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Technical report

Magnus Höijer

Comparison between
High Level Radiated Susceptibility Tests
and Coupling Measurements

Sensor Technology
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Report title

Comparison between High Level Radiated Susceptibility Tests and Coupling Measurements

Abstract (not more than 200 words)

It is well known that High Power Microwaves (HPM) can disturb, and even destroy modern electronics. In the recent years, FOI and others have shown that the sensitivity of electronic equipments shows a substantial dependence on the irradiation direction of the object. These results stem from low level coupling measurements. The reason for doing a coupling measurement rather than a high level Radiated Susceptibility test (RS-test) is that much lower field intensities can be used and is therefore much easier to perform.

However, the goal is to do a RS-test, and we have therefore performed a high level RS-test and compared the results to the results of coupling measurements. As test object we have used a generic missile (GENEC), which has been irradiated from many directions in one plane. The RS-test was performed by monitoring at which field strength a digital electronic inside GENEC failed to work properly.

This report shows that the apparent directivity differs in details between the RS-tests and the coupling measurements, but typical lobe widths and the maximum apparent directivity are almost identical.

Keywords

HPM, Electro-magnetic fields, Directivity, Antennas, RS-test, Coupling measurements

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Jämförelse mellan provning avseende tålighet mot strålad störning och kopplingsmätningar

Sammanfattning (högst 200 ord)

Det är väl känt att Högeffektsmikrovågsstrålning (HPM) kan störa, och även förstöra modern elektronik. Under de senaste åren har bl.a. FOI visat att känsligheten hos modern elektronisk utrustning beror i betydande grad på i vilket riktning som objektet bestrålas. Dessa resultat härstammar från lågnivå-kopplingsmätningar. Skälet till att vi utfört kopplingsmätningar istället för högnivå RS-provning är mycket lägre effekter kan användas, vilket gör dessa mätningar mycket enklare att utföra.

Målet är dock att göra en RS-provning, och vi har därför utfört en RS-provning och jämfört resultatet med resultaten från motsvarande kopplingsmätningar. Som provobjekt har vi använt en generisk robot (GENEC), som bestrålats från många riktningar i ett plan. RS-provningen utfördes på så sätt att vi kontrollerade vid vilken påstrålad intensitet som en digital elektronik inuti GENEC stördes.

Denna rapport visar att detaljerna i den synbara direktiviteten skiljer sig mellan RS-prov och kopplingsmätningar, men typiska lobbredder och den maximala synbara direktiviteten är nästan identiska.

Nyckelord

HPM, Elektromagnetiska fält, Direktivitet, Antenner, Tålighets Provning, Kopplingsmätningar

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Contents

Chapter 1

Introduction

It is very well known that High Power Microwaves (HPM) can disturb and even destroy modern electronics. The most common way to protect electronics from HPM is by using conductive shields, filters and transient protectors. However some electro-magnetic radiation will always leak into the electronics through antennas and other sensors, joints, cracks and/or other apertures and imperfections. The electro-magnetic field couples to the components via cables and wires. To test electronic equipments ability to withstand HPM, Radiated Susceptibility tests[1] (RS-tests) are performed. In many of the RS-tests performed today the test-object is only irradiated from one or a few directions. The result of the test is often expressed as whether the test object did, or did not, withstand the electro-magnetic irradiation. In this report we have gone a bit further by quantifying the electro-magnetic field that disturb the electronic equipment, and most important, we have irradiated the test object from many different directions to investigate the angular dependence of the susceptibility toward electro-magnetic irradiation.

The purpose of our study is not to test a specific test object's strength against HPM, but to test a representative, or generic, test object's strength against HPM. We are therefore grateful to the DIEHL company, which have provided us with the generic test missile GENEC [1]. GENEC is a test missile, which is so complex that it should include most of the effects that can be seen when a real missile is irradiated. At the same time the electronics in GENEC is so uncomplicated that we assumed that it should be possible to define a clear criterion for when we have a disturbance in the electronics, see section 2.3. Due to the fact that the electronics in GENEC are rather well shielded and that we do not have a sufficiently strong microwave source, it has not been possible to destroy the electronics and we therefore had to limit our test to disturbance of the electronics.

However, even to get a disturbance in the GENEC electronics, a strong electro-

[1]The word Radiated Susceptibility test (RS-test) is misleading. It is a test of the electronic equipments ability to resist electro-magnetic irradiation. A better word to use would be Irradiated Susceptibility test (IS-test). However the word Radiated Susceptibility test, and perhaps even more the abbreviation RS-test, are widely spread and hence they are also used in this report.

magnetic field is needed, of the order of several kV/m. Therefore we have used the Reverberation Chamber (RC) at FOI, as well as the Microwave Test Facility (MTF)[2], to perform tests on GENEC.

We [2] have earlier shown that for typical electronic equipments, e.g. missiles, army radios and avionics boxes, the shielding effectiveness of the electronics show a substantial dependence on the irradiation direction of the object. Typically a difference of $10 - 15\ dB$ can be seen between the least effective shielding and the average taken over all irradiation directions[3]. At the same time the difference between the least effective shielding and the most effective shielding is as large as typically $40 - 50\ dB$.

Therefore we [3] and others [4, 5] have studied the angular dependence in detail. However, until now only coupling measurements[4], i.e. measurements of the fraction of the available irradiated power which couples to the interior of the test object, and no true RS-tests[5] have been performed. The reasons for doing coupling measurement rather than true RS-tests are manifold. Some reasons to be mentioned are that a RS-test requires a much stronger irradiation source making the experiment much more expensive and precaution has to be taken due to the fact that the field is so strong that it is potentially dangerous to human beings. The strong irradiation sources often have to be located outdoor making the test conditions weather dependent. Many irradiation sources, like the MTF [6], can only operate at a few frequencies, and even if the frequency of the irradiation source can be tuned, the accuracy is not as exact as for e.g. a network analyser.

However, the goal is often rather to do a RS-test than a coupling measurement. It is reasonable to assume that there is some relation between a RS-test and a coupling measurement, but it is not obvious how strong it is. In this report we have therefore for the first time taken the step to perform a true angular resolved high level RS-test. This has been possible by using the MTF [6]. The results of the RS-test have been compared with the results of a similar coupling measurement.

Another way to get a high irradiation field level is to use a Reverberation Chamber. The Reverberation Chamber has the drawback that all angular dependence information is lost. On the other hand the test equipment is "irradiated from all directions" in one single measurement. Therefore the Reverberation Chamber constitute a tool to do more accurate measurements than can be done in an Anechoic Chamber (AC) or Open Area Test Site (OATS) in a reasonable time. For a more comprehensive description of the Reverberation Chamber see [7, 8]. The difference between using the Anechoic Chamber and the Reverberation Chamber has been investigated earlier for coupling measurements [2]. In this report we go a bit further by starting the investigation of the same difference for the RS-test. In this high level testing we have

[2]The MTF is owned by the Swedish Defence Material Administration and operated by Saab Avionics.

[3]As can be seen in e.g. [2] we have not done the measurements for all solid angles, but for so many irradiation directions that it is reasonable to assume that we have a good approximation of the true values.

[4]See section 3.1 for a more strict definition.

[5]See section 3.2 for a description of the RS-tests which we performed.

used the MTF instead of the Anechoic Chamber, but the MTF, which constitutes a form of an Open Area Test Site, gives us a similar environment as the Anechoic Chamber.

Chapter 2

Description of the test object: GENEC

As test object we have used a dummy missile, called GENEC [1]. Our Bavarian friends and colleagues at Diehl Munitionssysteme in Röthenbach a d Pegnitz, Germany have kindly put GENEC to our disposal. We especially thank Frank Sonnemann for the help to get GENEC working properly.

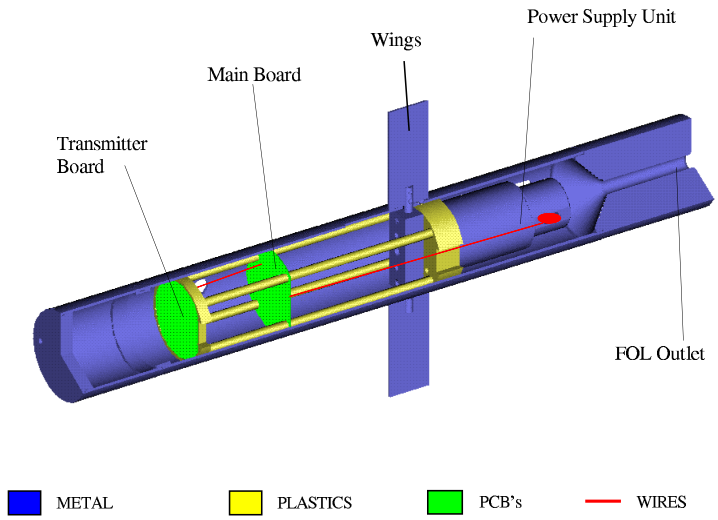


Figure 2.1: *The generic test object: GENEC act as a dummy missile. Reprint from [1] with permission of DIEHL.*

GENEC (Fig. 2.1) is built as a metallic cylinder with wings mounted on it. The total length is 815.5 mm and the diameter is 105 mm. In the measurements presented in this report all apertures, except the slots at the wing axes, were closed. The size of each wing slot is approximately 5 x 88 mm. The size of each wing is 50 x 120 mm. On the inside of the fuselage the wing axes are connected to the structure. The wings are attached in such a way that they do not have any electric connection to the fuselage. The wings are important due to that they act as antennas and the main Point-Of-Entry (P.O.E.) is via the wings and through the wing slots.

Inside GENEC there is a generic electronic device, which incorporates the functional behaviour of real missile electronics with a minimum number of components. The electronic device has an analog part as well as digital part. The electronics also include well-defined signal measurement points. The electronic device is kept in place inside GENEC with help of a plastic construction. The communication with the outside world is done through eight fibre optic leads. The fibre optic leads enter GENEC through a tube at one of the ends of GENEC. Inside GENEC there is an electro-optic converter for every fibre optic lead. Every electro-optic converter has an extra shield around them to ensure a proper operation even at strong electro-magnetic irradiation of GENEC.

A more comprehensive description of GENEC and the electronics inside GENEC is given in [1], but here are some facts necessary to understand the test procedure in this report, and as a general background, given.

2.1 General description of the GENEC system

The GENEC system consists of three parts: The dummy missile or the very GENEC, a control box and eight Fibre Optic Leads (FOL) connecting GENEC to the control

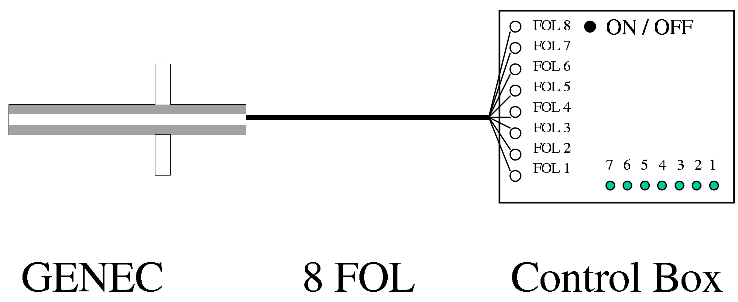


Figure 2.2: *Schematic figure of the GENEC system.*

box, see Fig. 2.2. By using a fibre optic link the communication between GENEC and the control box can be done without disturbance from the HPM-irradiation.

FOL 1 and 8 are used for communication to GENEC and the others for communication from GENEC. FOL 8 are simply a signal to switch GENEC on and off. In the control box an input signal for the electronics is generated, see section 2.2, and FOL 1 is used to send this signal to GENEC. The electronics inside GENEC consist of an analog and a digital part, see section 2.2. Through FOL 3 and 4 two digital signals are sent back to the control box, and through FOL 5, 6 and 7 three analog signals are sent back to the control box. FOL 2 is used to control the communication between GENEC and the control box[1]. Inside the control box there are opto-electric converters and through seven BNC-connectors an oscilloscope or a computer can be connected to all the six output signals from GENEC plus the input signal to GENEC. Thereby it is possible to monitor all signals going to and from the electronics in GENEC.

