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Modern Radar Signal Processor

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Abstract—In this paper a modern radar signal processing various stages have been studied. In modern radar sets the conversion of radar signals to digital form is typically accomplished after IF amplification and phase sensitive detection. The signal processor is that part of the system which separates targets from clutter on the basis of Doppler content and amplitude characteristics. All measures are referred to as radar signal processing and radar data processing that calculates from the received echo signal an evaluable image on the radar display. With radar signal processing is referred the part that is still dealing with the analogue (or often present even as a digital value) magnitude of the echo signal.

Index Terms— Introduction, Radar Signal Processor Design, Conclusion, refrences

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1 Introduction

The term "RADAR" was officially coined as an acronym by U.S. Navy Lieutenant Commander Samuel M. Tucker and F. R. Furth in November 1940. The acronym was by agreement adopted in 1943 by the Allied powers of World War II and thereafter received general international acceptance.

It refers to electronic equipment that detects the presence of objects by using reflected electromagnetic energy. Under some conditions a radar system can measure the direction, height, distance, course and speed of these objects. The frequency of electromagnetic energy used for radar is unaffected by darkness and also penetrates fog and clouds. This permits radar systems to determine the position of airplanes, ships, or other obstacles that are invisible to the naked eye because of distance, darkness, or weather.

Modern radar can extract widely more information from a target's echo signal than its range. But the calculating of the range by measuring the delay time is one of its most important functions.

The signal processor is that part of the system which separates targets from clutter on the basis of Doppler content and amplitude characteristics. In modern radar sets the conversion of radar signals to digital form is typically accomplished after IF amplification and phase sensitive detection. At this stage they are referred to as video signals, and have a typical bandwidth in the range 250 KHz to 5 MHz The Sampling Theorem therefore indicates sampling rates between about 500 KHz and 10 MHz Such rates are well within the capabilities of modern analogue-to-digital converters (ADCs).

Details of the Radar signal processor design are described.

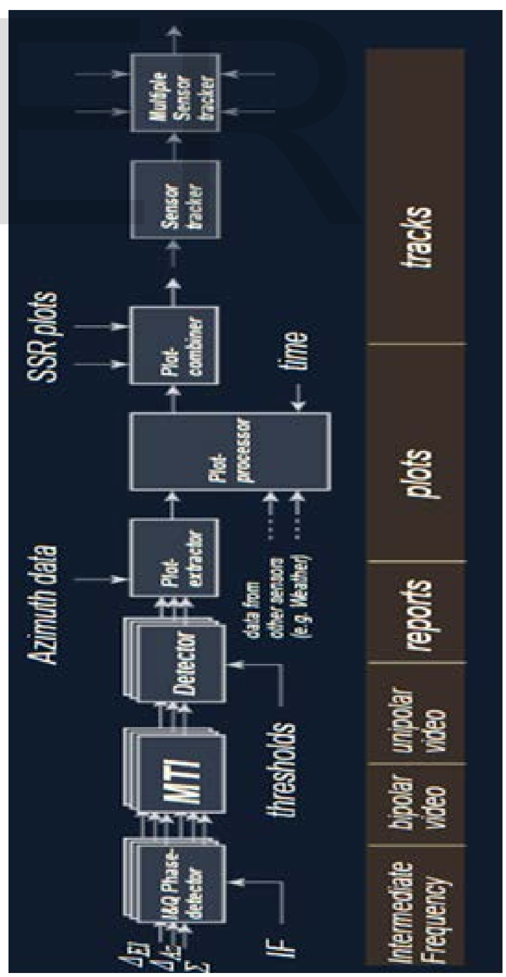

Figure 1: Flow of information in radar signal processing

2 Radar Signal Processor Design

The signal processor includes the following components:

- the I&Q Phase Detector,
- the Moving Target Indication and
- the Constant False Alarm Rate detection.

The complete proceeding may also be implemented as software in digital receivers.

The plot extraction and plot processing elements are the final stage in the primary radar sensor chain. The essential process is that of generating and processing plots as distinct from processing waveforms. The main components are:

i. The plot extractor or hit processor (translates hits from the signal processor to plots),
ii. The plot processor (combines primary radar plots and minimizes false plots) and
iii. The plot combiner (combines primary and secondary plots, uses complementary features to minimize false alarms).

