RECENT ADVANCES IN ELECTRONIC WARFARE-ESM SYSTEMS

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Abstract: Electronic warfare actually started with the introduction of RADAR systems. Many of the drawbacks of RADAR systems, until recently, have been a matter of concern. Efforts to overcome these drawbacks are still in the research level. One such widely used accomplished system is the ESM (Electronic-Warfare Support Measures) system. The ESM system is used to measure the parameters of Radar emissions in the operating frequency range along with pulse width, pulse repetition frequency, signal strength, antenna scan period, direction of arrival, etc.,. These systems are installed in warships, air crafts and submarines. The parameters are to be made available to operator during the peace and wartime. In the modern ESM systems these parameters are to be measured instantaneously for tactical purposes. Different techniques are used for measuring different parameters. The frequency coverage should be wider since the enemy's radar frequency is unknown to us. This is to be carried out in the factory using manual test set up in earlier ESM systems. The manual set up requires test equipment and associated instruments. This is also cumbersome and needs lot of time. This can be simplified by using online channel calibration which is very accurate. However, to perform the auto calibration, an interface circuit, AHU processor is installed. The AHU processor generates all the control signals to provide interface for auto calibration in the systems.

Keywords:
RADAR - Radio Detection and Ranging
ESM - Electronic-Warfare Support Measures
EW - Electronic Warfare
EM - Electromagnetic
AHU – Antenna Head Unit

I. INTRODUCTION

The major motivation behind the study is the requirement of high performance auto-calibration interface circuit called AHU Processor for the ESM system, which plays a major role especially during war time. The AHU processor basically receives various control signals from the receiver processor, which are known as command codes, and these command codes are decoded and are sent to the next stage, ESM processor and simultaneously to a BITE frequency generator. However, to perform the auto calibration by the AHU Processor we need many interface circuits namely Front end receiver, Receiver processor, ESM processor, etc. The AHU processor shall generate all the control signals to provide interface for auto calibration in the systems. Different techniques are used for measuring different parameters. The parameters except 'Direction of Arrival' use simple measurement techniques whereas direction of arrival uses "Amplitude Comparison Technique" and are very critical. The emergence of sophisticated technology in the field of Electronic-Warfare has led to the ingenious improvements in the existing circuitry of the presently working ESM system. Thus an auto-calibration circuit for sending the control systems to various parts of the system with very high speed of around 1.2 microseconds has to be designed. This circuit is named as AHU circuit as it acts as an interface between the RF signal processor and the main ESM processor of the ESM system.

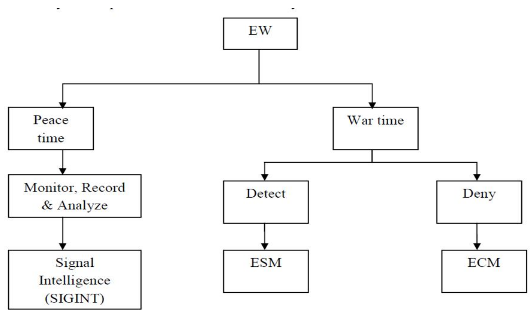
The parameters measured by the ESM system include frequency, pulse width, amplitude scan period, direction of arrival, angle of arrival, pulse repetition frequency, etc. The ESM system antenna receives the RF signals and is then sent to the front-end receiver, which removes the noise and other spurious data present in the received RF signal. This RF signal is sent to the receiver processor from the front-end receiver. In the Receiver processor, the RF signal is compared with various signals present in the data-base of receiver processor, and a corresponding command code is issued to the AHU Processor. The AHU processor decodes the command code and produces various parameters such as frequency, attenuation required, minimum threshold value of the corresponding signal and the mode. The Built-In Test Equipment (BITE) in the ESM system is used to generate the signals of certain frequency as of the input received by the AHU processor. The frequency control is given to the BITE source which is generated by the AHU processor. It uses 12 bits for the control signals of frequency. The AHU processor has two modes BITE mode and Normal mode. The switching of signals is done by the AHU processor to keep the system in NORMAL/BITE mode. The digital attenuator is used to control the power supply in the processor. The AHU processor uses 5 bits for the amplitude range given by the threshold level. The input to the AHU processor is a serial communication command codes which is given by the receiver processor. Another input to the processor is a blanking signal from the RADAR to keep the system in BITE mode i.e., off mode and the source is zero. In BITE mode the processor does not detect its own signals. Each input and output signals is sent through a line driver which helps in eliminating the noise. The essentiality of the AHU processor is that the entire ESM system will stop working if the AHU processor fails to work.