2.2 Description of the electronics

Figure 2.3 shows the electronics inside GENEC in a schematic view. As mentioned

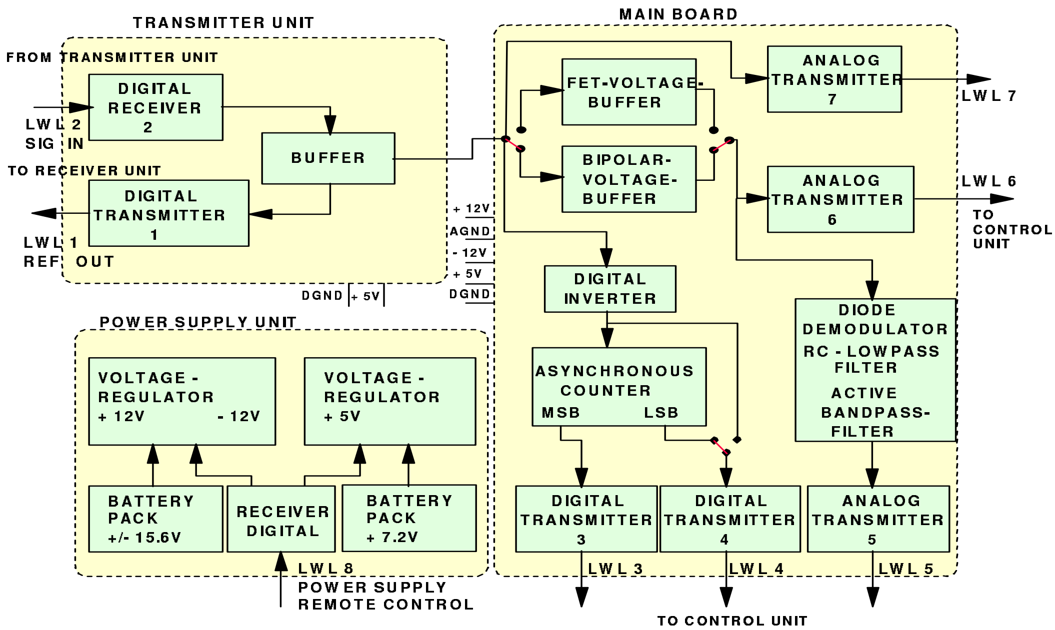


Figure 2.3: *Schematic figure of the electronics inside GENEC. Reprint from [1] with permission of DIEHL. (LWL = Lichtwellenleiter is German for FOL = Fibre Optic Lead)*

above the electronics consist of a digital and an analog part. They both have the same input signal (generated in the control box).

The input signal can be seen in Fig. 2.4. The signal is repetitive with a 50% duty-cycle and a pulse length of $65ms$. Every pulse consists in its own of 50 pulses with a pulse length of $650\mu s$.

[1]The input signal from FOL 1 is simply received in GENEC and resent back to the control box through FOL 2.

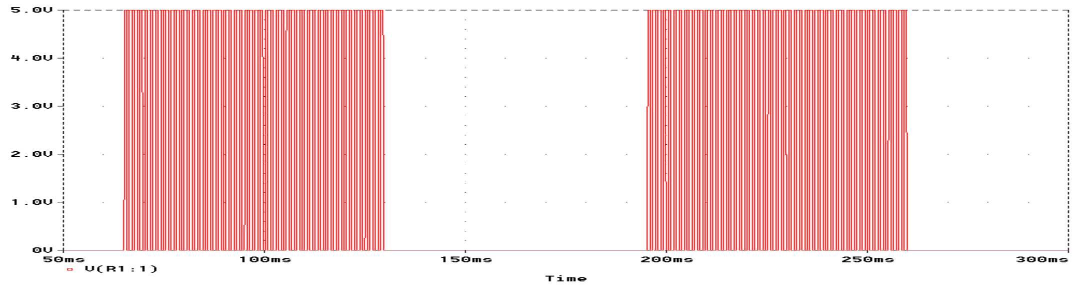


Figure 2.4: *The input signal to GENEC. Every* 65*ms long pulse consists of 50* 650*µs long pulses. Reprint from [1] with permission of DIEHL.*

2.2.1 Analog electronics

There are three well-defined signal measurement points within the analog part of the electronics. The corresponding signals of measurement points 6 and 5 can be seen in

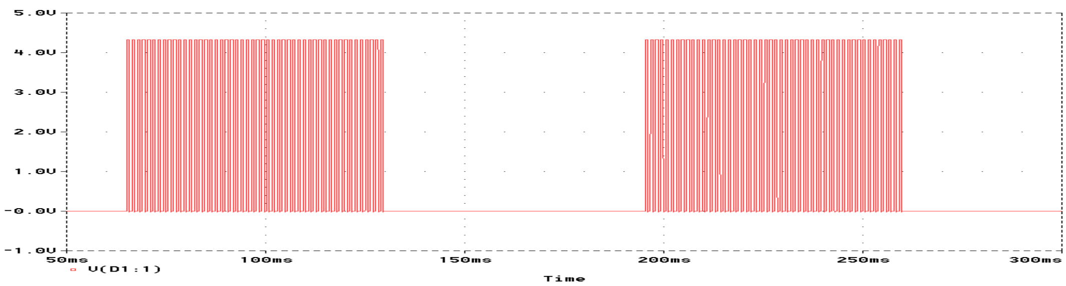


Figure 2.5: *In signal* 6 *the input signal has passed through an emitter follower. Reprint from [1] with permission of DIEHL.*

Fig. 2.5 and Fig. 2.6, respectively. The numbers 7, 6 and 5 correspond to the number of the fibre optic leads as seen in Fig. 2.3. Signal 7 is again nothing else than a copy of the input signal. It can be used to test that the analog electro-optic converters work properly. In signal 6 the input signal has passed through an emitter follower. In signal 5 the input signal has also passed through a mixer (diode demodulator) and a band-pass filter.

2.2.2 Digital electronics

The digital electronics has two well-defined signal measurement points. The input signal is connected to the clock input of an asynchronous counter. At the output

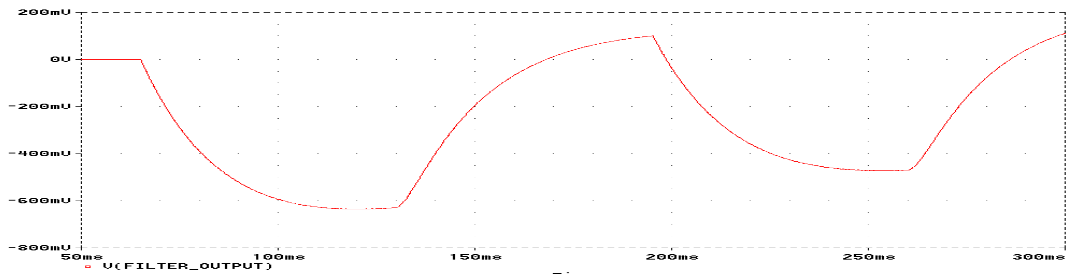


Figure 2.6: *Signal* 5 *consist of signal* 6 *after it has passed through a mixer and a band-pass filter. Reprint from [1] with permission of DIEHL.*

of the asynchronous counter signal 4 is measured. In signal 4 the 50 650μs long pulses have been decreased to 25 1.3ms long pulses (Fig. 2.7). Signal 4 re-enters the

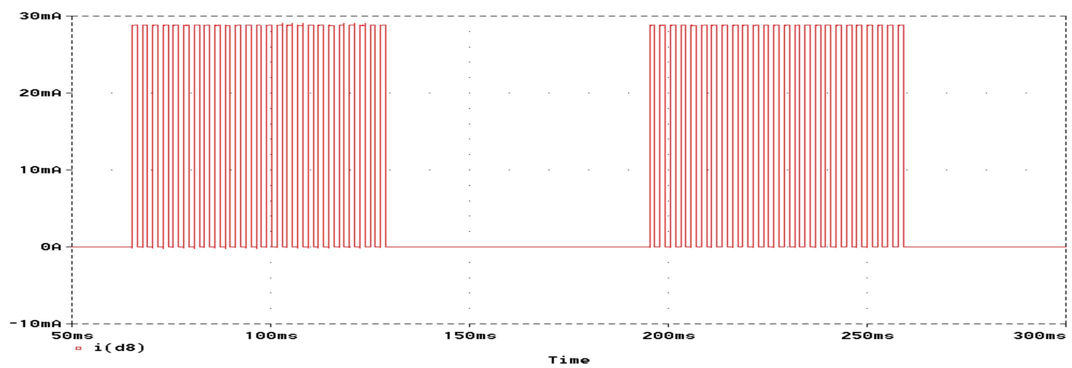


Figure 2.7: *In signal* 4 *the number of pulses has been halved and the pulse length has been doubled compared to the input signal. Reprint from [1] with permission of DIEHL.*

asynchronous counter through a second clock input, and at a second output signal 3 is measured. In signal 3 the 25 1.3ms long pulses have been decreased to five 2.6ms long pulses (Fig. 2.8). When the electronics is turned on, the signals sometimes are the inverse of the above signals.

2.2.3 Power supply unit

The digital electronics is driven by a 7.2V battery package, and the analog electronics is driven by two 15.6V battery packages. One of the analog battery packages also drives the electro-optic converters inside GENEC.

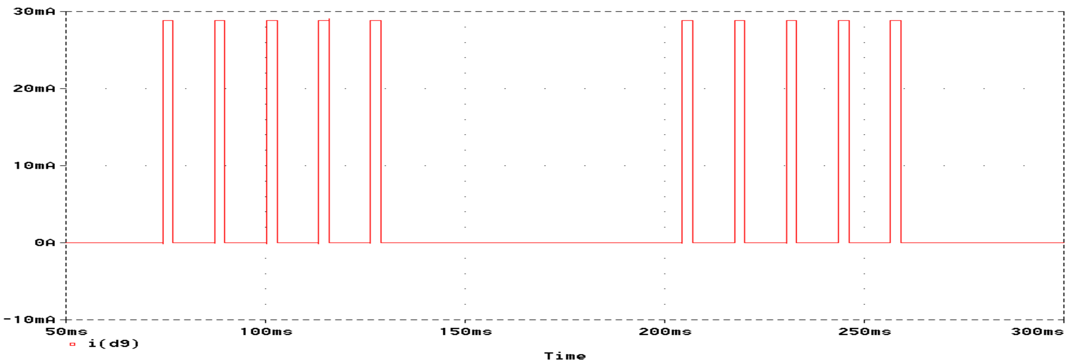


Figure 2.8: In signal 3 the pulse length has been doubled a second time, but the number of pulses is now only a tenth of the original number in the input signal. Reprint from [1] with permission of DIEHL.

2.3 Disturbance criterion

One very essential question is to define a malfunction, i.e. to define an unequivocal disturbance criterion for the electronics. In many RS-tests, e.g. [9, 10] the test object is put in a proper position while the operation of the test object is monitored during the irradiation.

In this report, one of the essentials is to examine the angular dependence of the disturbance in a RS-test of the test object, see section 3.2, but not to investigate how the disturbance changes with the strength of the irradiation field. One of the prerequisites to get a correct result is that we have a clear and unequivocal criterion for when the electronics is disturbed. It also has to be possible to apply the criterion in the same manner for all irradiation directions of the test object.

Still another restriction is that the evaluation of the criterion has to be fast. As the considerations in section 3.2.3 show we have to repeat the RS-tests for 120 irradiation directions. Let us assume that one single RS-test takes 5 minutes. That makes a

$$totaltime = 120\ angles \times 5\ minutes/angle = 600\ minutes = 10\ hours. \tag{2.1}$$

Also knowing that we have to be very focused during the whole test, we have to stop for eating, we have to take rests, it takes us one hour to start up the test, almost an hour to close down the test, accidents and mistakes happen during the test, other people want to talk to us during the experiment and the MTF does not work properly during the whole time; we are talking of 15-16 hours for doing this test. It should be noticed that this is for only one orientation of GENEC on the turntable and only one polarization of the irradiating field. Also knowing that there are regulations which does not allow us to do testing during 15 hours[2], we had to find a RS-test which for each angle of incidence is faster than 5 minutes[3].

Knowing these two conditions, we decided not to use the analog electronics, since any disturbance in the analog electronics will occur gradually, and hence it is hard to define an unequivocal disturbance criterion for the analog electronics. With help of e.g. [9] it can be seen that with some chosen criteria, the disturbance can in some regions decrease with an increased applied irradiation field.

For the digital electronics the disturbance criterion is in principle easier due to that a digital signal is all the time regenerated as a nice 0 or 1. So we can just look on our signals 3 and 4 (section 2.2.2), and when we have increased the strength of the irradiating field so much that a 1 switches to a 0 or vice versa, we say that we have a disturbance of the electronics.

Everyone who knows something about digital communication knows that we actually should apply a more statistical model. There is always a risk that a 0 switches to 1 or vice versa, due to noise. Often one say that we can accept if one bit are wrong out of 10^9 or 10^{12} bits. One say that a bit error rate (BER) of 10^{-9} or 10^{-12} is acceptable.

However, to do such a bit error analysis for every angle of incidence, would take by far to long time. (Compare with the result above that already 5 minutes is a too long time.) However in the tests done in the Reverberation Chamber at FOI it has been possible to show that at a certain field strength we have a distinct permanent switch from 0 to 1 or vice versa for a substantial part of the repetitive signals 3 and 4. This distinct permanent switch we define as the disturbance criterion. The field strength that only just causes the disturbance is monitored and saved.

A more accurate BER-analysis would possibly show that it is possible to disturb the electronics at lower field strengths. If that have any implication on the angular dependence is hard to say. A very accurate investigation in the Reverberation Chamber has shown that at slightly lower field strengths than necessary for disturbance, the electronics have problems to trigger and the pulses jump a bit forth and back in time. This only happens within $0.2 - 0.3\ dB$ before the disturbance in accordance with the above definition occurs.

In 99% of all tests, the disturbance has first occurred in signal 3. This is expected due to that the measurement point of signal 3 is positioned after the measurement point of signal 4 in the signal chain. When a disturbance has occurred in signal 4 first, only a slight increase of the field strength has implied a disturbance in signal 3 as well.

