Methods for determining power supply requirements based on RF spurious level on consumers

Catrine Anderson & David Runesson

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Abstract

In this project a measurement set-up will be developed, which will enable an injection of a controlled voltage ripple to a dc voltage. The resulting voltage will be feeding a power consumer. The set-up should also enable measurements of the amplitudes of the set spuriouses, which will be available on the output from the power consumer. Most of the power consumers can just allow a certain level of voltage ripple, which will result in a certain level of amplitudes for the spuriouses. Therefore the set-up will be measuring the maximum amplitude of the voltage ripple that can be applied to the dc signal before the spuriouses are becoming too large.

Since the spuriouses are spread throughout the RF-system there are specifications for the spurious free dynamic. In other words, there are indirect specifications for how distorted the dc voltage which is feeding the power consumer is allowed to be. The requirements from the power consumer can be plotted in a chart and compared to the output voltage from the power supply and a more optimal solution might be achieved. The set-up will facilitate the whole measurement of requirements procedure. Today power supply output voltage requirement is stated as a peak to peak voltage over a broad frequency range (0-20MHz) and hopefully will the new procedure be better comparing to the previous one.

The power consumers are often designed meanwhile the power supply and therefore is it preferable if the input impedance of the consumer is known in advance. An output spectrum from the power supply with an imitated power consumer can then be obtained. In this project a method for measuring impedances, for a frequency range been developed.

Preface

A company has been developing the idea of this project. The aim of the project is to derive and develop a measurement set-up to measure the affect of a power ripple on spuriouses in a system. The spuriouses do exist in certain applications such as in radar systems and in base stations and has before not been important to measure in the same extent, but as more advanced systems, the more refining measurements are needed.

The final thesis proceeds for 20 weeks and is a part of the Master of Science in Electric engineering education with direction Electric Power engineering, which has taken place at Chalmers University of Technology. The examiner and supervisor at Chalmers has been Torbjörn Thiringer.

This project will hopefully be of great use to the company and presumably facilitate for these kinds of problems within the area, which have previously been involved when measuring the spuriouses.

Many thanks to:

Torbjörn Thiringer

Other co-workers at the company

January 2006

Contents

Abbrevations and explanations

AWG – Arbitary Waveform Generator

CTQ – Critical To Quality

DMAIC – Define Measure Analalyses Improve Control

dB – decibel

dBc – dB relative to the carrier power

dBm – the power in relation of 1mWatt

GNAT – General Network Analyser Tool

GPIB – General Purpose Interface Bus

NA – Network Analyser

Power-CELL – Power Coducted Emission Limit Line

RF – radio frequency

SA – Spectrum Analyser

SFDR – Spurious Free Dynamic Range

Introduction

When two different frequencies are interfering, spuriouses will appear, which will be a problem for the products from the company. This will result in distorted signals that might harm the information, which is received in the radar as well as the one that is sent out. This will cause problem when decoding the signals. The spuriouses are also propagating themselves in the system and more spurious spikes in the frequency domain will appear. The amounts of spurioses will increase avalanche-likely the more frequencies are interfering with each other.

The purpose with this project is to present a measurement set-up that enables an easier and a more standardised way of performing measurements of spuriouses. The idea is to measure and plot a requirement limit line over frequency for the DC/DC-converter output voltage. The DC/DC-converter should then be verified together with the real power consumer. The outcome will be a better DC/DC-converter, which is better suited for the deliberated power consumer regarding spuriouses.

The structure of the report is that measurements and ideas regarding them are presented. Lots of measurements have been performed, for example measurements of the impedances, measurements of the amplitudes of the spuriouses as well as the amplitudes of the applied voltage ripple. The report will also describe the theory behind the spuriouses as well as the development of the measurement set-up.

1 Business Case and methods regarding the project work

Before starting a project a business case has to be made. This is an important step in the process, since this will convince people about the profits the project will bring, as well as the usefulness. It was also decided that the work in the project should follow the guiding principles of Six Sigma.

1.1 Business case

One of the first questions that should be answered before starting a project is; what is the economical outcome of the project? This project is about developing a measurement set-up, which in the end will lead to requirements on the power source. Once the requirements are stated a more optimal solution might be found. The performance of the products could be increased and more reliable and smarter products can be developed, with perhaps even less amounts of components. These kinds of measurements must sooner or later be performed and every time a new set-up has to be created. A new set-up will bring the drawback that the same results will never be achieved again (unless exactly the same equipment and set-up is used). This means that making true comparisons is totally impossible, since the continuity is lost.

The set-up can be used for early versions of the final design and will give the opportunity of changing the products in time. Some of the tests might even show that it is totally impossible to create the product and no more time has to be spent on it. Besides that it might even shorten the error searching time. In the end it comes down to faith in the company from the customers. And by selling reliable products to the customers the faith will remain.

To summarise it can be said that money will be saved in forms of time and keeping up the faith in a company is in the end invaluable.

1.2 Six Sigma

Six Sigma is a quality tool, which target is to satisfy the customers. Six Sigma highlights the attitude of a customer, if the customer receives a product that has a better performance one time, the customer will expect the higher level the following times as well. Therefore a standard level, which describes the average performance, has to be set and the customer will always be satisfied. Six Sigma can be applied everywhere, since small sub activities within the company can be regarded as producers and customers as well.

The central strategy in this theory is the DMAIC-tool. DMAIC stands for Define, Measure, Analyses, Improve and Control. The tool is explained in detail below.

Define - In the beginning of a project, before any work can be done the team is formed, the customers need to be identified as well as their needs and requirements. A high-level map is also created in the beginning.

Measure - To achieve more knowledge about the different parts in the project, measured data is collected at this stage.

Analyses - When data is collected the process as well as the root causes for current sigma performances can be analysed. This is also the most important step of the process.

Improve - In this stage different suggestions to solutions for the problem can be discussed. This is the most important stage in this project.

Control - A technical control over the new process is chosen and implemented, together with a so called: "Response Plan".

In this project Six Sigma will be applied to some extent, the parameters that are mentioned above will be followed, however further measuring of the satisfaction of the customers will not be measured.

1.2.1 CTQ-parameters

Six Sigma contains some further tools for improvements and in this project a tool called "Critical to Quality" (CTQ) is used. The idea with CTQ is that in the beginning of a project 5-10 parameters are stated. These parameters should, as the tool says, be critical to quality and be measurable ones. In the end the fulfillment of the parameters can be evaluated. Frequently used parameters are price, size, performance and time etc.

In this project the CTQ parameters have been defined to:

LabVIEW - It is of vital importance that the interface of the LabVIEW program is user friendly and logical. Some parameters should also be free to set for the user. The results should be easily accessible and easy to handle.

Equipment – The measurement set-up is dependent on how accurate and advanced the equipment is as well as how they are working with each other. These parameters are of course depending on the budget.

Time table – The given time has to be followed and everything should be done in a 20 weeks time.

The ripple signal – The essential parts are the accuracy of the amplitude and how pure sine-formed it is. It should also cover the required frequency range.

Performance – The measurements should be able to be performed with a continuity, which means that they should be reliable and the same result should be obtained every time.

2 The origin of spuriouses

When more than one frequency is applied to a system, unwanted spuriouses may appear. Spuriouses are frequently studied for RF signals, but it is rather uncommon that spuriouses, which are created from the input power are studied. The research below is at first taken from a RF signal and later on transferred into the input supply voltage.

A common case when spuriouses do appear is when using a carrier wave. A carrier wave is used in for example FM radio-, cell phones-, base stations- and in radar-applications. The carrier wave is often a high frequency sine wave, compared to the other frequencies in the system. The spuriouses of interest will be situated around the carrier wave and might sometimes disturb the information in the carrier wave.

2.1 Spuriouses in the signal domain

Spuriuses must be included when analysing signals since they might disturb other signals. This is of course dependent on the amplitude of the spuriouses and their placements in the frequency domain. A RF mixer is used in Figure 2-1 as an example. A mixer is for example taking the difference of two frequencies and has the new frequency as its output. Spuriouses will appear and are mathematically described in the figure below. The theory remains for other applications and not only for mixers.
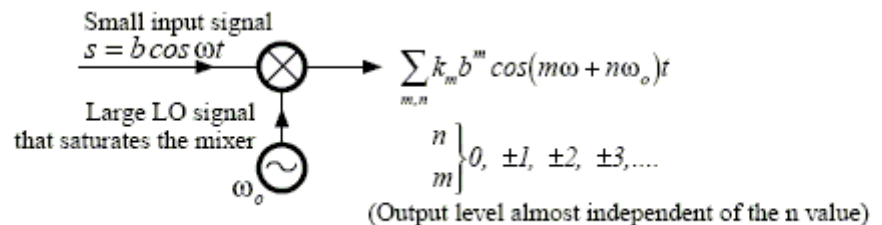
Figure 2-1 The figure describes the properties of spuriouses. The formula shows that they are created in an infinity amount of multiples. The amplitudes of the multiples are decreased the higher values of m and n gets.

Figure 2-1 is taken from a receiver mixer in a radio application. The "Small input signal" is the received signal and the "Large LO signal" is the local oscillator that separates the information from the carrier wave. With this background it is easy to understand that it is impossible to remove one of these signals. The frequency spectra for two added signals will be consisting of two spikes on either side of the spike with the highest frequency.

It is logical that the complexity of the equation in Figure 2-1 increases, the more frequencies that are involved in the system. Lots of waveforms contain more than one sine signal, which will be propagating through the system and create even more spuriouses.

The most interesting conclusion that can be drawn from the equation in Figure 2-1 is that it is the "Small input signal" that sets the amplitude of the spuriouses. This knowledge is of great importance and will be discussed further in the following section.

2.2 Spuriouses that are created by a power ripple

In this project the spuriouses are created from the power ripple and the carrier wave. The power ripple is an imitation of the DC/DC-converter where the dc signal is rippled. Therefore there are some differences in the theories regarding spuriouses. The ripple that is created in the DC/DC-converter is an undesirable side effect in the power application, contrary to RF signal, where there is a need for more than one frequency in order to transfer information.

Filters remove most of the undesired created ripple. Some of the ripple does however remain and unfortunately it does not have to be a great ripple in order to create spuriouses.

When applying the theory from Figure 2-1 the ripple from the power is described as the "Small input signal" and the carrier wave as the "Large LO signal" and the amplitude of the spurious will still be dependent on the amplitude. One method of preventing spuriouses is obviously to decrease the ripple but the best way is to remove the ripple voltage of particular sensitive frequencies. The switching frequency should be placed in a frequency span, where the equipment is quite robust and not very sensitive. The frequencies of the spuriouses can be described from the Equation 2-1.

