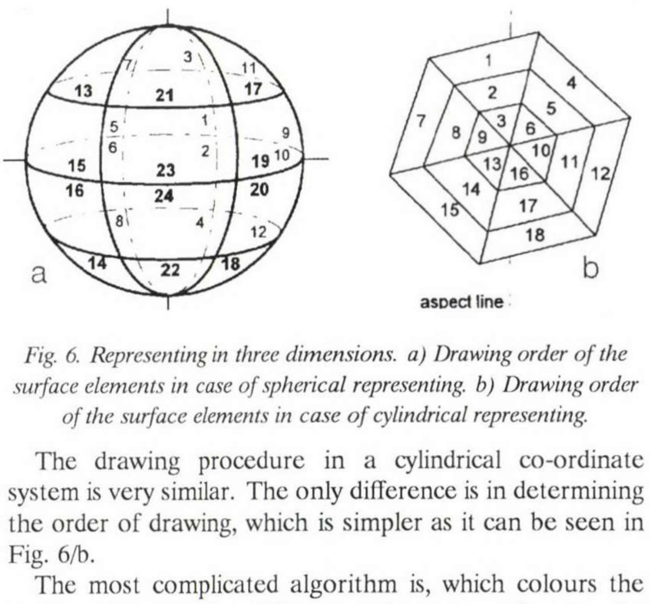


Fig. 6. Representing in three dimensions. a) Drawing order of the surface elements in case of spherical representing. b) Drawing order of the surface elements in case of cylindrical representing.

The drawing procedure in a cylindrical co-ordinate system is very similar. The only difference is in determining the order of drawing, which is simpler as it can be seen in Fig. 6/b.

The most complicated algorithm is, which colours the surface elements by different colours according to the antenna pattern function value (Figs. 3–5). The squares are divided into two triangles because only three points are in one plane. The algorithm determines which vertex belongs to which value interval. If two vertices are in different intervals, the program calculates the co-ordinates of the points, which are on the line determined by the two vertices and are exactly on the border of two intervals. When it is done for all three sides the algorithm selects the points to be connected with each other including the vertices. Thus the program draws filled triangles and rectangles, painting with the appropriate colour, which together give the original triangle. In Figs. 3–5 five intervals were chosen but more would also be possible.

Finally, in Fig. 7 an interesting pattern can be seen. It shows the pattern of a four element microstrip antenna with elements fed in antiphase. It causes that the antenna has zero direction in its aperture axis.

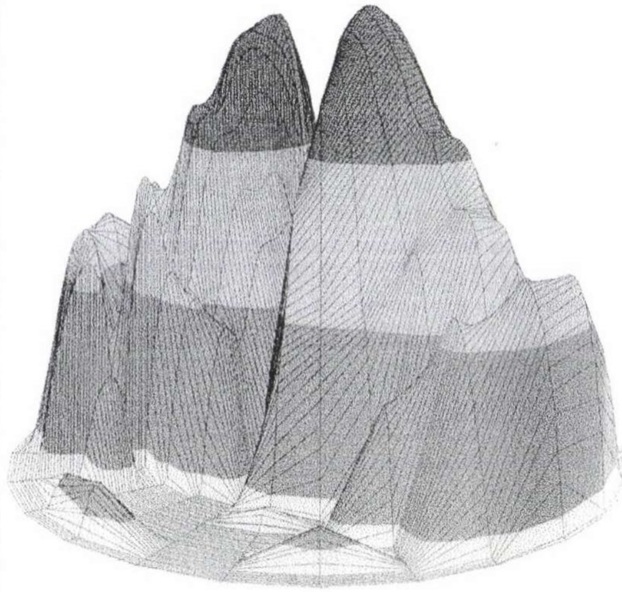
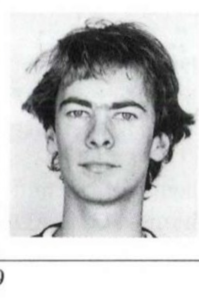


Fig. 7. Three-dimensional pattern of a microstrip antenna represented in cylindrical co-ordinate system

5. CONCLUSION

The above presented computer controlled antenna pattern measurement setup became an efficient and spectacular tool of professional and teaching work.

In the future the synchronous antenna rotator can be replaced by a step motor driven one, and the horizontal rotating can also be automated. Than the long lasting measurements, which are necessary for recording very detailed patterns, can be taken without supervision. The accuracy would increase and more options would become possible with using step motor driven equipment.



Tamás Marozsák graduated in the Faculty of Electronic Engineering at the Technical University of Budapest in 1995. His recent research related to the field of optical communication. From 1995 he is PhD student at the Department of Microwave Telecommunication at the Technical University of Budapest.

MICROWAVE RECONNAISSANCE

In this contribution I want to say some words about MW Reconnaissance, to show some results of Hungarian research and development in this field, to formulate some hard questions and to give also some answers according to my opinion.

After WW II. the Hungarian government established several factories to develop and produce communication and radar equipment for military purposes. In the productions Soviet licences were used , but there was a possibility also for Hungarian engineers to develop and produce equipments of Hungarian design. Due to this activity Hungary became a country with rich tradition in microwave technology.

