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AIR SURVEILLANCE RADAR ANTENNA PERFORMANCE MANAGEMENT AT HUNGAROCONTROL

This paper highlights the potential of the antenna performance check, based on the findings of the first and the second Radar Antenna Performance Check test results on four Air Traffic Control radars operated by HungaroControl. This knowledge is important, because antennas and their RADOMEs suffer from ageing, weather conditions, and lightning, scheduled/unscheduled maintenance activities and in some extreme cases, partial upgrades. The graceful degradation of the antenna performance can reach the limit where certain operational conditions may result in catastrophic failures in cases where Built-In Test Equipment (BITE) diagnostics do not cover the antenna. Consequently, the antenna performance has to be checked on a regular basis with special tools.

Keywords: *in situ, near field, far field, antenna performance test, Air Traffic Control*

BACKGROUND

HungaroControl (HC) Mission Statement is “Providing a safe and reliable air navigation service with efficient, environment orientated and transparent operation in our airspace.”

The NSPA Communications, Air and Missile Defence Programme mission is “Provide responsive, effective and cost-efficient “Cradle to grave” project approach. This includes Air and Missile Defence Systems development, acquisition, In-Service support and services such as Radar Engineering, RADAR System Performance Check (R-SPC), Calibration Services, Interactive Electronics Technical Manuals (IETM), and Integrated Logistics Support Solutions.”

The Radar System Performance Check is a periodic measurement of key radar system parameters aimed at maintaining a high standard of performance for modern radar systems after commissioning. The main goals of R-SPC are:

1. Detect system degradation and hidden problems early to avoid catastrophic and costly failures;
2. Support site technical staff in achieving and maintaining high standards of system performance;
3. R-SPC links a series of complex engineering tests, beyond the capability of System BITE utilizing a combination of extensive NSPA radar engineering expertise and specialized test equipment.

NSPA benefits from exclusive radar antenna performance test capabilities due to more than 20 years of R-SPC activities, and has built up experience and related databases [1]. Emerging customer requirements resulted in a need for a major R-SPC test equipment upgrade in the field of antenna measurements in-situ. The new test principles are inspired by the methods used in the industry for antenna testing and qualification (space, telecom, radar) in dedicated test chamber and bulk equipment. NSPA specificities are the compact equipment's, test conducted in situ and implementation acknowledged by scientific IEEE committees.

WHAT IS THE PURPOSE OF THE ANTENNA MEASUREMENTS IN-SITU?

The purpose of this test is to extract the MSSR uplink and downlink horizontal patterns. It is required for verification of the antenna performance, as BITE scope does not usually include the antenna. Specialized requirements are as following:

- Collecting antenna diagrams at any location;
- Failure analysis support;
- Measurements with full transmit power;
- Radar downtime suppression by validated antenna performance checks;
- Reduce cost of the radar maintenance and support.

The traditional method, hereby referred to as Far Field (FF), the MSSR antenna transmit horizontal pattern is measured with the use of a transmitter/receiver device called Radar Field Analyser (RFA), which is operated at a known remote location at least 500 meters away from the radar in the FF region of the antenna. This test requires two engineers, one at the radar and one at the remote position, with established voice communication. The remote position must be within the elevation coverage of the radar in the Far Field and at the same time close enough to attain the required signal strength. Fig.1 shows a remote position of an HC radar site. Weather conditions must be suitable for calibrating measurements such as rain, snow, strong wind is excluded. [2] The advantages of the FF method are:

- Simple in realization (amplitude measurement only);
- Direct overview of the Azimuth Antenna Pattern by recording of Tx/Rx pulses as a function of azimuth.

The shortcomings of the FF method are:

- Highly influenced by environmental driven effects, such as multipath and reflections;
- Lack of flexibility for the elevation angle related measurements.



Fig.1 Remote Position set up [9]

Pass / Fail Criteria of the tests and report format table with systems specific information:

- Beamwidth is within $A1 \pm 10\%$;
- Monopulse lobes are symmetric;
- Amplitude: ± 1 dB;
- Sum Channel peak and Delta channel notch aligned within: ± 0.1 degrees;
- Sidelobe levels are less than A2;
- SLB/RSL/ Omni channel covers sidelobes.

Parameters	Specified	MSSRx-NF Nov 2014	MSSRx-FF Nov 2014	MSSRx-NF May 2017	MSSRx-FF May 2017
SUM Channel -3 dB beamwidth [deg]	A1 ± 0.25	2.6	2.6	2.5	2.6
SUM Channel Azimuth Side Lobes [dB]	≤ -A2	-22.6*	-24.7	-24.8**	-25
DELTA Channel Difference peak amplitude[dB]	≤ 1	0.42	--	0.2	--
DELTA Channel Azimuth Side Lobes [dB]	≤ -A3	-22.5*	--	-21.5**	--
SUM/DELTA crossover level [dB]	-2.5 ± 0.5	-2.8	--	-2.78	--
SUM/OMNI(RSLs) crossover level [dB]	16.0–22.0	14–16.8**	--	13.35*	18.3
OMNI (RSLs) field strength compare to SUM Side Lobes [dB]	> 4	8.2	--	12	10

Note: NF – Near Field measurement; FF – Far Field Measurement

*Note: No RF probe compensation applied

**Note: Due to pattern unbalance

Table 1. Report format table with systems specific information of the CNF as example

Input data requirements for receive patterns test:

- PRF-Pulse Repetition Frequency, radar timing & beam pointing used by radar control program;
- Receiver Calibration data files (acquired from test Rx Calibration);
- Signal Source in Far Field.

An alternative method is the Circular Near Field method, hereby referred to as CNF. The objectives of the tests for a given antenna (array) are to determine **individual element** characteristics and defects (Amplitude, Phase) from measurements of the **global radiation performance**. The CNF method uses a computer controlled 4 Channel Vector Network Analyser (4ChVNA) device in the measurement setup shown in Fig.2.

In 2013, NSPA engineering developed the Technical Specifications and contract development requirements for the delivery of a 4ChVNA device capable for in situ calibrated measurements of the harsh environment condition from -10 to 50 °C. A Hungarian Company won the International Competitive Bidding and one year later, the new Vector Network Analyser was ready for site acceptance. See details in [3]. TAR1 antenna operates at the Liszt Ferenc airport in open-air condition for more than 20 years indicated some degradation observed by the local radar maintenance team, which required deeper investigation of the antenna pattern related uncertainties. The HC radar support team recognised the potential of the new antenna test methods in the field of improved HC maintained radar support and allowed to test TAR1 radar antenna performances with the new 4ChVNA device. This activity has grown to the permanent fruitful cooperation between HungaroControl and NSPA-LD.