The radar data chain can include the following devices:

i. A sensor tracker (it combines some plots of a target to a track), and
ii. The Multiple Sensor tracker (it combines plots or tracks of other radar sensors).

The difference between a correlator and a tracker being, that in the case of a correlator the plot positions are not changed by the process.)

Some of these devises can carried out as a software-module after the digitalizing of the radar data. is a Radar Data Extractors for all types of radars and is designed to upgrade analogue radars.

2.1 In-phase & Quadrature Procedure

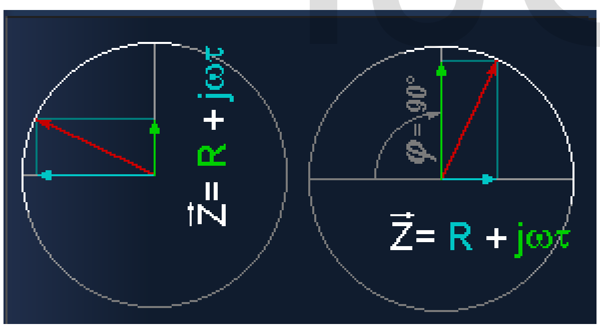

Figure 2: Real and imagine quantities

If already the IF-frequency with a fast but simple Analog and Digital Converter is digitized, then each range cell has a digital amplitude value. This one represents the real part of the complex echo signal, and the phase information is lost.

Synchronous Detector

A complex quantity always consists of a real part (light green) and an imaginary part (light blue). However, an analog/digital converter always will take only the real part lying in the X-axis into account.

This is no problem by older radars. The blip is composed of a minimum of 12 to 15 pulses. If one or two pulses have the real amplitude of zero (by maximum of phase shift), the blip is visibly anyway. But the newer radars use a so called Monopulse Technology often. All data are a result of one transmitted pulse only. So we need the imagine data too!

Synchronous detector provides a representation of the IF signal, including phase and amplitude without loss of information. The baseband in-phase (I) and quadrature-phase (Q) signals are digitized using a pair of A/D converters. The synchronous detector is also referred to as a quadrature channel receiver, quadrature detector, I/Q demodulator, or coherent detector.

Turn the whole construct by 90° then the former imaginary part then is exactly on the X-axis and can be digitized but the former real part is dropped now.

But the amount of the original vector can be calculated again with help of the theorem of Pythagoras from these two results.

The resulting digital data can then be processed using a wide variety of digital signal-processing algorithms.

The I and Q components are related as

$I = A \cos(\Phi)$

$Q = A \sin(\Phi)$ ------ (1)

From this, the signal magnitude A and phase an angle Φ can be calculated as

$A^2 = I^2 + Q^2$

$\Phi = \arctan(Q/I)$ --- (2)

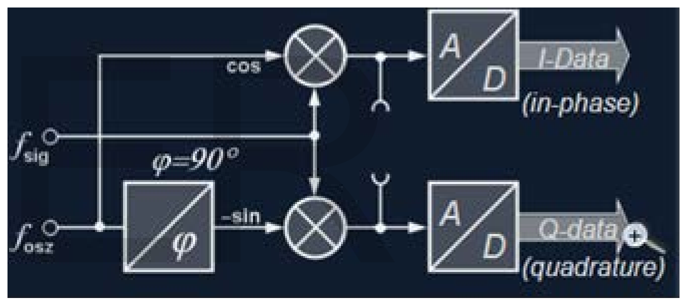

Figure 2: Block diagram of synchronous detector

2.2 DETECTOR

The output of the receiver is a signal, which contains the required target plus various forms of noise and clutter. In the case of the MTI output, this clutter residue is the result of imperfect cancellation due to various factors such as equipment instability, antenna modulation, lack of dynamic range or Doppler content within the clutter itself. The detection process separates the required target from the noise and clutter. Detectors are normally designed to carry out this process with a constant false alarm rate (CFAR).

The Fig-3 shows the location of the detector in the chain of signal processing. This device forms the information on a point like target as a digital report. The up to this point existing information about the analog value (or digital description of) of the received power in a particular binary cell will be transformed to information about the co-ordinates of a target. The value of the power is included in this report mostly.

