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COMPARISON OF DIFFERENT METHODS OF END TO END CALIBRATION OF THE UK WEATHER RADAR NETWORK

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Abstract

This paper presents a summary of a study performed by Gematronik GmbH for The Met. Office under contract CB/Met 1b/2335 to investigate the feasibility of various methods of end to end calibration of the UK weather radar network.

Weather radar calibration is typically restricted to component level, e.g. transmitter power measurements and receiver characterisation. In order to achieve a complete calibration of the radar system, it is necessary to include the complete signal path through every radar subsystem, from the transmitter output power to the receiver A/D converter input. This requires external calibration activities with active or passive tools. The different methods considered have been classified into

- Remote sources
- Targets (active and passive)
- Existing tools for other types of radar (such as ATC radars)

All methods have been assessed on their feasability and accuracy. The final result is a table comparing all calibration methods.

2 Introduction

The applicability of various calibration methods were discussed. Calculations were executed to establish whether each method is really appropriate for calibration purposes of

- signal amplitude,
- phase and
- antenna pointing

based on the performance specifications of the weather radars currently used by the UK Met Office :

Reflector Gain at 5,625MHz	43dB
Reflector Beamwidth at 5,625MHz	1°
Operational Frequency	5,625MHz
Positioning Accuracy	0.1° r.m.s.
Peak Power	230kW
Pulse Width	2µs
PRF	300Hz
MDS (measured)	-108dBm

With respect to the radar performance parameters the signal strength at the receiver output port has been calculated and compared with the system MDS. A calibration method was assumed to be feasable, if the expected signal strength was higher than the system MDS and therefore detectable by the radar. In most cases the difference between the signal strength and the system MDS was large enough for a clear decision.

Every calibration method with an acceptable signal level has been investigated further for amplitude, phase or positioning calibration. The criteria for this investigation have been

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- repeatability
- accuracy of test signal
- stability of test signal in time and space
- ease of implementation

Accuracy is the most critical point in any type of calibration. The highest accuracy is only possible with a well known signal sources or attenuation, otherwise the uncertainty of the radar itself will be added up with the uncertainty of the test signal. The test signal level has to be stable in time and space at least for the actual calibration activity, especially if the test signal is measured with a reference tool at a different location or at a different time. Additionally, any calibration method has to be repeatable for a longer period of time, otherwise the calibration method would not be practical for any operational weather radar network. As a last consequence, a calibration method has to be implemented with a reasonable effort. High expenses and physics are here the most restraining parameters.

The following sections briefly describe the results of the considerations regarding different methods of calibration. Some are well known to the weather radar community like transponders or spheres. Other are used in other radar or radio applications like radio astronomy or air traffic control radars. The calculations are very simple based on radar equation and antenna physics.

3 Remote Sources

3.1 Sun

The emission of electromagnetic energy by the sun extends down to microwave frequencies. Some weather radar users are using the sun for calibration efforts. In most cases (Bulgaria (ATSA), Canada (AES), Finland (FMI), Germany (DWD+DLR), Germany (IMK Karlsruhe), Switzerland (SMA), UK (UK Met Office), USA (S-Pol+NEXRAD)) the sun is used for antenna positioning, but one organisation relies on the sun for amplitude calibration (USA (S-Pol)).

The calculation of the received signal corresponding to solar flux results in the following theoretical signal strength at the receiver output :

$P_{rec,min} = 2.2429 * 10^{-13}$ W = -102.469dBm
$P_{rec,max} = 2.2429 * 10^{-11}$ W = -82.469dBm

This corresponds with the typically observed signal power of the sun at approximately 5dB to 10dB above noise level.

This highlights the most significant problem with using the sun for amplitude calibration. The sun is not a constant source of microwave emissions. The sun activity changes over time and can vary by a factor 20dB ! These variations are slow longterm variations and can be neglected during the typical calibration time, but they make the sun radiation unpredictable. Therefore the accuracy of the amplitude calibration has to rely on a the accuracy of a reference receiver like a radio astronomy system.

