Precision measurement of the operating parameters of uncooperating radars.

QUALITY ELINT

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Most of electronic intelligence is devoted to the intercept and analysis of radar signals in order to locate radar sites and establish the general characteristics of radar systems. This type of Elint, usually called "radar order of battle," has proved to be of great value in the Viet Nam air war, where the U.S. Air Force and Navy both conduct large-scale Elint operations in support of air strike missions.

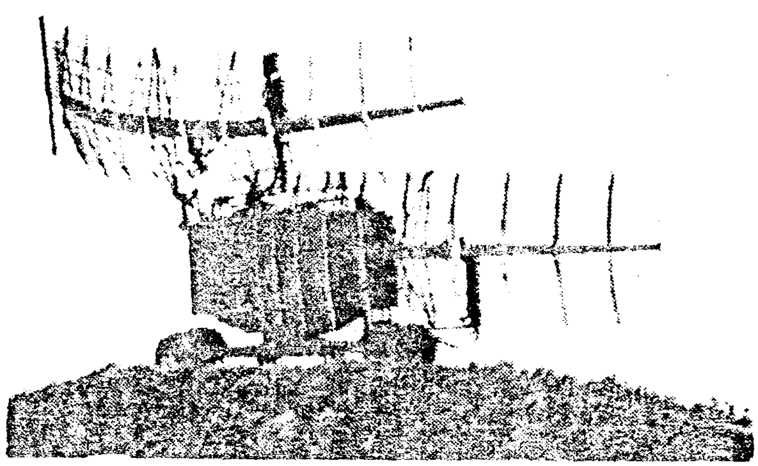
Another category of Elint receiving wide recognition in the intelligence community is called "precision parameter measurements." This technique involves either the measurement of radar signal characteristics to a very high order of accuracy or measurements to determine something about a radar's operation that will reveal its detection and tracking capabilities. Of greatest importance are measurements which will reveal a radar's vulnerability to electronic countermeasures.

As advanced radar systems with complex modes of operation have been evolved to achieve greater range, accuracy, and immunity to countermeasures, electronics intelligence groups are being pressed harder and harder to develop equipment and techniques for meaningful measurements of their parameters. Rather large-scale research programs are being carried out to develop special receiving and recording systems, and these often incorporate electronic computers to process the vast quantity of information bits in a typical radar signal. Studies of technical and operational feasibility are also undertaken to devise methods of deploying these systems in collection operations.

In 1962-63 the CIA Office of Elint expanded its program of precision measurements to determine the vulnerability of reconnaissance vehicles and to develop equipment for electronic countermeasures. This program has been highly successful in a variety of projects, developing a number of new approaches to the collection of electronic intelligence. One of the most interesting of these is the technique for accurately measuring the radiated power of an operating radar and describing the fine-grain structure of the radiation pattern. A simplified review of this power-pattern technique, although it represents only one facet of the precision measurements program, should give some insight into the technical and operational problems encountered and some idea of the accomplishments of the program.

Power Measurements 1957-1967

The first serious attempt to measure the radiated power of a radar for intelligence purposes was made by CIA in 1958 on the Soviet early-warning radar known as Bar Lock. The Bar Lock was a new version of the Soviet multi-beam S-band[1] family of radars which had undergone a rapid and widespread deployment in East Germany and other areas peripheral to the USSR. Intelligence indicated this new radar was deployed to detect and track the U-2 aircraft which were just beginning to make deep penetrations over the Soviet Union.



The Bar Lock Radar

Estimates of the Bar Lock's radiated power output, based largely upon photographic evidence, ranged as high as 5 megawatts peak pulse power from each of its 5 transmitters. With 5 megawatts in each beam the Bar Lock would have had ten times the power of previous similar radars and would have significantly improved the

[1] 2 to 4 GHz, or 2,000 to 4,000 megacycles per second.

detection and tracking capabilities of the Soviet air defense system. To meet this threat to the U-2, those responsible for the reconnaissance program demanded firmer information on the Bar Lock's power output and radiation pattern coverage.