Equation 2-1 The equation describes the placements of the spuriouses.

$$f_{spurious} = |m \cdot f_1 + n \cdot f_o|$$

$$m \neq 0$$

$f_1 =$ The ripple frequency

$f_0 =$ The carrier frequency

To easier understand the theories above an example is shown in Figure 2-2 below.
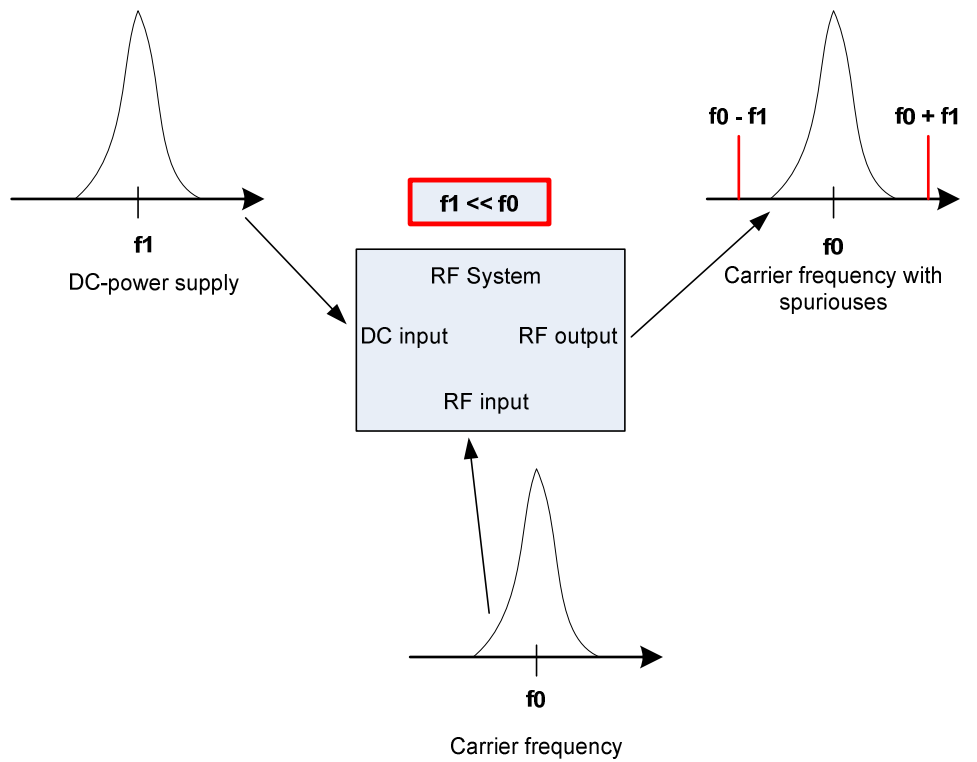
Figure 2-2 To sum up chapter 2 in one picture and make it more understandable this figure was created. In theory the dc-supply is a pure dc without harmonics. In practise this is not the case, almost all dc-sources has harmonics except from batteries and capacitors. When the power ripple is propagating in the RF-system spuriouses can be created and the output signal is disturbed.

3 Theoretical approach for the measurement set-up – background

A measurement set-up and an injection card had been developed before, but were in need of some refinement. It was determined that a programme in LabVIEW should be controlling with the measurement equipment.

3.1 The purpose of the measurement set-up

The function of the measurement set-up is meant to be an ideal dc source for the measurement object. However by adding a discrete ripple, a controlled disturbance is produced with measurable amplitude and determined frequency. This produced voltage will be feeding a measurement object, the output spectrum of the measurement object can sometimes be measured and the affect from the voltage ripple can then be investigated.

3.2 The summation of a dc and ac voltage with a transformer and an injection card

A connection of an ac voltage source and a dc voltage source cannot be done directly neither in serial nor in parallel. But there is a possibility to add an ac voltage through a transformer. This has been done in this project. The summation is taking place in a specially designed injection card, see chapter 5.2. In Figure 3-1 the set-up is shown, further explanations of devices in the system will be described later.
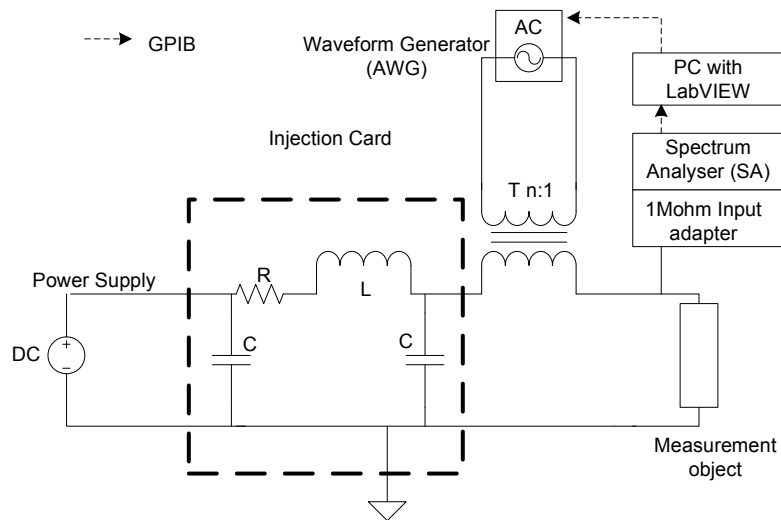
Figure 3-1 An overview of the measurement set-up.

3.3 Arbitrary waveform generator

An Arbitrary Waveform Generator (AWG) was used as a ripple source. The requirements for the generator are; a sine wave output with a frequency range up to at least 10MHz. GPIB interface and some sort of LabVIEW drivers are also required.

3.4 Spectrum analyser for measuring the ripple voltage

To be able to measure the injected ripple, a spectrum analyser (SA) had to be used. The main advantage with a SA compared to other voltmeters is that the SA can perform accurate measurements of voltage levels for discrete frequencies. The requirement for this SA is that it has to be able to work at frequencies between 10Hz-10MHz and possibility to have a connection with a computer through a GPIB interface together with LabVIEW drivers.

3.5 The LabVIEW program

It was at an early stage decided that the LabVIEW program should control the measurement set-up and should be helpful for the user in order to obtain measurements results easily. LabVIEW is a graphical program language, in block diagram form. The high-level language makes it easy to use but with the drawback of less influence for the user. The other main advantage is that it can communicate and control the instruments via the GPIB interface, for this purpose it controls and communicates with the SA and the AWG. This enables the injection of a ripple with a desired voltage level.

4 Requirements for the measurement set-up

Before starting the project, some requirements regarding the final set-up were stated.

4.1 Requirements for the measurement system

Some requirements, which the set-up should fulfill were stated by the company in the beginning of the project.

Table 4-1 The requirements for the measurement set-up, presented in a table.

Requirements of the output from the measurement set-up	dc voltage	dc current
	0-60 V	0-10 A
Requirements of the voltage ripple, that should be fulfilled	ac voltage	Frequency range
	0 – 50 mV	50 Hz – 10 MHz

4.2 The final set-up measurement fulfilled the following requirements

The requirements which were fulfilled for the set-up.

Table 4-2 The requirements which were fulfilled.

Requirements of the output from the measurement set-up	dc voltage	dc current
	0-60 V	0-10 A
Requirements of the voltage ripple, that was fulfilled	ac voltage	Frequency range
	0 – 50 mV	50 Hz – 16 MHz

5 Development of the devices in the system and verification of the voltage ripple in the set-up

An existing card was analysed and measured. This in order to provide useful information before developing a new one that would fulfill the requirements.

5.1 Basic measurements

In the first measurements different objects were used as test objects: a power amplifier, a resistance and a downconverter (which is a special application of the mixer previous mentioned). A verification of the voltage ripple for these objects was performed. The available transformer was inadequate for the whole frequency range according to stated requirements.

5.1.1 The result for the basic measurements

A voltage ripple was obtained, however it was found that its amplitude was too low according to the requirements mentioned in chapter 4.1. The higher the frequency, the lower output ripple amplitude was obtained, why conclusions concerning attenuating parts in the system for especially the higher frequencies were drawn. To sum up, a better design of the existing injection card as well as the nowadays-used transformer was required.

5.2 The existing injection card

In the early measurements an injection card, which designed by ref X was used. The aim of the card is to have a stiff voltage close to the input and a rippled dc voltage as its output. The resistance together with the inductance, but also the capacitance will act as a filter and prevent the ac voltage from reaching the dc power supply. There will be an ac current circulating in the circle between the two capacitors and by using a smaller capacitance over the output connection more oscillation in forms of ac voltage will appear there. This card was used in a slightly different application with a load that consumed a pulsed current. This gave a rather stiff output voltage as well, for a quite wide range of frequencies it was found that the output ripple was even lower than the firm dc voltage, close to the power supply. See Figure 5-1, for the equivalent circuit of the card.
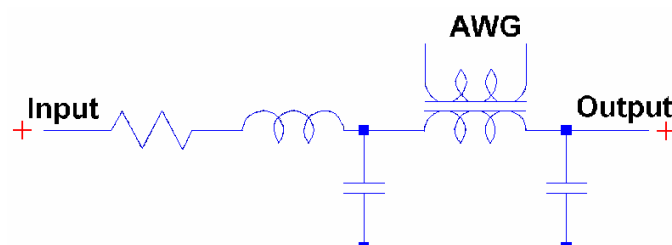

Figure 5-1 An overview of the method of injecting the voltage ripple to the dc voltage for the old card.

Simulations of the existing card were made over the input as well as the output in Linear Technology LTspice/SwitcherCADIII see Figure 5-2. Authentic measurements were performed for the real card, which were compared with the simulated ones. The simulated values resembled to the measured ones to some extent. This could be seen by studying the Bode diagrams over the results and compare the simulations with the measured values. The transformer was the most difficult part to simulate and it is presumably that one, which causes the bad resemblance. Measurements showed that the grounding plate was not working satisfying and therefore needed to be simulated with an inductance.
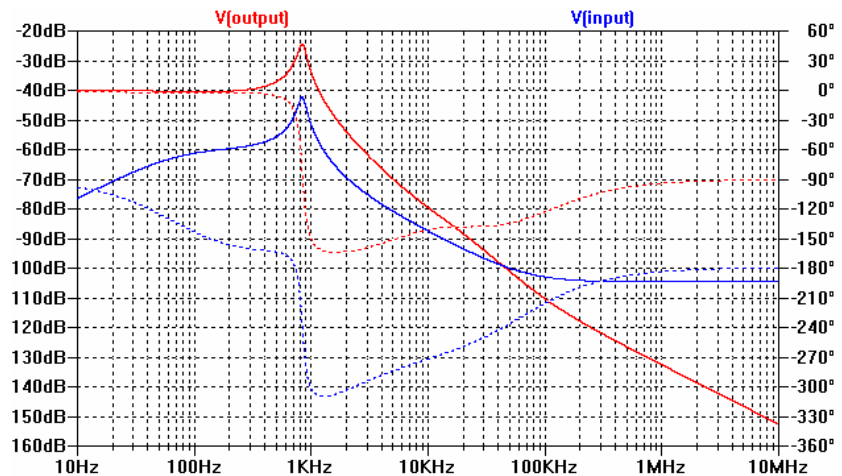
Figure 5-2 The simulation for the existing card, the dotted lines in the figure describes the phases, whereas the lines describes the amplitudes. Notice that the voltage over the output is becoming smaller than the voltage over the input at approximately 40kHz. The V(input) and V(output) are according to the Figure 5-1.