The sun is an excellent source for positioning accuracy, because the position is well known and can be calculated. The highest positioning accuracy is achieved by using the 3dB points of the antenna main beam in order to center the antenna correctly.

It is not possible to perfom phase calibration with the solar signal, because the sun is an incoherent source of radiation.

3.2 Test Signal Transmitter

Test signal transmitters are based on the same principal as the test signal generator used for receiver calibration. A well defined and calibrated signal is injected into the system. This calibrates the antenna, waveguides and receiver.

By careful selection of the test signal transmitter components the received power can cover the dynamic range of the weather radar. Even antenna pattern measurements are possible, if the power level of the receiver is more than 40dB above the MDS.

Phase calibration would need an additional way to transport the phase information to the radar.

The test signal transmitter is an excellent source for positioning accuracy, because the position is well known and it is practically a point source.

3.3 Test Receiver

Test receivers perform the opposite function of the test signal transmitter. The calculations are very similar, but in this case the transmitter, waveguides and the antenna of the weather radar are calibrated. A test receiver used in conjunction with the test signal source could be used to verify the homogeneous properties of the radar antenna. Even antenna pattern measurements are possible, if the power level of the receiver is more than 40dB above the MDS.

Phase calibration would need an additional way to transport the phase information to the radar.

The test receiver is an excellent source for positioning accuracy, because the position is well known and it is practically a point source.

3.4 Satellite Sources

Satellites could provide an extraordinary opportunity for all calibration purposes from a technical point of view. By careful selection of the satellite components the received power can cover the dynamic range of the weather radar and all calibration aspects like antenna positioning, amplitude and phase calibration from antenna to receiver and antenna pattern measurements.

Unfortunately satellite technology is very expensive and there is no existing satellite (not in geostationary orbits or in other orbits) neither transmitting nor receiving at the typical operating frequencies of c-band weather radars. If a satellite is to be used for weather radar calibration it would be necessary to employ a dedicated unit in a geostationary orbit or integrate a unit into an existing space project.

Both approaches could be realized only as a combined effort by several weather radar users in order to divide expenses.

3.5 Radio Stars

The theoretical signal power radiated by the strongest radio source in the sky at 1GHz is at most –14.66 dB below the theoretical MDS of the receivers as used by the UKMetOffice. This number is significantly below current and possible future capabilities of any radar receiver and therefore radio stars cannot be used for weather radar calibration.

4 Targets

4.1 Transponder

Transponders can simply be thought of as active targets. They take an incoming pulse and return it with a well defined attenuation to the radar. They include the functionality of a test signal transmitter as a calibration signal source and add to it the calibration of the weather radar transmitter.

Transponders provide an extraordinary opportunity for all calibration purposes. By careful selection of the transponder components the received power can cover the dynamic range of the weather radar and all calibration aspects like antenna positioning, amplitude and phase calibration from antenna to receiver and antenna pattern measurements.

Transponders could be employed as fixed installations for continuous calibration efforts or for off-line calibration from a temporary fixture at certain points in time. They are easy to handle and available at reasonable costs.

4.2 Sphere

Spheres are passive radar targets with a well defined radar cross section. They have been used or tested for calibration purposes by several weather radar operators (e.g. USA (S-Pol), USA (NEXRAD), Sweden (SMHI), ATC (Air Traffic Control) and ASR (Airport Surveillance Radar)).

In theory, a sphere provides a good opportunity for all calibration purposes, apart from the problem of keeping the sphere in a fixed known position in space. With the appropriate radar cross section of the sphere, this technique could theoretically be used in the calibration of antenna positioning, amplitude and phase calibration from antenna to receiver and antenna pattern measurements.

Spheres are only useful for off-line calibration (i.e. when the radar is not in operational use). Fortunately the weather conditions which will allow this calibration method to be used are the same conditions that allow the radar to be switched off for calibration purposes.