Electronic Warfare can be defined as an action that involves the use of electro-magnetic energy to determine and that retains friendly use of electromagnetic (EM) spectrum. Such an action can be used to control the EM spectrum, attack an enemy, or impede enemy assaults via the spectrum. EW can be applied from air, sea, land, and space by manned and unmanned systems, and can target communication, radar, or other services. RADAR is an electromagnetic system for the detection and location of reflective objects such as air crafts, ships, space crafts, vehicles, people and the natural environment. It operates by radiating energy into space and detecting the echo signal reflected from an object, or target. This energy that is returned to the RADAR not only indicates the presence of a target, but by comparing the received echo signal that was transmitted, its location can be determined along with the target-related information. A transmitter generates an electromagnetic signal that is radiated into space by an antenna. A portion of the transmitted energy is intercepted by the target and reradiated in many directions. The reradiated directed back towards the RADAR is collected by the RADAR antenna, which delivers it to a receiver. There it is processed to detect the presence of the target and determine its location. A single antenna is usually used on a time-shared basis for both transmitting and receiving when the RADAR waveform is repetitive series of continuous wave. The range, or distance, to a target is found by measuring the time it takes for the RADAR signal to travel to the target and return back to the RADAR. The term RADAR is contraction of the words “Radio Detection and Ranging”. The name reflects the importance placed. As stated earlier, there are several drawbacks of RADAR systems such as, High responding time, limited frequency range coverage, ambiguous range, etc.,. But, for tactical purposes the responding time should be as low as possible, and this has been overcome by the ESM system, which responds with very high speed of around 1.2 microseconds, approximately five times faster than the conventional RADAR system. Modern EW systems can be broadly classified into 3 divisions:

1. Passive Electronic Support Measure (ESM)
2. Active Electronic Counter Measure (ECM)
3. Anti-ECM Electronic Counter- Counter Measure (ECCM)

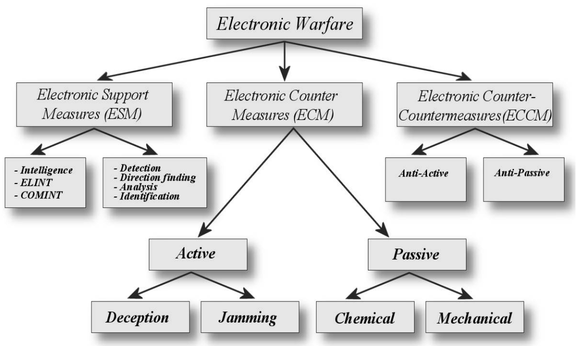
Military operations are executed in an information environment increasingly complicated by the electromagnetic (EM) spectrum. This portion of the information environment is referred to as the electromagnetic environment (EME). In EW systems, reconstruction of electromagnetic environment depend both on detection of the electromagnetic signals input to the antennas and on characterization of signals.

EW systems operate in two scenarios namely **Peace time** and **War time**.