5.3   Developing a new injection card

A new card was developed through simulations and the result was later on verified on the real card. Since capacitors in the right side of the card are not needed in this application, it was at an early stage decided to remove these.

5.3.1   The simulated attenuation in the card

Before assembling the new card some simulations were performed in the same program as for the existing card. Since the simulations of the old card hardly resembled reality, the strategy for the new simulations was to achieve as little attenuation as possible for the output voltage, a late intersection between the input voltage and output voltage is also preferable. The most essential is to obtain, as little attenuation in the injection card as possible. The ripple voltage over the output should as long as possible remain larger than over the input voltage.

5.3.2 Filter for the laboratory power supply

Since most of the laboratory power supplies are voltage regulated it was decided to improve the input filter of the card. A capacitor in parallel with the laboratory power supply together with the RL-circuit should prevent the laboratory power supply to attenuate and regulate the ac ripple. This capacitor should have a large capacitance comparing to the output capacitors of the laboratory power supply. The equivalent circuit for the card is shown in Figure 5-3.
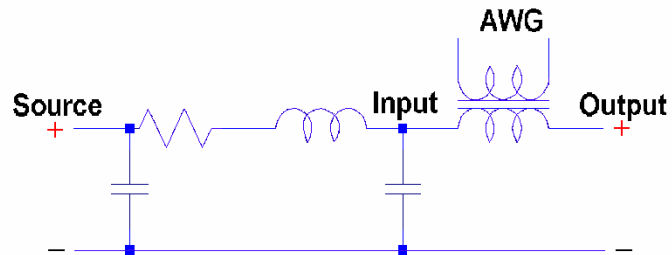
Figure 5-3 An overview of the method for injecting the voltage ripple to the dc voltage for the new card.

5.3.3 The result, plotted in a bode plot in a simulation program

These two ideas resulted in the following simulation results. The plot shows that these two small changes in design and some optimization of the parameters for the passive component resulted in a card with much less attenuation than the previous one, see Figure 5-4 compare this result with Figure 5-2.
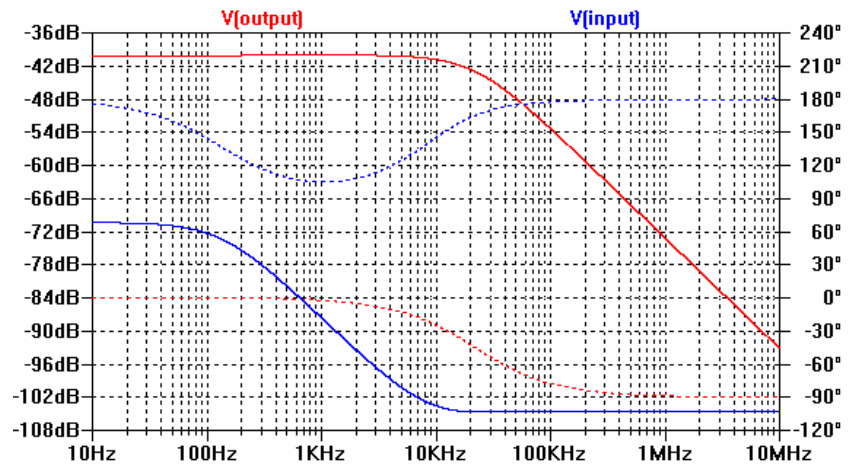
Figure 5-4 The dotted lines in the figure describes the phases, whereas the lines describes the amplitudes. V(input) and V(output) are placed as in Figure 5-3.

The cards were assembled with available components at the company and not the ones that were tested in the simulations. However, new simulations with the used ones showed equivalent results. The performance of the new card was, as expected, superior to that of the previous card for this specific use. The attenuation for example had decreased, several hundreds times. Also the intersection between them occurs at a higher frequency, see Figure 5-2 and Figure 5-4. The measurement result can be studied in Figure 5-5 the ripple amplitude was held at a constant value of $10mV_{rms}$ and the output voltage from the AWG (V_{pp}) was compared.

Comparison between the cards

Figure 5-5 The figure shows clearly that the second version of the card has less attenuation than the existing one. A greater input voltage was required to obtain the same ripple voltage. Notice the difference in scales for the two cards.

The simulated values were inserted into the same graph as the measured ones, in order to see how they were corresponding to each other, see Figure 5-6.

The attenuation for the new simulated card versus the actual new card.

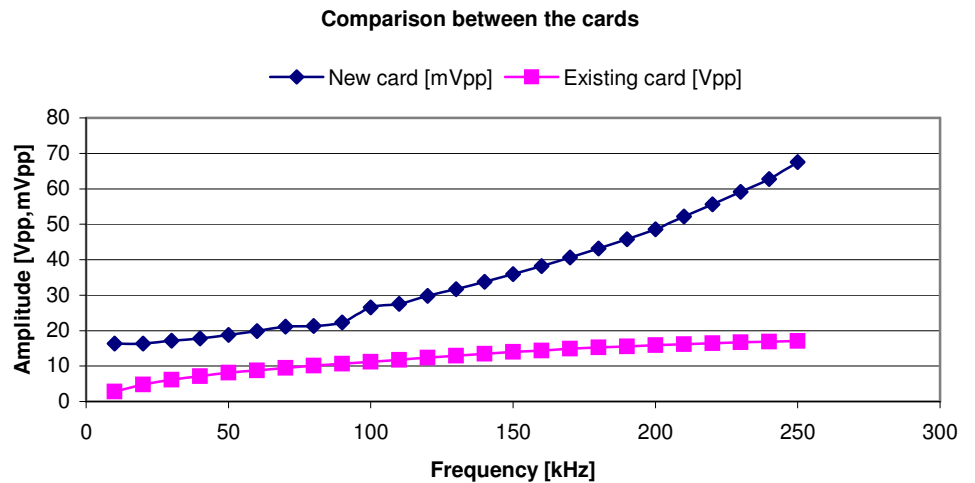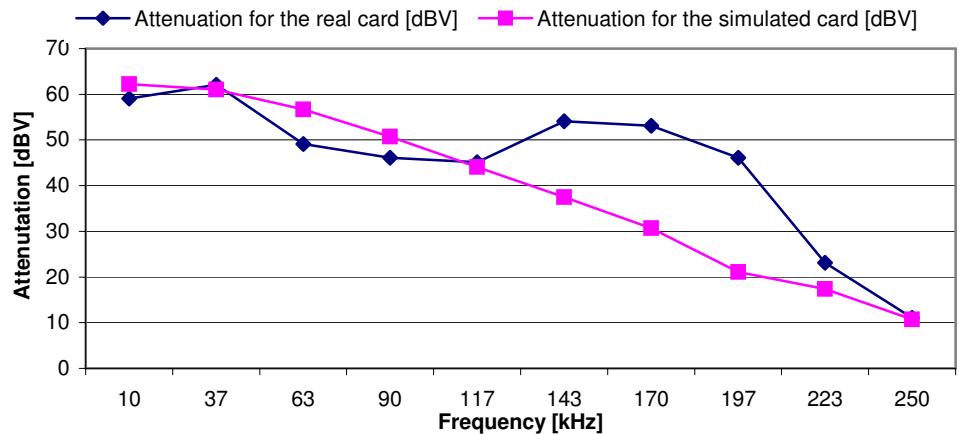Figure 5-6   The amplitude difference in dBV, is the difference between the output voltage compared to the input voltage, see Figure 5-3.The measured values for the second version of the card are compared to the simulated ones for the same card.

The actual load might not be purely resistive for the higher frequencies, which might be one of the explanations for the difference in the 1-4MHz regions. However the most likely explanation is that the simulated card has incorrect transformer parameters. There is also some insecurity regarding the simulated grounding plate.

5.4   The development of an improved injection transformer

For better perception of the currently used transformer it was decided to measure its parameters, in the purpose of enabling more accurate simulations of the injection cards. The measurement showed that the transformer turned out to be capacitive for frequencies somewhere above 250kHz. The transformer's specified frequency range: 30Hz – 250kHz, so this was somewhat expected. This transformer is therefore inadequate for the whole frequency range according to the requirements mentioned in chapter 4.1

5.5   The progress regarding finding a final transformer solution

A transformer, which covers the whole frequency range had to be custom made. It should cover a very wide frequency (at least six decades) and will therefore be a rather difficult device to produce. A transformer that will have good high frequency quality performance should have a core made of some ferrite material and have as few windings as possible, in order to decrease the inductances. This compared to a low frequency transformer that must have a thick iron core with large number of winding turns. This theory will be explained later in this chapter.

A suggestion was to use a current probe instead of an ordinary transformer. In normal case the current probe is used for measuring the current in a single cable without connecting anything physically to the cable. The current is measured by sensing the magnetic field around the cable in the core of the probe. By using a second winding around this core, the induced current from this winding can be measured. This gives the possibility of calculating the current in the cable. In fact current probes are transformers but due to the difference in use they have their own name. If the probe is used the other way around there is a possibility to inject a ripple via the measuring output of the probe. The ripple is then injected to the dc cable, which is placed in the middle of the core of the probe.

One problem, which probably arises, is that for lower frequencies it might not be sufficient if the cable just is inserted in the hole. The cables must be wounded a certain amounts of turns around the core as well. This will cause problem for higher frequencies, when the impedance will be increased. Some minor measurements were performed with the probe, which worked insufficiently for the lower frequencies, this might be due to the material in the probe which is not suitable for the lower frequencies.

5.5.1 Two transformers that will cover the whole frequency span

Since the transformer solution mentioned above did not meet the demands, it was suggested that two different transformers should be used. A custom made transformer with a ferrite core was chosen for the higher frequencies. The ferrite material was chosen due to its good quality for the higher frequencies. A toroid, for 50Hz, made of iron should be used for the lower frequencies. The intention was to use this transformer up to around 20kHz.

5.5.2 Theories regarding design of magnetic components

Perception regarding magnetic materials and general transformer designs had to be studied. The torrent equations have especially been studied and the conclusions and derivations, which have been drawn from them, have given a good theoretical background. See Equation 5-1, which state the relation between the voltage and the magnetic flux in the core.