A laboratory that provided scientific back-up to the U-2 program assembled power-measurement equipment, crude by present-day standards, and installed it in a C-119 aircraft. With little advance testing, a series of flights was made through the air corridors to Berlin, where Bar Lock signals were easily intercepted. The resulting power measurements at various vertical angles in the antenna pattern were not of high accuracy because of uncontrolled errors in the equipment. The data did indicate, however, somewhat less than one megawatt of peak power for each Bar Lock transmitter, and this was later confirmed by other sources. Although not entirely successful in power measurement, this project suggested solutions to many technical problems and opened the way for follow-on developments.

In 1963 a contract was let with a major electronics laboratory for research on the technical problems of precision power-pattern measurement and for the development of measuring equipment. Before the end of the year a prototype system was flown against the acquisition radar for a U.S. Nike Ajax and produced good results. At the same time the procedures to be used in overseas deployment were being simulated and studied, and a special laboratory was set up to process and analyze the unique data to be collected. The first two overseas deployments took place in 1963 against the Soviets' Tall King radar in the Far East and Fan Song in Europe, and both were successful. The appended Table lists the projects that followed, producing precision data on the majority of the radar types used in the Soviet, Chinese, and North Vietnamese air defense systems.

Antenna Pattern Measurements

The total radio frequency power fed to a radar antenna is essentially determined by the type of output tube used in the transmitter, the characteristics of the pulse train, and the losses by attenuation in the system. The function of the antenna is to concentrate this power in the desired direction, and its ability to do so is called *gain*. The relative distribution of the energy in all directions is called the antenna radiation pattern, generally consisting of a main beam plus side and back lobes. This antenna pattern and the level of power radiated are critical parameters in establishing the performance of the radar. These parameters are priority requirements for intelligence and ECM purposes.

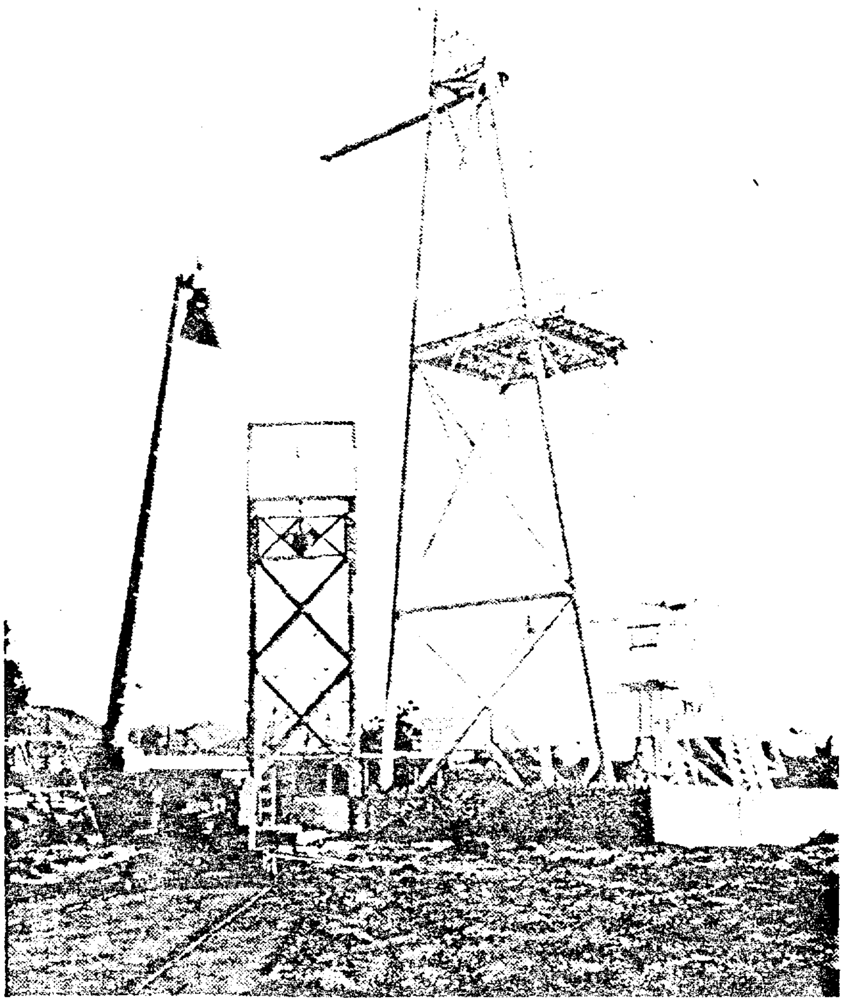
The accurate and comprehensive measurement of a radar antenna pattern is a tedious process even for the designer. Test ranges with elaborate instrumentation are necessary to insure that the finished antenna has a beam of the desired shape and that the side and back lobes are properly suppressed. Moreover, the patterns seen on the test ranges are not always maintained in operational use, because environmental and ground effects at the site can make significant changes in the pattern.