The 4ChVNA device performs parallel RF sampling to measure the amplitude and phase distribution in the Near Field as the antenna rotates. A probe antenna (RF sensor – for transmitting or receiving the test signals) is mounted a few meters away from the Antenna Under Test (AUT) at the lower part of the vertical beam of the MSSR antenna pattern. 4ChVNA generated test signals are received by the AUT and are fed back to it to produce the Amplitude and Phase distribution as a function of azimuth. The amplitude resolution is required

to be better than 0.001 dB and the phase resolution better than 0.001 degree. The collected phase and amplitude data consist of more than 600 measurement samples per one antenna rotation and it is optimized for Nyquist sampling [4]. Then the data is used by a NSPA developed MATLAB program to produce the Far Field antenna pattern. The algorithm used by the program, microwave circular holography algorithm called Back Projection, is based mainly on Circular Waves Spectrum theory. It uses Hankel functions and Kalman filters with related components of the wave vectors, while the hologram transforms the Planar Wave Spectrum to the antenna surface. The hologram depicts exact amplitude and phase distribution of the antenna elements' excitation [5][6][7]. A Kalman filter with smoothing coefficients and variable thresholds is applied, related to curves in the amplitude and phase distribution holograms figures, to support failure analyses of the phased array. By taking into account the exact physical dimensions of the measured antenna, the individual element performance can be examined and localized identification of defects/degradation can be achieved. The CNF method can help in troubleshooting the in-service phased array antennas.

OVERVIEW OF HUNGAROCONTROL RADAR ANTENNA PERFORMANCE CHECKS

The operational frequencies of the TAR1 and TAR2 radars at Liszt Ferenc airport were interfered with heavily by local users. The side effects of this interference were minimized by covering the RF sensor surface with a special absorber material, with a hole pointing in the direction of the AUT. Furthermore, based on the lessons learned during the first campaign, the digital filtering method of the unwanted signals has improved. The CNF test performed at frequencies 1030, 1060 and 1090 MHz consecutively, while the FF test performed only at 1030 and 1090 MHz. The uplink and the downlink frequencies used only for test set up and fault finding confirmation. The near field and far field results were evaluated separately, and the findings compared with each other.

Measurement data have been collected and analysed for Channel A and Channel B of the MSSR. All differences of the results could be observed between the two channels should be within the measurement tolerances.

Experience of the NSPA engineers points that the antenna pattern degradation could be caused by lack of proper RADOME maintenance. The main sources of the beam-shape degradation caused by RADOME are as follows:

- Surface degradation, due to weather, solar radiation, lightning and breeze, e.g. in case of Fig. 5;
- Reflections, due to ice, electrical and grounding cables on the RADOME surface, e.g. in case of Fig. 23;
- Ribs effect, which is not the case for HC used RADOMES.
- The following sections are introducing observations that are useful for further improvement of the civilian radar antenna maintenance processes.

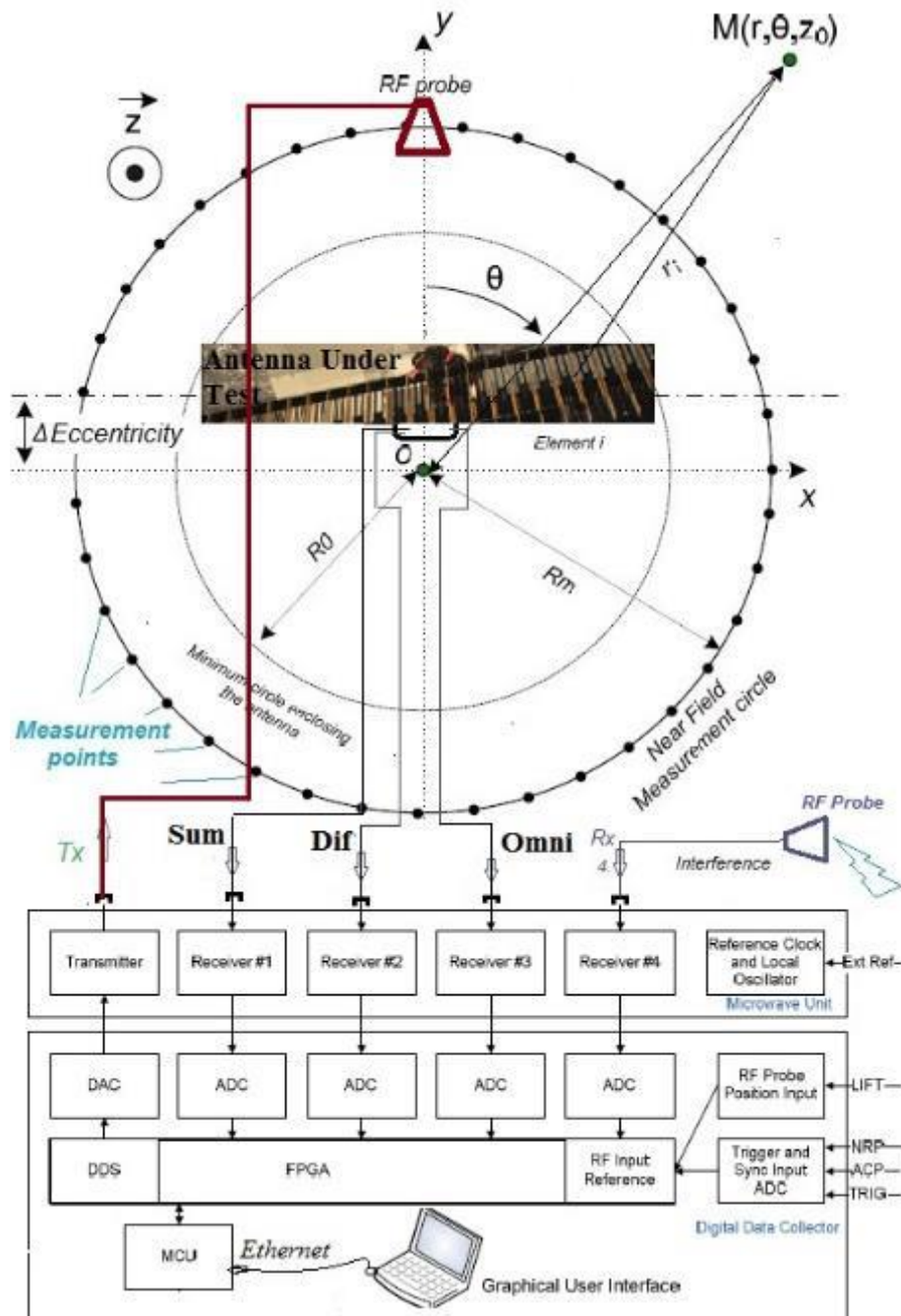


Fig.2 Measurement set up of the 4ChVNA [4]

Measurements of the RADOME degradation

Measurement of antenna pattern degradations related to RADOME require measuring of the electro-magnetic energy, strength inside the RADOME and at the same height/position of the RF probe outside the RADOME for every pallet of the RADOME. If there is no requirement for full RADOME performance check the measurement points have to be minimized for the saving of time and effort during the test. Consultation with the local HC engineers at the radar sites concluded in streamlining the effort of the collected information. Raw Order of Magnitude (ROM) analyses of the RADOME influence on the antenna pattern are extracted from the data collected, when twice two measurement results for next RADOME pallets are compared. Two

by two, CNF measurements are taken from 1.5-2 m distances to each other in azimuth inside and outside the RADOME. The CNF measurement setup pictures are shown in Fig.3, while Fig.4 depicts the perfect antenna patterns that are measured inside the RADOME.

