

## THE USE OF PATTERN COMPARISON METHODS FOR SATELLITE ANTENNA TESTING

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### ABSTRACT

Nowadays, the standard facility for accurate satellite antenna testing is the Compensated Compact Range (CCR). In order to increase measurement accuracy several techniques can be applied, which are based on antenna pattern comparison. The theory of these techniques together with experimental results have been described in several papers in the past [1][2][3]. This paper presents how pattern comparison techniques are applied for space programs and is another step to official qualification of the Advanced Antenna Pattern Comparison (AAPC) method at Dornier Satellitensysteme (DSS).

Keywords: Antenna Measurements, APC-Method, Antenna Pattern Correction

### 1. INTRODUCTION

Pattern comparison implies that the complete satellite antenna structure is positioned at different locations across the test zone where the pattern is being measured. The acquired patterns can either be amplitude averaged or coherently processed in order to improve the accuracy. This paper will emphasize on the practical application in satellite communication antenna programs. In subsequent sections it will be explained what kind of correction method is the best suitable for which measurement application. Thereby, the following aspects have to be taken into account: the kind of test zone field deviations (e.g. taper, ripple, standing wave, cross-polarization), antenna radiation characteristics, applicable frequency range, drift of the RF signal and mechanical alignment requirements. Measurement results of the actual antenna programs at DSS will be presented comparing results of amplitude averaging [1] and coherent processing [2][3].

### 2. COHERENT DATA PROCESSING

The popularity of the Advanced APC method, is explained because of the easy implementation and successful results. It is based on a simplified error model which applies the best for high gain antennas. The APC-measurements are performed in the usual way by recording pattern cuts at different locations across the test zone. However, the distances between the positions is chosen such that the response to any unwanted stray fields, mainly picked up by the main lobe, can be considered as a single error component. Hence, the total measured signal ( $E_t$ ) can be decomposed into two vectors:

1. The main field response ( $E_d$ ).
2. A single error term ( $E_r$ ) due to unwanted stray fields, picked up by the main lobe.

According to this error model all APC measurement vectors will be lying on a circle after being compensated for freespace phase shift of the main plane wave, as illustrated in Figure 1.

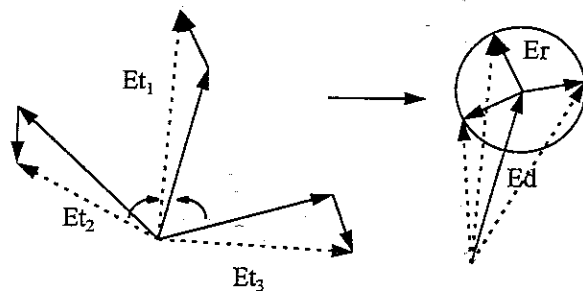


Figure 1. Principle of the AAPC Correction.

The distances and direction of movement between successive measurement positions must be such that pattern errors due to stray signals can be well distinguished. Separation distances can be calculated according the interference period of two plane waves having different angles of incidence. Generally, both transversal (in equiphase plane) and longitudinal (in propagation direction of plane wave) positioning lead to good results. The advantage of longitudinal over

transversal is that stray field components in elevation and standing waves give recognizable pattern deviations. On the other hand transversal positioning is often more convenient and requires less distance between measurement positions.

### 3. ADVANCED APC VERSUS AMPLITUDE AVERAGING

There are fundamentally two different alternatives for processing APC measurements:

1. Coherent processing as demonstrated in Figure 1. This means that phase data of the acquired pattern is compensated for free space phase shift (FSPS). After FSPS compensation, data can either be complex averaged or circle reconstruction can be performed. The restriction on phase data is that the accuracy typically must be better than  $\pm 1^\circ$ . Moreover, circle reconstruction is according to the single term error model.
2. Amplitude averaging is the conventional method to improve measurement data. Because phase data is not being used there is no risk, i.e. the method can always be used and the averaged pattern will never be less accurate than each individual measured pattern. However, for good correction optimal positioning is required so that the minimum and maximum of the interference period are detected. Furthermore, the error signal has to be smaller than the desired signal.

The advantage of coherent processing over amplitude averaging is that the obtained corrections are much more accurate when pattern deviations are significant. In addition, the phase pattern will be improved by means of coherent processing and not be lost as occurs after amplitude averaging. It is obvious that circle reconstruction is more advanced than coherent averaging although almost the same correction results are obtained at the increase of measurements on different locations (practical experience shows more than 5).