The important procedure is that up to this point all binary cells (containing the received power) must be processed. After the detector the only reports about selected binary cells exists. However, there may be several **reports about a single target**

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exists, generated by adjacent binary cells. This will be processed in the next device.

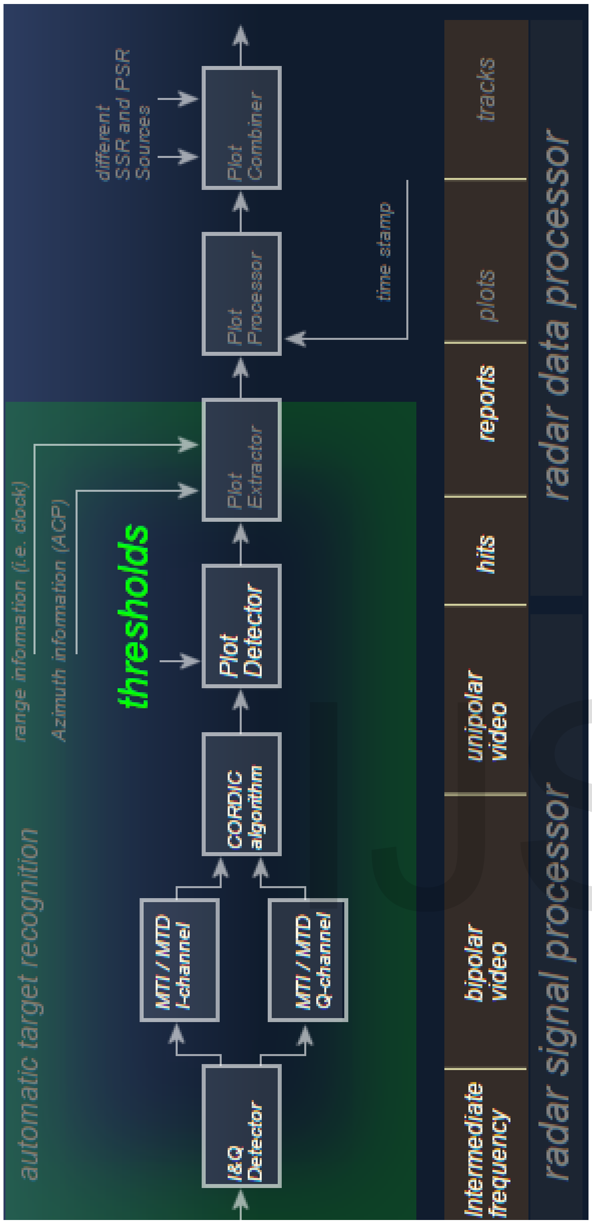

Figure 3: Information flow in radar signal processing

2.3 Plot Extractor

Plot Extraction is sometimes called **Hit Processing**.

The plot extractor takes the output of the signal processor i.e. the hits generated across the beam width and declares a plot position which may also include course and radial speed information. Plot extraction ranges from a simple position declaration to advanced hit processing, which takes the output of an MTI filter bank and generates plots taking account of amplitude information and Doppler.

As the antenna scans past any one target, there may be threshold crossings at one or more Doppler filter outputs, in several inter pulse periods, different CPIs and perhaps in adjacent range resolution cells. The function of the hit processor is to correlate all threshold crossings, grouping together all those which appear to come from the same target (can be 100 items for one target).

The hit processor generates target reports comprising range, azimuth, amplitude and radial velocity information, on all validated targets. The most common method of correlating hits to form a plot report is known as the sliding window process. More modern plot processors generally employ a more sophisticated correlation process - Centre of Mass Correlation.

The hit processor can make an assessment of plot energy based on the hit amplitude distribution across the beam width. This plot energy parameter is a valuable discriminator between targets and angels and is normally passed to the plot processor.

Hit processing functions are:

- Declare detection (given false alarm rate)
- Declare centroid position
- Declare radial speed
- Declare energy/amplitude (for removing angels)

2.4 Plot Processor

The principal role of the plot processor is to combine primary plots from the various primary radar channels or sources into a single best estimate plot. The plot processor may also incorporate a range of other functions to improve the quality of the primary radar plot.

