Some aspects about Radar: Past - Present - Future

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The concept of detecting remote objects using electromagnetic waves is probably inherent in the understanding of their propagation characteristics and thus might be traced to Heinrich Hertz. The first formal mention of the radar idea appears to have been made by Tesla after his experiments he had carried out in Colorado in 1899. However, as many other ideas pointed out by Tesla, the concept to determine the relative position or course of a remote object wasn't very clear defined. In the early 1900's the German Hülsmeyer tried to build a shipborne apparatus for the detection of remote objects. Hülsmeyer's apparatus was based on Hertz's famous experiments with electromagnetic waves carried out some fifteen years earlier.

Although Hülsmeyer had filed several patents he failed to demonstrate a successful method for range measurement, which is an essential feature of the radar principle. However patents that are not followed up with a working device have little value outside the courtroom, so no further activities happened for over twenty-five years. His work faded from memory, even in Germany where it had to be re-invented in the 1930's.

It is interesting to explore a little bit the reason why the radar idea died in the early part of the 20th century and was re-born to life in the 1930's. The explanation is to be found mainly in the advancing state of the art and particularly with electronic circuits and components which were essential to the development of pulse radar, but did not exist before the 1930's.

The most difficult problems in the development of early pulse radars were the stable high gain and wide bandwidth of the receiver and the precise measurement of a series of varying time intervals of only a few microseconds duration and display them continuously to the operator. Other rather hard problems to be solved were the transmitters and their suitable tubes as well as the pulse modulators for the transmitters. Pulse radars need a pulse modulated transmitter that would generate thousands of watts of power in a pulse only a few microseconds long at a frequency of hundreds or thousands of megahertz.

The early radar pioneers did not have a good theoretical basis for radar design. The enterprising engineers had to feel their way forward with a lot of trial and error.

One of the earliest scientific analytical study about the radar context was carried out 1935 in Britain by Watson-Watt with his two memoranda. Later during WW II the MIT Radiation Laboratory in the approximately five years of its existence devoted a large part of its program to build up the theoretical basis for the radar design. The MIT Radiation Laboratory ceased operation in 1945, but many of the talented scientist and researcher who worked on radar development moved to the Lincoln Laboratory after its formation in 1951.

Four significant theoretical contributions in the 1940's and 1950's were of great importance for the further progresses in radar technique:

1. Matched Filter

The matched filter, usually found in the IF stage of a radar receiver, has a frequency response function that maximizes the output signal-to-noise ratio, which means maximizing detection. It was first described in a classified 1943 WWII report, but wasn't widely known until reprinted in the Proceedings of the IEEE in 1963. Fortunately, the matched filter confirmed the practice of the early radar engineers who made the receiver bandwidth equal to the reciprocal of the radar pulse width. The matched filter concept also provided the means for receiver filter design when the waveform was more complex than a simple pulse, as it is with pulse compression.

2. Statistical Detection Theory

In 1947, J. I. Marcum of the Rand Corporation published a highly significant classified report mathematically describing the detection of a sine wave in noise in statistical terms based on the probability of detection and the probability of false alarm. His work extended the simple radar equation which produced overly optimistic estimates of the range of a radar. Marcum's work became the basis for the prediction of the range of a radar and helped initiate statistical detection theory. His classified report was known to the US military radar community, but it didn't become available to the general public until it and its companion Rand report by Peter Swerling were reprinted in the IRE Transactions in June 1960.

3. Ambiguity Function

This was due to P. M. Woodward, in the UK, who developed a theory of radar detection and information extraction built around what he called the ambiguity function. It allowed the radar engineer to evaluate the effectiveness of radar waveforms in terms of their accuracy, resolution, ambiguities, and clutter suppression ability.

4. Doppler Processing Theory

The classic Rand Corporation report of R. C. Emerson is describing the basic methods for MTI radar. A major task in moving target indication (MTI) radar is to obtain a time-domain filter, or its equivalent, that can separate the Doppler shifted echo signals of small moving targets from the large echoes signals produced by stationary clutter.

The 1954 report by R. C. Emerson described what must be done to achieve Doppler processing using delay line cancelers, but it was seldom that more than two delay lines could be used in the early MTI radar filters when only acoustic (analog) delay lines were available. Many more delay lines (and consequently, many more pulses) are needed for good filter operation. This became feasible with the introduction of digital technology, where the delays are obtained by storing numbers in a computer memory. One can now achieve digital transversal filters, recursive filters, and filter banks with many more degrees of freedom than was conceivable with analog technology. With digital technology, engineers now make real what were only unfulfilled dreams in the 1950s and 1960s. This report also was classified, but appeared in the open literature in 1978.

Phased array antennas

Phased array radars were employed in WWII by the British, Germans, and the US, Beam steering was in one dimension using electromechanical phase shifters. Starting in the early 1950s, there were continuing attempts to produce electronic beam steering in both azimuth and elevation, which culminated in the first successful modern phased array, the AN/FPS-85. Much can be said about the interesting history of phased array radar development and there exist a great bibliography about phased arrays. In the 1950s and 1960s, the U.S. Army, Navy, and Air Force each built and demonstrated phased array radars. These were one of a kind. The key advantages of a phased array that determine where or how it is used are its ability to (1) steer a beam rapidly so as to maintain many targets in track; (2) be hardened against nuclear blast, as in ballistic missile defence systems that encounter nuclear attack; (3) be flush mounted, as in the Israeli Phalcon airborne air-surveillance radar; and (4) allow the beam from a large antenna to be rapidly steered without mechanically moving the antenna, as in the Pave Paws ballistic missile detection radar. Advances in digital processing have been beneficial to improving the phased array. There is interest in putting the A/D converter as close to the antenna element as possible so that beam forming as well as signal processing are clone digitally.