The first important Hungarian results in microwave RECCE technology appeared at the beginning of the '70s, when the Hungarian designed complex RECCE station against the FM radio relay stations was overtaken to serial production. It operated with a complex mobile antenna system from 20 MHz up to 2400 MHz. It was capable to receive and intercept four independent communication sources, to demultiplex 2x48 FM radio relay channels. It had crystal-controlled super-heterodyne type receivers.

The next important step came at the end of the '70s with the spreading of the new TDMA communication technology. A new mobile MW complex RECCE station working in the frequency band from 5 GHz up to 18 GHz was developed In the "SUNFLOWER" station synthesized frequency tuning was used. The station was supplied with an antenna system comprising of the antennas from the VU-141 station (20–100, 100–500, 500–1000, 1000–2400 MHz) and from the newly designed 3 m diameter parabolic antenna dish. This station was designed to work against the radio-relay, SATCOM and tropo-scatter communication.

The third important step in MW technology was in the middle of the '80. At that time a new MW RECCE station working from 1 GHz up to 40 GHz. was developed. It was a computer-controlled, monitoring, intercepting and pre-evaluating station, designed against the analog and digital radio-relay, SATCOM and tropo-scatter communication.

The next important step in the Hungarian MW technology began at the end of the '80s. According to the new receiver concept all frequency-conversion components up to 18 GHz were integrated into a front-end unit, so the RF and I. IF units of the high accuracy new superheterodyne receiver were integrated with the antenna system. The measuring accuracy of the new MW RCVR is 1 kHz. In parallel with the MW COMINT equipment development the following equipment and devices were developed in Hungary:

- integrated IFR MW ELINT RCVR working from 2 to 18 GHz to monitor and intercept the various kinds of radar signals;
- integrated acoustic-optic spectrum analyzer using $LiNbO_3$ AO-cell, working in the MW 2/4 GHz band with a 1.000 MHz real-time analysis band and with 1 MHz accuracy, 1 μs reaction time;
- a new generation of computer-controlled TDM demultiplexers for PSK, QAM, TCM modulations, PCM, AD-PCM and DM signals up to 10 Mbit/s and up to 34 Mbit/s;
- a new SAW filter based MW compression RCVR for chirp and frequency hopping radar signals.

I would like to underline, that all of these equipment are Hungarian designed, including system concept, SW and HW components.

Today the microwave reconnaissance has a new challenge: the revolution in communications opened a wide spectra of new transmitting methods, modulation modes, data speed data, multiplexing and signal transforming. Because of this fact, there are some very hard questions regarding the "traditional" MW RECCE:

- Which type of the transformed and transmitted data is the most important?
- Which receiving, demultiplexing and demodulating method is the most powerful to resolve new problems?
- Can we go on the way of the traditional development?
- Is the "old philosophy" to develop universally usable complex MW receivers and RECCE system acceptable or is it necessary to reduce some or most of the parameters of the newly developed MW RCVRs and systems?
- How can be made the production rates for MW RCVRs and RECCE systems more efficient?
- We have to decide whether we wish to be in the EW business long term.

The answers could be the following:

- We have to continue developing, and producing new MW RECCE equipment according to the new challenges of the communications.
- The MW RECCE development should be a complex RECCE system. About complexity there is a difference of opinion between developers and end-users which can be focused in the financing possibilities of the R&D and production. The rapid progress in communications requires much more money and scientific capacities, however on the other hand there is the cutting of the budget. We have to do efforts to create working posts for simulating the complex signals used in modern communication and radar systems. This working post could be new basic posts with capability for simulating of the simultaneous digital, amplitude, frequency, phase and pulse modulation. Of course potentially we have to use in these working posts ready made special signal generators and modulation analyzers for digital communication from the ruling companies of this field.
- The new digital communication systems makes the MW RECCE to be driven toward the technical spectral analysis of the radio signals. The FFT and IFT analysis has to be closely real-time not only after the channel demodulators, but also in the IF or the RF spectra.
- There is only way to reduce long-term costs: to develop theoretically complex systems, by building systems step-by-step from nearly ready made elements in minimum time, to perform CAD-CAM design of high performance systems.
- The last question is the hardest one. The finances of military enterprises are in some instances irreversible. Financing of R&D and industrial capacity has extremely

changed. Defence budget has been generally cut. Defence production is on a downward spiral as the defence budget plummets. The Hungarian EW industry is now fragmented. In the last 7 years it was fighting for survival. Now they have made changes. Everybody understands that the consolidation comes from the market. But here we have individual interests of producers and end-users, so we have to find common interests. I think the progress will be long. But Hungary has no option because the alternative is so clear: losing this technical culture and that is – I think – completely unacceptable. We have to find ways for greater participation by domestic industry in EW projects In western countries the defence industry has a widespread support, despite of cutting the military budget. It means that the big western multinational companies must have some government investment, too. We have to maintain the production for the greater part of the Hungarian need and to continue the export of our equipment. There have to be new government supports for defence companies seeking for export. But only government subsidies cannot solve the most critical problem of defence industry. It is essential to establish a really working government fund for converting military production to civilian production. In this case the MW RECCE RCVR's and analyzing technology could be successfully transformed to the EMC and EMI field. The primary task of this fund could be to guarantee investors return and growth on their money. We have to undertake work to formulate new domestic private-sector investment funds to finance the presently government-controlled Hungarian defence industry. I believe that this way several Hungarian companies would join the EW business in the near future.