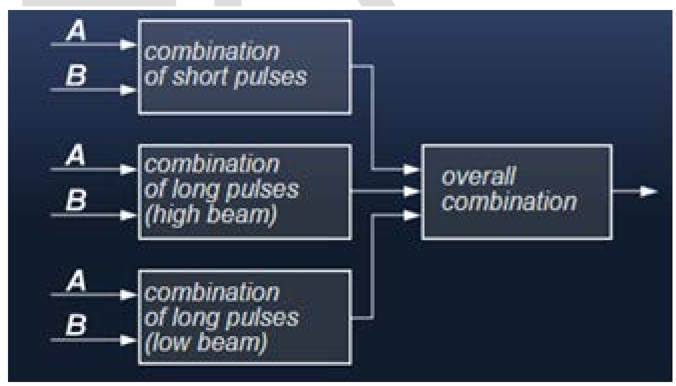

Figure 4: Block diagram of a plot processor in a frequency-diversity radar using high- and low-beam feeding of the antenna

Typical modern primary radar will generate plots from some or all of the following:

- Each radar channel can produce plots
- Multi-pulse working can produce plots from each of the pulses (e.g. short and long pulses)
- Frequency diversity produces plots from each of the frequencies (frequency diversity can be implemented within one channel or utilizing two channels)
- Separately processed high and low beams.

In general the combination of information from all these sources is best carried out at plot level. Combining data earlier in the system usually involves loss of information, particularly, if carried out before coherent integration. Plot combination can be carried out in a general purpose computer which permits full control of the characteristics of the combination process. Typically, the plot combination will include a weighted average of position of the related plots modified by other parameters such as the energy level.

2.5 Plot Combiner

The plot combiner combines primary and secondary radar plots. In this respect it has to be distinguished from the plot processor which combines only primary plots (amongst other functions).

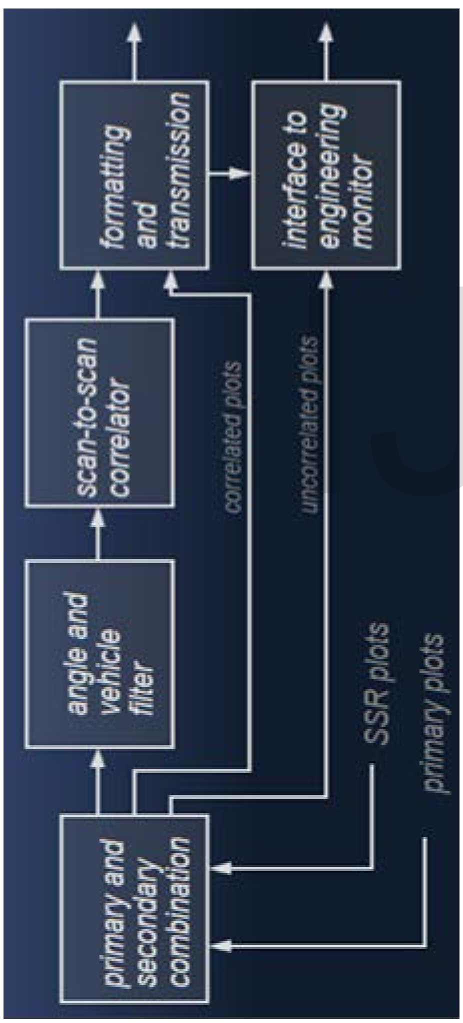

Figure 5: Block diagram of a plot combiner

2.6 Sliding Window

The most common method of correlating hits to form a plot report is known as the sliding window process.

The detected hits for each pulse repetition period are inserted as „1"s in the stored range cell dimension. For ATC radars, the range cells are typically 1/16 of a nautical mile (ca 0.8 microseconds).

A number of results for previous pulse intervals are stored - typically results from 8 - 16 PRTs may be stored (depending upon the Dwell Time) - this represents the window size (N).

A window is applied at each range cell, to count the number of hits that are present in the window at the same range. Due to a degree of uncertainty regarding the precise range cell in which a hit will be declared, it is normal practice to include hits in adjacent range cells. The number of hits found in the window is used as the target detection criteria.