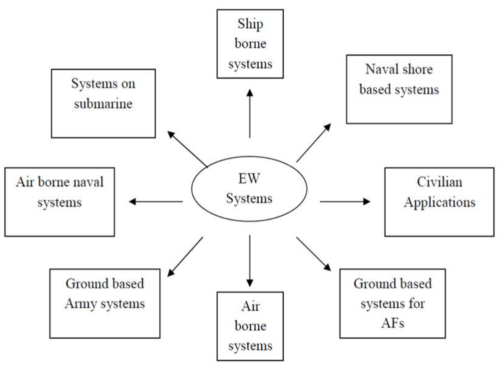


One of the problems with the last two types is the continuous development of one equipment to counter the other. As the ECM specialist produces systems to provide jamming and decoy methods so the ECCM engineer develops equipment to overcome these methods. Frequently the same manufacturers are doing both. The electronic warfare scene is a continuously evolving battle between the various aspects of ESM, ECM and ECCM. With the complexity of modern weapons, and the speed of reaction necessary to combat them, the weak link in the chain would appear to be the human being who has to make the decision! This is not necessarily the case, because in some instances an operator is far better than an automatic processor. He can interpret situations based on previous experience more readily and can alter his thresholds easily to perform basic functions such as detecting a signal in heavy background clutter, whereas a machine can only operate at the threshold for which it has been programmed. Nevertheless, great strides have been made in artificial intelligence systems and, although there is still a long way to go, the era of complete automation will eventually arrive. The amount of raw information from modern sensor systems is so vast that better and better processors, employing highly complex software programs, are vital to analyze the inputs. This speed and complexity is such that the operators must be highly efficient, and an extensive business in providing EW training and simulation systems has grown up over the past years. Even so, this does not help, say the pilot of a single-seat fighter who is being presented with a vast amount of electronic information and, perhaps, only a second or so to react against a missile attack. All that this means, in that type of situation, is that the warning system must be fully automatic in its countermeasures role, with an overriding manual facility as a safety measure.

Another vital component is the provision of programmable software so that the system program can be changed easily. It is interesting to note that EW systems used in the Gulf War were designed to cope with Soviet missiles and radars but, in some cases, found themselves faced with Western systems. Fortunately the most up-to-date radar warning receivers and jammers are software controlled and were able to be reprogrammed to meet the threats.



Applications of EW Systems:

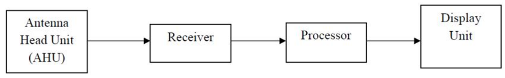


ESM Systems:

Electronic Support Measure (ESM) involves actions taken to search for intercept, locate and immediately identify radiated EM energy for the purposes of immediate threat recognition and the tactical employment of forces. The ESM system is used to measure the parameters of radar emissions in the operating frequency range along with pulse width, pulse repetition frequency, signal strength, antenna scan period, direction of arrival, etc.,. These systems are installed in warships, air crafts and submarines. The major difference between an ESM and RADAR is that ESM is a receiver alone while the latter is a trans-receiver. The advantages of ESM systems are that they are completely passive and provide greater ranges than the maximum range of sensors such as RADARs, lasers, SONARs.

Key functions of ESM systems are:

1 Intercepting
2 Identifying
3 Analyzing
4 Locating sources of RADAR signals



Flow Diagram of ESM Systems

(i) Antenna Head Unit (AHU)

It converts the detected RF signal into the video signal. The main function of video signal is, it is used to measure RADAR parameters.

(ii) Receiver

It measures Pulse Width (PW), Time of Arrival (TOA), amplitude and generation of Pulse Descriptor Words (PDW). It also measures radar parameters within 1.2 micro seconds.

(iii) ESM Processor

It de-interleaves the PD words, measures Pulse Repetitive frequency (PRF), scan rate, tracks data generation and does verification /identification of library data.

(iv) Display Unit

The main function of the display is to obtain the track data file from ESM processor and display the emitter details on the screen. The display also provides a keyboard for issuing commands that operator is interested. The display contains a processor with serial ports, a monitor with graphic controller and a keyboard.

The display is also organized with byte capability. The display subsystem consists of monitor, processor, peripherals and MMI Module. The monitor is a colour monitor. The processor is based on Single Board Computer (SBC) with the necessary interface and graphic hardware. The application software for display processor is developed on Windows-NT operating system. The peripherals include operator's desk keyboard, tracker ball and mouse. A separate interface is provided for printer. The system control and management, maintenance and diagnosis are provided in display subsystem.