The objectives of Elint power-pattern measurements are to obtain precise data on the maximum beam power, the total radiated power, the antenna gain, and variation in gain (side and back lobe distribution) around the antenna. This requires the use of an airborne measuring platform to avoid ground effects and to make measurements at various angles of elevation. In theory, the Elint approach is the same as that used on the antenna test range; the power density is measured and then converted to radiated power on the basis of the known geometric relationship between the radar antenna and the measurement system. In practice, the Elint operation has all of the problems encountered on the test range plus additional ones intrinsic to intelligence collection; the target radars are non-cooperative and may not radiate at the time and in the direction desired; all of the instrumentation to measure power density and locate the aircraft's position must be carried in the aircraft. These handicaps increase the number of potential sources of error which must be eliminated, minimized, or calibrated.

The primary sources of error for power density measurements lie in uncertainties in the gain of the receiving antenna, losses in the transmission line, characteristics of the receiver, and the sources used for calibration. Errors in the geometric data may be associated with the position, altitude, and attitude of the aircraft, the location of the target, atmospheric conditions, or ground effects.

Special Equipment

The design of the measuring equipment is centered upon the need for very accurate measurement of individual pulse amplitude and the use of calibration signals from laboratory standard power meters.



Test range for antenna design. The verticle boom on the left holds the mock-up nose section of a C-97 aircraft.

During collection operations provision is made for the accurate calibration of the receiving antennas, the transmission lines, and the receiving and recording systems with respect to attenuation losses or other errors which may degrade the data. A description of the laboratory-type receiving equipment, calibration sources, and data encoders would be comprehensible only to electronic specialists. A brief discussion of antenna problems, however, should give some idea of the development work behind power-pattern measurement systems.

The pattern of the receiving antenna is critical because the angle at which the energy arrives is constantly changed by the movement of the aircraft, including its roll, pitch, and yaw. In order that the precise gain of the receiving antenna may be known and used in the calculations for absolute power, it is highly desirable to have smooth

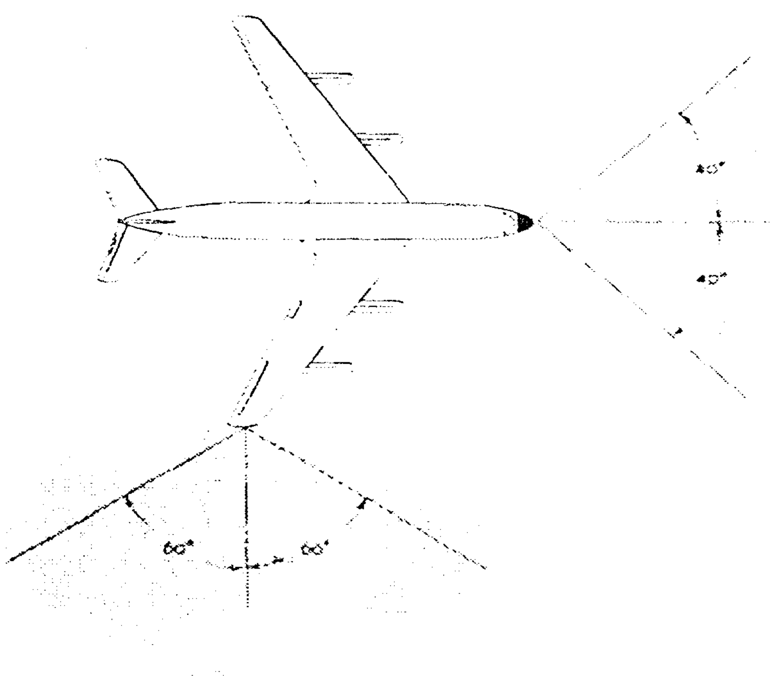


Figure 1. Typical omnidirectional patterns possible from aircraft-mounted antennas (above 1,000 MHz.)