2.7 Radar Data Transmission

The plot combiner formats the data ready for transmission through the radar data network. The European standard radar data format Asterix, is normally adopted for (new) systems although the plot combiner may be required to provide additional formats for legacy systems. A dual channel feed is normally provided to the main radar data network. It is important that the peak loads on the link do not cause overloads. Under these conditions, the plot combiner may send a priority message warning of potential loss of data.

The plot combiner usually has a direct link to the onsite engineering monitor display. For analysis purposes, this monitor can be provided with access to discarded data as well as operational output. Finally the plot combiner may be required to output status information to the control and monitoring system. This information can include such parameters as primary and secondary plot load, combination rate and rejected plot counts.

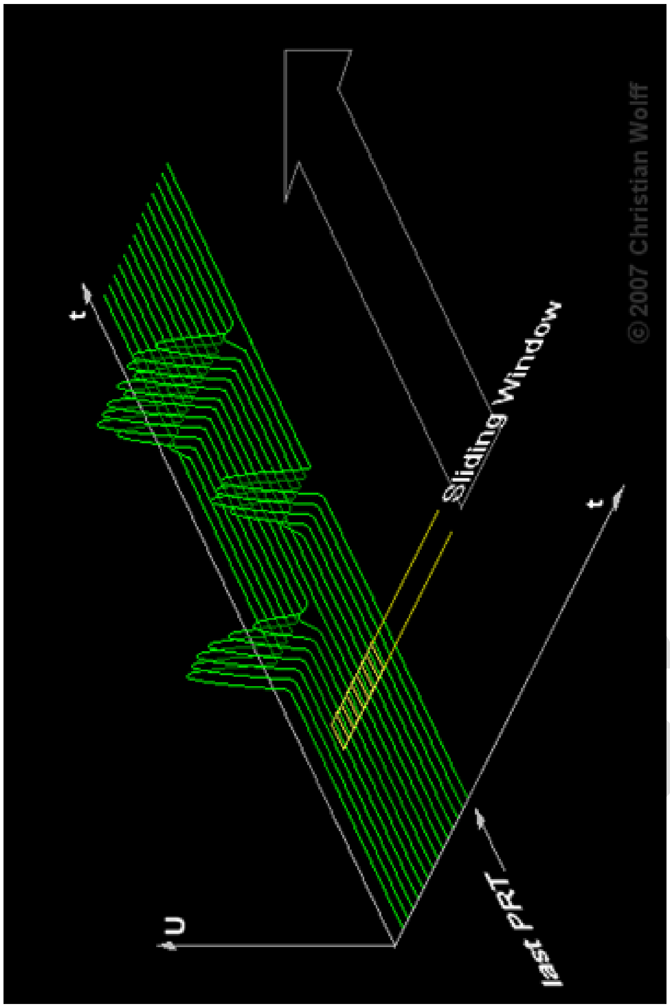

Figure 6: Procedure of “Sliding Window”

2.8 CENTER OF MASS CORRELATION

More modern plot processors generally employ a more sophisticated correlation process than the simple sliding window.

One possible method is the retrieving of the centre of mass correlation. The correlator first assembles the hit pattern including azimuth over a prescribed area of range azimuth cells. These are then grouped in range and then in azimuth. The plot position is computed by algorithms, which determine the centre of mass of the signal processor output. This method makes better use of the signal information and provides more accurate positional declarations

Figure 7: The Signal Processor provides hits including information about received power

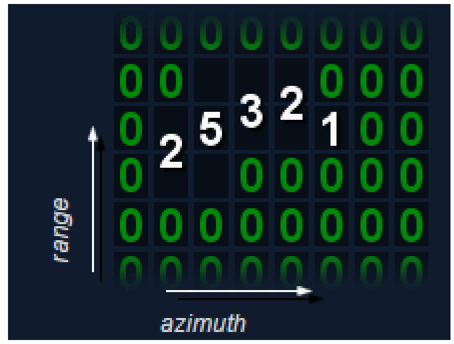

Figure 8: A range correlation provides groups.