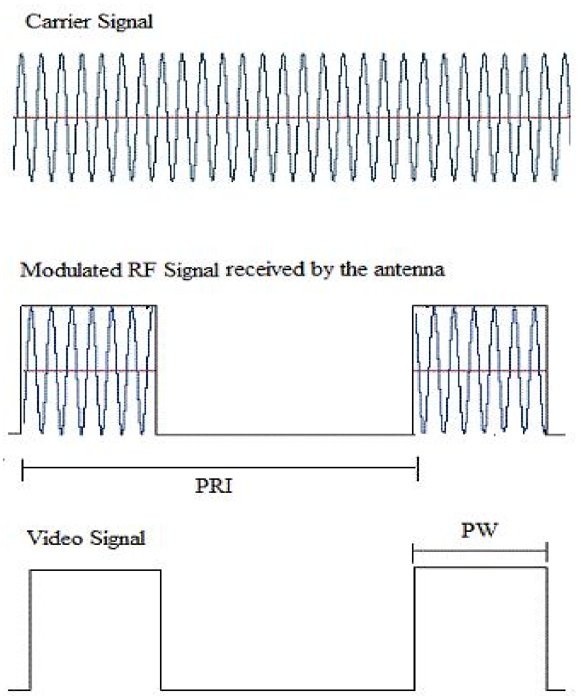
2.1.1 ESM System Features

(1) Low weight ESM system, Split AHU for ship suitability

(2) Wide frequency range, Single rack for receiver processor and monitor

(3) 4-antenna configuration, Menu driven MMI online help menu

Fundamental Concepts in ESM:



1. Carrier Signal
   The frequency of carrier signal used in RADAR is around 2-18 GHz.

2. Video Signal
   It is the signal demodulated by the front end receiver in the AHU of the ESM system.

3. Pulse Descriptor (PD) Word

It is a 128 bit word formed by the receiver block of the ESM containing digitized values of frequency, amplitude, pulse width, DOA, TOA and flags. TOA helps in determining PRI from two PDWs.

4. De-interleaving of PDWs

Binning (of one RADAR) PDWs back based on primary parameters of the RADAR Signal namely frequency (F), pulse width (PW) and direction (DF).

5. Data Validation

The erroneous Continuous Waves will be added to the data coming from the receiver. These Continuous Waves are removed by the ESM Processor.

6. Track Formation and Decision making for its formation

Some continuous waves transmitted by the RADAR are received by the ESM processor, and it will make decision of which has to be selected and track formation will also help in converting the coded data into digital data by using mapping process.

7. Track maintenance

The processor is made active only when ESM receives radiation otherwise it is made passive.

8. Command Execution

If ESM does not want to receive radiations in any direction then the user can send some command to the ESM processor for executing this operation.

PD Word Bit Format (128 bits)

It is a 128 bit word formed by the receiver block of the ESM containing digitized values of frequency, amplitude, pulse width, DOA, TOA and flags. TOA helps in determining PRI from two PDWs.

Frequency (12 bits)	Pulse Width (8 bits)	TOA (36 bits)	Amplitude (9 bits)	DOA (9 bits)	Flags (54 bits)

PDW Format

Frequency

It is the number of occurrences of a repeating event per unit time. the period, usually denoted by T is the length of time taken by one cycle, and is the reciprocal of the frequency f:

$$T = 1/f$$

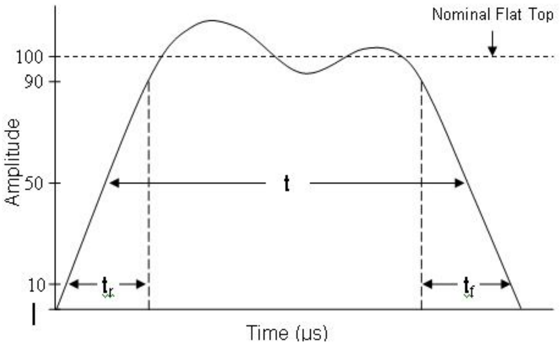
The SI unit for period is the second.