Equation 5-1

$$U = \frac{\partial}{\partial t}\phi = \frac{d}{dt}\oint_{surface} B \cdot \partial S = \frac{d}{dt} B \cdot N \cdot S_{corearea}$$

$S_{corearea}$ = Area for the flux to path through

N = Amount of laps

B_{max} = Maximal flux that can be permitted in the material

By differentiating this equation, the expression in Equation 5-2 is obtained;

Equation 5-2

$$U \cdot \Delta t = S_{corearea} \cdot N \cdot B$$

In the theories about transformers a frequently mentioned parameter is voltage/time window, which can be seen in the Equation 5-2 and in Figure 5-7. The relation between frequency and amount of turns can also be studied. If the frequency decreases, the left side of Equation 5-2 increases, which sets the requirements for the right side as well. If a large Δt should be obtained one or more of the terms in the right side must be increased.
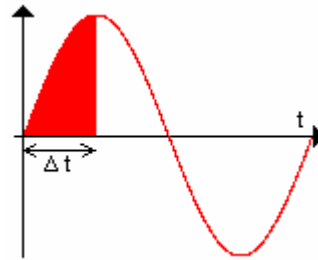

Figure 5-7 The marked area is the voltage/time area (Δt) and this is the area where the voltage is building up the magnetic flux within the core of the transformer. The higher frequency the shorter time for the voltage to build up the magnetic field.

Without any knowledge of how the magnetisation inductance and the leakage inductance are behaving it appears that all three parameters can be changed but that is not the case. Since the inductance increases with frequency they must be kept as low as possible to achieve good high frequency quality, see Equation 5-3 & Equation 5-4.

Equation 5-3

$$L_{leakage} = \mu_0 \cdot \frac{l_{avg}}{B} \cdot (\Delta_{iso}) \cdot N^2$$

l_{avg} = The average length of the magnetic flux

Δ_{iso} = The parameter which is based on how tight the laps are wounded, the tighter the less Δ_{iso}.

Equation 5-4

$$L_{magnetisation} = \mu_0 \cdot \mu_r \cdot \frac{S_{corearea}}{l_{avg}} \cdot N^2$$

Both the magnetisation- and leakage-inductances are proportional to N^2 which makes it very costly, in terms of losses, to increase the amount of laps in the windings. The magnetisation inductance is proportional to $S_{coreearea}$, which makes it costly to increase the area of the core. The flux density B is the last parameter that can be increased. The flux density has an upper limit that depends on the choice of the material of the core, for ferrites it is typically about 0,3T and for iron approximately 2T. This implies that a ferrite is not very suitable for the lower frequencies if the parameters; $S_{coreearea}$ and N must be kept at reasonable values.

5.5.3 Calculations for a customised transformer

The working range for the high frequency transformer is from 20kHz-40MHz and it is the lower value that is the designing criteria. The core was chosen to be a ferrite material (consisting of the material N87) and the area was decided by inserting different core areas into Equation 5-6. The areas that were tested were of course table values for different ferrite cores. The Δt in Equation 5-2 can be expressed in frequency instead by applying Equation 5-5, for better understanding of this equation, please see Figure 5-7.

Equation 5-5

$$f_{lowest} = \frac{1}{4 \cdot \Delta t}$$

Equation 5-6

$$f_{lowest} = \frac{V_{average}}{N \cdot S_{Ferritearea} \cdot B_{max} \cdot 4}$$

The low frequency transformer is most possibly inadequate for frequencies over 20kHz. It is therefore important that the high frequency transformer works sufficiently for that frequency as well. To achieve a transformer that works for 20kHz the design criteria must be chosen lower, the maximum allowed frequency was chosen to 10kHz. Calculations were performed for different ferrite cores and it turned out that Siemens ETD 54, N87 met the demands very well. In the calculations parameters were kept the same: an average ripple voltage of 1V, one lap, and a flux saturation density of 0,2T.

To increase the amount of dc current that can be tolerated in the secondary winding an air gap must be inserted in the ferrite core. Differentiating Equation 5-7 together with Equation 5-2 gives the relation between the current, the flux and the magnetisation inductance, the final expression can be seen in Equation 5-8.

Equation 5-7

$$U = L_{magnetisation} \cdot \frac{di}{dt}$$

Equation 5-8

$$\Delta i = \frac{S_{corearea} \cdot B \cdot N}{L_{magnetisation}}$$

The result of the calculations can be studied in table. The calculations can found in appendix.

Table 5-1 The result for the produced high frequency transformer.

	Without an air gap	With an air gap
f_{lowest}	$8116 Hz$	$8116 Hz$
$L_{magnetisation}$	$2{,}2 \mu H$	$0{,}33 \mu H$
Δi	$14 A$	$93{,}3 A$

The ferrite core was winded with one lap on the secondary side as in the calculations above and with ten laps on the primary side. The reason for ten laps on the primary side is to decrease the attenuation for low frequency usage. The results for this customised transformer was very good and the thoughts regarding other choices were discarded. The performance of the customised transformer, is compared with the old current probe, see Figure 5-8, the output ripple was held constant and the output value from the AWG was measured, a small value as possible from the AWG is desirable.
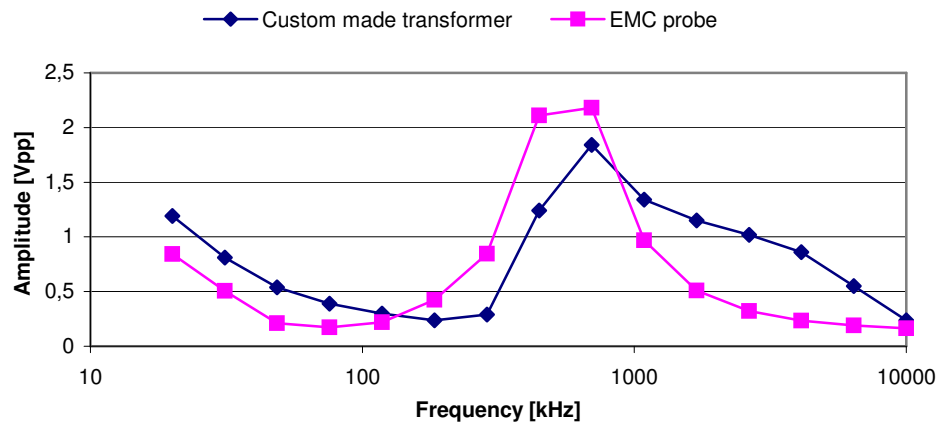
Output amplitude of the AWG

Figure 5-8 The applied voltage from the AWG was measured, while an output voltage of 10mV was obtained. The custom made transformer is the one described in this chapter.

An ordinary 50Hz toroid transformer was used for the lower frequencies. The idea was to improve this toroid by improving the secondary side and only have one lap on the secondary side as well. Only one lap on the secondary side would have decreased the leakage inductance. However it was found, that it worked agreeable without any further improvements and a test with only one lap on the secondary side did not give any good results.

5.5.4 The connection between the transformers

The first thought was to have the secondary sides of the transformer connected in series. This would make the changes of the transformers in the system a lot easier. This was although not working, the impedance of the toroid for the higher frequencies increased too much and the attenuation in the system was far too high, due to the fact that the toroid has 30 laps on its secondary side.

5.5.5 The breakeven measurement for the change of transformers

A measurement was performed to find out when the optimal change of transformers should be held. This was tested with an ordinary resistive load. The output dc current and voltage was altered, but the optimal change should be around 30kHz.

5.6 AC Ripple Injection Box (ARIB)

The transformers together with the injection card were inserted into a box, called ARIB, see Figure 5-9.
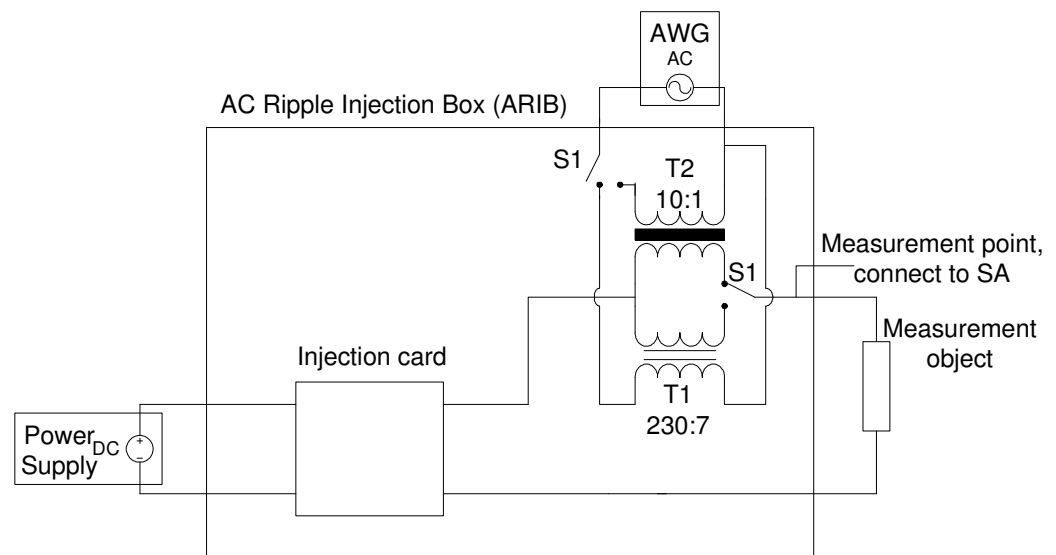

Figure 5-9 A schedule of the ARIB.

6 Mapping RF spurious free dynamic range to the input dc signal

To be able to analyse how the optimised measurement set-up works, a measurement on a real product was made. The measurement object was chosen to be an evaluation board RF mixer that takes the difference between two frequency signals. The idea with the measurement is to introduce a ripple to the dc supply of the downconverter and measure how this ripple affects the output signal. The reason for choosing a downconverter was that the output signal is discrete and that it resembles (to) the real radar application that this set-up might be used for. Measurements on a real DC/DC-converter were also performed.

