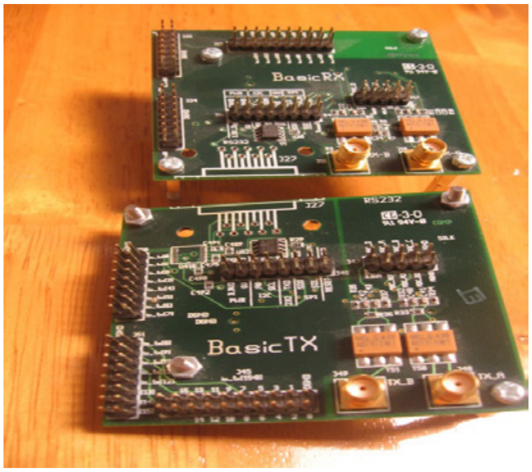
Controlling Modern Radars

To the layman, radars evoke the image of large rotating parabolic antennas bolted to a stationary structure and managed by human operators. Although such radars still exist, modern radars can be rather small, and their antennas may be electronically steered. Modern radars are typically mobile, either flying on aircraft, moving on the ground, or located aboard ships. Their outputs are exploited by algorithms as complex as those used to produce the outputs themselves. Below the surface, the changes are equally impressive, mainly brought about by advances in antenna technology and signal processing. Despite earlier isolated efforts, radar control has only attracted the interest of researchers in the past 20 years, under the headings of sensor management and sensor scheduling. The wide adoption of active electronically steered array (AESA) antennas starting in the 1970s and the conception of software-defined radio (SDR) in the 1990s bring a combination of agility and flexibility to radar systems operation and design that is only now being fully exploited.

The face of the COBRA DANE AESA in Alaska; the antenna contains 34,000 modules, each measuring 5 inches in diameter.



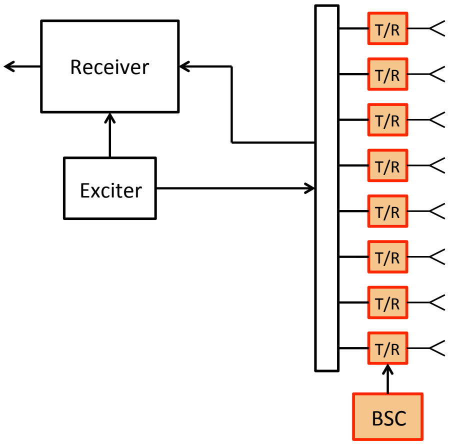
Basic transmitter and receiver daughterboards for the Universal Software Radio Peripheral (USRP)

Enabling Technology I: Software-Defined Radio

Software-defined radio is an emerging technology in which several radio frequency (RF) functions, such as mixing, filtering, and modulation/demodulation, are performed in software instead of hardware. An example of SDR is the GNU Radio project, a free and open source development toolkit providing signal processing blocks to implement SDRs.

Enabling Technology II: AESA Antennas

Active electronically steered array antennas are obtained by combining numerous miniature transmit/receive (T/R) modules placed behind each radiating element, as shown at right. The beam-steering controller (BSC) controls the phases and amplitudes of the radio waves transmitted and received by each radiating element. AESA antennas are far more agile than their mechanically steered counterparts, allowing the formation of almost arbitrary space-time configurations for the antenna beam. The ability to rapidly switch beams permits multiple radar functions to be performed, interleaved in time.



Source: George Stimson, "Introduction to Airborne Radar," SciTech Publishing, Inc., 1998; reprinted with permission.

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Modern Radars and Echolocation in Bats

Although echo feedback is only recently being used for waveform adaptation in radars, nature has it is own version of the process in the form of the echolocation systems of various species of bats.

Echolocation signals in bats are very brief sounds, varying in duration from 0.3 to 300 ms and in frequency from 12 to 200 kHz. In most species, the sounds consist of either frequency-modulated (FM) components alone or a combination of a constant-frequency component with FM components. Most species studied to date show changes in their sonar signal parameters (for example, duration, bandwidth, and repetition rate) with varying foraging conditions, such as their proximity to vegetation, water, and buildings. Sonar signal design is widely believed to reflect the bat's control over acoustic information gathered from the echoes.

Interestingly, bats may or may not be capable of multipulse, coherent processing as performed by pulse-Doppler radars. However, bats (and dolphins) are believed to produce synthetic aperture sonar images without coherent processing.

Research Challenges at the Crossroads of Signal Processing, Estimation, and Resource Management

Radar waveforms (the transmitted signals) are selected on the basis of the desired application. Fundamental uncertainty principles apply; as an example, one cannot have arbitrarily precise estimates of range and radial velocity at the same time. The faint echo reflection is processed in the receiver using advanced signal processing techniques—phase array processing—developed over the course of several decades. In most cases, however, the waveform remains unchanged for large periods of time (i.e., the transmitter/receiver system operates in open loop).

The advent of SDR systems enabled programmability of the waveform generator and opened the possibility of closing the feedback loop in modern radars. Some of the theoretical underpinnings for echo feedback were established in the early 1990s, but much work still needs to be done on the theoretical front:

- Fundamental performance bounds of the Cramér-Rao type need to be established for radar systems in the presence of echo feedback;
- Coding, coherent processing, and waveform adaptation need to be brought together within a unified framework;
- Mechanisms for real-time, pulse-to-pulse interleaving of adapted waveforms need to be developed. Multiple-input, multiple-output (MIMO) radars and radar networks make the problem even more formidable as the multiple transmitter/receiver pairs need to operate in coordination.

As the ultimate challenge, consider a network of unmanned aerial vehicles (UAVs), each carrying a radar capable of waveform adaptation. To complete a surveillance mission successfully, the UAV ensemble needs to coordinate its radar operation. At the same time, the UAVs exchange information about the environment, providing yet another input to the control loop. The radar controllers must optimally combine their native echo reflections with the inputs from the other UAVs to produce their transmission schedules.

For more information: S. Haykin, Cognitive radar—a way of the future, IEEE Signal Processing Magazine, January 2006; F. Gini and M. Rangaswamy (eds.), Knowledge Based Radar Detection, Tracking and Classification, John Wiley & Sons, Inc., 2008.