Amplitude

It is the magnitude of change in the oscillating variable with each oscillation within an oscillating system. If a variable undergoes regular oscillations, and a graph of the system is drawn with the oscillating variable as the vertical axis and time as the horizontal axis, the amplitude is visually represented by the vertical distance between the extreme of the curve and the equilibrium value.

Pulse Width

It is the time interval between the leading edge and trailing edge of a pulse at a point where the amplitude is 50% of the peak value.



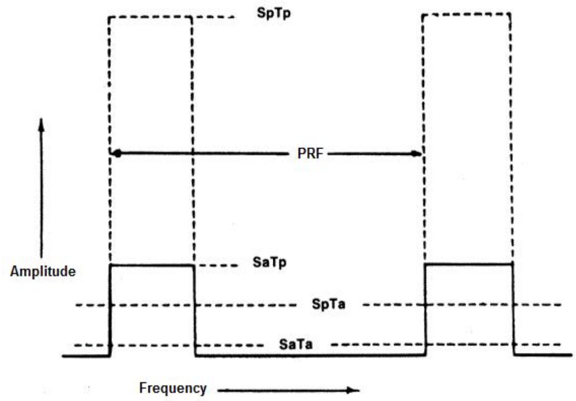
Pulse Width

Time of Arrival (TOA)

Time of Arrival (TOA or ToA), sometimes called time of flight (TOF), is the travel time of a radio signal from a single transmitter to a remote single receiver.

Pulse Repetition Frequency (PRF)

Pulse repetition frequency (PRF) or pulse repetition rate (PRR) is the number of pulses per time unit (e.g. Seconds). It is a measure or specification ("pulses per second") mostly used within various technical disciplines (e.g. Radar technology) to avoid confusion with the unit of frequency hertz (Hz or "cycles per second" - mainly used for describing the continuous wave base frequency) of the transmitted electromagnetic signal. It is calculated using the difference between the two TOAs.



Pulse Repetition Frequency

Range Ambiguity

(i) Single PRF

In simple systems, echoes from targets must be detected and processed before the next transmitter pulse is generated if range ambiguity is to be avoided. Range ambiguity occurs when the time taken for an echo to return from a target is greater than the pulse repetition period (T); if the interval between transmitted pulses is 1000 microseconds, and the return-time of a pulse from a distant target is 1200 microseconds, the apparent distance of the target is only 200 microseconds. In sum, these 'second echoes' appear on the display to be targets closer than they really are.

The maximum non ambiguous range varies inversely with PRF and is given by:

$Range_{unambiguous} = C/(2PRF)$

If a longer unambiguous range is required with this simple system, then lower PRFs are required and it was quite common for early search radars to have PRFs as low as a few hundred Hz, giving an unambiguous range out to well in excess of 150 km. However, lower PRFs introduce other problems, including poorer target painting and velocity ambiguity in Pulse-Doppler systems.

(ii) Multiple PRF

Modern radars, especially air-to-air combat radars in military aircraft, may use PRFs in the tens-to-hundreds of kilohertz and stagger the interval between pulses to allow the correct range to be determined. With this form of staggered PRF, a packet of pulses is transmitted with a fixed interval between each pulse, and then another packet is transmitted with a slightly different interval. Target reflections appear at different ranges for each packet; these differences are accumulated and then simple arithmetical techniques may be applied to determine true range. Such radars may use repetitive patterns of packets, or more adaptable packets that respond to apparent target behaviors. Regardless, radars that employ the technique are universally coherent, with a very stable radio frequency, and the pulse packets may also be used to make measurements of the Doppler shift (a velocity-dependent modification of the apparent radio frequency), especially when the PRFs are in the hundreds-of-kilohertz range. Radars exploiting Doppler effects in this manner typically determine relative velocity first, from the Doppler effect, and then use other techniques to derive target distance.