6.1 The measurement set-up

The purpose of the downconverter is to take the frequency difference between two input signals and have it as its output. Two extra signal generators were needed to generate the input signals to the mixer.
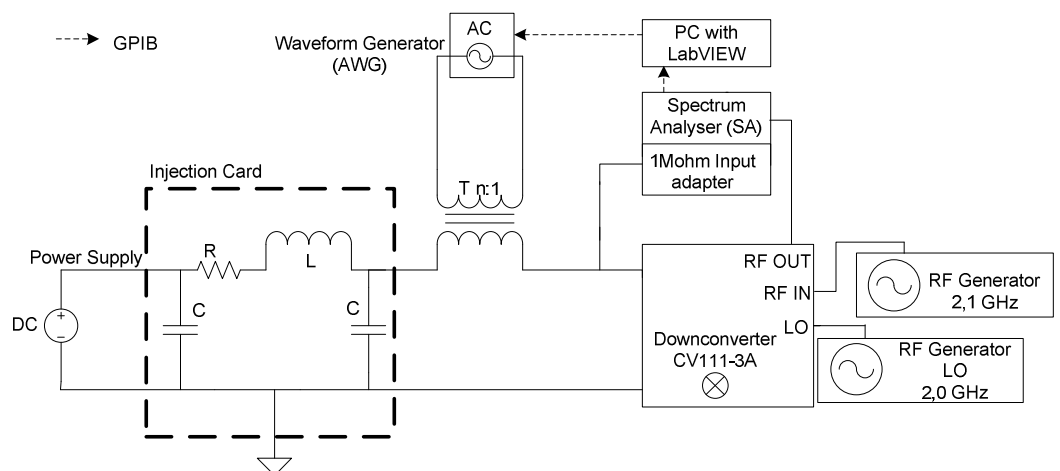

Figure 6-1 The measurement set-up, with a downconverter as a load. All instruments except from the AWG were synchronised.

6.2 Background information regarding the measurement

As a typical example, the output signal is allowed to have a maximum SFDR of −100dBc for frequencies up till 2MHz and −80dBc for higher frequencies. See Figure 6-2.
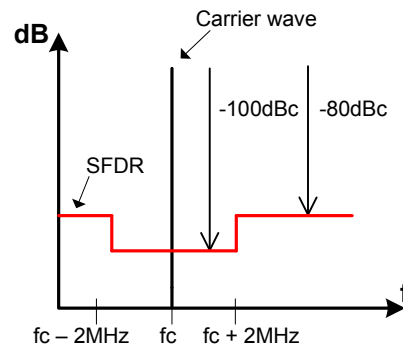
Figure 6-2 The requirement for the downconverter regarding RF signal quality, which include SFDR.

The amplitudes of the spuriouses are related to the amplitude of the voltage ripple and will then lead to requirements on the DC/DC-converter. Since the equipment and products are becoming more sensitive, the importances of the possibility of stating the requirements of the DC/DC-converters are of great significance. Therefore these kinds of measurements will most likely be very important in the future.

6.3 The aims for the measurement with the downconverter

The aims of the measurements were stated before starting the measurement, see below.

6.3.1 Verification regarding the set-up

This first proper measurement was done in order to provide information and knowledge regarding the measurement set-up as well as the measurement instruments. When knowing the instruments well, it will facilitate when developing a programme in LabVIEW, which can perform these measurements automatically.

6.3.2 Measuring the spuriouses above the SFDR requirements

It was in early test measurements found that such accurate measurements, as measuring dBc values of −100 were impossible for most of the frequencies and it is the level of the noise that sets the requirement. The spuriouses were then hidden in the surrounding noise or in the spikes close to the carrier wave, see Figure 6-4. Therefore the amplitude of the ripple will in these measurements be increased just as much in order to see at least one clear spurious on one side of the carrier wave and the downconverter will have a spurious above −100dBc.

6.3.3 Relation between the amplitude of the output voltage ripple and the spurious level

As a result of the problem with measuring spuriouses which are hidden in the surrounding noise. It was suggested that inquiries regarding a relation between the amplitude of the voltage ripple and the amplitude of the spruiouses should be made. If a relation was found, a measurement with lower dBc value could be performed, the desired dBc value could thereafter be calculated.

6.3.4 Mapping between the output of the DC/DC-converter and the tolerated input values for the downconverter

The measured or calculated output voltage could be presented as a limit line. This limit line should then be compared with the output voltage from the DC/DC-converter when it is loaded with the downconverter. It is then of great interest to see the margins.

6.3.5 Measurements performed on a real DC/DC-converter

Measurements of the output signal of a DC/DC-converter were made with the SA. This was done in order to see how much of the switching frequency, together with its harmonics that propagates and becomes a part of its output voltage. The DC/DC converter was loaded with different types of impedances; purely resistive, a RC-circuit and finally the downconverter. The aim of this kind of measurement is to see how the impact of the load affects the output ripple voltage from the DC/DC-converter. Most of the power consumers are adding decoupling capacitor filters in order to attenuate signals for sensitive frequencies. Therefore these kinds of measurements are of relevance.

6.4 Measurement result

The results from will the measurements be presented here below.

6.4.1 The performance of the set-up

The set-up worked fine, the measurements, which were performed manually, gave lots of knowledge for the development of an automatic LabVIEW program for measuring spuriouses. The spuriouses are visible in figure Figure 6-3, notice that the fundamental spuriouses have been measured and no measurements have been performed on their harmonics.
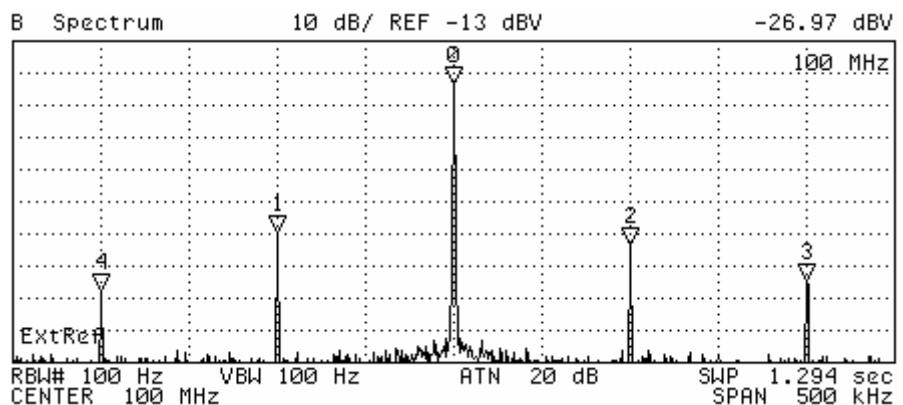
Figure 6-3 The spuriouses are clearly visible on either sides of the carrier wave.

6.4.2 The performance of the measurements for the spuriouses

Values for the dBc values between (-60) – (-80) were measured. However spuriouses for the frequencies over 5MHz were impossible to find. This might be a result of filters in the downconverter. In Figure 6-4 is the veil visible, which supports the idea about finding a relation between the voltage ripple and spurious level.

Figure 6-4 The surrounding noise to the carrier wave is visible in this figure. The width of the noise is approximately 4kHz for the downconverter.

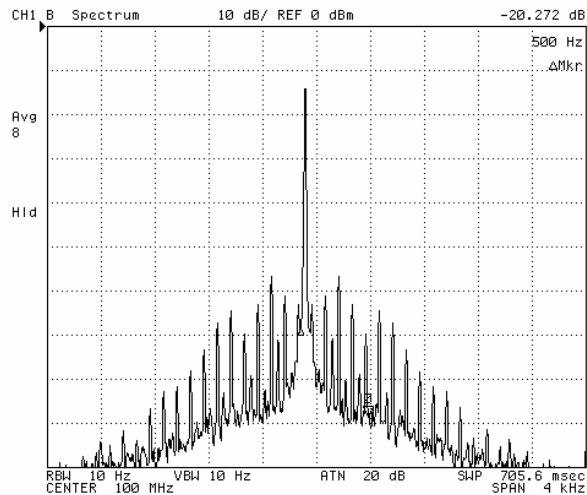It is now easy to understandable that too low spriouses are impossible to measure, the dBc levels that were measured are visible in the Figure 6-5.The figure is indicating that there is a linear relation between the amplitude of the spurious and the amplitude of the voltage ripple.

A chart for the requirements of the dBc values: -60 to -80.
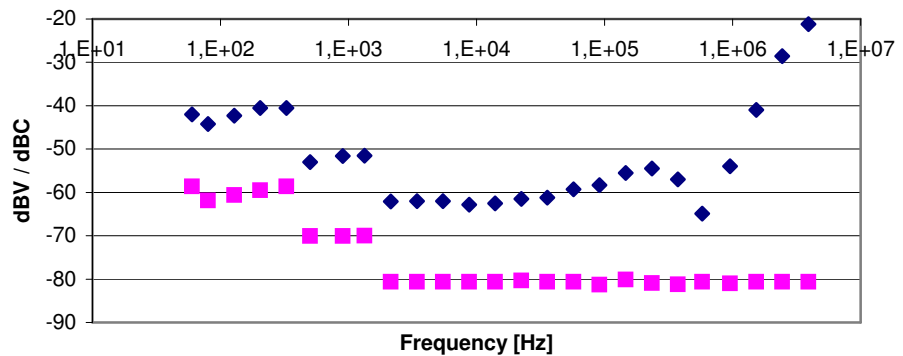
Figure 6-5 The measured amplitude of the voltage ripple for different dBc values.

6.4.3 Linearity between the amplitude of the voltage ripple and spurious level

The linearity was tested. A relation between the spriouse levels and the amplitude of the ripple voltage was found by calculating the linear regression to a value of approximately 1. For the higher frequency the applied effect will be distorted, which is shown in Figure 6-6, where the high frequency values are declining. It is also obvious that there might be some measurement errors when a low effect is applied for the higher frequencies, since the noise level is quite high in this regions. A real value for all the measurements was calculated to 0,93, but when taking into account the measurement errors, the value 1 seems to be a better final result.