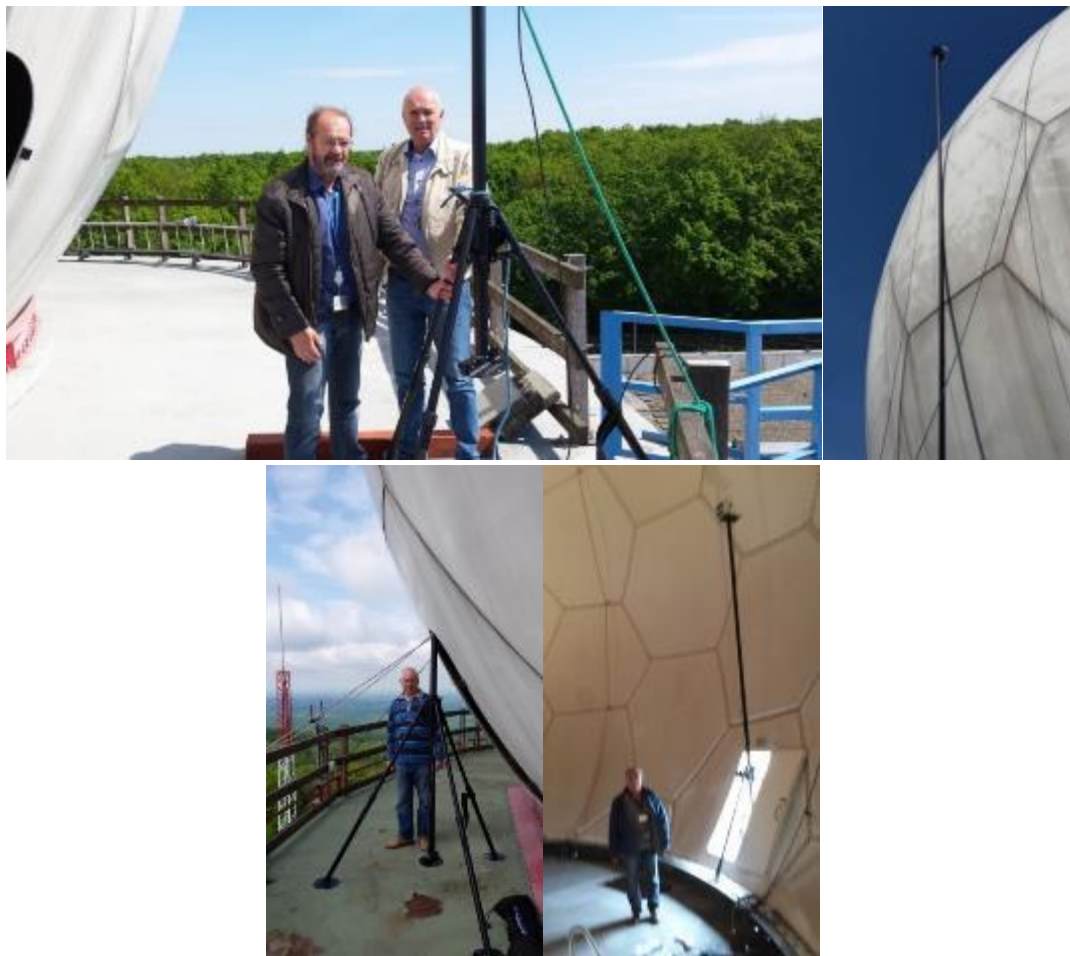


Fig.3 RADOME performance measurement set up [9]

Fig. 6 shows the horizontal MSSR Interrogation patterns as measured from the far field with RASS-S/RFA. The observations are that the P1-P3 pattern has a beamwidth within the expected limits. The SUM channel side lobes are within the specifications. Passive component of the Channel A and channel B have the same RF performances as the repeated measurement of the channels produces the same results. The Omni channel strength, notch is correct and covers the Sum channel sidelobes with required margin. Several punch-through around +90, +115 degrees and at -90, -115 degrees. This phenomenon can be observed in all systems of this antenna. Fig. 5 indicates some pattern degradation on the front part of the beams measured with CNF outside the RADOME and in the measurement at the FF remote position. Detection of the antenna pattern degradations caused by RADOME is very problematic with type of measurements other than CNF. E.g., the observation of the degradation on the PPI console is possible only when the target detection characteristics drop to an unacceptable level. Fig.7 and 8 depict MSSR antenna surface holograms, amplitude distribution are calculated from CNF data, which are collected inside the RADOME. Fig.7 shows small excitation disturbances at #5 due to loose connectors and icy RADOME condition at #22, and at #32.

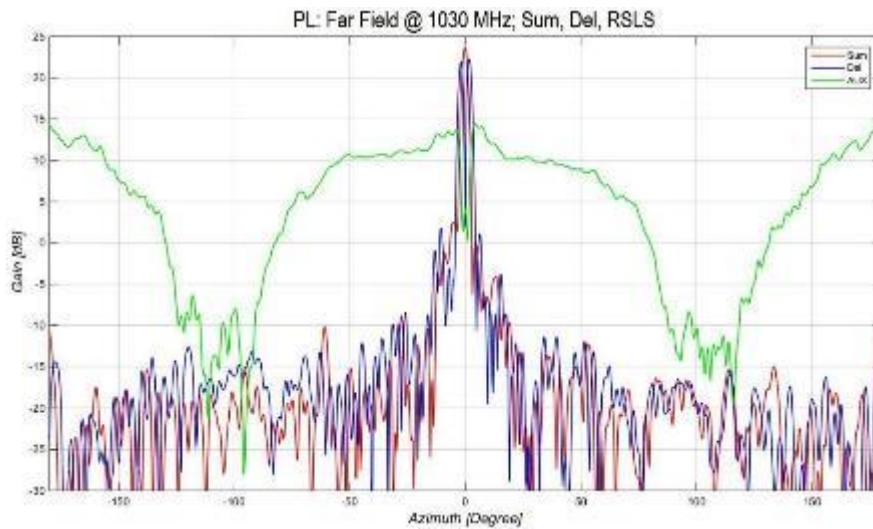


Fig.4 MSSR far field antenna patterns are calculated from circular near field measurement data [9]