[2]Anyhow, we did work almost 12 hours per day at the MTF, and almost all the time the work was concentrated with no time for relax and very little variation in the work.

[3]As it would turn out it was a necessary condition that we could tune the field strength of the irradiating field (section 3.2), and did not have to increase it by steps.

Chapter 3

Description of measurements

The purpose of our work is to investigate the angular dependence of the susceptibility in a RS-test and compare it with the angular dependence of a similar coupling measurement. We are typically interested to find out if the two measurements give the same angular dependence, directivity, lobe widths etc.

3.1 Coupling measurements

The coupling measurements were performed in the large Anechoic Chamber at FOI. Two field probes, A and B, were installed inside GENEC, see Fig. 3.1. Each probe

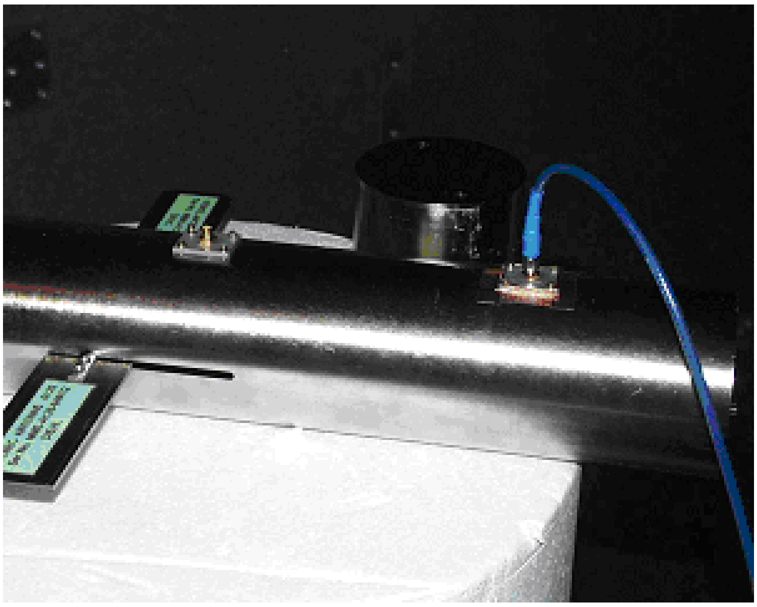


Figure 3.1: *The figure of GENEC shows the wings, one wing slot, and the location of the two field probes. Probe A, located close to the wing slots, is not connected in this figure, but Probe B, located closer to the electronics is connected.*

consists of a SMA connector in which a 20 mm centre conductor is inserted, see Fig. 3.2. The probes are regarded to be representative for the receiving properties of

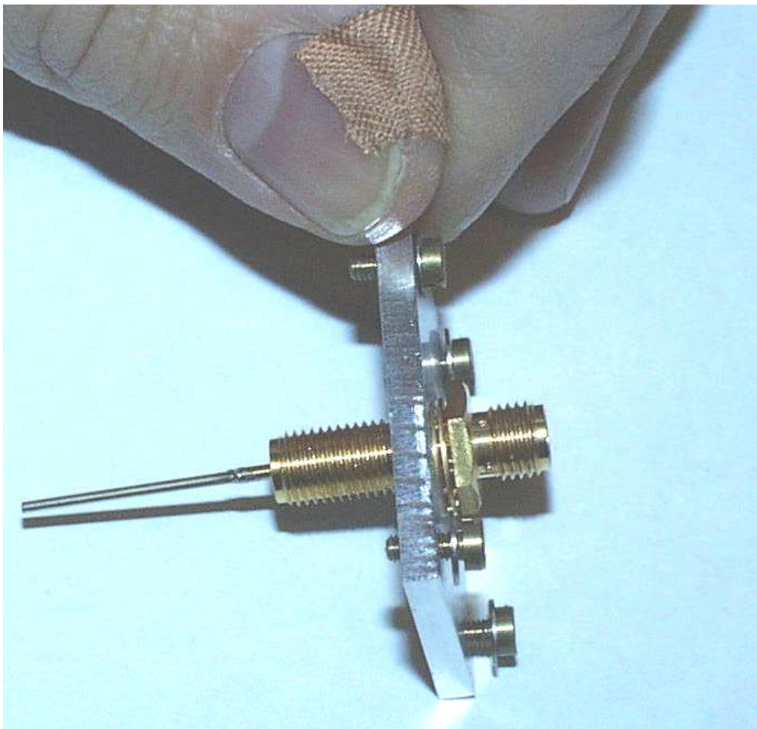


Figure 3.2: *A close-up of the field probe and its connector. The part left of the metal plate is inside GENEC.*

typical cables and wires.

The measurements are well described in [11], but there are a few things we would like to point out here. GENEC is irradiated with a plane wave of power density S_{inc}, and the field probes inside GENEC receive the power $P_{rec,probe}$. To quantify the coupling measurements we use the cross section,

$$\sigma \triangleq \frac{P_{rec,probe}}{S_{inc}}, \tag{3.1}$$

which is a sort of an effective area for the field probe inside GENEC with reference to the incident power density.

The coupling measurements were performed in three planes with an angular resolution of one degree. Two polarizations were used in each plane.

3.2 RS-tests

The high-level RS-tests were carried out using the Microwave Test Facility (MTF), owned by the Swedish Defence Material Administration (FMV) and operated by Saab

Figure 3.3: *The Microwave Test Facility (MTF). On top of the MTF the S-band* (2.857 GHz)*, the L-band* (1.300 GHz)*, the C-band* (5.710 GHz)*, the X-band* (9.300 GHz) *and the Ku-band* (15.00 GHz) *antenna, respectively, can be seen.*

Avionics in Linkping, see Fig. 3.3. The MTF is described in [4]. High-level tests were also performed in the FOI Reverberation Chamber.

3.2.1 General description of the RS-test at the MTF

To irradiate GENEC, it was put 15 m in front of the S-band antenna in the middle of the main antenna lobe, see Fig. 3.4. In the control room the operating personal was watching the oscilloscope screen to see if any disturbance on the electronics occurred. All communication between GENEC and the control room was done through the Fibre Optic Link.

As stated above, a purpose of the work is to investigate the angular dependence of the RS-test. Of course we would like to investigate the whole solid angle but due to limited time and equipment, we had to limit the RS-test to radiation in one plane of GENEC. By putting GENEC on the top of a turntable, see Fig. 3.5, we could rotate GENEC 360 degrees in this plane. The irradiation was made in the wing plane of GENEC, see Fig. 3.5 and cf. [11]. Two different polarizations of the irradiation field were used, vertical and horizontal, respectively, to the wing plane of GENEC.

For every orientation of GENEC, the field strength of the irradiating source (MTF) was slowly increased, until we finally saw a disturbance (section 2.3) in the GENEC electronics. The minimum power density that caused this disturbance (S_{min}) was monitored. Then the irradiating field was turned off, GENEC was rotated a little bit, and the same procedure was repeated. All measurement data can be found in appendix A. All information in appendix A is given exactly as it was written down

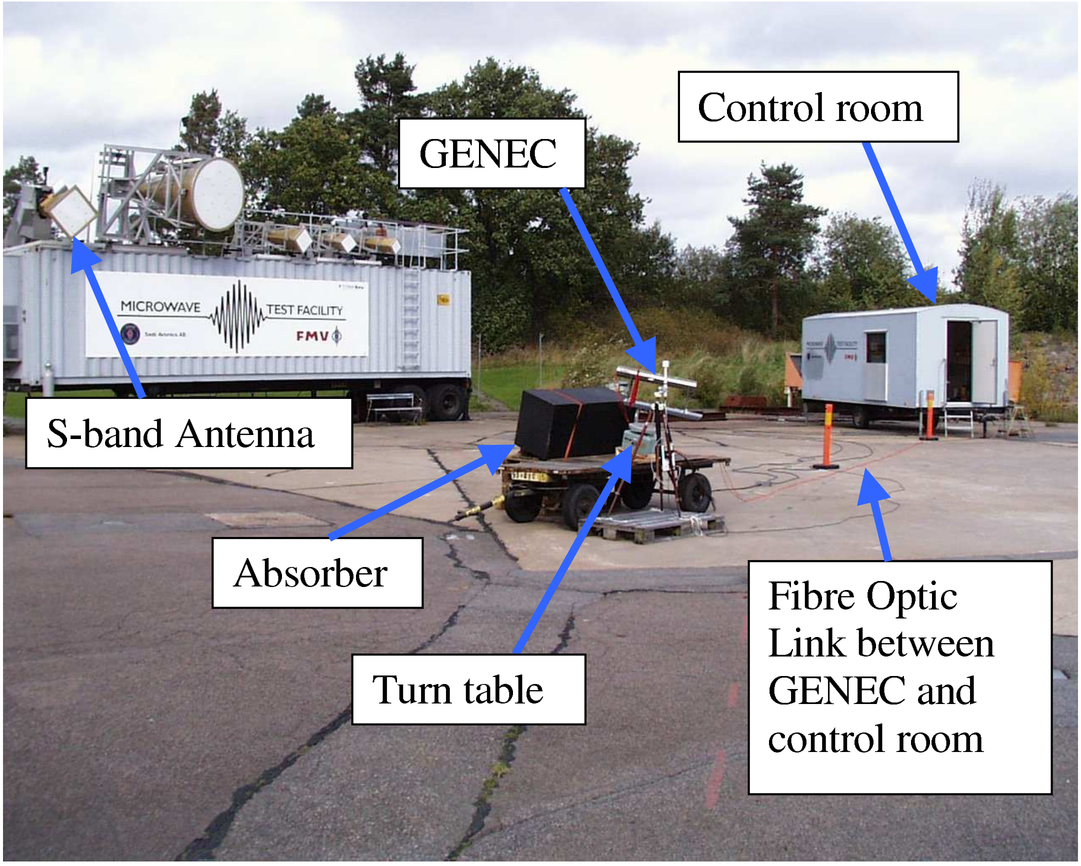


Figure 3.4: *GENEC is irradiated from the S-band antenna. All communication to and control of GENEC is monitored in the control room with help of the Fibre Optic Link. To ensure that the irradiation do not disturb the turn table an absorber is put in front of the turn table.*

at the test site. We hope that nobody find the familiar touch shocking.

The field strength (rms) was varied between 250 V/m and 13 kV/m, i.e. the power density between 0.17 kW/m^2 and 0.45 MW/m^2. As can be seen in appendix A, it would have been beneficial to go outside this interval for a few orientations of GENEC. That was not possible due to that we did not have any accuracy for irradiation fields below 250 V/m. At the time of our test, the MTF did not work properly and hence we did not get the maximum irradiation field of 30 kV/m according to specification [6], but had to accept a maximum field of 13 kV/m.

The MTF worked in a pulse mode with a pulse length of 4.7 μs and a pulse repetition frequency of 30 Hz. That was the maximum pulse length we could get from the MTF. We wanted it to be as long as possible, to be able to compare the results with the RS-test results from the Reverberation Chamber. Due to the high Q-value in the Reverberation Chamber, the field does not reach its steady state value when short pulses are used, and hence the result in the Reverberation Chamber is doubtful for short pulses. A pulse repetition frequency of 30 Hz was the maximum

Figure 3.5: *GENEC on top of the turntable. GENEC does here rotate in the wing plane. During all RS-test GENEC was positioned on the turntable as in this figure.*

pulse repetition frequency we could get in the continuous mode operation of the MTF.

To quantify the RS-test we define the Susceptibility of a RS-test as,

$$Susc(\varphi) \triangleq \frac{1}{S_{min}(\varphi)}. \tag{3.2}$$

For the angles (φ) where only a small power density is necessary to create a disturbance in the electronics, the susceptibility is large, and vice versa. This is in good agreement with the common meaning of the word susceptibility. This definition gives the susceptibility the unit m^2/W.

3.2.2 Choice of frequency

It would be very interesting to do the RS-test as function of frequency. However, the MTF only has five fixed frequencies (1.300 GHz, 2.857 GHz, 5.710 GHz, 9.300 GHz and 15.00 GHz). Due to limited time and resources we also early understood that we would only manage to do the RS-test for one frequency.

Our early RS-tests in the Reverberation Chamber showed that to see a disturbance in the GENEC electronics a field strength of the order 1 kV/m was necessary. We also knew from coupling measurements on GENEC that the difference between the average and minimum coupling is of the order 30 dB [12]. Hence, if the difference in the RS-test is of the same order[1], a field strength of the order 30 kV/m would be

[1] As can be seen in chapter 4 the difference is smaller in the RS-test, but that we did not know at this time.

necessary to see a disturbance in all irradiation directions during the RS-test. Also knowing that 30 kV/m is the maximum field strength which can be reached in the MTF, we assumed that it probably would be quite close if we should be able to disturb the GENEC-electronics for all angles of incidence. Hence it was essential to choose the frequency with the smallest disturbance field.