Looking in the past, we can say that till the '90s Hungary had a wide spread R&D and producing capacity creating high complexity, high accuracy MW reconnaissance products and systems.

Looking in the future, taking view on the late '90s and the early years of the next century Hungarian EW industry may have a reduced, but good quality level activity. This depends on us, first of all.

B. SZABÓ
Hungarian Armed Forces

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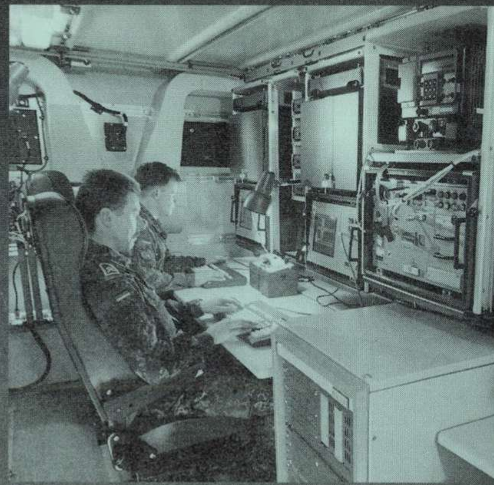

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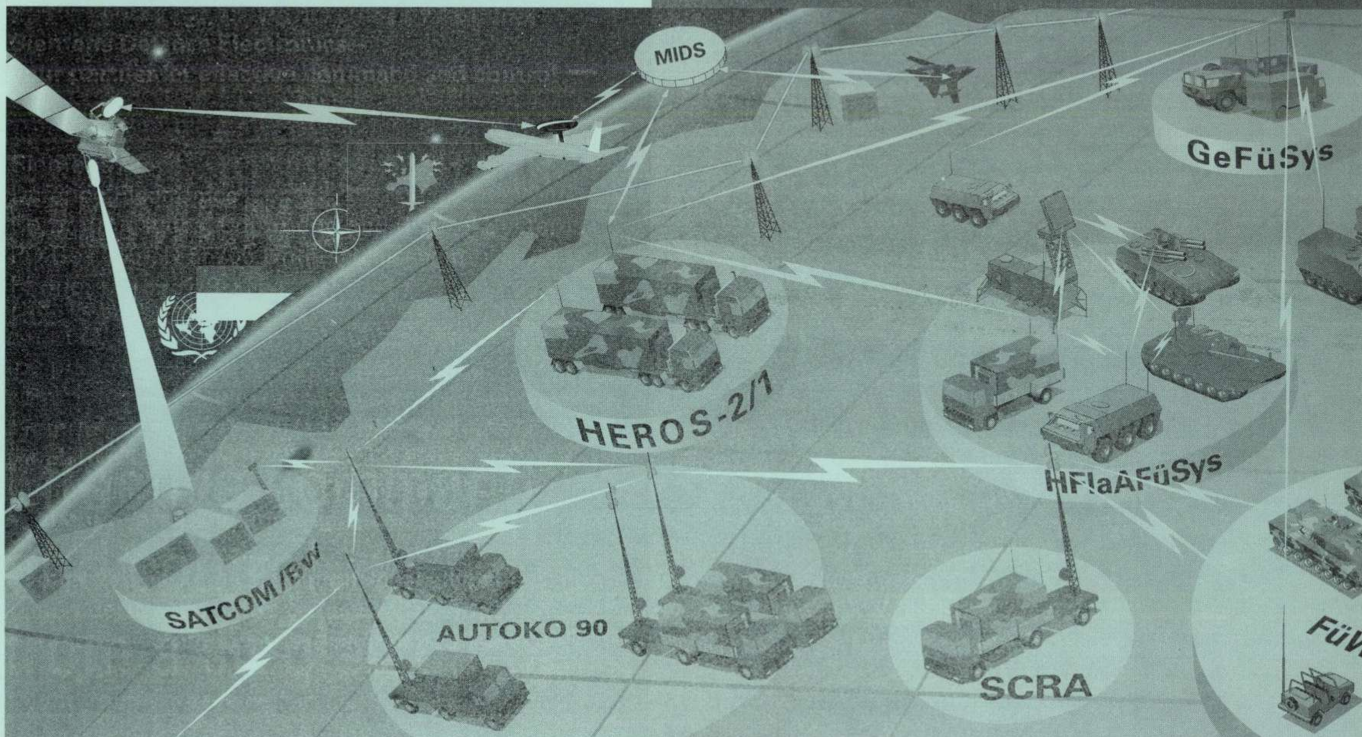

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