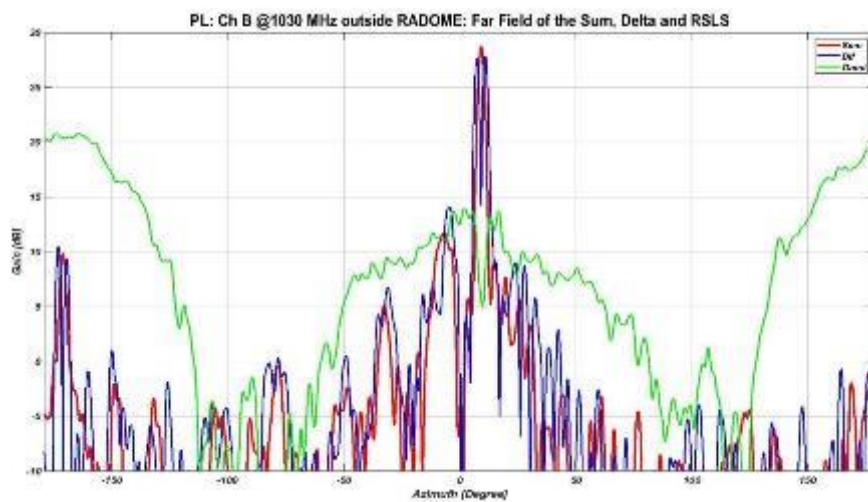


Fig. 5 MSSR far field antenna patterns are calculated from CNF outside the RADOME data [9]

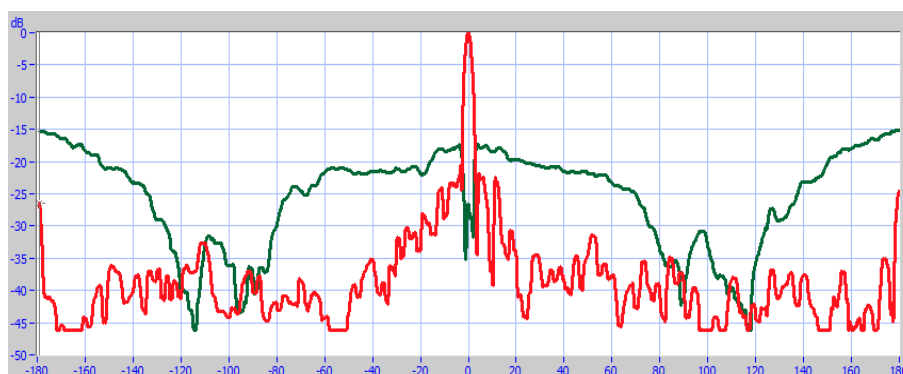


Fig. 6 Horizontal MSSR Interrogation patterns as measured from far field with RASS-S/RFA [9]

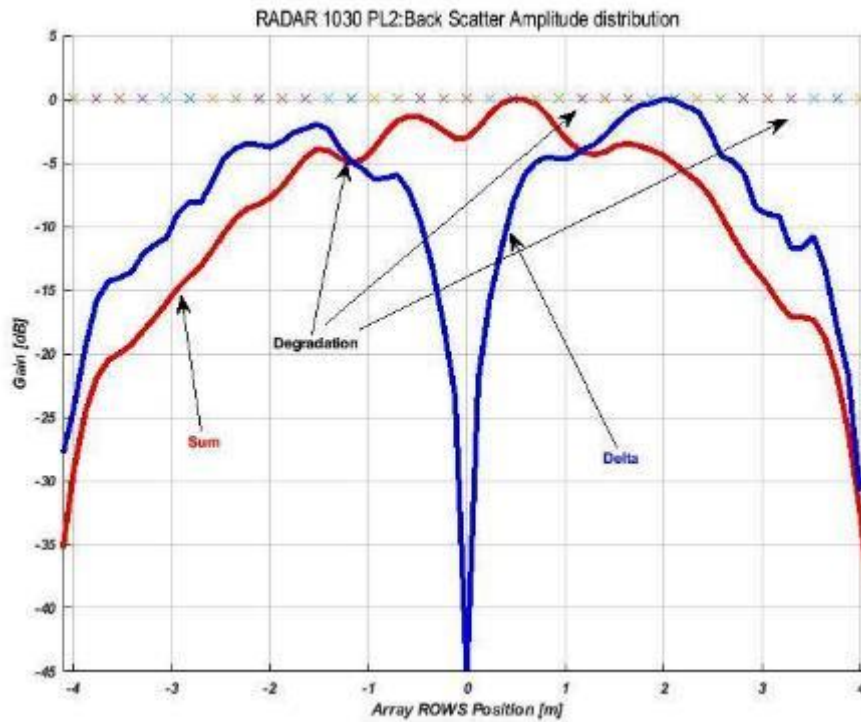


Fig. 7 Calculated MSSR antenna surface amplitude distribution in 2014 (icy RADOME surface) [9]

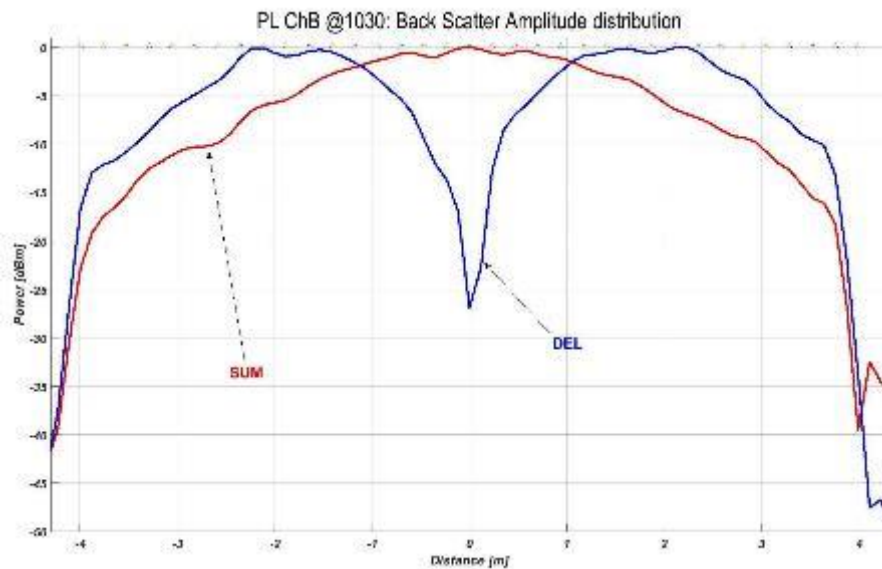


Fig.8 Calculated MSSR antenna surface amplitude distribution in 2017 [9]

Fig. 8 shows the same MSSR hologram patterns as Fig.7 after loos connectors fixed and the ice melted away on the RADOME surface.

Measurement of the Radar Antenna not protected by RADOME

Fig. 9 shows degraded MSSR FF antenna patterns, which are still within the operational requirements, while the FF patterns shown in Fig.10 produced at Remote Position indicates close to the failure status of the antenna. The amplitude distribution on the antenna surface, Fig.11, indicates several bad connections, cables and even columns of the array, which required site and Original Equipment Manufacturer (OEM) intervention.