Equation 6-1

$$\frac{\Delta Spurious\ [dBV]}{\Delta Ripple\ [dBV]} \approx 1$$

The relation can easy be seen in Figure 6-6, where ripple voltage is varying for different frequencies and the spuriouse levels are measured.
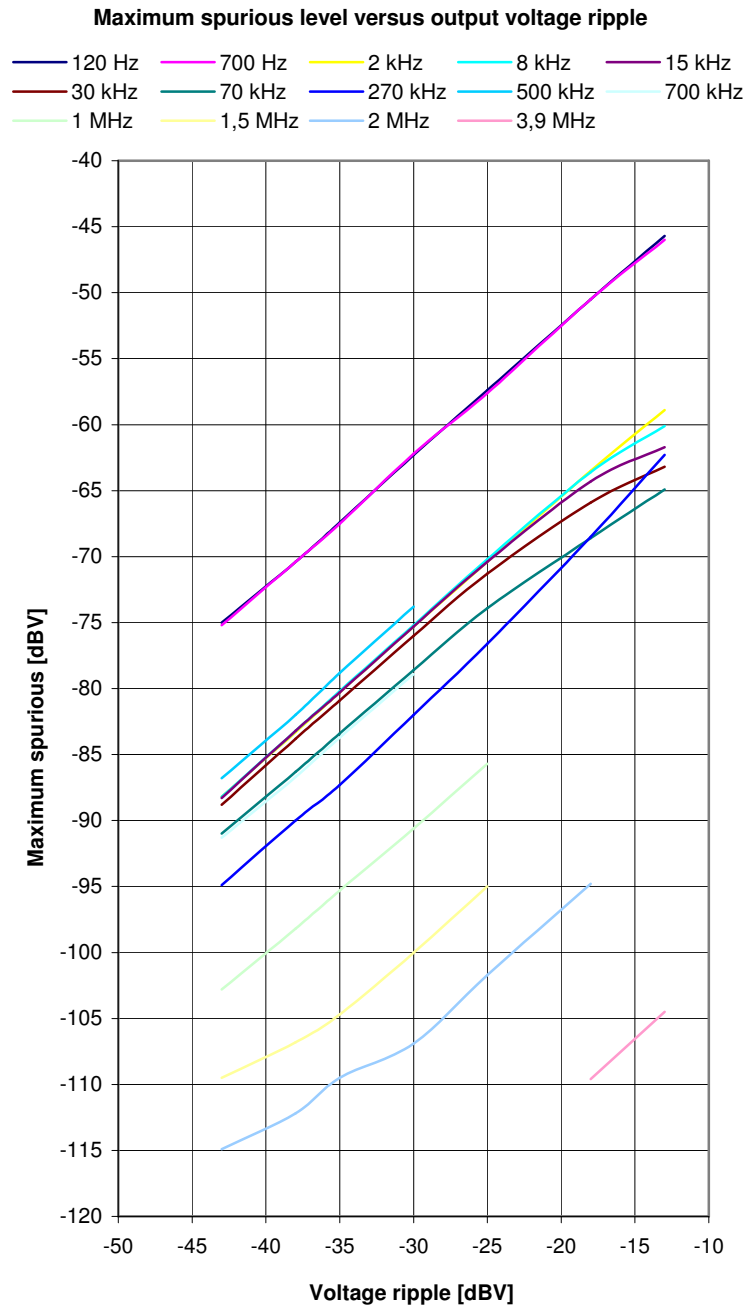
Figure 6-6 The voltage ripple is added to the dc signal, which is feeding the measurement object. The spuriouses are found on the output signal, of the downconverter and there is relation between them in forms of linearity.

6.4.4   Conducted susceptibility of the downconverter

If the linearity value is expected to be equal to one, than requirements for the DC/DC-converter, which is feeding the downconverter can be stated, see Equation 6-2 and

**Mapping of DC/DC-converter spectrum
to consumer requirement line**
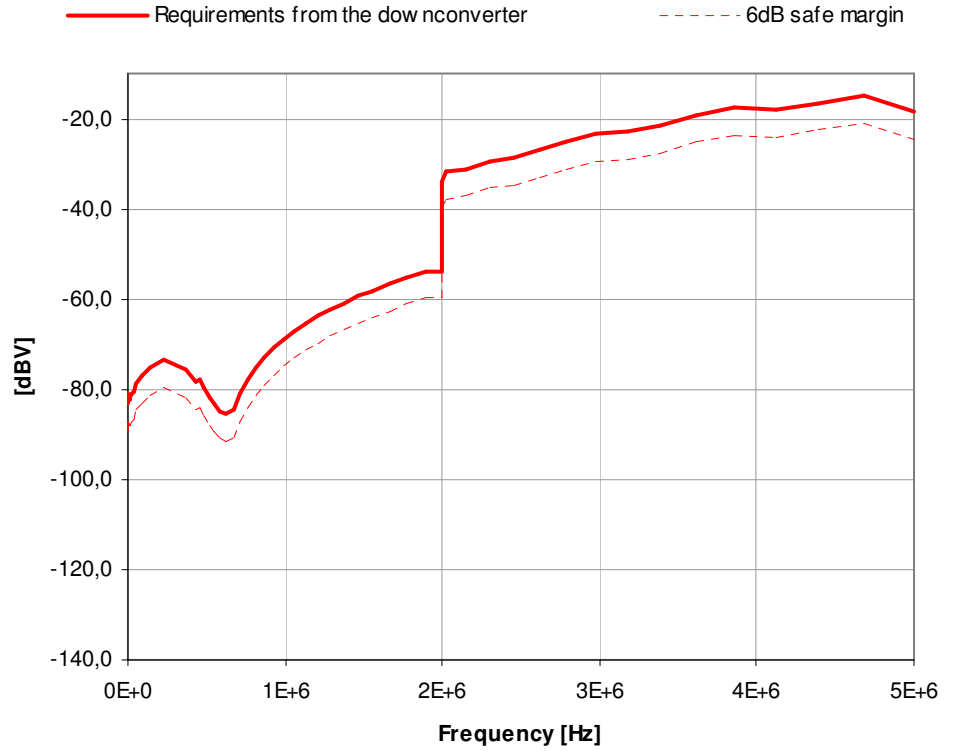
Figure 6-7. The figure of the mapping shows the requirements of the dBc values which were stated earlier in 6.2.

Equation 6-2

$$Tolerated\ ripple[dBV] = Applied\ ripple[dBV] + SFDR[dBV] - Spurious[dBV]$$

**Mapping of DC/DC-converter spectrum
to consumer requirement line**
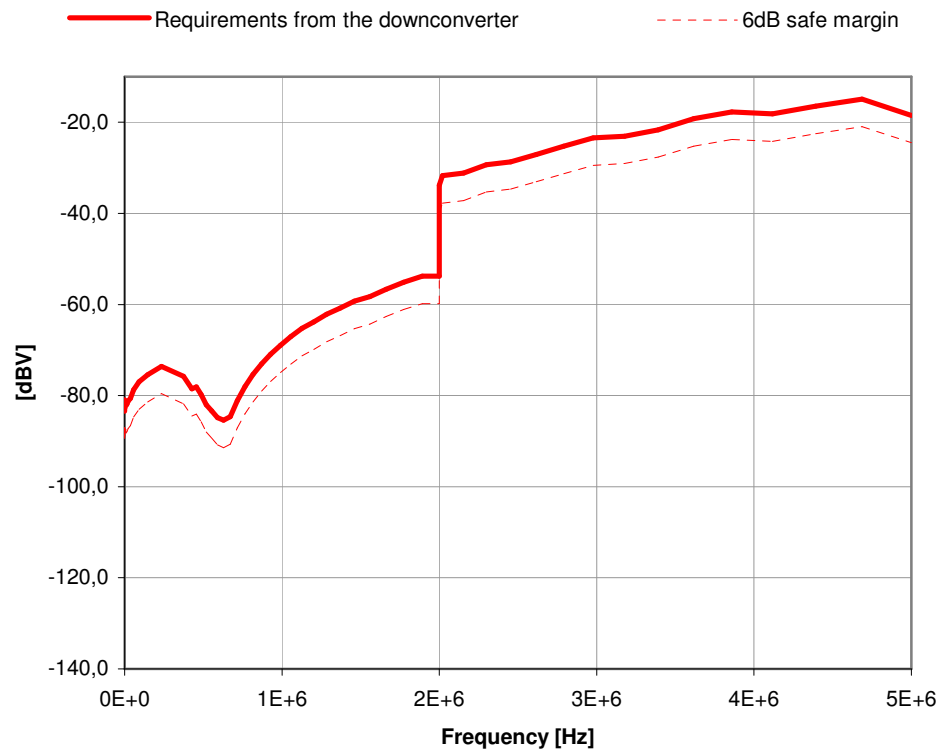
Figure 6-7 The requirements (−100dBc up till 2MHz and −80dBC for the higher frequencies) for the downconverter. The dBc values are calculated with the linearity factor.

6.4.5 DC/DC-converter and its output voltage spectrum

The frequency content in the dc signal was measured with a SA to obtain the amplitude of the different frequencies. The DC/DC-converter was firstly loaded with the downconverter. As expected and as is shown in Figure 6-8 the switching frequency has propagated through all filters. Due to this switching frequency there is also a lot of higher harmonics. In Figure 6-8 the first six tones are measured but a lot of harmonics are observable. During these measurements, the importance of keeping the cables as short as possible was shown.

```
                                                          7.6252375 MHz
```



```
RBW# 100 Hz      VBW 100 Hz          ATN 0 dB          SWP  25.42 sec
START  1 kHz                                           STOP  10 MHz
```
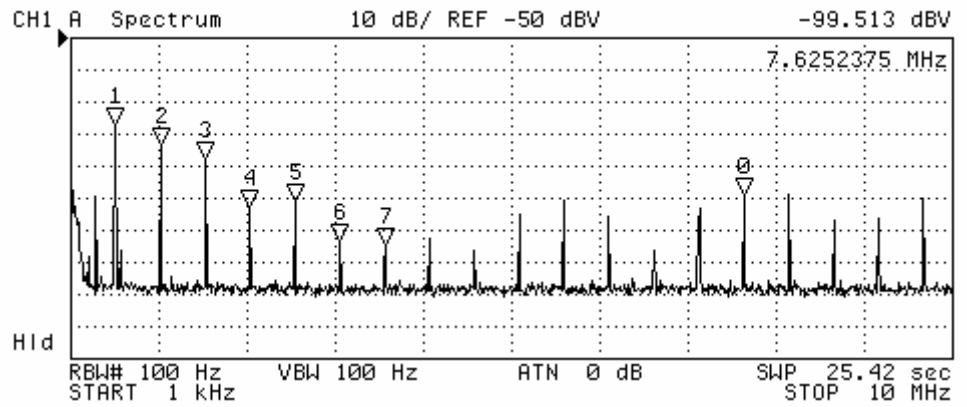
N	SWP PARAM	VAL
0	7.6252375 MHz	-99.513 dBV
1	500.95 kHz	-77.663 dBV
2	1.01339875 MHz	-83.699 dBV
3	1.5258475 MHz	-87.873 dBV
4	2.0257975 MHz	-102.93 dBV
5	2.53824625 MHz	-101.26 dBV
6	3.050695 MHz	-113.81 dBV
7	3.56314375 MHz	-114.83 dBV

Figure 6-8 The DC/DC-converter is loaded with a downconverter. The switching
frequency for the DC/DC-converter is clearly seen at the frequency
500,95kHz.The upper harmonics are unmistakably visible.