To find the frequency with the smallest disturbance field we can go through some calculations and considerations. We assume that the receiving properties of the electronics inside GENEC can be modelled as some sort of antenna. It is also very well known that the receiving cross section of an antenna can be calculated as [13],

$$\sigma = \frac{\lambda^2}{4\pi} D(\nu,\theta,\varphi) p(\theta,\varphi) q(\nu) \eta(\nu), \tag{3.3}$$

where $D(\nu,\theta,\varphi)$ is the directivity of the antenna, $p(\theta,\varphi)$ is the polarization mismatch factor (between the antenna and the electro-magnetic irradiation field), $q(\nu)$ is the impedance mismatch factor of the antenna and $\eta(\nu)$ is the radiation efficiency, which accounts for ohmic losses. The directional dependence is given through the dependence of the two polar coordinates, θ and φ, and ν is the frequency.

The electro-magnetic field environment inside GENEC is rather isotropic, and hence it is a rather good approximation to interchange $D(\nu,\theta,\varphi)$ and $p(\theta,\varphi)$ with their average values, which by definition are [14],

$$D_{av} = 1, \tag{3.4}$$

and,

$$p_{av} = \frac{1}{2}. \tag{3.5}$$

With (3.4) and (3.5) put into (3.3), we get,

$$\sigma_i = \frac{\lambda^2}{8\pi} q(\nu)\eta(\nu), \tag{3.6}$$

where the index i has been introduced to denote that σ_i refers to the isotropic field inside GENEC.

The impedance mismatch factor ($q(\nu)$) fluctuates strongly with the frequency [11], but if frequencies below 3 GHz are excluded there is no general trend. For the coupling measurements done in [11], there are e.g. more than 40 maximum and minimum points between 4 GHz and 5 GHz. We assume that the radiation efficiency ($\eta(\nu)$) is frequency independent.

Hence we can conclude, as a general trend, that the susceptibility increases with the wavelength as,

$$Susc. \propto \lambda^2. \tag{3.7}$$

If we also include that the susceptibility of the components itself increases with the square of the wavelength [15], we get,

$$Susc. \propto \lambda^4 \propto \frac{1}{\nu^4}. \tag{3.8}$$

An indication of the validity of (3.8) is that it is in general agreement with RS-tests done on poorly shielded objects, which show that it is very hard to show any disturbance in the electronics for higher frequencies, see e.g. [10].

Hence, it could be easy to conclude that we should use the lowest frequency, 1.300 GHz. However, GENEC is rather well shielded and in the considerations above we have referred to the internal field inside GENEC. In [11] it is shown that the shielding effectiveness of GENEC increases with the order of 30 dB just for 1.3 GHz and lower frequencies. The impedance mismatch factor also decreases with around $10-15$ dB between 3 GHz and 1.3 GHz [11]. We therefore decided to use the second lowest frequency, 2.857 GHz. Using a higher frequency also has the advantage that at higher frequencies the directional variation is larger [13, 11], and hence we probably get a more interesting directional pattern.

3.2.3 Choice of angular resolution

In the coupling measurements we had a resolution of one degree, but as stated in section 2.3, it is very critical to limit the number of measurements. Hence, it was satisfying to have a formula that gives the maximum sampling increment [16, 11],

$$\Delta\theta_{max} = \frac{180^\circ}{kr_0 + 10}\ , \tag{3.9}$$

where $k = 2\pi/\lambda = 2\pi\nu/c$ and r_0 is the radius of the smallest possible spherical surface circumscribing GENEC. Equation (3.9) is a sampling formula corresponding to the minimum number of samples necessary to include the highest significant wave mode present in the radiating field from GENEC [16].

By putting the frequency 2.857 GHz and half the length of GENEC, 408 mm, into (3.9), we get a maximum sampling increment of 5°. We decided to choose a sampling increment of 3° to have a small safety margin.

Chapter 4

Results

This chapter shows the results of the RS-tests and compare the results with the coupling measurements. In all measurements GENEC has been irradiated in the wing plane (see section 3.2.1).

4.1 RS-test

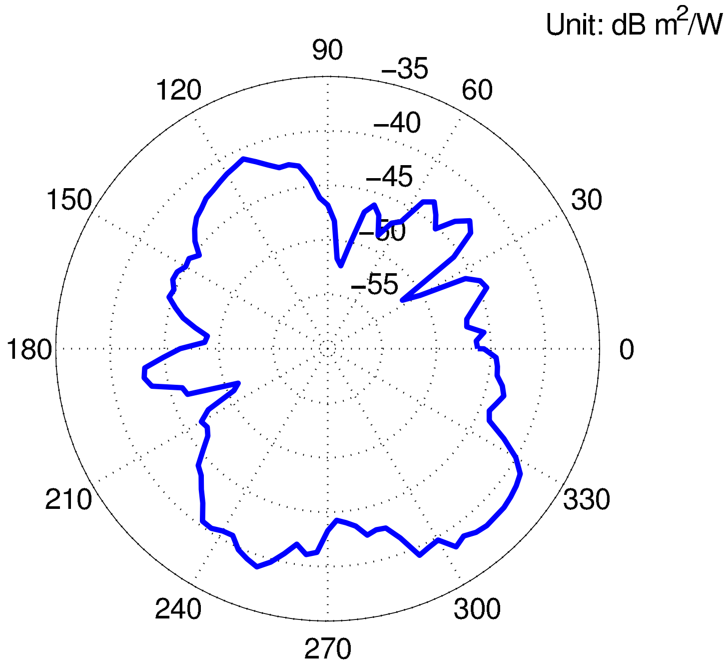


Figure 4.1: *The susceptibility of GENEC when irradiated in the wing plane. The polarization of the electro-magnetic irradiation is horizontal to the wing plane.*

The figures 4.1 and 4.2 show the susceptibility of GENEC in the wing plane for horizontal and vertical polarization, respectively, of the electro-magnetic irradiation.

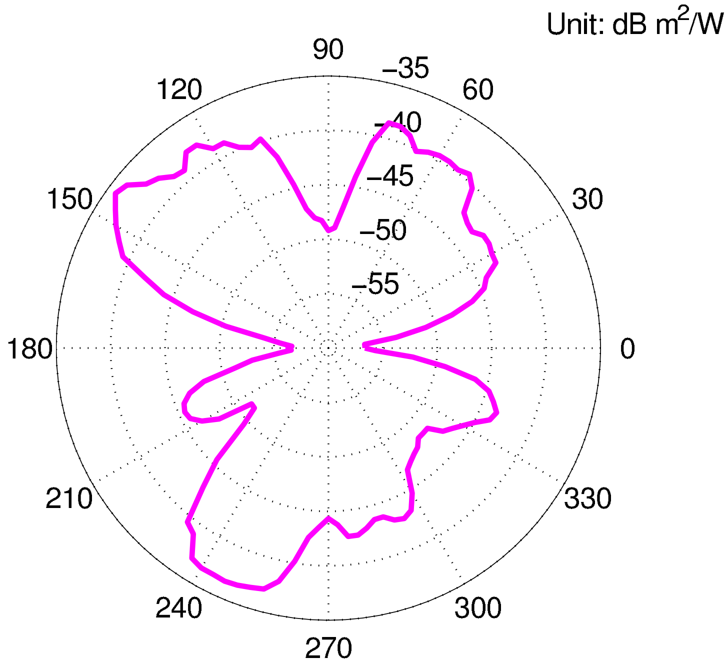


Figure 4.2: *The susceptibility of GENEC when irradiated in the wing plane. The polarization of the electro-magnetic irradiation is vertical to the wing plane.*

Figure 4.3 shows how the directions are defined. In Fig. 4.4, the figures 4.1 and 4.2 has been merged together in one figure. The first most obvious notation is that the susceptibility differs between the two different polarizations, but the general looks of the two curves, e.g. lobe widths, are similar. The maximum susceptibility is approximately 3 dB larger with the vertical polarization applied[1]. For the irradiation directions 0° and 180°, the susceptibility is small for the vertical polarization. This is due to that for 0° and 180°, only the ends are directed toward our irradiating source (MTF). The ends are very well shielded, and hence the susceptibility is low for these two directions.

However, the argumentation above is equally true for the horizontal polarization, and for the horizontal polarization no similar decrease can be seen in the susceptibility for the directions 0° and 180°. The cause is probably the wings which act as antennas. The horizontal polarization will in difference to the vertical polarization drive current in and out of the wing axes. The current is reradiated inside GENEC and thereof might disturbances in the electronics inside GENEC be caused. This can explain why there is no decrease in the susceptibility for the directions 0° and 180°, when the horizontal polarization is applied. The phenomenon might be affected by resonances in the wings, but so far we have not been able to develop any simple theory for that.

[1]This can be explained knowing that most of electro-magnetic coupling to the interior of GENEC is done through the wing slots. For the vertical polarization, the electric field is perpendicular to the wing slots and hence giving a stronger coupling. This can also be shown more strict by use of the so called Babinet's principle, see e.g. chapter 10.8 in [17].

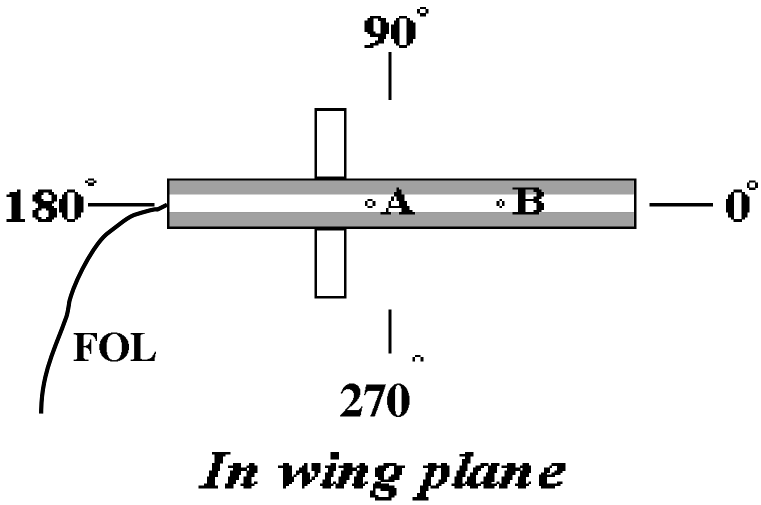


Figure 4.3: *GENEC is rotated* 360° *in the wing plane, and the different directions are defined in accordance with this figure.*

4.2 Repeatability of RS-test

Because it was the first time we did this kind of investigation, we did not know if we had any repeatability in our measurements. Our results could have occurred by chance. We therefore decided to completely dismount the test-up. We went home for the night. It rained during the night. The next day we rebuild our test set-up as equally as possible as we had done the day before. It was not easy to get all equipment in the exact same position, and the differences might have been a few centimetres. However the error in direction of the orientation of GENEC toward the MTF was not larger than one degree.

The results in Fig. 4.5 show that the repeatability is good and that we can show confidence in our measurements. The source of errors to the differences which, after all, can be seen are manifold including that the operation of MTF is a bit uncertain sometimes, the position of our test set-up did differ a little bit between the two days, our disturbance criterion (see section 2.3) might not be unequivocal and hysteresis etc. in the electronics might change the condition of the electronics.

The normal operation uncertainties of the MTF is known to be ±14% for the electro-magnetic field strength [18]. In Fig. 4.6, the upper and lower bounds for the susceptibility, when the MTF uncertainties are included, is shown. Thereof it follows that the discrepancy of the two curves in Fig. 4.5 can largely be explained by the uncertainty in the field strength from the MTF except for a narrow angle interval around 270°.

The small susceptibility for the narrow angle interval around 270° for one of the RS-tests is apparent. We repeated the RS-test around 270° and decreased the sampling interval to one degree. We did the same also for a few other directions, and as can be seen in Fig. 4.7, the repeatability between two RS-test done just after each

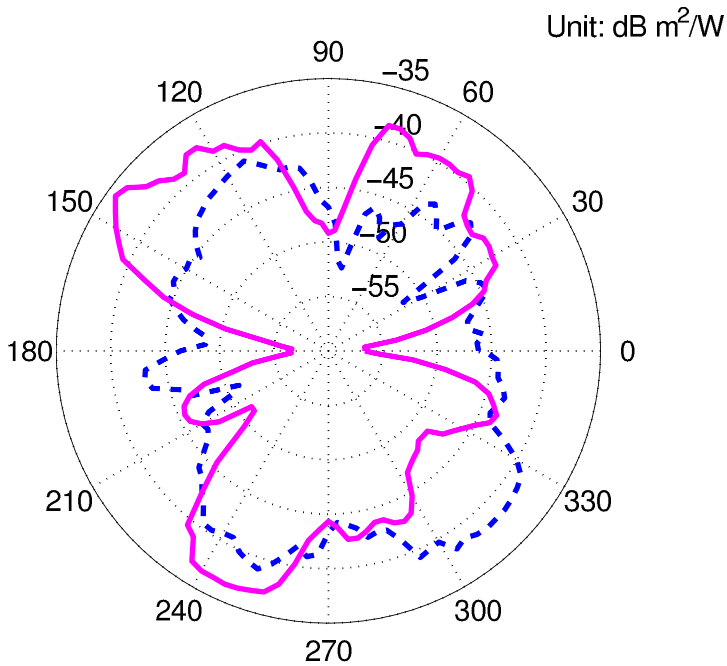


Figure 4.4: *The blue dashed curve shows the susceptibility of GENEC when the polarization of the electro-magnetic irradiation is horizontal to the wing plane. The magenta solid curve shows the susceptibility of GENEC when the polarization is vertical to the wing plane.*

other is very good. It is also clear that there is a narrow angle interval around 270° where the susceptibility is very small.