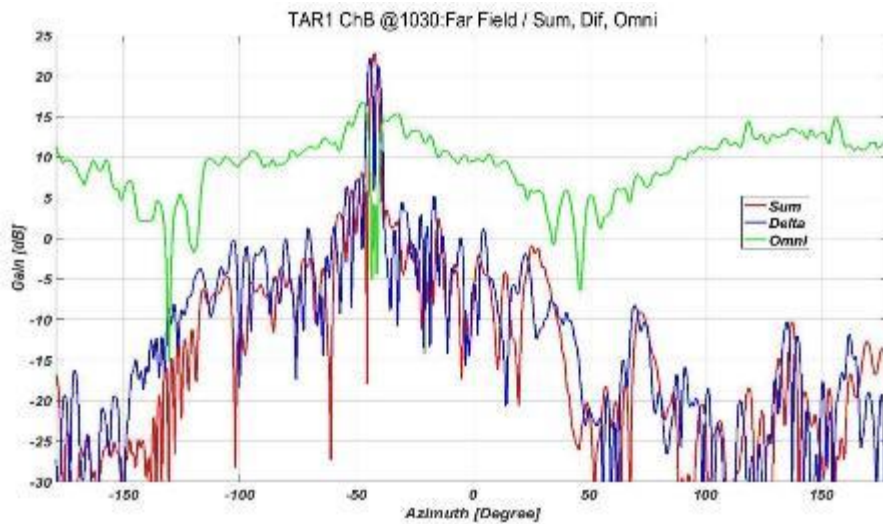


Fig.9 MSSR far field antenna patterns are calculated from circular near field data [9]

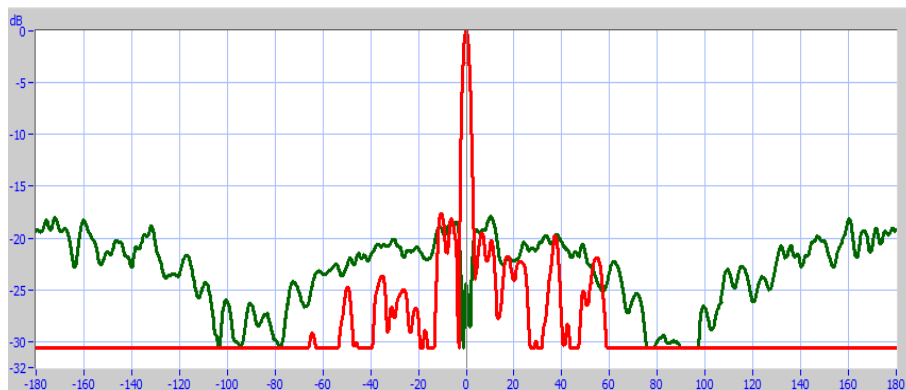


Fig.10 Horizontal MSSR Interrogation patterns as measured from far field with RASS-S/RFA [9]

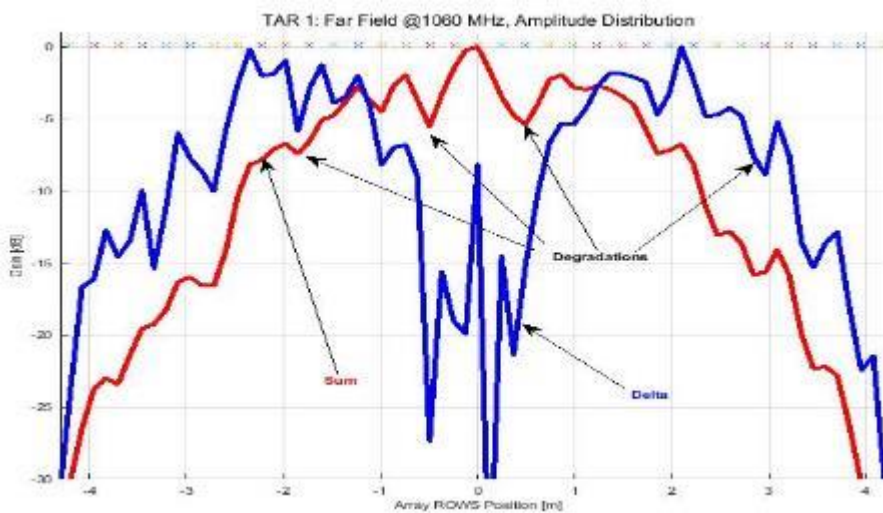


Fig. 11 Calculated MSSR antenna surface amplitude distribution for Sum and Delta channels in 2014 [9]

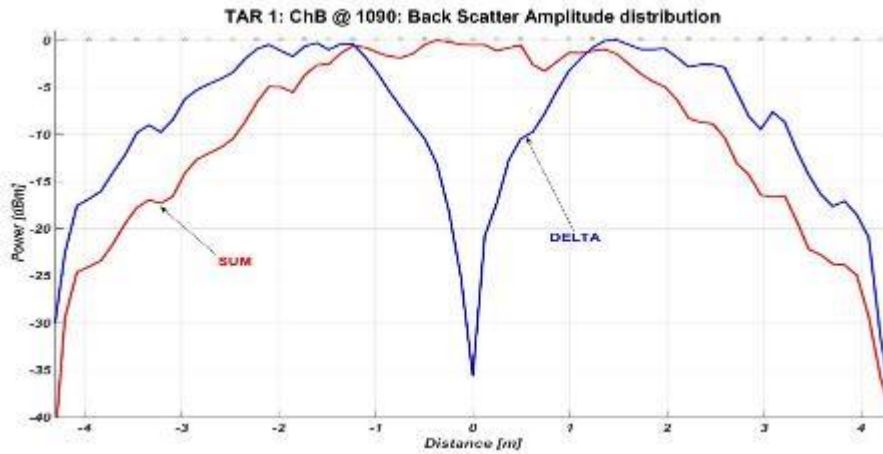


Fig.12 MSSR antenna surface amplitude distribution for Sum and Delta channels in 2017 [9]

Fig. 12 shows the same MSSR antenna amplitude distribution on the antenna surface after OEM and site engineers have implemented the corrective measures. There are still degradations in the element excitation that required further investigation. Fig.13 shows a measurement set up of the Planar Near Field (PNF) data collection and the calculated FF measurement results for the data has been collected on the column feeds of the degraded and good vertical element. Simulation results and comparison of theoretical correct column amplitude and phase distribution with the measured data results have shown that the vertical radiation pattern degrades in case of not correct phase distribution of the columns feeding. These results proved that the remote position of the Fig.10 data collection is well below the pointing of the MSSR antenna and the produced results could not be validated.