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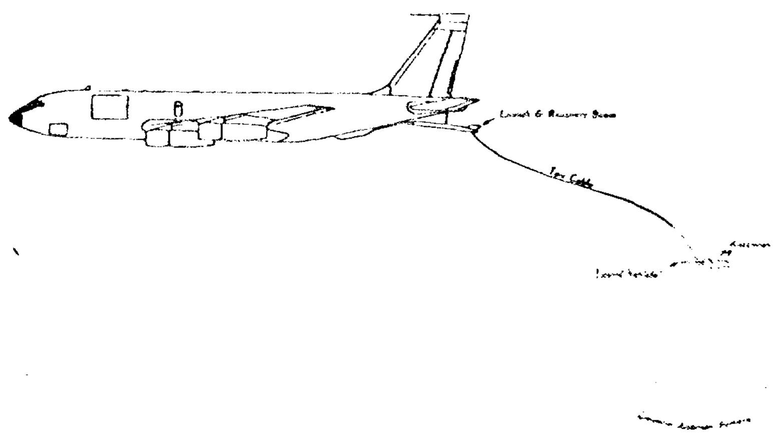

Figure 2. The towed, antenna-carrying vehicle used for power-pattern measurements below 1,000 MHz. The RC-135 aircraft has a special A-frame boom structure for launching and recovering the vehicle in flight. The specially developed towing cable serves as the RF transmission line between the antenna and the receiving system in the aircraft. It also carries the electric cable to control the vehicle from the aircraft.

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omni-directional receiving patterns, with equal gain over a wide sector. Airborne omni-antenna patterns are difficult to achieve because of interference from the aircraft structure, whose complex shape breaks the pattern into sharp peaks and deep nulls. A special test range was established for this program to find interference-free locations on aircraft surfaces which would yield patterns with smooth contours. Mockups of complete aircraft nose sections and wingtips were tested and in some cases new antenna elements were developed.

When the desired patterns were obtained the antenna elements were carefully transferred from the mockups to the real aircraft. Even with these meticulous efforts good patterns could be developed only for the higher frequencies and only off the nose and wingtips of certain aircraft, as shown in Figure 1. This limitation has often been a handicap in collection operations.

In the radio frequencies below 1,000 MHz, where some important Soviet radars operate, it proved impossible to produce good patterns from antennas mounted on the aircraft. To solve the problem at these frequencies a new phase of research was begun—the development of aerodynamic antenna-carrying vehicles to be towed behind the aircraft. Antennas mounted in these vehicles could be designed to produce a smooth cardioid pattern with the one sharp null pointed toward the towing aircraft. This null eliminates interference from the aircraft, leaving patterns that are ideal for power measurements. Although the towing of the antenna greatly increases the complexity of the system, it has proved to be a good technical solution to the receiving pattern problem at the lower radio frequencies. A typical configuration is shown in Figure 2.

The collected data consist of measurements of pulse amplitude taken from different portions of the radiation pattern as the radar antenna rotates, or scans, and the aircraft moves through the pattern. Measurements are recorded digitally, reduced, and read out on continuous-chart paper rolls which display the varying amplitudes making up the pattern. The chart paper format is of sufficient accuracy to allow antenna specialists to make direct measurements from the display. Successive scan patterns together with geometric and other calibration data, as shown in Figure 3, are processed by computer to make up three-dimensional radiation patterns.