Pulse compression

In a pulse compression radar the transmitted waveform is modulated in phase or frequency so as to increase its bandwidth. The received echo signal is processed so that the temporal resolution is determined by the reciprocal of the signal bandwidth rather than the long pulse width. Pulse compression is important in that it allows a waveform to be obtained with the energy of a long pulse but with the resolution of a short pulse without the problem of voltage breakdown that would occur if a high peak-power pulse were used. It is a necessity with solid-state transmitters that must use a high duty cycle waveform.

There are several different types of pulse compression waveforms and processing from which to chose. Without pulse compression, many important radars would have been limited in range or in range resolution.

Ultra Wideband Technology

The early radar systems and most of the nowadays conventional pulse radar systems operate in a relative narrow frequency band; they use harmonic (sinusoidal) signals as carrier oscillations to transmit the information. The resonance features of such a system make possible frequency selection of the large number of information channels operating in the common environment (space, guiding, and optical communication lines). So, the frequency selection is now the main method to divide these channels, most radars now in use are narrow band systems with frequency bands much less than the carrier frequency. The theory and practice of current radar systems are based of this specific feature. But as known, it is a frequency band that determines the information content of radar systems, as the volume of information transmitted per time unit is directly proportional to a frequency band. To rise the information capability of a radar system, the widening of its frequency band is needed.

The only alternative approach is an increase in information transmission time. With continuous increase of information streams, this problem becomes more actual both for radio communication and radars. Actuality oft this problem determined rapid development in the last years of the development using ultra wide band signals.

A definition that has come into common use is:

Ultra wide band radar is any radar whose fractional bandwidth is greater than 0.25 regardless of the centre frequency or the signal time - bandwidth product.

At present, most radar developers use precisely this definition although it does not cover all varieties of UWB systems and signals. The problem of going to UWB signals is of particular interest for radars:

The matter is that conventional radars with frequency bands no more than 15 % from the carrier frequency provide only target detection and coordinates measurement (with relatively low accuracy), but they cannot form target "portraits" or images.

Such radars are similar to a person with weak eyes, he sees an object but cannot recognize it. So, in present-days practice, many efforts are being taken to increase the information received from the object observed.

In military aviation, identification mode (friend or foe) is used; in civil aviation, they use secondary radar channels operating in interrogation - respond mode.
To rise the information content in radar data, the target recognition mode is sometimes used; using such a mode does not provide forming a target image but makes it possible to obtain additional information on the target using some target features (portrait), which we can get after special processing. Going to such a mode requires an essential increase in a radar frequency band and, as a result, new widening frequency bands and going to UWB signals help to receive more information on a target and to obtain radar target images.

The increase in radar information content with using UWB signals is the result of reduction in range pulse volume. For example, reducing a radiated pulse duration from 1 microsecond to 1nanosecond, we decrease the depth of pulse radar volume from 300 m to 30 cm. So, we can say that the instrument we use to ob-serve the space becomes finer and more sensitive.

Thanks to the reduction in pulse volume, UWB radar gets some new features:

- higher range measurement accuracy and range resolution; this leads to a rise in radar resolution along all coordinates, as target resolution along one coordinate does not require target resolution along other coordinates.

- reduction in radar "dead" zones;

- recognition of targets class and type as well as formation of target's radar image, as the received signal contains the information not only on the target as a whole but also target's separate elements;

- higher radar immunity to all passive interference, such as rain, fog, clutter, aerosols, metallized strips, and etc.; the reason for this is that interference radar cross section (RCS) in small pulse volume becomes comparable with target RCS.

- increase in radar immunity to extraneous electromagnetic radiations and noises.

- increase in target detection probability and reliable target tracking resulted from increasing target RCS.

- increase in target detection probability and target tracking reliability caused by elimination of lobe structure of targets' secondary patterns as signals scattered by separate target's elements do not interfere.

- reliability of target tracking at low elevation angles increases, that is a result of eliminating interference nulls in antenna pattern, as a signal scattered by the target and a signal re-scattered by the earth surface are time divided and can be selected.

- it is possible to change radiation parameters (pattern's width and form) by varying radiated signal parameters, among them, obtaining an ultra-narrow antenna pattern.

- increase in radar operation security.

The process of radar observation by using UWB signals differs essentially from the same process with using narrow band signals. This happens in the cases when signal space duration is less than an antenna aperture or target sizes.

Differences between UWB and narrow band radars and their specific features show themselves in practically all radar operation stages; for example, in UWB signal formation, radiation, scattering by a target, reception and processing.

Nowadays, great scientific resources are concentrated in the field of UWB technology in many leading countries. In fact, an invisible racing in the field of UWB technology has begun. The country that will be a winner will increase its information capabilities exponentially.

Radar Wish List for the future

Although one cannot reliably predict what will be in the future, one can wish for desired improvements in radar so long as they don't violate the laws of physics and they would make a difference.

A/D converters

Digital processing has already exceeded most prior expectations and will likely continue to do so. An exception, however, is the A/D converter, which hasn't always advanced as fast as other areas of digital technology.

Eliminate the need for CFAR

As digital technology improves, it is hoped that there will no longer be a need for CFAR (constant false alarm rate) processing to eliminate clutter echoes that are not rejected by Doppler processing or other processing methods.

CFAR is an unwelcome “crutch” to prevent overload of the tracking computer and it degrades radar detection and resolution.