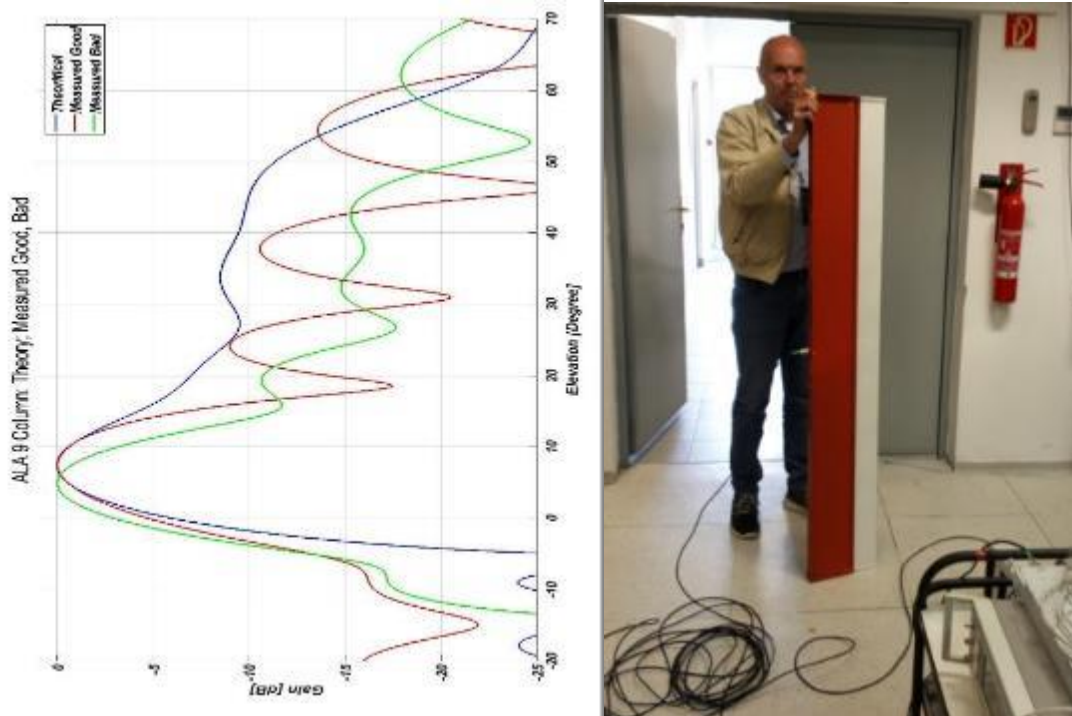


Fig.13 MSSR Vertical Antenna Patterns: Theoretical, Good and Degraded columns [9]

Measurable degradation of the Radar Antenna with Back Radiator issue

Fig.14, 15 and 17 prove that the MSSR antenna back lobes are degraded, due to the connections or tilting of the Back Radiator. See Fig.16. The P1-P3 pattern has a beamwidth within the expected limits. The Delta channel shape is as expected. The SUM channel side lobes are within the specifications, but Omni Pattern back lobes do not cover them.

Fig.18 and 19 plot holograms, which indicate minor degradation of amplitude distribution at column #4 and two artificial excitation problems at column #7 and #15 used for calibration of the test setup. These figures prove the observation that the Sum and Delta channels are working correctly, while the Back Radiator needs maintenance.

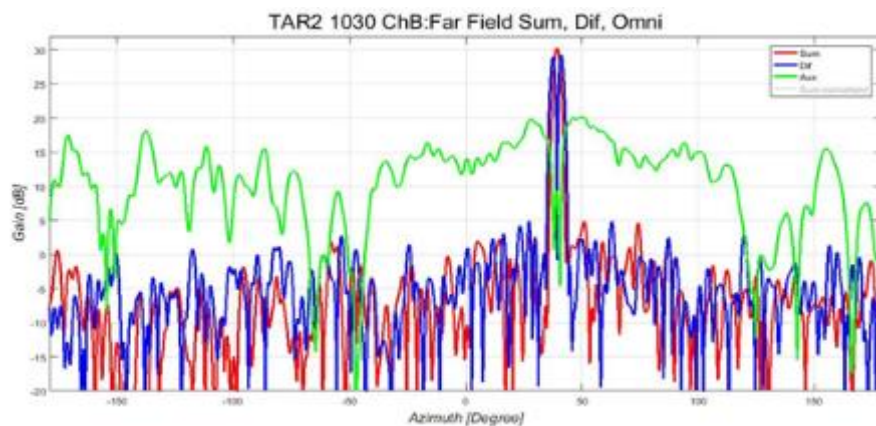


Fig.14 MSSR far field antenna patterns are calculated from circular near field measurement data [9]

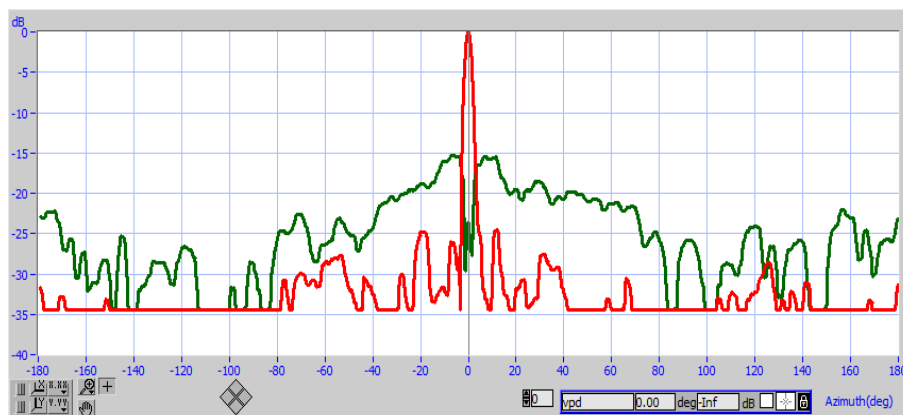


Fig.15 Horizontal MSSR Interrogation patterns as measured from far field with RASS-S/RFA [9]



Fig.16 MSSR LVA Antenna Back Radiator [9]

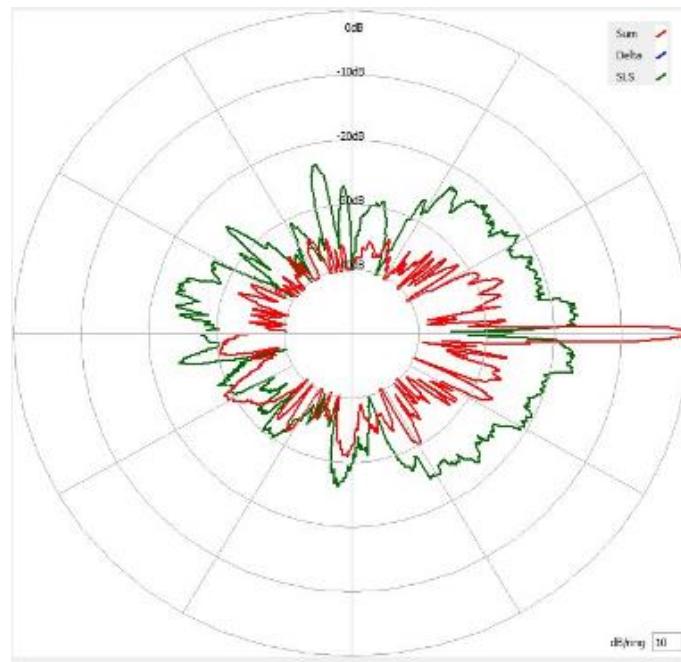


Fig.17 Horizontal MSSR Polar Antenna patterns as measured from far field with RASS-M [9]