Circle reconstruction imposes the highest accuracy requirements on measurement data. Therefore the following error sources have to be considered:

1. Correctness of the AAPC error model. The constantness of the single error component is dependent on the specific antenna under test (spatial filtering behaviour).
2. Error in FSPS determination of the main plane wave. When a digital distance meter is applied, its accuracy has to be taken into account plus mechanical

instabilities affecting the phase center positions of the test antenna. Another way to derive FSPS is the relative boresight phaseshift of each pattern. In the latter case the FSPS error includes boresight measurement errors.

3. Amplitude and phase measurement errors. These include RF-cable bending, rotary joint performance, temperature drift, measurement equipment instabilities, PIN diode switch performance, etc.
4. Positioner inaccuracies, leading to small differences in azimuth and elevation angles between APC measurements.
5. Data processing errors, which incorporate approximations in the circle reconstruction algorithm.

### 4. TEST RESULTS OF SPACE PROGRAMS

Experimental results of AAPC have been presented in several papers in the past [2][3]. During latter experiments, single pattern cuts have been made with the positioner in step mode and at least 32 RF signal averages. On the other hand due to measurement through put times, test conditions in industrial applications cannot be optimized for AAPC w.r.t. positions in the QZ, dynamic range, etc.. Therefore, this section demonstrates the suitability of AAPC for satellite antenna testing. Measurement results of actual space programs at DSS are presented.

For satellite antenna testing the earth coverage of different global beams and spot beams are of interest. Typically, beam patterns are measured in azimuth and elevation over a range of  $-10^\circ$  to  $+10^\circ$ . Raster scans in C-band with  $0.2^\circ$  step require 1 hour approximately. In order to keep measurement times to a minimum fast mode scanning is performed without RF averaging. As a consequence critical aspects as noise, drift, and positioning inaccuracies have to be considered when coherent processing has to be applied.

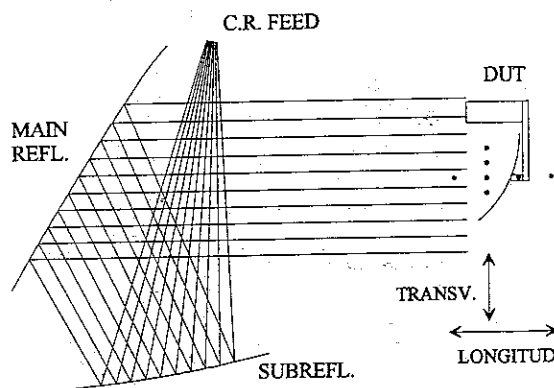


Figure 2. Pattern Comparison in the CCR (Top View).

In the Compensated Compact Range of DSS in Ottobrunn, Germany the measurement program for the Intelsat VIII antenna currently has been completed successfully. At the end of the program the opportunity has been used to perform AAPC measurements. For this occasion pattern measurements have been performed at four different locations in longitudinal direction, with separation distances of 0.5 m. Figure 2 shows a schematic view of the test setup with the positioning capabilities of the CCR.

has the lowest sidelobes and therefore is the most interesting to investigate. In Figure 3 a contour plot is shown of the zone B pattern at 3.905 GHz in the first measurement position. At low side lobe levels this pattern exhibits errors due to small test zone field deviations. The measurement data on the four positions has been coherently processed according to the principle shown in Figure 1, to obtain a pattern corrected for stray signals. The latter is shown in Figure 4.

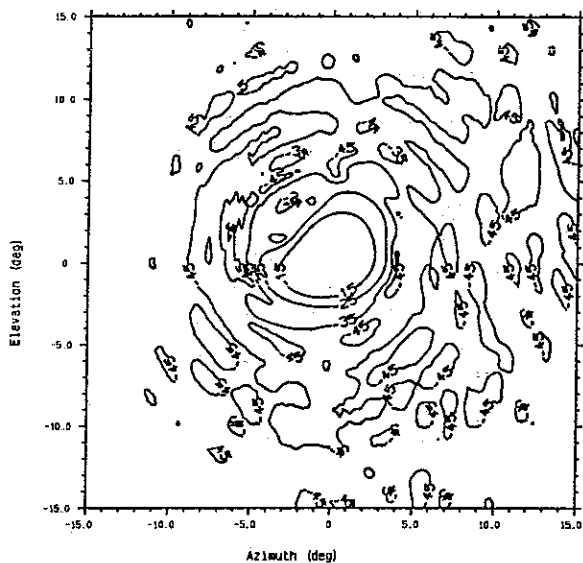


Figure 3. Contour Plot of First Pattern Measured.