When the load impedance is changed to an ordinary resistor the amplitude of
the harmonics increases a lot. This is shown below in Figure 6-9. The
explanation for the increased amplitude of the switching frequency with its
upper tones might be due to the fact that there are no filters in the resistor as
it is for the dc input of the mixers.

```
CH1 A  Spectrum         10 dB/ REF -50 dBV          -93.413 dBV
                                            5.9754025 MHz
```

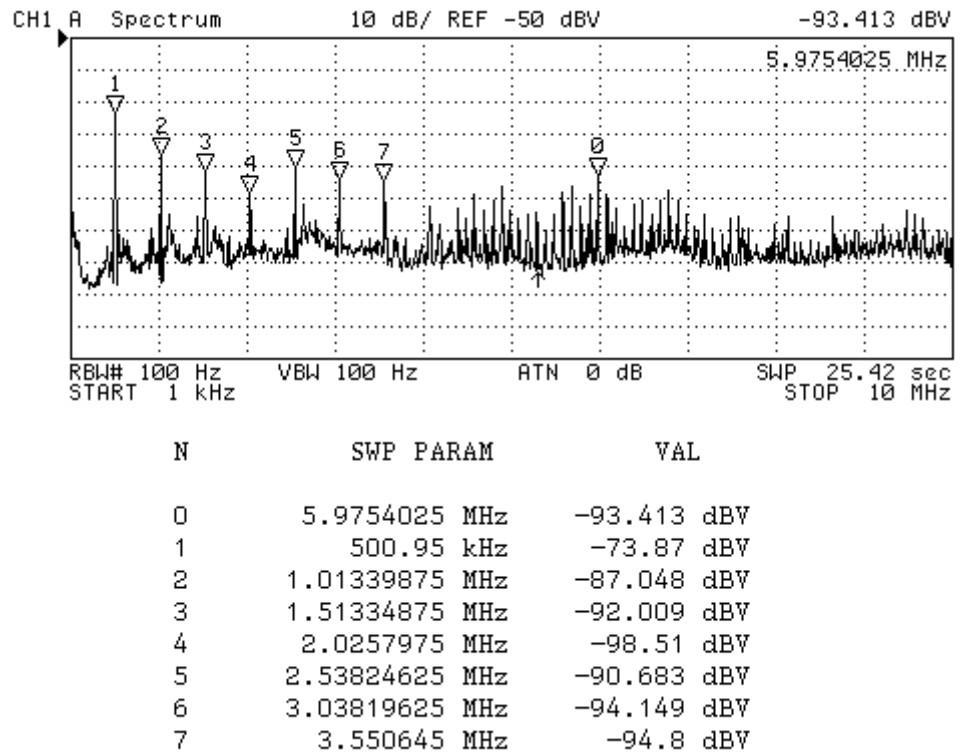| N	SWP PARAM	VAL
0	5.9754025 MHz	-93.413 dBV
1	500.95 kHz	-73.87 dBV
2	1.01339875 MHz	-87.048 dBV
3	1.51334875 MHz	-92.009 dBV
4	2.0257975 MHz	-98.51 dBV
5	2.53824625 MHz	-90.683 dBV
6	3.03819625 MHz	-94.149 dBV
7	3.550645 MHz	-94.8 dBV

Figure 6-9 The resistance was increased just as much to obtain a current of 400mA, which is the same current that is drawn from the downconverter. Notice that the amplitude of the switching frequency is greater for the resistance comparing to the amplitudes in Figure 6-8.

No major difference when a capacitor was connected in parallel to the resistance. This was performed since it was believed that the downconverter could be estimated as a RC-circuit.

6.4.6 Mapping of DC/DC-converter spectrum to downconverter requirement line

The measured output voltage from the DC/DC-converter, is inserted into the chart of the requirement line, see Figure 6-10.

**Mapping of DC/DC-converter spectrum
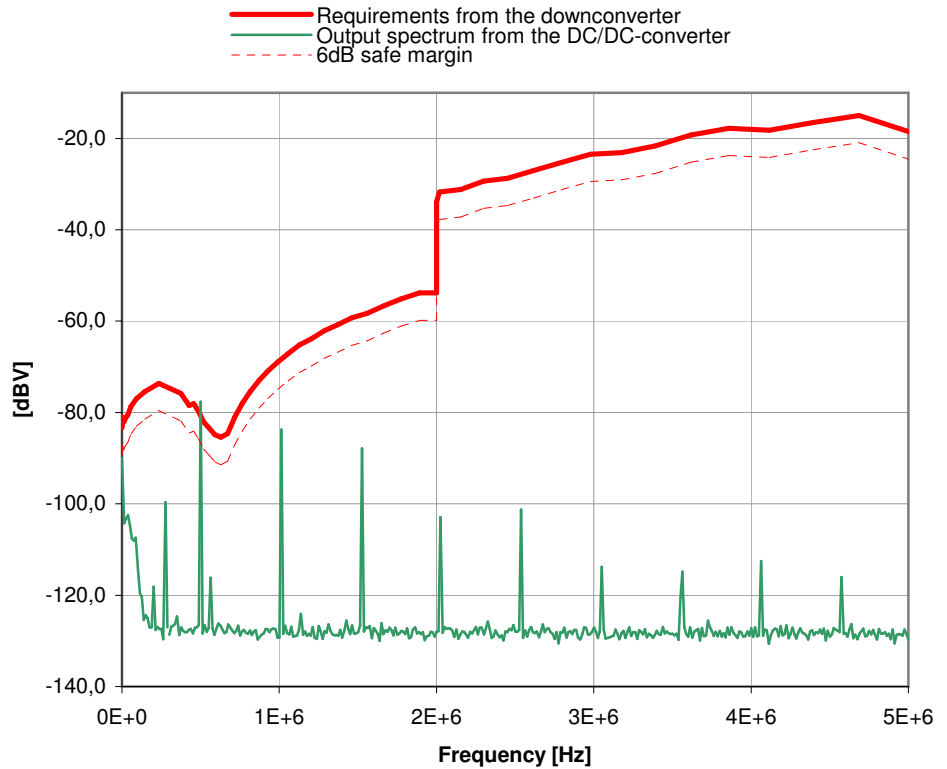to consumer requirement line**

Figure 6-10 The margins between the spikes from the DC/DC-converter is obviously
too low. However by using another switching frequency the intersection
between the requirements and the output signal could have been avoided.

This outcome from the measurement is not a verifying one, see Figure 6-10,
but the result is clear. The output voltage from the DC/DC-converter is too
high. The switching frequency should have been almost double as high to
avoid the most sensitive parts of the downconverter, care must although be
taken to subharmonics.

This way of performing the measurements would be of great use for the
developments of different DC/DC-converters for example. However in most
applications the measurement object are developed at the same time as the
DC/DC-converters are being developed. The consequence is that these kinds
of measurements cannot be performed until the very end or possibly on early
versions of the final products. It would therefore be convenient if the
impedance that will be fed by the DC/DC-converter could be stated at an early
stage.

7   Impedance measurements

Since most of the consumer's designs are developed at the same time as the DC/DC converter, the measurements which results in a DC/DC converter limit line are impossible to measure before the first version of the consumer is ready. It might therefore be useful to approximate the impedance of the consumer and use it as a load to the DC/DC converter. The output signal could then be analysed.

7.1   Measuring the impedance with the network analyser in the theory

A Network Analyser is used for measuring the impedance. By using its RF-output signal as the injected ripple and measuring the voltage, current and the phase in the same sweep, the impedance can be calculated. However the NA measures the voltage- and the current-values in dB, which had to be recalculated to voltages. Investigations of the results and a final equation for the connection between the amplitude of the impedance had to be derived and verified. In the measurement a current probe was used and a conversion factor, C_{probe} was needed in order to convert V_{rms} into an I_{rms}.

Equation 7-1 An already known formula.

$$dB = 10 \cdot \log\left(\frac{P}{1W}\right) = 10 \cdot \log(\frac{V_{rms}^{2}}{Z_0 \cdot 1W})$$

Equation 7-2 The V_{rms} is solved out of the Equation 7-1.

$$V_{rms} = 10^{dB/20} \cdot Z_0 \cdot 1W$$

Equation 7-3 A similar equation can be derived for the I_{rms} and notice the difference of the conversion factor; C_{probe} which in this case was equal to two.

$$I_{rms} = C_{probe} \cdot 10^{dB/20} \cdot Z_0 \cdot 1W$$

Equation 7-4

$$Z = \frac{V_{rms}}{I_{rms}} = \frac{10^{dB_V/20} \cdot Z_0 \cdot 1W}{C_{probe} \cdot 10^{dB_I/20} \cdot Z_0 \cdot 1W} = \frac{10^{dB_V/20}}{C_{probe} \cdot 10^{dB_I/20}}$$

By dividing the voltage value with the current the impedance value is obtained. The phase is measurable directly from the NA-screen in degrees for a chosen frequency span.

7.2   Performing the measurement practically

The idea is to perform the measurement described in the previous section with a NA. The connections should be as for the spurious measurements except from that an additional current probe is needed. The current probe should be connected to channel R and the RF OUT should be connected to the measurement object. No other reconnections comparing to the other measurement set-ups are necessarily. For set-up see Figure 7-1.
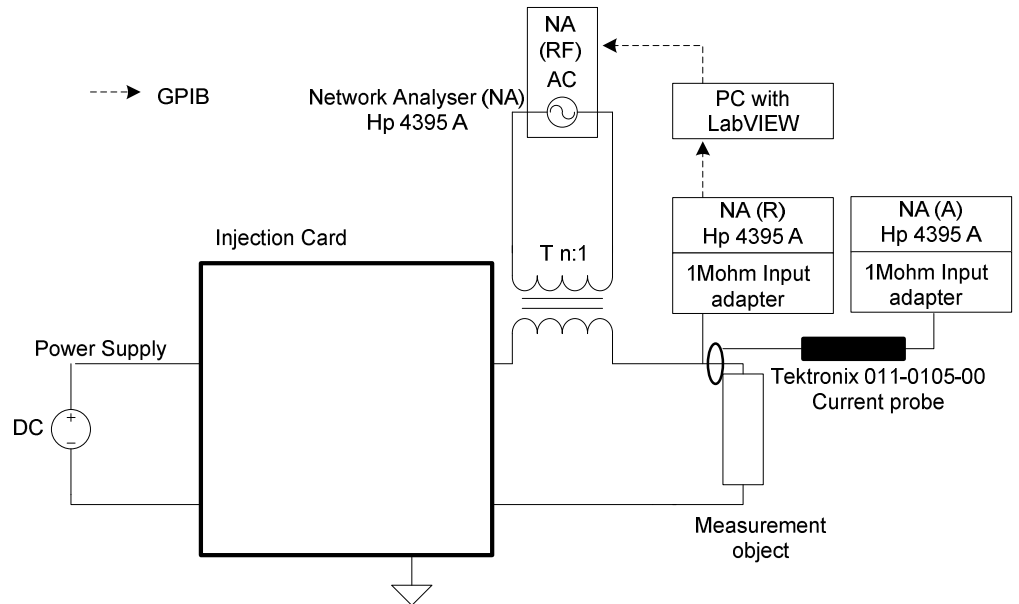

Figure 7-1 The impedance measurement set-up, notice that there are hardly any differences from the "previous" set-up.