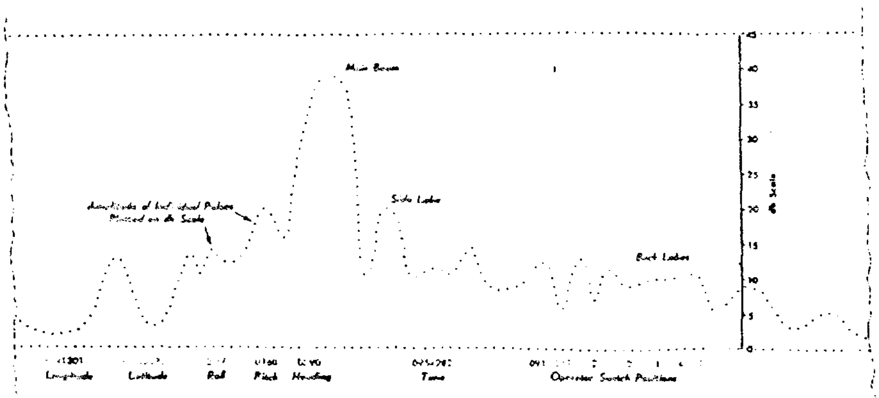

Figure 3. An example of the chart paper roll readout of the antenna pattern data.

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Collection Operations

Ideally the flight path for power-pattern measurement is a radial path from the horizon to directly over the radar site. If the radar antenna is making 360-degree scan rotations the radial flight will yield continuous measurements around it at increasing angles of elevation. This provides data from which the complete three-dimensional radiation pattern can be described. Such flight paths, of course, are not often possible; sometimes the data are limited to elevations of 15 degrees or less. Fortunately, the lower angles of a radar pattern are of greatest importance for intelligence; that is where target detection and tracking begin.

Each of the deployments shown in the Table was the result of months of preparation, which included calibration and installation of the equipment, detailed planning of the mission, operator training, and the coordination of a multitude of technical and operational matters. The radar types were selected on the basis of intelligence priority and the particular target sites on the basis of air access, with preference to isolated areas where other radars would not offer interference. The location of the site was known beforehand; the target signals were identified by direction-finding equipment which was part of the airborne system. During collection runs the aircraft's position and attitude were recorded by special navigational instruments so that the exact geometric relationships between the radar and the measurement system would be known. Several of the projects were completed in fewer than six missions; others required more than 40 to get the desired results.

The power-pattern measurement program has been carried out with the full cooperation of U.S. Air Force organizations, which have furnished the aircraft and crews and have also given the extensive support required for airborne reconnaissance operations. The flight missions have been conducted for the most part within the framework of world-wide peripheral reconnaissance programs carried out by the Strategic Air Command and other USAF elements. Exceptions to established flight restrictions and security rules have been necessary on only a few occasions.

As of this writing the most recent deployment was that listed as Project See Top, in which a C-97 aircraft flew over the Gulf of Tonkin to make measurements of the SA-2 Fan Song radar during U.S. air strikes in the Haiphong-Hanoi area. The antenna patterns recorded were used in the development of guidance systems for new anti-radiation missiles designed to home on and destroy target radars.

Table

Power/Pattern Measurement Projects

Project Code Name	Deployment Dates	Aircraft Used	Target Radar	Frequency Band	Location	STR No.
Field Day	Jul–Sep '63	C–97	Fan Song	S, C	Cuba, E. Germany	1–65
New Breed I	Jul–Aug '63	RB–47H	Tall King	VHF	Sakhalin	2–65
New Breed II	Jul–Aug '63	RB–47H	Spoon Rest A Knife Rest B	VHF VHF	Sea of Japan.	
Iron Lung	Oct '63	RB–47H	Spoon Rest A	VHF	Cuba	4–65
New Breed III	Sep–Oct '63	RB–47H	Tall King Spoon Rest A	VHF VHF	Arctic above USSR	2–65
New Breed IV	Jan '64	RB–47H	Spoon Rest A Knife Rest B	VHF VHF	Arctic above USSR	2–65
Winesap I	May–Sep '64	C–97	BG07/BG06 Fan Song A, B, C, E	S, C	E. Germany	—
Iron Lung I	Jan–Sep '64	RB–47H	SCR–270 BKEH, KNB BK08, BKDQ Tall King	VHF	Yellow and East China Sea.	5–65
Iron Lung II	Feb–May '65	RB–47H	BK08, BKEN SCR–270 Knife Rest B Spoon Rest A & B Tall King	VHF	Yellow and East China Sea.	8–65