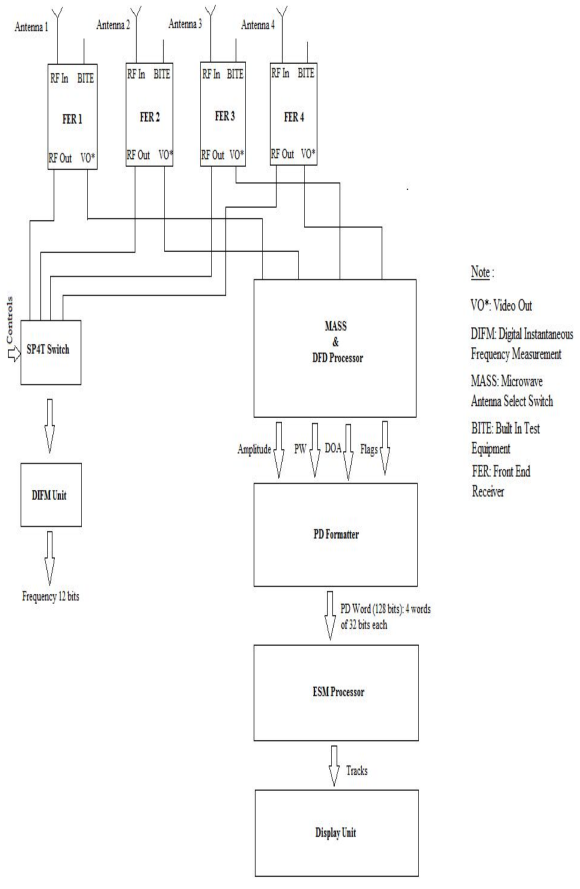
(iii) Maximum Unambiguous Range

At its most simplistic, MUR (Maximum Unambiguous Range) for a Pulse Stagger sequence may be calculated using the TSP (Total Sequence Period). TSP is defined as the total time it takes for the Pulsed pattern to repeat. This can be found by the addition of all the elements in the stagger sequence. The formula is derived from the speed of light and the length of the sequence.

MUR = (C * 0.5 * TSP)

where c is the speed of light, usually in meters per microsecond, and TSP is the addition of all the positions of the stagger sequence, usually in microseconds. However, it should be noted that in a stagger sequence, some intervals may be repeated several times; when this occurs, it is more appropriate to consider TSP as the addition of all the unique intervals in the sequence.

II. ESM BLOCK DIAGRAM



Front End Receiver:

It comprises of an antenna and BITE source.

(i) Antenna

An antenna is a specialized transducer that converts radio-frequency (RF) fields into alternating current (AC) or vice-versa. There are two basic types: the receiving antenna, which intercepts RF energy and delivers AC to electronic equipment, and the transmitting antenna, which is fed with AC from electronic equipment and generates an RF field. Here we make use of Log Periodic Antennae as they provide wide frequency range (i.e. 2 to 18 GHz). Moreover they are frequency independent and exhibit constant beam width with constant gain.

(ii) BITE (Built-In Test Equipment)

Built-in test equipment (BITE) is a function that verifies all or a portion of the internal functionality of the equipment. It is the technique of designing additional hardware and software features into the equipment to allow them to perform self-testing, i.e., testing of their own operation (functionally, parametrically, or both) using their own circuits, thereby reducing dependence on an external automated test equipment (ATE).

SP4T Switch: It is an electronic switch connecting four terminals to a common terminal.

Digital Instantaneous Frequency Measurement (DIFM): It provides the digital output of RF frequency.

Microwave Antenna Select Switch (MASS): The main function of the MASS circuit is to receive the video signals from different antennas and identify the maximum amplitude signals and generate the switch control signals to select the antenna with highest amplitude signals received by its antenna unit. MASS circuit consists of stacks of PCB boards for calculating various parameters such as DOA, pulse width etc.

PD Formatter: It continuously generates PD words to the ESM Processor.

CONCLUSION

In this thesis work, the need and advances in the Modern electronic warfare has been presented. The most commonly used ESM system has been introduced. Various design parameters available at the system level were highlighted and the use of various tools has also been presented. The major directions for further study and development lies in the improvement of circuitry to face extreme conditions and optimization of the circuit for the best use of the system for tactical purposes.

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