We do not know why this dip in the susceptibility curve could not be seen the first day. It is possible that it is due to that this narrow dip can only be seen for a very specific orientation and position of GENEC, and that the difference of the position and orientation of GENEC between the two days was too big to see the dip in the susceptibility curve both days. See also section 4.4.

4.3 Comparison between RS-test and Coupling measurements

As can be seen in chapter 3 the unit in a coupling measurement is m^2 but m^2/W in a RS-test. To be able to compare the two different quantities we calculate the directivity for both measurements. We define the directivity in accordance with the IEEE-standard [19]. For the coupling measurements we calculate the directivity as,

$$AD(\varphi_i) = \frac{\sigma(\varphi_i)}{\overline{\sigma}}, \quad (4.1)$$

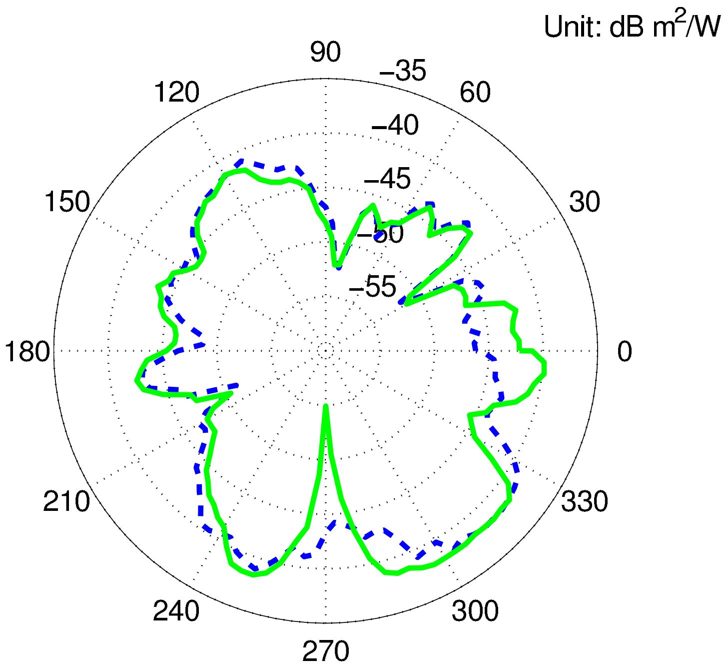


Figure 4.5: *Repeatability of RS-test. The blue dashed curve shows the susceptibility of the first day's RS-test. The next day, the same RS-test was repeated and the green solid curve shows that the repeatability of the first day's RS-test is good.*

where $\{\varphi_i\}$ is the set of angles in the wing plane, where we have measured the cross section $(\sigma(\varphi_i))$ according to (3.1), and $\overline{\sigma}$ is the average cross section over all this angles. To calculate the true directivity we should have placed the average over all solid angles in the denominator of (4.1), but as stated in 3.2.1 it has not been able to do the measurements for all solid angles, but only in one plane. To emphasize that we actually introduce an error by doing the averaging in only one plane, we use the expression apparent directivity (AD) [20]. In an equivalent way the apparent directivity of the RS-test is calculated as,

$$AD(\varphi_i) = \frac{Susc(\varphi_i)}{\overline{Susc}} \ . \tag{4.2}$$

By the introduction of the apparent directivity we have two comparable dimensionless quantities. The (apparent) directivity is also in itself a very valuable quantity telling us e.g. how much larger the susceptibility is one direction compared to the (apparent) average susceptibility over all directions.

Before going on to show the actual results, the author would like to stress one thing. Strictly speaking, what we have defined above in (4.1) and (4.2) is not the directivity in accordance with the IEEE-standard [19], but the product of the directivity and the polarization mismatch factor. However, knowing that there is no common accepted expression for this product, also knowing that people in the field use the word directivity for the product and every time we have tried to introduce

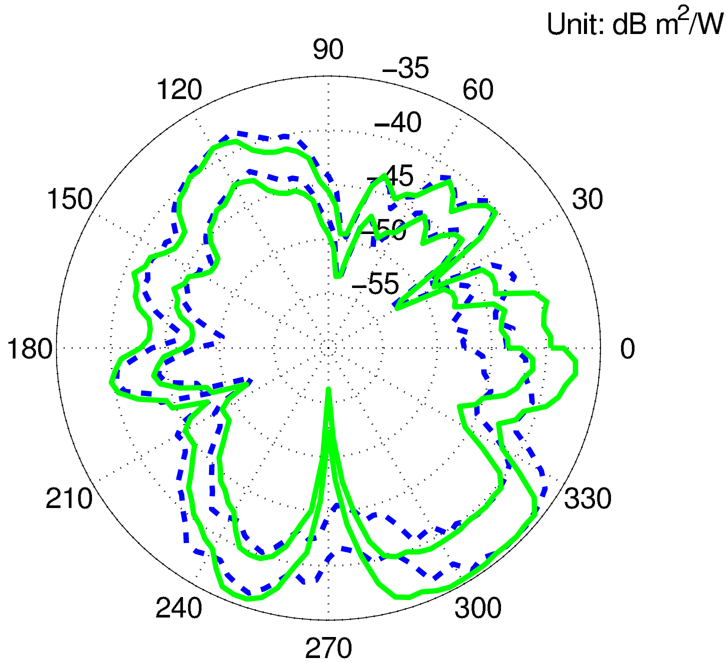


Figure 4.6: *Repeatability of RS-test with uncertainty margins. This figure is in principal the same as Fig. 4.5, but here are the maximum and minimum susceptibilities shown when the uncertainties of the MTF are taken into account. As long as one of the green solid curves are within the two blue dashed curves, or one of the two blue dashed curves are within the two solid green curves, the discrepancy of the two curves in Fig. 4.5 can be explained with the uncertainty of the MTF.*

a new expression it only causes confusion, we have decided to use the word apparent directivity for the definitions in (4.1) and (4.2). To exemplify, we can take an isotropic environment, where the polarisation mismatch factor can be replaced with its average, $\frac{1}{2}$, and hence the true directivity is double the directivity given in (4.1) and (4.2).

In Fig. 4.8-4.11 the apparent directivities are plotted in polar diagrams. In all diagrams GENEC has been irradiated in the wing plane. In Fig. 4.8 and 4.9, the polarization of the irradiating field is horizontal to the wing plane, but in Fig. 4.10 and 4.11 the polarization is vertical to the wing plane. In all four figures the apparent directivity of the susceptibility has been plotted as a dashed line and the apparent directivity of the cross section has been plotted as a solid line.

The first most obvious result is that the apparent directivity of the susceptibility differs from the apparent directivity of the cross section. That is to be expected, because we have a standing wave pattern inside GENEC, and hence the field differs from position to position inside GENEC. The cross section does also differ between probe A and probe B, see e.g. Fig. 4.8 and 4.9. However, it is reasonable to assume that if we put our field probe closer to the electronics, the directivity of the cross section would become more similar to the directivity of the susceptibility. By comparing

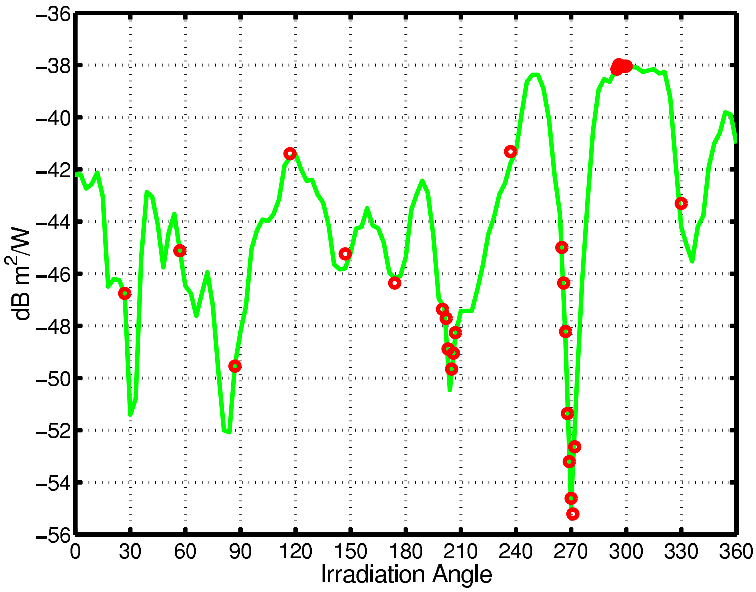


Figure 4.7: *For some angles the RS-test the second day was repeated. In the figure the repeated susceptibility measurements are indicated with red circles. Obviously the short time repeatability is very good. At some points the RS-test was repeated with a sampling increment of one degree, and as there are no red circles outside the green curve, this indicates that the sampling interval of three degrees is sufficient.*

Fig. 4.8 to 4.9 and 4.10 to 4.11, we can see that it is the case in reality too.

The important result is however, that even if the apparent directivity patterns differ, the principal shapes of the curves are similar. E.g. the lobe widths are similar, and most important, the maximum apparent directivity is almost identical. For the horizontal polarization in Fig. 4.8 and 4.9, the maximum apparent directivity of the cross section is 5.4 dB and 4.9 dB for probe A and probe B respectively, and the maximum apparent directivity for the susceptibility is 4.6 dB. For the vertical polarization in Fig. 4.11, the maximum apparent directivity of the cross section is 4.9 dB for probe B, and the maximum apparent directivity for the susceptibility is 6.0 dB[2].

This result is important. We have to remember though, that so far, we have little data and the results ought to be confirmed by more measurement and tests. However, if our data is confirmed, it tell us e.g. that we can get the average susceptibility from a RS-test in a Reverberation Chamber, and the difference between the maximum and average susceptibility can be found in a low level coupling measurement. A typical difference between the maximum and average cross section in a coupling measurement

[2]The one who studies our reports carefully, will notice that in e.g. [2] the maximum apparent directivity is said to be typically $10 - 15$ dB, but here we have a difference of only ≈ 5 dB. The explanation is twofold. First, the difference decreases for lower frequencies and in [2] the results were given up to 18 GHz. Secondly, we have only done the RS-test for one frequency ($2.857GHz$), and for some discrete frequencies the apparent directivity is smaller than our rule of thumb, $10 - 15$ dB. It would, once again, be interesting to repeat the RS-test for other frequencies.

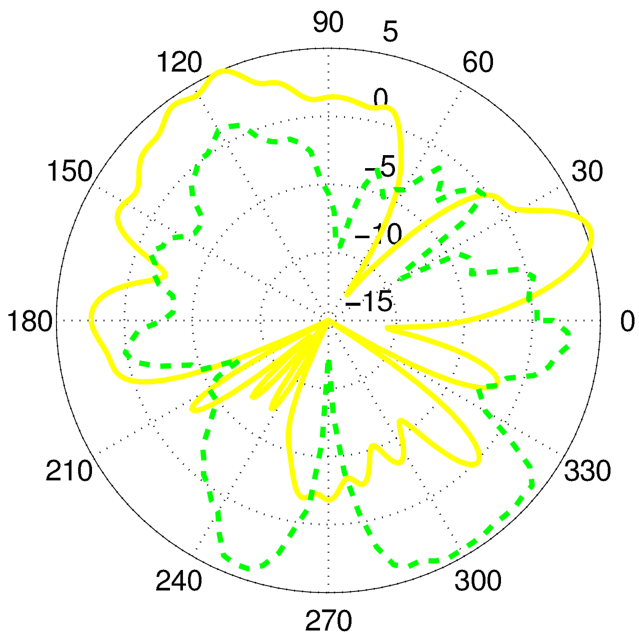


Figure 4.8: *The yellow solid curve shows the apparent directivity of the cross section of probe A. The green dashed curve shows the apparent directivity of the susceptibility of the electronics inside GENEC. GENEC was irradiated in the wing plane with the polarization horizontal to the wing plane.*

can also be found in earlier reports [2]. Thereby we have fulfilled the desire to avoid the high level RS-test as described in the Introduction of this report.

Figure 4.10 needs an extra comment. The maximum apparent directivity of the cross section in the coupling measurement is here much larger (11.7 dB) than in the other measurement. The reason is that probe A is located so close to the wing slots that it is hit by a direct wave when GENEC is irradiated at the long sides, see Fig. 3.1. Due to the location of the wings the largest apparent directivities of the cross section do not occur at 90° and 270°, but at 75° and 285°. The large apparent directivities do occur for the vertical polarization, but not for the horizontal polarization due to the orientation of our field probe, see Fig. 3.1 and 3.2. For the horizontal polarization, the electric field of the incident wave and the field probe are orthogonal, and hence the field probe is not affected by any direct wave.