Table (*Continued*)

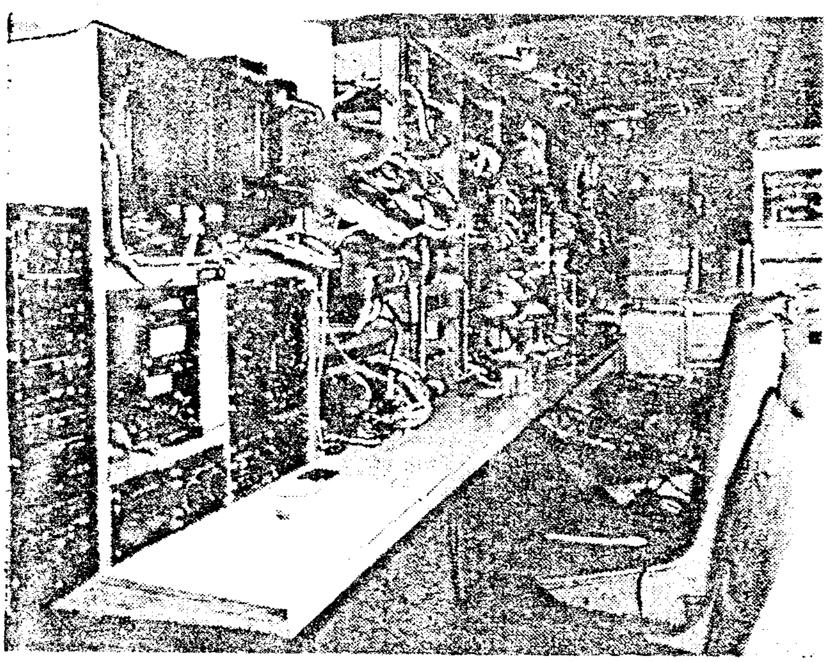
Project Code Name	Deployment Dates	Aircraft Used	Target Radar	Frequency Band	Location	STR No.
Winesap II	Jun–Aug '65	C-97	Flat Face	L	E. Germany	2–66
Lead Off	Aug–Sep '65	RB-47H	Back Net	S	Black Sea	1–66
High Pitch	Jan–Mar '66	RB-47H	Bar Lock Big Mesh Token	S	Sea of Japan Yellow and East China Sea.	4–66
Low Pitch	Sep '66	RB-47H	Bar Lock Big Mesh Fan Song	S	Cuba	—
Cross Field	May–Oct '66	C-97	Fan Song C & E	C	E. Germany	5–66
Top Hat	....	C-97	Bar Lock Big Mesh Fan Song Side Net	S	E. Germany	7–66
Briar Patch	....	C-135	Hen House	VHF	Barents Sea	—
See Top	....	C-97	Fan Song	S	Gulf of Tonkin	4–67

SECRET

A series of reports on the power-pattern measurements have been disseminated throughout the intelligence community, where the accuracy and significance of the data have been widely accepted.

Present Capabilities

The Office of Elint power-pattern measurements are unique; there is no other comparable program in the U.S. intelligence community or in the Elint organizations of allied countries. Even the radar design and development laboratories have as yet produced no similar self-contained airborne measurement systems. Because of these unique capabilities, the USAF Air Proving Grounds Command and other groups have several times arranged for the use of the OEL system to compare the patterns of simulated Soviet radars with those of the real ones operating in the USSR.



Airborne instrumentation required for power-pattern measurement

As each project was carried out, improvements were made in the instrumentation to enhance the system's accuracy and the convenience of its use. Now, instead of re-engineering the equipment for each new project as was required in the early days, the use of adaptable equipment is being emphasized. Receivers and recording equipment are now available, along with the associated antenna configurations and modified aircraft, for quick-reaction deployment against any radar in the normally used frequency bands. Additional instrumentation is being incorporated for the precision measurement of other parameters in the signals, such as radio frequency coherency, intra-pulse modulation, and pulse train characteristics.