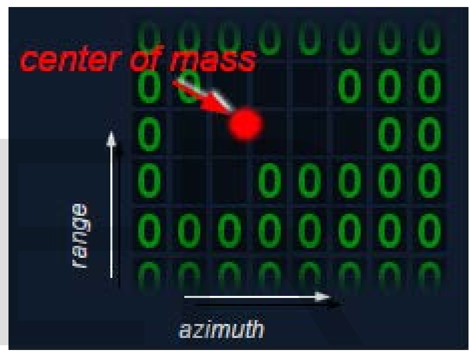

Figure 9: An azimuth correlation provides plots.

2.9 Time Stamp

Until the radar data processing can be assumed a real-time processing. Minor delays ranging from a few microseconds are equal for all targets, so they can be calculated out in the estimation of the targets range. Even the delays during the Pulse-Pair Processing (one or several pulse periods) for all echo signals are from the same size and can also be calculated. These delays of up to several milliseconds have no effect on the calculation of the associated bearing angle.

But, at least after the plot extractor this time reference is lost. Some plots can be processed immediately and other plots have to go through several filters, without the knowledge how long was this delay. Plot data is no longer real time information and is subject to un-quantified delays in subsequent data processing. e.g. into the plot combiner may be processed the radar data from different primary radars. The delays between data from one source to the data from the other source can take up to one complete revolution of the antenna: thus it lies e.g. in the range of 5 to 15 seconds. During this time, a fast-flying aircraft can travel a long distance so that this combination of data without a time reference is impossible.

So it is essential that the plot has an associated time stamp, otherwise the accuracy of the positional declaration will have

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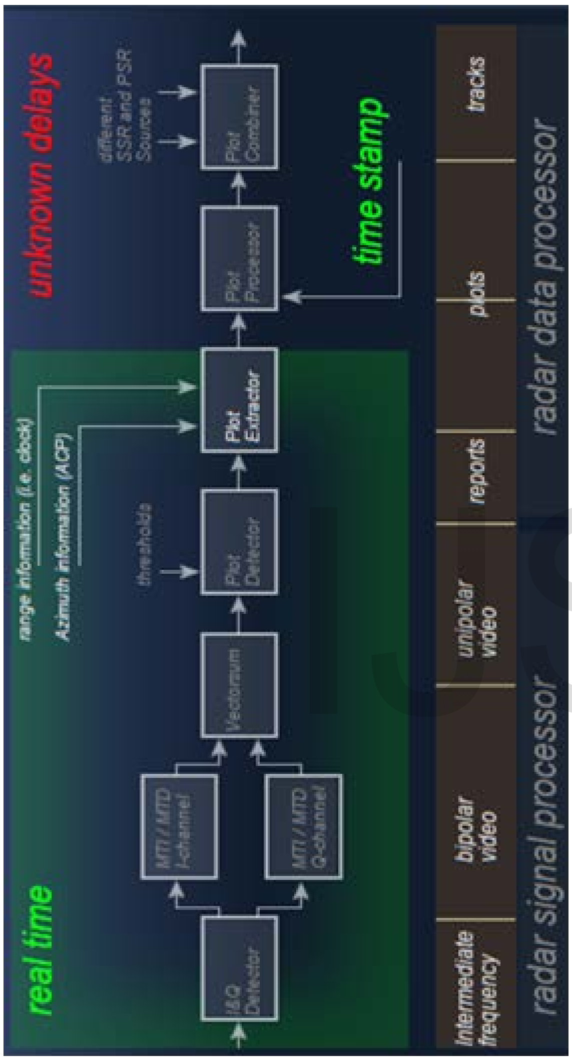
no value in subsequent plot correlation and tracking systems.

Time information is normally added by the hit processor or plot extractor or plot processor. Modern radar data formats make full provision for the time to be incorporated in the plot message. Normally an accurate time source is provided at a radar station and this provides a master source for both primary and secondary radar systems. Typically, the time reference can be an atomic clock or a GPS based time reference.



3. Conclusion

In this paper, it has seen that the signal processor is the part of the system which separates targets from clutter on the basis of Doppler content and amplitude characteristics. In modern radar sets the conversion of radar signals to digital form is typically accomplished after IF amplification and phase sensitive detection. So it is essential that the plot has an associated time stamp, otherwise the accuracy of the positional declaration will have no value in subsequent plot correlation and tracking systems.

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