In Fig. 4.8-4.11, we can clearly see that the apparent directivities of the cross section and susceptibilities are most similar in Fig. 4.11. That is, as stated above, partly due to that probe B is located closer to the electronics than probe A, but that does not explain the difference between Fig. 4.9 and 4.11. The explanation is probably that with the incident field being vertically polarized, the vertical electric field component inside GENEC will be larger than the horizontal component[3]. Hence it is reasonable to assume that it is the vertical electric field component rather than the

[3]Despite we have a standing wave inside GENEC, GENEC does not act as a perfect Reverberation Chamber and many of the incident field's properties are kept inside GENEC.

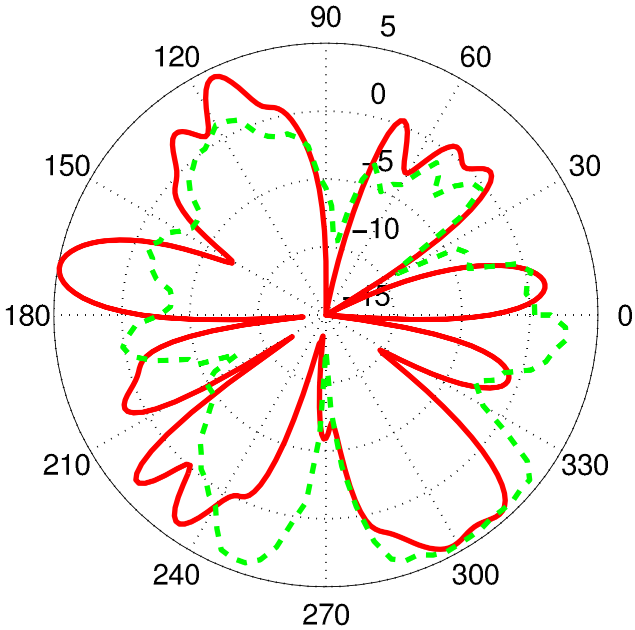


Figure 4.9: *The red solid curve shows the apparent directivity of the cross section of probe B. The green dashed curve shows the apparent directivity of the susceptibility of the electronics inside GENEC. GENEC was irradiated in the wing plane with the polarization horizontal to the wing plane.*

horizontal field component that creates a disturbance in the electronics. Similarly, if the incident field is horizontally polarized the horizontal component of the electric field inside GENEC will create the disturbance. However, our field probe is vertically oriented, see Fig. 3.1 and 3.2, and hence the correlation between the apparent directivity of the cross section and the apparent directivity of the susceptibility is larger in Fig. 4.11 than in Fig. 4.9.

Probe B was actually not located exactly at the position of the electronics, but a few centimetres away from the electronics. It is possible that a closer location of probe B to the electronics, would have created an even closer correspondence between the two apparent directivities in Fig. 4.11.

4.4 The difference in the minimum apparent directivities

In difference to the maximum apparent directivity, the minimum apparent directivity is not at all the same for the susceptibility as for the cross section. That is not so clear in the polar diagrams in Fig. 4.8-4.11, partly because directivities below -15 dB are not shown there, but in the Cartesian diagram in Fig. 4.12 it is easy to see that the minimum apparent directivity is much lower (≈ 25 dB) for the cross

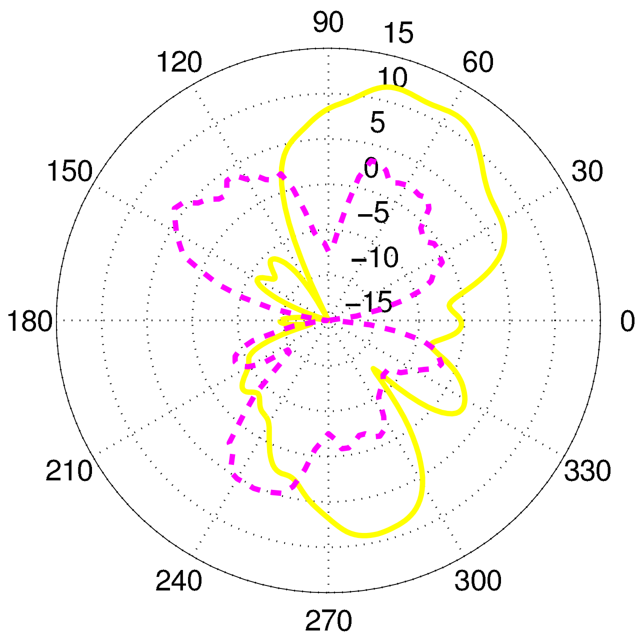


Figure 4.10: *The yellow solid curve shows the apparent directivity of the cross section of probe A. The magenta dashed curve shows the apparent directivity of the susceptibility of the electronics inside GENEC. GENEC was irradiated in the wing plane with the polarization vertical to the wing plane.*

section.

The effect has little practical impact, because there is probably no practical use in knowing that the cross section has very low values within a few narrow directions. It is the maximum directivity that has the most practical impact. However, knowledge of why it occurs might be useful during other circumstances, and here we propose one possible explanation.

The inside of GENEC does not work as a well closed (perfect) cavity, and hence the field pattern inside GENEC is not only a function of the GENEC geometry, but also of how GENEC is irradiated. For some irradiation directions our field probes become located in a node, and consequently the cross section of our field probe is very low there. This phenomenon creates the dips in the apparent directivity curves in Fig. 4.12.

The wires inside GENEC and within the electronics act as antennas, creating a complex linear antenna, as shown in Fig. 4.13 (a). The field received by this complex antenna creates the disturbance in the electronics. However, even a complex linear antenna will for some irradiation directions become located in a node, and consequently we should also for the RS-test see dips in the apparent directivity curves, but, as we can see in Fig. 4.12, we do not.

One possible explanation can be found in Fig. 4.13 (b). The electronics include non-linear elements (transistors, diodes etc.), and in the non-linear elements our digital electronic signals are regenerated. Hence we cannot model our wires as being one

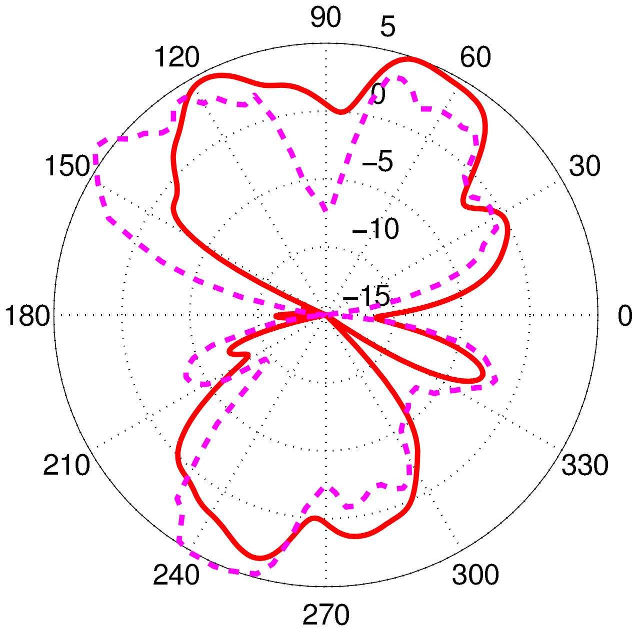


Figure 4.11: *The red solid curve shows the apparent directivity of the cross section of probe B. The magenta dashed curve shows the apparent directivity of the susceptibility of the electronics inside GENEC. GENEC was irradiated in the wing plane with the polarization vertical to the wing plane.*

antenna, but has to, as indicated in Fig. 4.13 (b), model the wires as two or more antennas.

So what happens when we see a disturbance in the electronics? One of this antennas works as principal antenna, creating the disturbance. When the irradiation direction is changed this principal antenna enters a node, and we should, as in the coupling measurements, see a dip in the apparent directivity curves, but now one of the other antennas start to receive electro-magnetic energy and creates a new disturbance in the electronics. Hence, no deep dips can be seen for the apparent directivity of the susceptibility in Fig. 4.12.

Of course there is a probability, though not very likely, that when the principal antenna enters a node the other antennas enter a node as well. That could possibly explain why we in Fig. 4.5 can see a dip in one of the susceptibility curves in the direction 270°. See also section 4.2.

4.5 Conclusions

The apparent directivity in an RS-test does generally differ in details from the low level coupling measurements, but they have similar lobe widths and the maximum apparent directivities are almost identical.

By choosing the position and direction of the field probe, such that it corresponds to the susceptibility of the electronics, a good agreement, between the directivities for

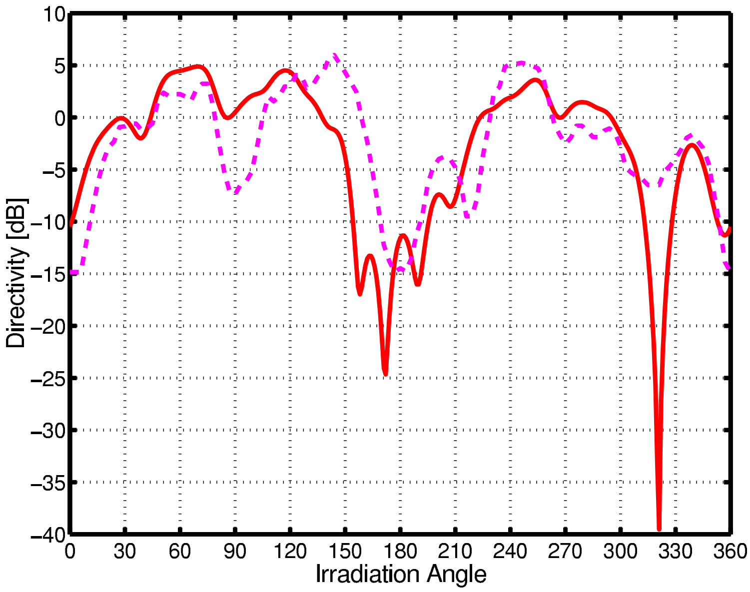


Figure 4.12: *The same graphs as in Fig. 4.11 but in a Cartesian diagram. The maximum apparent directivity of the cross section of probe B is almost the same as the maximum apparent directivity of the susceptibility, but the minimum apparent directivity is* ≈ 25 *dB lower.*

the susceptibility of the RS-test and the cross section of the coupling measurement, is found.

The conclusions are given with the reservation, that they are drawn outgoing from limited amount of data.

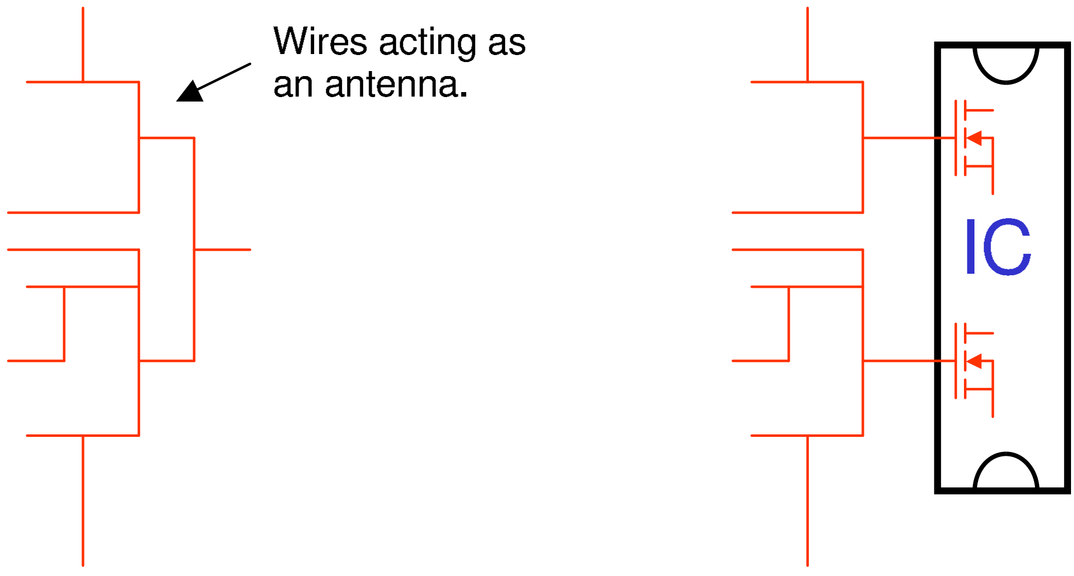
Acknowledgement

The Swedish Armed Forces and the Swedish Defence Material Administration financially supported this work.

Our thanks go to our German partners, Klaus Ruffing at WTD81 and the people at the Diehl Company for providing us with GENEC. Special thanks to Frank Sonnemann for all technical information about GENEC, and kindness in getting GENEC repaired.

Thanks to Gudrun Gjellan and Leif Jansson, both Saab Avionics, for a strong working spirit out at the MTF those autumn days in 2001.

Finally we thank our colleagues here at FOI. Especially, we thank Jörgen Lorén who performed the coupling measurements, Mats Bäckström for support and discussions, and Olof Lundén for help in performing the measurements.