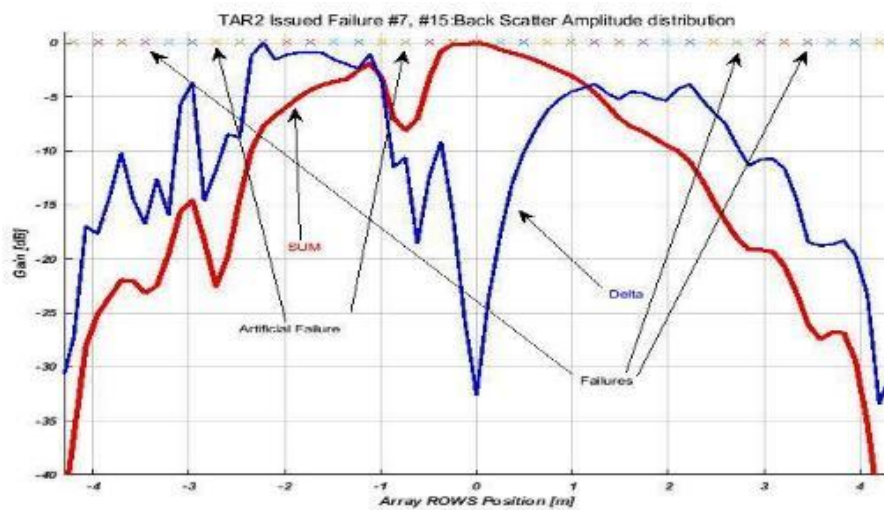


Fig.18 Calculated MSSR antenna surface amplitude distribution with artificial failures [9]

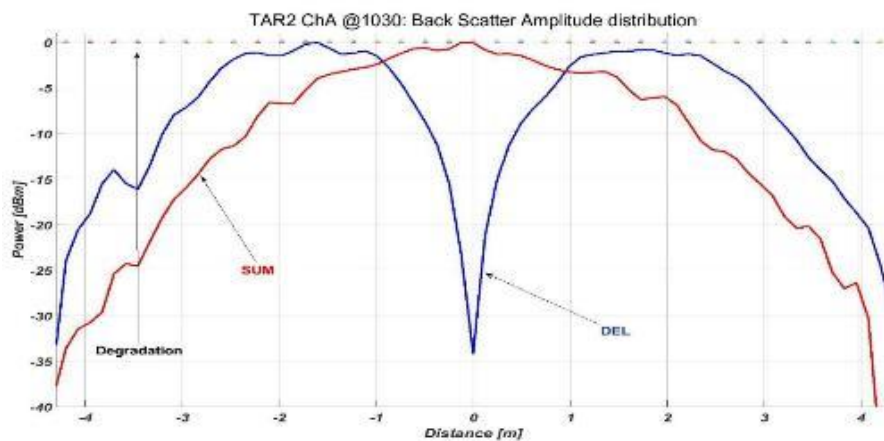


Fig.19 Calculated MSSR antenna surface amplitude distribution after correction [9]

Perfect MSSR Antenna performances

Figures from 20 to 24 show perfect antenna conditions calculated from CNF data and confirmed by Far Field measurement results.

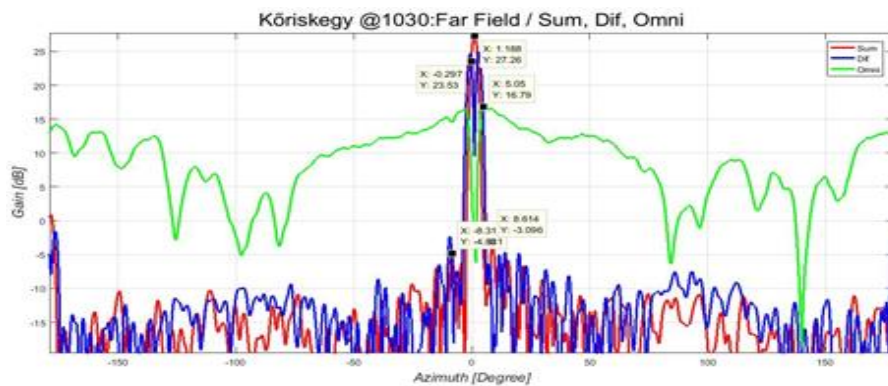


Fig. 20 MSSR far field antenna patterns are calculated from circular near field measurement data [9]

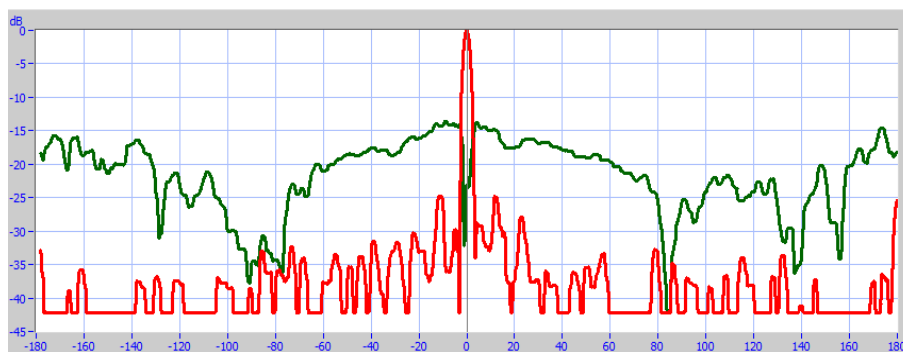


Fig. 21 Horizontal MSSR Interrogation patterns as measured from far field with RASS-S/RFA [9]

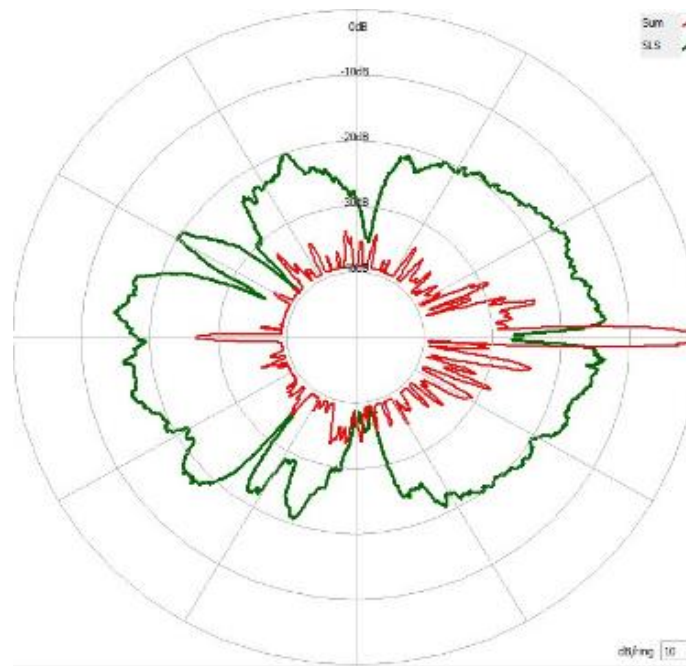


Fig.22 Polar view of the MSSR Interrogation patterns as measured from far field [9]

