Tour through one type of space-flight tracking system.

THE DIYARBAKIR RADAR

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In September of 1938 five British radar stations which had just been set up to cover the approaches to the Thames estuary were able to monitor Mr. Chamberlain's historic flight to Munich. These stations were the first of an extended network that was soon maintaining twenty-four-hour radar surveillance of the English coast. With this act the art of war entered a new technological stage, and intelligence acquired a new instrument for data gathering. Today collectors of scientific and technical intelligence use radar for gathering denied information on missile and space activities, as well as aerodynamic developments, which is necessary for the analysis of opposing weapon systems.

Today's radar is much more powerful and more complex than that of 1938, but its operation is not beyond lay understanding. The analyst, though he will probably never be called upon to operate a radar system, will find his appreciation of and confidence in the data produced by these systems increased by an acquaintance with how they work. Here we describe a ground-based radar at Diyarbakir, in eastern Turkey, which is not unlike other radar systems currently deployed to satisfy S&T intelligence collection requirements.

The first installation (designated AN/FPS-17, XW-1) at Diyarbakir was originally intended to provide mere surveillance of the USSR's missile test range at Kapustin Yar south of Stalingrad—that is to detect missile launchings. The data it came to produce, however, transcend surveillance, permitting the derivation of missile trajectories, the identification of earth satellite launches, the calculation of a satellite's ephemeris (position and orbit), and the synthesis of booster rocket performance. The success achieved by this fixed-beam radar has led to the co-location with it of a tracking radar (AN/FPS-79) which, beginning in mid-1964, has given an additional capability for estimating the configuration and dimensions of satellites or missiles and observing the reentry of manned or unmanned vehicles. This article, however, will confine its attention to the fixed-beam AN/FPS-17.

Genesis

Experimentation with the detection of missiles by a modified SCR 270 radar in 1948 and 1949 at Holloman Air Force Base, along with U.S. experience in the use of high-power components on other radars, created a basis for believing that a megawatt-rated radar could be fabricated for operation over much longer ranges than ever before. The need for intelligence on Soviet missile activity being acute, a formal requirement for such a radar was established, and Rome Air Development Center was given responsibility for engineering the system. In October 1954 General Electric, which had experience in producing high-power VHF equipment and radars, was awarded a contract for the fabrication, installation, and testing of what was to be at the time the world's largest and most powerful operational radar. The contract stipulated that the equipment was to be in operation at Site IX near Diyarbakir within nine months, by 1 June 1955. Construction began in February, and the scheduled operational date was missed by fifteen minutes.

The original antenna installation was a large D.S. Kennedy parabolic reflector, 175 feet high by 110 feet wide, radiating in the frequency range 175 to 215 megacycles. Standard GE high-power television transmitters, modified for pulse operation, were used at the beginning. Surveillance was carried out by six horizontal beams over the Kapustin Yar area. In 1958 a second antenna, 150 feet high by 300 feet long, and new 1.2-megawatt transmitters were installed as part of a modification kit which provided three additional horizontal beams, a seven-beam vertical fan, and greater range capability. The elaborated system includes automatic alarm circuitry, range-finding circuitry, and data-processing equipment; it is equipped to make 35-mm photographic recordings of all signals received. A preliminary reduction of data is accomplished on-site, but the final processing is done in the Foreign Technology Division at Wright-Patterson.

From 15 June 1955, when the first Soviet missile was detected, to 1 March 1964, 508 incidents (sightings) were reported, 147 of them during the last two years of the period.

Operation

The system has eight separate radar sets or channels, each with its own exciter, transmitter, duplexer, receiver, and data display unit. These eight channels feed electromagnetic energy into sixteen fixed beams formed by the two antennas, each channel, or transmitter-receiver combination, being time-shared between two beams. Pneumatically driven switches operate on a three-second cycle to power each beam alternately for 1.5 seconds. There are antenna feeds for two additional beams which could be made to function with some patchwork in the wiring.

The antenna feeds are positioned to produce in space the beam pattern depicted in Figure 1. Beams 1 and 18 are those not ordinarily energized. Beams 1 through 7 use the older of the two antennas; 8 through 18 are formed by the newer, "cinerama" antenna, whose 300-foot width gives them their narrow horizontal dimension. Beams 2 through 9 are projected in horizontal array; 10 through 17 (although 10 actually lies in the horizontal row) are grouped as the vertical component. All beams of each group are powered simultaneously.