(a) (b)

Figure 4.13: *Due to that the electronics include non-linear elements which regenerates the electronic signals, the wires can not be modelled as one single antenna as in (a), but need, as in (b), to be modelled as two or more antennas.*

Appendix A

RS-test Measurement data

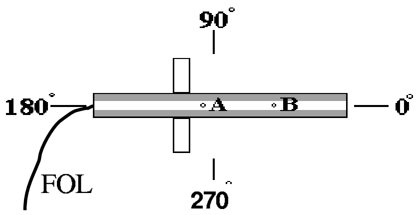
This appendix contains the measurement data. All information is given exactly as it was written down at the test site. We hope that nobody find the familiar touch shocking.

IN WING PLANE HORISONTAL POLARISATION 2001-10-03

Magnus Höijer, FOI
Leif Jansson, Avionics

GENEC vrids runt vingaxel

Irradiation directions:



In wing plane

S-band prf = 30 Hz Δt = 4.7μs

Vädret: Växlande molnighet, uppehåll, rätt soligt, >10*C, Måttlig vind, Behagligt

Narda prob snett bakom GENEC för att proba fältet.

E(kV/m) kolumens värden, avser de av Gudrun på plats skattade värdena.
Med hjälp av filerna Ucal.txt och Ecal.txt interpoleras mer exakta värden fram.

VINKEL(*)	Utfall (LWL)	U (mV)		E (kV/m)		Tid	Kommentarer	
0	3	9.8		4		10:28		
3	3 & 4	10.2		4.05				
6	4	8.1		3.65				
9	3	13		4.4				
12	3	12.5		4.2				
15	3	9.8		4				
18	3	7.6		3.55				
21	3	5.8		3.1				
24	3	6.3		3.3				
27	3	8.7		3.7		10:41	Kort break	
30	3	27.4		6.25		10:45		
33	3	38.8		7.5				
36	3	8.4		3.67				
39	3	4.1		2.75			Fasaner bakom GENEC	
42	3	3.28		2.55		10:52		
45	3	4.56		2.8				
48	3	7.2		3.5				
51	3	5.6		3.1				
54	3	4.4		2.8				
57	3	5.2		3		11:00	Kort Break	
60	3 & 4	11		4.1		11:04		
63	4 & 3	13		4.4				
66	4 & 3	18.8		5.1				
69	3	12.3		4.2				
72	3	9.6		3.95				
75	3	12.8		4.25				
78	3	27		6.25				
81	3	44		8				
84	3	37.6		7.5				
87	3	17.2		5		11:19	Kort Break	
90	3	12		4.25		11:26		
93	3	9.6		3.95				
96	3	5.8		3.1				
99	3	4		2.75				
102	3	3.64		2.7				
105	3	3.72		2.72				
108	3	3.08		2.5		11:36		

111	3	2.68		2.3		11:37		
114	3	2.32		2.15				
117	3	2.48		2.24		11:39	Kort Break	
120	3	2.6		2.3		11:44		
123	3	2.76		2.35				
126	3	2.92		2.45				
129	3	3.04		2.5				
132	3	3.56		2.68				
135	3	3.92		2.75				
138	3	4.68		2.85				
141	3	5.76		3.18				
144	3	7.7		3.6		11:55		
147	3 & 4	6.5		3.3		11:58	Lunch!	
150	3	6.7		3.45		13:42		
153	3	6		3.25				
156	3	5.9		3.2				
159	3	6.6		3.42				
162	3	6.3		3.33				
165	3	8		3.65				
168	3	10.5		4.05				
171	3	15.2		4.65		13:55	Mats B. ringer uppehåll	
174	3	20.2		5.45		13:59		
177	3	19.2		5.25				
180	3	10.6		4.05				
183	3	6.6		3.42				
186	3	4.1		2.75		13:04	Lite regnstänk upphörde	
189	3	3.88		2.7				
192	3	4.6		2.85				
195	3	9.7		3.9				
198	3	10.7		4.05				
201	3 & 4	33.4		7				
204	3	29.4		6.5				
207	3	15.2		4.65		14:15	Litet Break	
210	3	11.2		4.2		14:19		
213	3	12		4.25		14:23		
216	3	10.4		4				
219	3	7.4		3.55		14:25	Lite regnstänk God	
222	3	5.3		3.15			överensstämmelse	
225	3	4.7		2.85			nardaprobe vid GENEC	
228	3	3.52		2.65			och kal-värden	
231	3	2.76		2.35				
234	3	2.08		2		14:32	Blåser!	
237	3	2.04		2		14:33		
240	3	2.2		2.1		14:43		
243	3	2.24		2.12				
246	3	1.8		1.8				
249	3	1.6		1.7				
252	3	1.44		1.6				
255	3	1.76		1.8				
258	3	2.24		2.12		14:50		
261	3	2.8		2.4		14:53		
264	3	2.36		2.16				
267	3	2.5		2.25				
270	3	4.36		2.75		14:57	Fikapaus	
273	3	5.64		3.15		15:52		
276	3	5.24		3.05				

279	3	4.64		2.8		15:54		
282	3	3.36		2.6				
285	3	3.72		2.65				
288	3	3.6		2.63				
291	3	2.56		2.27				
294	3	1.56		1.65			Enbart tidsförkjutningar i LWL3-pulser	
297	3	1.68		1.7				
300	3	1.76		1.8		16:05	Litet break blåshål!	
303	3	1.2		1.55		16:10		
306	3	1.36		1.6				
309	3	1.2		1.55				
312	3	1.14		1.53				
315	3	1.16		1.53				
318	3	1.16		1.53				
321	3	1.22		1.55				
324	3	1.3		1.6				
327	3	1.42		1.63				
330	3	1.9		1.95		16:21	Liten paus	
333	3	2.8		2.4		16:26		
336	3	4.96		2.95				
339	3	5.44		3.1				
342	3	4.88		2.9				
345	3	4.28		2.78				
348	3	4.74		2.81				
351	3	5.64		3.15				
354	3	5.76		3.2				
357	3	6.04		3.25				
360	3	8.3		3.72		16:40	Varvet färdigt!	

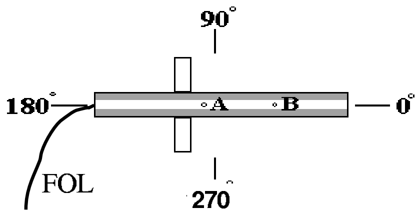
87	3	16.8		5		11:21		
117	3	2.32		2.15		11:42		
144	3 & 4	7.5		3.55		11:57		
147	3	9.4		3.8		13:37	Åter efter lunch	
147	3	7.4		3.55		13:40		
207	3	14.4		4.55		14:21		
237	3	1.76		1.85		14:41		
270	3	4.44		2.75		15:46	1:a efter fikat	
270	3	3.96		2.73		15:48		
270	3	3.92		2.73		15:50		
270	3	3.92		2.73		15:51		
300	3	1.36		1.6		16:09		
330	3	2.04		2		16:25		

IN WING PLANE HORISONTAL POLARISATION 2001-10-04

Magnus Höijer, FOI
Leif Jansson, Avionics

GENEC vrids runt vingaxel

Irradiation directions:



In wing plane

S-band prf = 30 Hz Δt = 4.7μs

Vädret: Växlande molnighet, uppehåll, rätt soligt, >10*C, Svag vind på morgonen, Behagligt.

Syfte: Reproducerbarhet av mätning utförd 2001-10-03 (S-band, H-pol., In wing plane)

Narda prob snett bakom GENEC för att proba fältet.

E(kV/m) kolumens värden, avser de av Gudrun på plats skattade värdena.
Med hjälp av filerna Ucal.txt och Ecal.txt interpoleras mer exakta värden fram.

VINKEL(*)	Utfall (LWL)	U (mV)		E (kV/m)		Tid	Kommentarer
0	3	3		2.5		09:38	
3	3	3		2.5			
6	3	3.64		2.65			
9	3	3.44		2.6			Bestrålning på 9s
12	3	2.96		2.45			
15	3	4		2.75			
18	3	10.8		4.2			
21	3	9.8		3.9			
24	3	9.9		4			
27	3	11.9		4.25		09:51	
30	3	35.2		7.25		09:56	Liten paus
33	3	30.8		6.5			
36	3	7.6		3.65			
39	3	3.8		2.7			
42	3	4.04		2.8			
45	3	5.48		3.2			
48	3	8.6		3.75			
51	3	5.9		3.25			
54	3	4.9		2.95			
57	3	7		3.5		10:09	Liten paus
60	3	10.7		4.1		10:16	Motorkörning fpl
63	3 & 4	11.8		4.4			Motorkörning fpl
66	3 & 4	15		4.65			Motorkörning fpl
69	3	11.8		4.4			
72	3	9.1		3.9			
75	3	13.7		4.5			
78	3	24.8		6			
81	3 & 4	40.8		7.85			
84	3 & 4	41.6		7.9			
87	3	23.4		5.8			
90	3	17		5		10:35	Liten paus Motorkörning fpl
93	3	13.8		4.5			
96	3	6.9		3.5			
99	3	5.8		3.2			
102	3	5.2		3.1			
105	3	5.28		3.1			Motorkörning fpl
108	3	4.92		3		10:41	

111	3	4.16		2.8		10:42		
114	3	2.8		2.4				
117	3	2.64		2.3		10:45	Liten paus	
120	3	2.56		2.25		10:50		
123	3	2.88		2.45				
126	3	3.28		2.6				
129	3	3.24		2.6				
132	3	3.92		2.75				
135	3	4.32		2.8				
138	3	5.52		3.15				
141	3	8.3		3.75				
144	3	8.8		3.8				
147	3	8.7		3.8		11:05	Liten paus 11:10 Barbro	
150	3	7.2		3.6		11:21	& Mats B. drar	
153	3	5.7		3.2				
156	3	5.6		3.2				
159	3	4.6		2.85				
162	3	5.52		3.15				
165	3	5.68		3.15				
168	3	6.5		3.4				
171	3	9.1		3.85				
174	3	9.7		3.95		11:31	Liten paus	
177	3	9.5		3.9		11:37		
180	3	7.6		3.6				
183	3	4.7		2.9				
186	3	3.9		2.75				
189	3	3.28		2.6				
192	3	3.84		2.7				
195	3	6.08		3.25				
198	4	12.6		4.3				
201	3 & 4	13.9		4.5		11:47		
204	3	28.8		6.5		11:52		
207	3	17.8		5.15		11:57	Lunch!	
210	3	14.4		4.55		13:22		
213	3	14.4		4.55				
216	3	14.4		4.55				
219	3	11.2		4.2				
222	3	8.4		3.75				
225	3	6		3.25				
228	3	5.1		3				
231	3	3.92		2.75				
234	3	3.4		2.65				
237	3	2.76		2.4		13:34	Liten paus blåser	
240	3	2.52		2.25		13:39		
243	3	1.84		1.8				
246	3	1.32		1.7				
249	3	1.22		1.65				
252	3	1.22		1.65				
255	3	1.42		1.7				
258	3	1.92		1.95				
261	3	3.02		2.5				
264	3	4.92		2.95				
267	3	18.8		5.25			Skumt!	
270	4	71.6		10.75		13:59	Liten paus	
273	3	28.8		6.5		14:16		
276	3	10.2		4		14:18		

279	3	4.3		2.8		14:19		
282	3	2.12		2.1				
285	3	1.44		1.7				
288	3	1.28		1.65				
291	3	1.32		1.7				
294	3	1.16		1.95				
297	3	1.08		1.5		14:27		
300	3	1.1		1.5		14:31	Liten paus, Regnskydd	
303	3	1.11		1.5		15:19	under paus	
306	3	1.12		1.5				
309	3	1.18		1.55			Regn!	
312	3	1.16		1.55				
315	3	1.14		1.55				
318	3	1.2		1.6			Uppehåll	
321	3	1.18		1.55				
324	3	1.56		1.75				
327	3	2.78		2.4				
330	3	5.6		3.2		15:30	Liten paus	
333	3	6.68		3.4		15:35		
336	3	8		3.7				
339	3	5.6		3.2				
342	3	5		3				
345	3	2.84		2.45				
348	3	2.36		2.2				
351	3	2.16		2.15				
354	3	1.8		1.8				
357	3	1.84		1.8				
360	3	2.36		2.2		15:47	Varvet klart blåser	
27	3	11.8		4.25		09:54		
57	3	7		3.5		10:15	Barbro kom!	
87	3	23.6		5.8		10:33		
117	3	2.56		2.25		10:49		
147	3	7.3		3.6		11:19		
174	3	10.3		4		11:35		
200	4	14.2		4.5		11:45		
202	4	15.3		4.75		11:48		
203	4	20.2		5.4		11:50		
205	3	24.2		5.9		11:54		
206	3	21		5.5		11:55		
207	3	17.2		5.05		13:20	Åter efter lunch	
237	3	2.52		2.25		13:37		
265	3	6.8		3.45		13:53		
266	3	10.3		4.05		13:52		
267	3	17		5		13:49		
268	3	34.8		7.25		13:54		
269	4	52.8		8.8		13:56		
270	4	68.4		10.45		14:06		
271	3	76		11.2		14:12		
272	3	47.2		8.3		14:14		
295	3	1.14		1.55		14:25		
296	3	1.08		1.5		14:26		
298	3	1.1		1.5		14:29		
299	3	1.1		1.5		14:30		
300	3	1.1		1.5		15:18	Fikapaus orsakad av regn 14:50	
330	3	4.36		2.7		15:34		

IN WING PLANE VERTICAL POLARISATION 2001-10-02

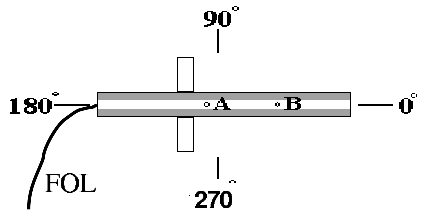
Magnus Höijer, FOI
Leif Jansson, Avionics

GENEC vrids runt vingaxel

S-band prf = 30 Hz $\Delta t = 4.7\mu s$

Vädret: Rätt varmt, >10*C, Regntunga mål på fm men uppehåll. Uppsprucket molntäcke på em och en hel del sol. Hård vind hela dagen.