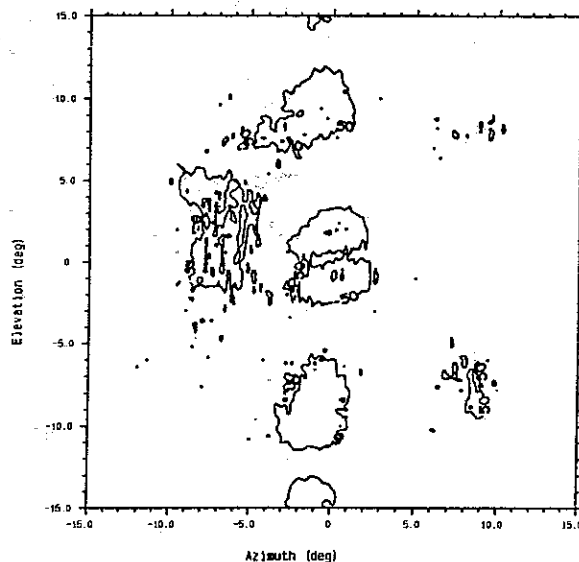


Figure 5. Contour Plot of Error Component after Coherent Processing.

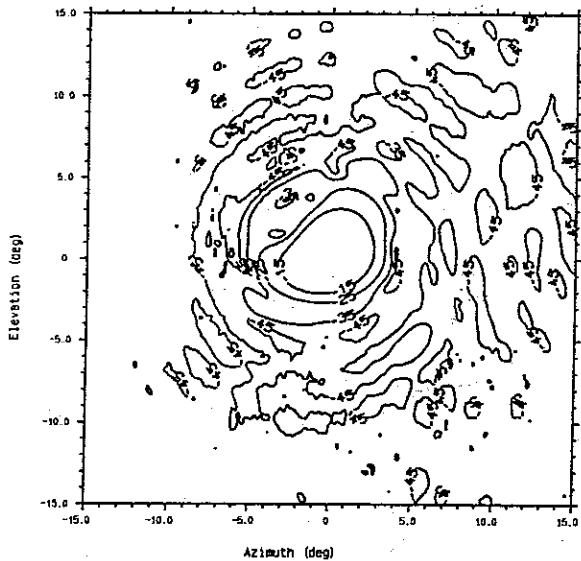


Figure 4. Contour Plot of Corrected Pattern.

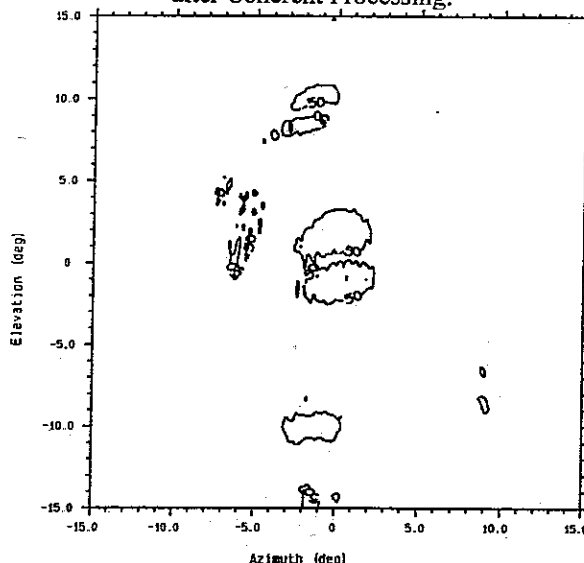


Figure 6. Contour Plot of Error Component after Amplitude Averaging.