An advantage of using a sphere is the low cost for capital equipment and the flexibility of the fixture. But unfortunately all advantages are outbalanced by the fact that the accuracy of this calibration method depends heavily on the stable known position of the sphere, which is even on a calm day with low winds not controllable as different tests have shown.

4.3 Fixed Objects

Fixed targets are defined here as any fixed large object in direct line of sight from the radar system, which is visible as a discrete target on the radar screen. In most cases this will be a man-made object like a building, a tower, a mast or a natural target like a large rock or even a hill. They have been used or tested for calibration purposes by many radar operators.

The radar cross section, σ, of any object can be calculated for several simple geometrical shapes.

Unfortunately most natural or man-made object are rather complicated in shape rarely facing the radar with their broadside. There are formulae available to describe simple shapes, but not for all possible shapes which can occur in a real situation. In addition the target is unlikely to be metallic, therefore the reflection coefficient of the surface is unknown and inhomogeneous.

The best way to determine the radar cross section of a discrete exposed fixed target may be to make the measurement independently with a calibrated system. Therefore the accuracy of the amplitude calibration has to rely on a the accuracy of a reference.

Use of a fixed target would provide a reasonably good calibration technique based on the provison that the target properties can be independently measured using a calibrated test system. There is no annual calibration required for the fixed target itself as long as the form or surface is not changed (i.e. dirt, moss) and the line of sight is not disturbed by other objects (i.e. growing trees). The strongest disadvantage of a fixed target is its inflexibility. Unless the radar user builds and owns the target, they will have no control over the radar properties and availability of a fixed target.

4.4 Satellite Targets

A spacecraft would need a radar cross section of approximately 72 10^6 m^2 in order to achieve a return at the receiver of –110dBm for a typical c-band weather radar. Due to the limited dimensions of spacecrafts it is obvious that a satellite target or even a space station is not suitable for calibration purpose.

4.5 Moon

The calculation has shown that the signal power reflected by the moon is at most 1.35dB above the theoretical MDS of the receivers as used by the UK Met Office. This number is only of theoretical nature and does not account for several real losses like fog, clouds, rain, moon surface roughness or receiver imperfections. In reality the signal power will be significantly below the current and possible future capabilities of any c-band weather radar receiver.

5 Existing Tools

Two existing tools have been investigated :

- PARC (Polarimetric Avtive Radar Calibration)
- RASS-S (Radar Analysis Support System for Site Measurements)

The PARC transponder was specificially developed for the needs of the DLR radar including the conditions of the surrounding landscape. It shows that the transponder concept can work with acceptable accuracy under real life conditions.

The RASS-S concept itself offers no revolutionary new approach for weather radar calibration, execpt that all calibration aspects of amplitude, phase and antenna positioning are included. The complete RASS-S suite covers power meter, test signal generator, test signal transmitter, test receiver and signal processing originally designed for frequencies around 1 GHz. Therefore it cannot be directly adapted for weather radar calibration purposes. Especially the signal processing is matched to qualitative ATC signal processing which is very different from the quantitative weather radar signal processing, but RASS-S is an interesting pool of design ideas.

6 Conclusion

Several possible calibration for modern c-band weather radars have been investigated and compared. There is no ideal calibration method which outperforms all other methods in expenses and performance. In addition, there is always the possibility of using calibration methods which do not cover all parameters of the radar equation.

If accuracy was the only consideration for off-line calibration method, then a sphere would seem to be the obvious choice with two major disadvantages not being considered in this comparison. The problem of sphere positioning and the time interval between two possible calibration efforts. A sphere can not replace the on-line use of a power meter and a test signal generator in order to detect faults in a short time.

Best choice for a complete on-line or off-line system calibration would be a transponder. It can be designed to be robust and easily maintainable. The placement is flexible and can be adjusted to the local conditions and existing infrastructure. The accuracy is very good.

The best compromise for calibration would be a power monitor and a test signal generator in order to monitor transmitter and receiver performance on-line. One or two transponders could be used off-line in order to check the antenna diagram and positioning once or twice a year which is completely sufficient for these parameters.

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