Irradiation directions:



In wing plane

E(kV/m) kolumens värden, avser de av Gudrun på plats skattade värdena.
Med hjälp av filerna Ucal.txt och Ecal.txt interpoleras mer exakta värden fram.

VINKEL(*)	Utfall (LWL)	U (mV)		E (kV/m)		Tid	Kommentarer	
0	3	>100		>13.2		17:30	Inget utfall	
3	3	>100		>13.2			Inget utfall	
6	3	100		13.2			Obekräftat utfall	
9	3	58		9.5		17:39		
12	3	31.2		6.75				
15	3	17.2		5				
18	3	9.5		3.9				
21	3	6.3		3.3				
24	3	5.5		3.1				
27	3	3.64		2.7				
30	3	3.56		2.7				
33	3	3.24		2.6				
36	3	3.24		2.6				
39	3	4		2.75				
42	3	3.76		2.7				
45	3	3.24		2.6				
48	3	2		2				
51	3	1.64		1.8				
54	3	1.78		1.85				
57	3	1.7		1.82				
60	3	1.7		1.82				
63	3	1.8		1.86				
66	3	1.98		2		18:03		
69	3	1.5		1.75		11:15		
72	3	1.3		1.6		11:20		
75	3	1.3		1.6				
78	3	2.2		2.2				
81	3	5.4		3				
84	3	12.7		4.25				
87	3	20.4		5.5		11:30		
90	3	21.8		5.5				
93	3	17.2		5				
96	3	16.2		4.8				
99	3	13		4.4				
102	3	6.2		3.25				
105	3	2.8		2.4				
108	3	1.8		1.9				

111	3	2		2		11:45		
114	3	1.8		1.9				
117	3	1.4		1.7				
120	3	1.4		1.7				
123	3	1		1.5				
126	3	1		1.5				
129	3	1.46		1.7				
132	3	1.38		1.7				
135	3	1.06		1.5				
138	3	0.94		1.45				
141	3	0.7		1.25				
144	3	0.64		1.2		12:02	Lunch	
147	3	0.78		1.3		13:28	Åter	
150	3	0.94		1.45				
153	3	1.24		1.6				
156	3	1.6		1.8				
159	3	2.86		2.45			LWL4 polvänd	
162	3	5.48		3.12				
165	3	13.2		4.45				
168	3	28.2		6.5				
171	3	61.6		9.7				
174	3	(>83) 90		(>11.6) 12.4			Utfall! 12.4 kV/m	
177	3	100		13.2				
180	3	94		12.7				
183	3	99		13.1				
186	3	79		11.4				
189	3	50		8.6				
192	3	34		7.1				
195	3	16.8		5				
198	3	11.2		4.1				
201	3	8.7		3.8				
204	3	8.1		3.7		14:05		
207	3	8.6		3.8			Justera (sic) FOL	
210	3	11.2		4.1				
213	3	16.4		4.95				
216	3	34.2		7.1				
219	3	34		7.1				
222	3	23.6		5.8				
225	3	8		3.6				
228	3	3.7		2.75				
231	3	1.64		1.8				
234	3	1.42		1.7		14:23		
237	3	0.84		1.35				
240	3	0.78		1.3				
243	3	0.78		1.3				
246	3	0.76		1.3				
249	3	0.78		1.3				
252	3	0.82		1.33				
255	3	0.86		1.36				
258	3	1.12		1.55				
261	3	1.96		1.95				
264	3	3.36		2.6				
267	3	4.64		2.85				
270	3	5.8		3.2				
273	3	4.96		2.95				
276	3	3.48		2.6		14:45		

279	3	3.48		2.6		14:45		
282	3	4.08		2.75				
285	3	4.88		2.9				
288	3	4.88		2.9				
291	3	4.08		2.75				
294	3	3.8		2.7				
297	3	4.32		2.8				
300	3	6.2		3.3				
303	3	11.5		4.1				
306	3	13.3		4.45				
309	3	14.6		4.55				
312	3	15.4		4.7				
315	3	8.6		3.6				
318	3	7.8		3.55				
321	3	7.4		3.55				
324	3	8.1		3.6				
327	3	7.6		3.55			Fikadags!	
330	3	31		6.75		16:05	??? 327* & 330* testas igen	
333	3	19.6		5.25				
336	3	14.4		4.55				
339	3	11.8		4.1				
342	3	9.2		3.9				
345	3	8.1		3.6				
348	3	7.6		3.55				
351	3	7.6		3.55				
354	3	9.1		3.9				
357	3	15.4		4.7				
360	3	31.6		6.75				

69	3	1.66		1.8		18:05		
327	3	51		8.7		16:07		
330	3	31		6.75		16:30-16:36		
351	3	21.2		5.5		17:15		

Olika utfallsnivåer vid 327* före och efter fikat!

Det visar sig att GENEC vridit sig vad vi uppskattar som arcsin(11/81.5) = 8*. Värdena är 8* för stora från någon vinkel.

17:15 Plastvaggan, som GENEC vilar på, tog i absorbent som skymmer vridbordet vid bestrålning. Det vred vaggan tills en list på vaggan tog i metallfixturen som vaggan sitter monterad på. Det hela orsakade en offset i vinkel på 8*.

En ommätning görs, som är sparad under fliken 2.10.01(2).

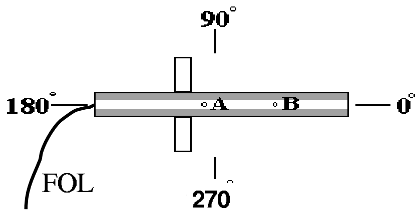
IN WING PLANE VERTICAL POLARISATION 2001-10-02 Magnus Höijer, FOI
Leif Jansson, Avionics

GENEC vrids runt vingaxel

S-band prf = 30 Hz Δt = 4.7μs

Ommätning av fliken 2.10.01.

Irradiation directions:



In wing plane

E(kV/m) kolumens värden, avser de av Gudrun på plats skattade värdena.
Med hjälp av filerna Ucal.txt och Ecal.txt interpoleras mer exakta värden fram.

VINKEL(*)	Utfall (LWL)	U (mV)		E (kV/m)		Tid	Kommentarer	
354	3	42.8						
357	3	85						
360	3	>100		>13.2		17:22	Inget utfall!	
321	3	17.4		5		18:10		
324	3	12.8		4.3				
327	3	10.6		3.9				
330	3	8.6		3.65				
333	3	6.7		3.35				
336	3	5		3				
339	3	4.56		2.85				
342	3	5.4		3.1		18:25		
345	3	6.4		3.3		18:27		
348	3	9.8		4				
351	3	21.4		5.5		18:32	Slut för idag!	

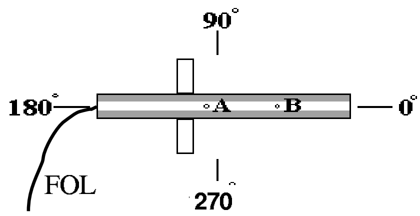
IN WING PLANE VERTICAL POLARISATION 2001-10-03

Magnus Höijer, FOI
Leif Jansson, Avionics

GENEC vrids runt vingaxel

S-band prf = 30 Hz $\Delta t = 4.7 \mu s$

Irradiation directions:



In wing plane

E(kV/m) kolumens värden, avser de av Gudrun på plats skattade värdena.
Med hjälp av filerna Ucal.txt och Ecal.txt interpoleras mer exakta värden fram.

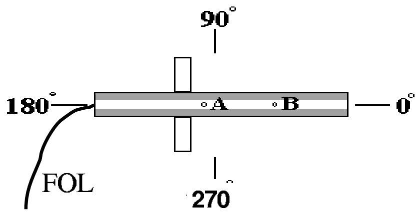
VINKEL(*)	Utfall (LWL)	U (mV)		E (kV/m)		Tid	Kommentarer	
309	3	48		8.4		16:48		
312	3	86		11.9				
313	3 & 4	92		12.5		16:54		
314	3 & 4	97		12.9				
315	4	82		11.5				
316	4	77		11.25				
317	3	107		13.85				
318	4	99		13				
319	3	84		11.75				
320	3	71		10.9				
321	3	59		9.5				
324	3	26		6.1				
327	3	11.8		4.25				
306	3	24		5.9				
303	3	14.4		4.5				
300	3	9.2		3.95				
297	3	6.3		3.8				
294	3	5.56		3.12				
291	3	6.24		3.77				
288	3	5.76		3.2				
285	3	5.2		3.05				
282	3	4.2		2.8				
279	3	4.08		2.75				
276	3	4.28		2.8		17:31	Slut för idag!	

IN WING PLANE VERTICAL POLARISATION 2001-10-04 Magnus Höijer, FOI
Leif Jansson, Avionics

GENEC vrids runt vingaxel

S-band prf = 30 Hz $\Delta t = 4.7 \mu s$

Irradiation directions:



In wing plane

E(kV/m) kolumens värden, avser de av Gudrun på plats skattade värdena.
Med hjälp av filerna Ucal.txt och Ecal.txt interpoleras mer exakta värden fram.

VINKEL(*)	Utfall (LWL)	U (mV)		E (kV/m)		Tid	Kommentarer	
0	3	58.8		9.45		15:55		
3	3	64.8		10.1				
6	3	77		11.25				
9	3	90		12.3				
12	3	84		11.8				
15	3	70.8		10				
18	3	61.2		9.65				
21	3	61.6		9.65				
24	3	73		11				
27	4	83		11.7				
30	3	85		11.75		16:15-16:20	Krångel med MTF. Kör flera gånger.	
36	3	57		9.25		16:22		
42	3	18		5.12		16:25	Gudrun ensam i MTF.	
48	3	12.2		4.25		16:26		
54	3	3.56		2.65		16:31		
60	3	2.56		2.25		16:30		
81	3	4.4		2.85		16.34	> 4 försök i MTF'n	
84	3	11.5		4.2		16:35		
87	3 & 4	29.8		6.65		16.37		
90	3 & 4	22.2		5.65		16:39		
93	3	11.4		4.2		16:41		
96	3	7.1		3.5		16:43		
102	3	3.24		2.6		16:44		
135	3	1.52		1.75		17:30		
165	3	5.48		3.12		16:46		
171	3	14.6		4.55		16:47		
177	3	27.6		6.27		16:49		
180	3	31.6		6.75		16:51		
183	3	33.4		7		16:52		
186	3	34		7.1		16:54		
189	3	26		6.1		16:56		
192	3	15.6		4.65		16:58		
198	3	8.1		3.65		16:59		
204	3	9.6		3.9		17:00		
231	3	4.92		3		17:27		
261	3	9.1		3.85		17:05		
264	3	11.3		4.2		17:10		

267	4	14		4.5		17:03		
270	3 & 4	12.7		4.35		17:02		
273	4	12.6		4.3		17:07		
276	3	6.8		3.45		17:08		
300	3	1.76		1.8		17:26		
324	3	2.52		2.25		17:25		
330	3	3.04		2.5		17:24		
336	3	4.4		2.8		17:23		
339	3	7.5		3.6		17:22		
342	3	11.4		4.2		17:21		
345	3	20.2		5.4		17:20		
348	3	24.2		5.9		17:18		
351	3	27.8		6.4		17:12		
354	3	32.4		6.95		17:13		
357	3	36.4		7.35		17:15		
360	3	46.4		8.2		17:17		

Appendix B

MTF calibration data

This appendix contains the calibration data between the electromagnetic field at the position of GENEC and the, at operation, measured voltage inside the MTF. (The left column is Ecal and the right column is Ucal.)

S-Bandets kalibrering oktober 2001

Fältstyrka [kV/m]	RF-nivå [mV]
0.25	- - -
0.5	- - -
1.0	- - -
1.5	1
2.0	2
2.5	3
3.0	5
3.5	7
4.0	10
4.5	14
5.0	17
5.5	21
6.0	25
6.5	29
7.0	33
7.5	38
8.0	44
8.5	49
9.0	54
9.5	59
10.0	64
10.5	69
11.0	73
11.5	81
12.0	87
12.5	92
13.0	98
13.5	103
14.0	109
14.5	115
15.0	121
15.5	128
16.0	132
16.5	138
17.0	146
17.5	152
18.0	159
18.5	164

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