Except for being controlled by a master timing signal, each of the eight channels operates independently of the others. Each trans-

BEAM PATTERN

AN/FPS 17 (XW-1)

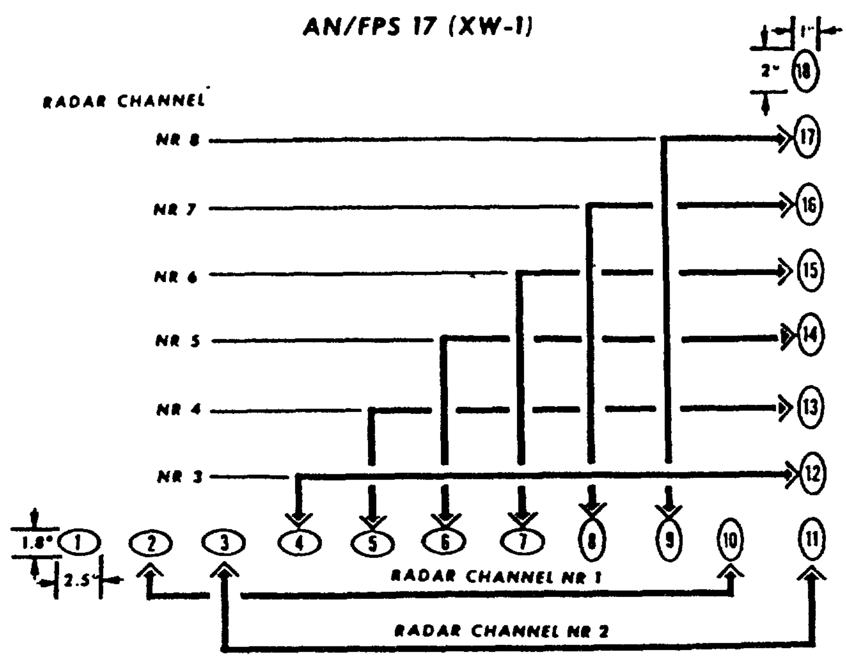

FIGURE 1

39

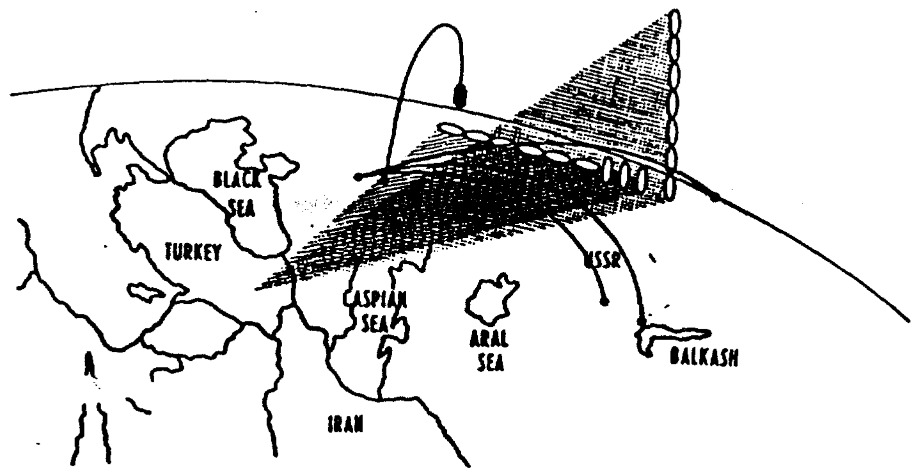

FIGURE 2

mitter is on a slightly different frequency to prevent interaction with the others. The transmitted pulse, 2000 microseconds long, is coded, or tagged, by being passed through a tapped delay line which may reverse the phase at 20-microsecond intervals. Upon reception the returned signal is passed through the same tapped delay line and compressed[1] 100:1, to 20 microseconds, in order to increase the accuracy and resolution of the range measurement, which is of course a function of the interval between transmission and return.

Figure 2 shows the beam pattern superimposed on the target area. The total azimuthal coverage is from 18° to 49.7°. The system normally detects missiles or satellites launched from Kapustin Yar at a nominal range of 800 nautical miles; it tracks one type of missile out as far as 1625 NM. The missiles and satellites are not sensed at their maximum detectable range because the coverage of the fixed-beam configuration does not conform with the test range layout.

[1] A delay line is what it sounds like, an artificial transmission detour that serves to retard the signal. Here it is made up with series inductances and parallel capacitances that yield a constant delay. Pick-off points at 20-microsecond intervals permit these sub-pulses to be extracted in such sequence that they all arrive together, to achieve the compression effect.