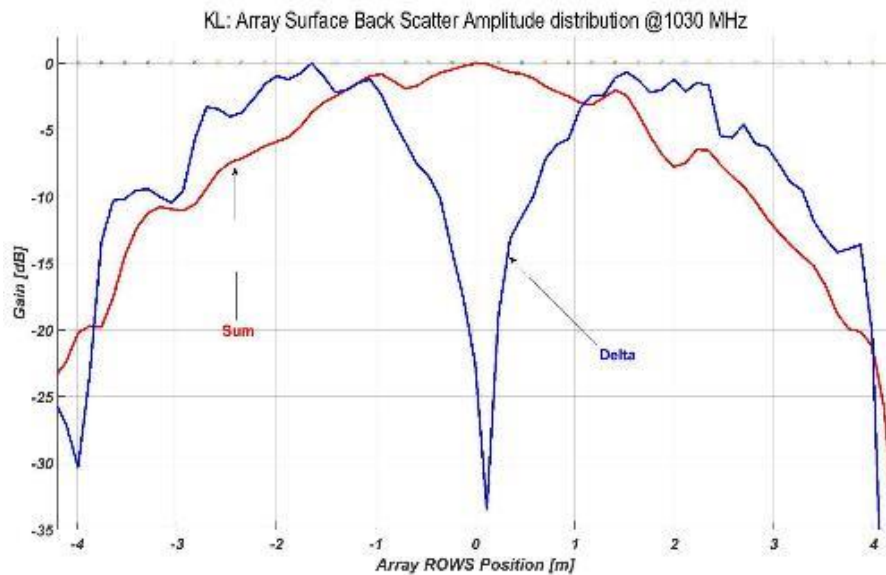


Fig. 23 Calculated MSSR antenna surface amplitude distribution, in icy RADOME condition [9]

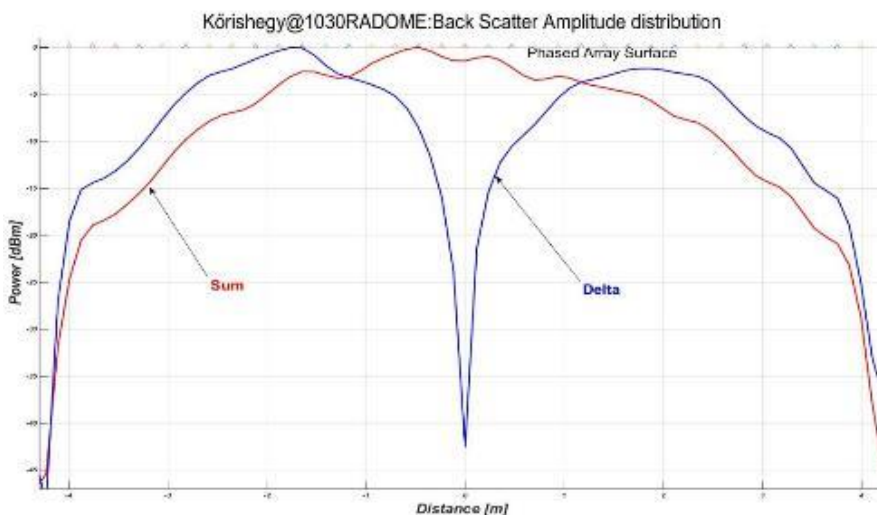


Fig. 24 Calculated MSSR antenna surface amplitude distribution in good weather condition [9]

CONCLUSIONS AND WAY AHEAD

The article highlighted the fact that radar antenna performance tests significantly enhance the engineer's understanding of phased array operational statuses and improves the ability to detect antenna system degradation and hidden problems. This could not be detected by Built In Test Equipment of the radars, at an early stage, thus avoiding catastrophic and costly failures. HungaroControl radar support engineering and management have recognised these advantages and with support of Hungarian MoD and NSPA started to explore the possibilities.

Briefly the benefits of the antenna performance measurements are:

- ➔ Independent assessment of system performance and corrective action;
- ➔ Early detection of degradation;
- ➔ Minimized unscheduled urgent contractor interventions;
- ➔ Focused contractor interventions & overhauls;

- ➔ Information sharing on systemic failures and corrective actions between users;
- ➔ Better understanding of system by site technical staff;
- ➔ Feedback from previous campaign exercises allowing for continuous improvement and further optimization.

Campaigns at HC radar sites have uncovered issues that have assisted, with the cooperation of the OEMs, the sites in maintaining optimal and even better antenna performances.

The way ahead for HC and NSPA cooperation is to develop and apply for the HC maintained radar systems a tailored version of NSPA used Radar System Performance Check procedures with the cooperation of other users supporting similar or the same type of radars.

This type of Lifecycle Radar System Support services will assist site-engineering staff in achieving even higher standards of the system performance compared with the past characteristics.

Special thanks to the experts on Hungarocontrol Radar Technical Staff who provided professional and continuous assistance and contribution both technically and logistically.

This article is a result of a collaboration of NSPA R-SPC engineers who work untiringly to carry out and maintain the methods and practices of the R-SPC to the highest level.

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Légtérelenőrző radar antenna performancia menedzsment a Hungarocontrolnál

A cikk az antenna performancia tesztekben lévő lehetőségekre hívja fel a figyelmet a Hungarocontrol által üzemeltetett négy légtérelenőrző radar antennán szerzett antenna performancia mérések tapasztalatainak összefoglalásával. Ez fontos feladat, mivel az antennák és a RADOME-jaik ki vannak téve az öregedés, az időjárás, a villámcsapások, a tervezett/terven kívüli javítások és néha részleges felújítás okozta teljesítményromlásnak. Az antenna performanciák fokozatos csökkenése észrevétlenül elérheti azt a szintet, amikor a következmények végzetes performancia csökkenéssel járnak, mivel a radarokba beépített önteszt rendszerek nem ellenőrzik az antennák állapotát. Következésképpen az antenna performanciákat külön erre a feladatra kidolgozott „in-situ” mérési eljárásokkal és teszt eszközökkel kell rendszeresen ellenőrizni.

Kulcsszavak: In-Situ, közel-tér, távol-tér, antenna performancia teszt, légiforgalmi irányítás

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