Four different beams, hemi A, hemi B, zone B and zone C have been scanned over an angular range of  $-15^\circ$  to  $+15^\circ$  in elevation and azimuth. Ten discrete frequencies have been measured between 3.629 and 4.200 GHz for horizontal and vertical polarization. The zone B pattern

A comparison of Figure 3 and 4 shows differences of the  $-45$  dB pattern contour lines, in elevation at  $-10^\circ$  and  $+10^\circ$  and in azimuth at  $-10^\circ$ . Note that the peak gain is normalized to 0 dB. Figure 5 shows an error contour

plot, which actually is a plot of the component being removed in the corrected pattern by means of coherent processing (Er, see Figure 1). The plotted contour lines are at -50 dB level and the maximum error is well below -43 dB. The achieved error levels are extremely low which proves the excellent range performance. Only small diffraction at the serrations on top and bottom and left side of the reflector are visible whereas on the right side no disturbance is seen at all due to the billboard replacing the serrations. In Figure 6 an error contour plot is shown after determination of the maximum deviations of all four patterns from the amplitude averaged pattern. The difference between measured and corrected diagrams, obtained in latter way are smaller than when coherent processing is applied so that the averaged pattern must be less accurate. Figure 7 and 8 show single elevation cuts of the zone B beam raster scan measurement. Once again, both Figures clearly demonstrate that the pattern deviations at  $-10^\circ$  and  $+10^\circ$  are entirely corrected by the circle reconstruction procedure whereas a residual error remains in the averaged pattern. The Intelsat sidelobe accuracy requirement of  $\pm 0.75$  dB at -27 dB level is easily feasible using Advanced APC (corresponds to -48 dB error level).

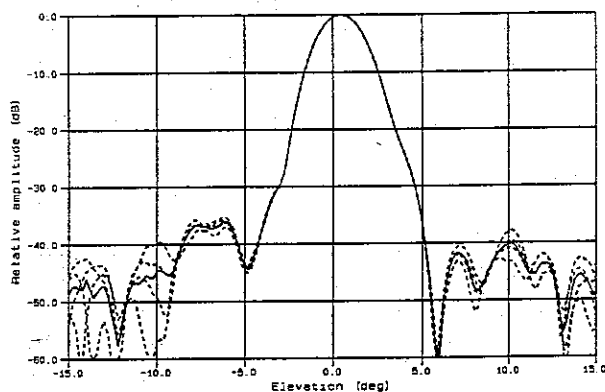


Figure 7. Measured (4x Dashed) and Amplitude Averaged (Solid) Pattern Cuts.

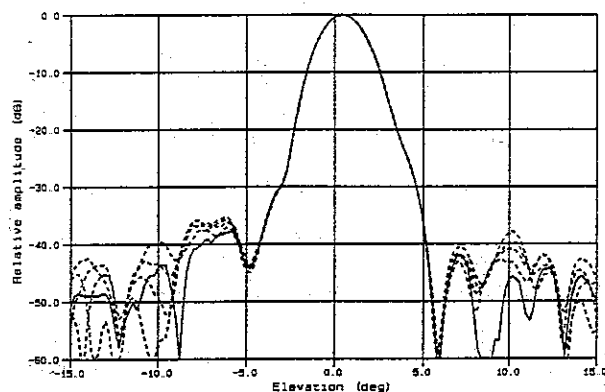


Figure 8. Measured (4x Dashed) and Coherently Processed (Solid) Pattern Cuts.

## 5. CONCLUSIONS

The suitability of the described methods to improve pattern data can be summarized as follows:

- Coherent processing: circle reconstruction for low sidelobe antennas and significant pattern deviations (e.g.  $> \pm 1$  dB at -40 dB level), and coherent averaging when sidelobe deviations are relatively small. In latter occasions circle reconstruction will not be effective because the phase data will not provide enough resolution.
- Amplitude averaging when the measured amplitude and phase data are not reliable enough because other error sources such as drift and noise are more dominant.

It has been demonstrated that instead of relying on quiet zone correction techniques, it is the best to measure in a high performance compact range (i.e. long focal length, high surface accuracy, accurate alignment, temperature stabilized, cross-polar compensated design). The first reason is that the extra measurement overhead which is required to fulfil test specifications, can be reduced considerably. It should also be noted that current quiet zone correction techniques only account for stray radiation errors. Amplitude and phase taper, cross polarization, alignment errors, temperature drift effects, etc. still rely on an excellent range design. Since measurement speed is very important with today's commercial satellite projects, the range which does not need any kind of measurement error correction is still to be preferred.

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