The electrical characteristics of each of the channels can be recapped as follows:

Frequency	175–215 megacycles
Peak power per beam	1.2 megawatts
Pulse length	2000 microseconds
Pulse repetition rate	30 cycles per second
Duty cycle (portion of time transmitting)	0.06
Beam width (horizontally elongated)	2.5° x 1.8°
Beam width (vertically elongated)	1° x 2°
Pulse compression ratio	100:1
Range accuracy	within 5 nautical miles

To illustrate how the capability of the system is calculated, we can take typical logs which show channel 4, for example, operating with the following parameters:

Peak power output	1.0 megawatt
Minimum discernible signal	130 decibels below one milliwatt
Frequency	192 megacycles

Channel 4's maximum range of intercept capability for a target one square meter in cross section is then determined by using these parameters in the radar range equation

$$R=\left(\frac{P_t\ G^2\ \lambda^2\ A}{(4\pi)^3\ S}\right)^{1/4}$$

where:

R=Range in meters
P_t=Peak power transmitted in watts
G=Antenna gain over isotropic (omnidirectional) radiator
λ=Wave length in meters
S=Minimum discernible signal in watts
A=Target size in square meters

Substituting,

$$R^4=\frac{10^6\text{ watts }(5000)^2\ (1.56\text{m})^2\ 1\text{m}^2}{(12.57)^3\ (1\cdot 10)^{-16}\text{ watts}}$$

and

Range=2250 nautical miles.

Sightings made by the fixed-beam system include vertical firings (for upper-atmosphere research vehicles or booster checkout), ballistic missiles fired to the nominal 650, 1050, and 2000 NM impact areas, launches of Cosmos satellites, orbiting satellites, and natural abnormalities such as ionospheric disturbances or aurora.

Measurements and Processing

Data on target missiles or satellites are recorded in each radar channel by photographing a five-inch intensity-modulated oscilloscope with the camera shutter open on a 35-mm film moving approximately five inches per minute. The range of an individual target is represented by its location across the width of the film, the time by a dot-dash code along the length. In addition to this positional information, the target's approximate radial velocity (velocity in the direction of observation) is determined by measuring the doppler frequency shift in the radar signal when it is returned. The doppler shift is found to within 500 cycles by determining which of eighteen frequency filters covering successive bands 500 cycles per second wide will pass the return signal. This measurement of radial velocity runs from —4 to +4 nautical miles per second in increments of .219 NM. All these data, together with the elevation and azimuth of the observing beam, are automatically converted to serial form, encoded in standard teletype code, and punched on paper tape for teletype transmission.

Data is thus received at Wright-Patterson first by teletype and then on film, the latter accompanied by logs giving data on the target as read by site personnel and data on equipment performance such as peak transmitted power, frequency, and receiver sensitivity. The film when it arrives is edited and marked to facilitate reading on the "Oscar" (preliminary processing) equipment. Targets are sorted one from another by differences in range and rate of range change, and the returns on each are numbered in time sequence.

The FTD Oscar equipment consists of a film reader which gives time and range data in analog form, a converter unit which changes them to digital form, and an IBM printing cardpunch which receives the digital data. The Oscar equipment and human operator thus generate a deck of IBM cards for computer processing which contains the history of each target's position through time. The first step in the computer processing is to translate Oscar units into actual radar range, "Z" (Greenwich mean) time, and beam number, the latter fixing the azimuth and elevation of the return. During this first step three separate quality-control checks are made on each IBM card to eliminate erroneous data.

Those observations that succeed in passing all these tests are taken to the second step of computer processing, the fitting of a second-degree polynomial curve to the raw range/time data in accordance with the criterion of least squares.[2] A standard deviation from this curve is established, and any raw datum point showing a deviation as large as three times the standard is discarded. Then second-degree curves are similarly fitted to the azimuth/time and elevation/time data. The three second-degree polynomials—for range/time, azimuth/time, and elevation/time—are used to generate a value for position and velocity at mean time of observation, and on the basis of these values an initial estimate of the elliptical trajectory is made.

In computing the elliptical path the earth is physically considered a rotating homogeneous sphere and geometrically considered an ellipsoid—that is, its equatorial bulge is ignored in the gravitational computation but not with respect to intersections of its surface. An ellipse not intersecting the earth's surface represents a satellite orbit; one intersecting the earth's surface describes a trajectory above the point of intersection.

The parameters of the ellipse are iterated with the computer, establishing a best-fit ellipse constrained by a weighted least-squares criterion. Along this ellipse the target's track is computed—the history through time of latitude, longitude, altitude, and such velocity and angular parameters as may be of interest. A missile's actual range is probably shorter than that of its computed trajectory because of its non-elliptical thrusting path and atmospheric drag after its reentry. The difference is on the order of 10 to 25 nautical miles for short and medium range missiles, 50 NM for ICBM's.

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[2] Under which a mathematical function is judged to be the one best approximating a series of observations if the sum of squares of its residuals (deviations from the raw data) is least. If there is systematic irregularity in the reliability of the data the residuals are weighted accordingly.