The most vital part is to avoid too long cables since they will turn inductive for higher frequencies. In order to increase the accuracy; coaxial cables are preferable.

7.3   Passive measurements

A passive measurement without an applied DC current was performed. These were quite successful but it would have been very interesting to perform an active impedance measurement.

7.3.1   The verification performed on already known impedance

Verifications of the impedance measurement set-up were performed on already known impedance. This was tested on a capacitance with known characteristic and the measured values were compared to the datasheet. It turned out that the NA was relatively good on determining the impedance see Figure 7-2.
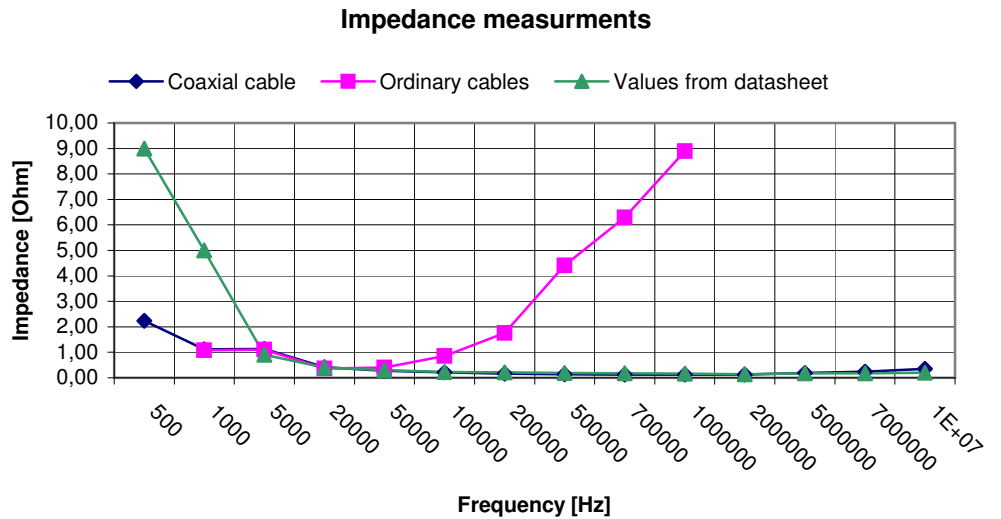
Impedance measurments

Figure 7-2 The impedances measured with coaxial cables and with ordinary ones. The measured values are compared with the ones from a data sheet for the capacitance.

However it seems that the measured phase is not totally reliable, this was confirmed when analysing the capacitance values for the measured value of the capacitance and the datasheet of the capacitance, see Figure 7-3.

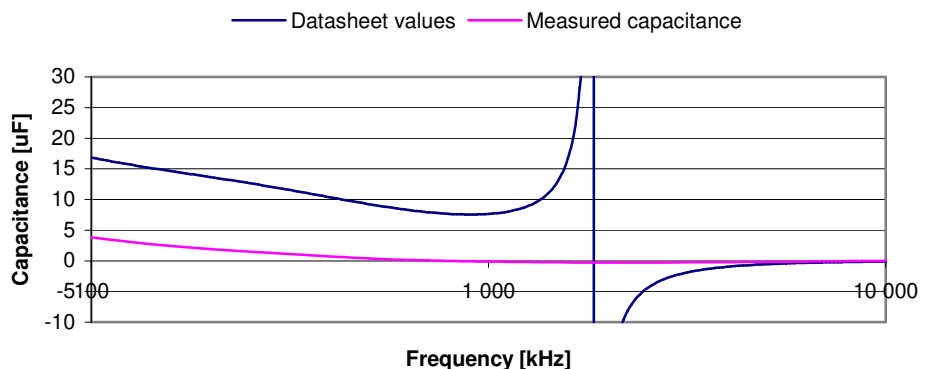**Measurement values and data sheet values for the capacitance**

Figure 7-3 The measured capacitance differs a lot from the data sheet values.

This result was quite surprising since the comparisons of the impedances turned out well. More verifying measurements must be performed before this method can be stated to be reliable.

7.3.1.1   Further studies of how to measure the capacitance with the GNAT system

Investigations regarding the problem with stating the capacitance were done. The same measurement was performed with the GNAT system. Measuring the impedance phase failed with this procedure as well, however the suggested probe was not used.

7.3.2   Measuring an inductance

An inductance was measured with the two different measurement systems and the same result was obtained for both the systems. An inductance from Coilcraft was measured with an inductance of 47µH and by looking at the graph values in Figure 7-4. A similar graph is visible in Coilcraft's data sheet see Figure 7-5.
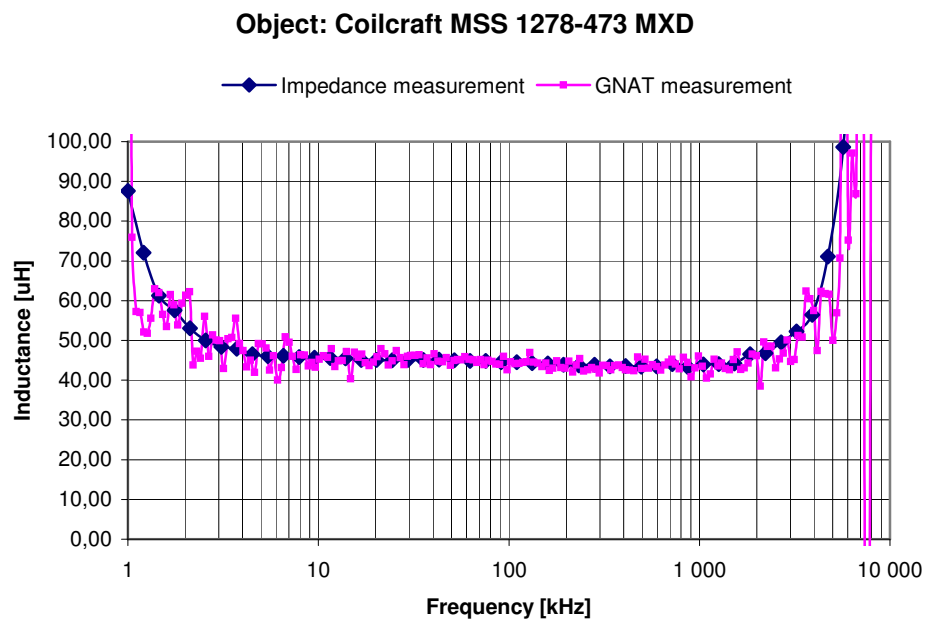
Object: Coilcraft MSS 1278-473 MXD

Figure 7-4 The impedance measurement comparing to an impedance measurement performed by the GNAT-system.
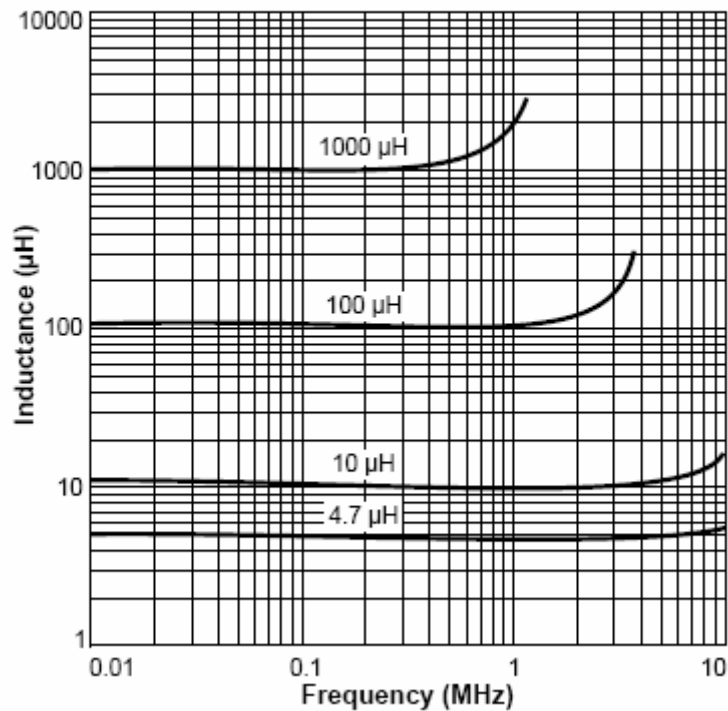
Typical L vs Frequency

Figure 7-5 The impedance that was measured was 47µH and the shapes from this figure which is done by Coilcraft is similar to the measured one, compare with Figure 7-4.

7.4 Active measurement

The problem is that an active impedance measurement is desirable, whereas a passive measurement is possible. An active measurement means that the measurement object is fed by a DC power supply, while being measured. The input impedance will presumably change for the consumer if it is fed with a DC current. Therefore is an active impedance of importance. It is presumably the transformers in the ARIB, which results in a phase shift and therefore makes it impossible to measure the phase.

7.4.1 Analysing the impedance of the downconverter

It would have been useful to measure the downconverter in an active mode, but since it failed for ordinary components this was never performed.

8 LabVIEW interface and ideas for the performance of the automatic measurements

In the beginning of the project some inquiries were made in order to decide what kind of functions the LabVIEW programmes should be able to handle. It was decided that the program should have three different tasks and therefore the task was divided into three different programs.

8.1 The purposes of the LabVIEW programme and its structure

The LabVIEW programme will have three different tasks.

1. Automatic adjustment of the applied amplitude voltage ripple.

2. Automatic adjustment of the spurious level.

3. Measure the input impedance.

8.2 Measure the voltage ripple

The first purpose of the programme is that it should be able to inject a determined ac voltage ripple into the dc voltage. The programme will be controlling and communicating with the instruments in order to apply the right amplitude of the ripple. Since the applied voltage ripple is substantially decreased, due to the ratio of the transformer and the rest of the set-up, a regulation in the LabVIEW programme is needed. The very same regulation, see Equation 8-1, is also used for the second purpose of the program, see the following section. The obtained data will be saved in an Excel sheet.

e[k] = reference value – current value

Equation 8-1 U(k) is the new output signal to the AWG, which means that this will be the next value for the AWG to apply. A PI-regulation is used, since it has a better performance since it also takes the previous value into consideration and there is no risk for a stationary error.

$$U[k] = K \cdot e[k] + 0{,}2 \cdot K \cdot e[k-1]$$

The basic idea behind the program:

- The measurement procedure starts by feeding the program with data input
- LabVIEW adjusts the chosen ripple amplitude which feeds the measurement object
- The ripple amplitude and frequency are stored in an Excel sheet
- As an option the user can write manually measured data regarding spuriouses to the same sheet

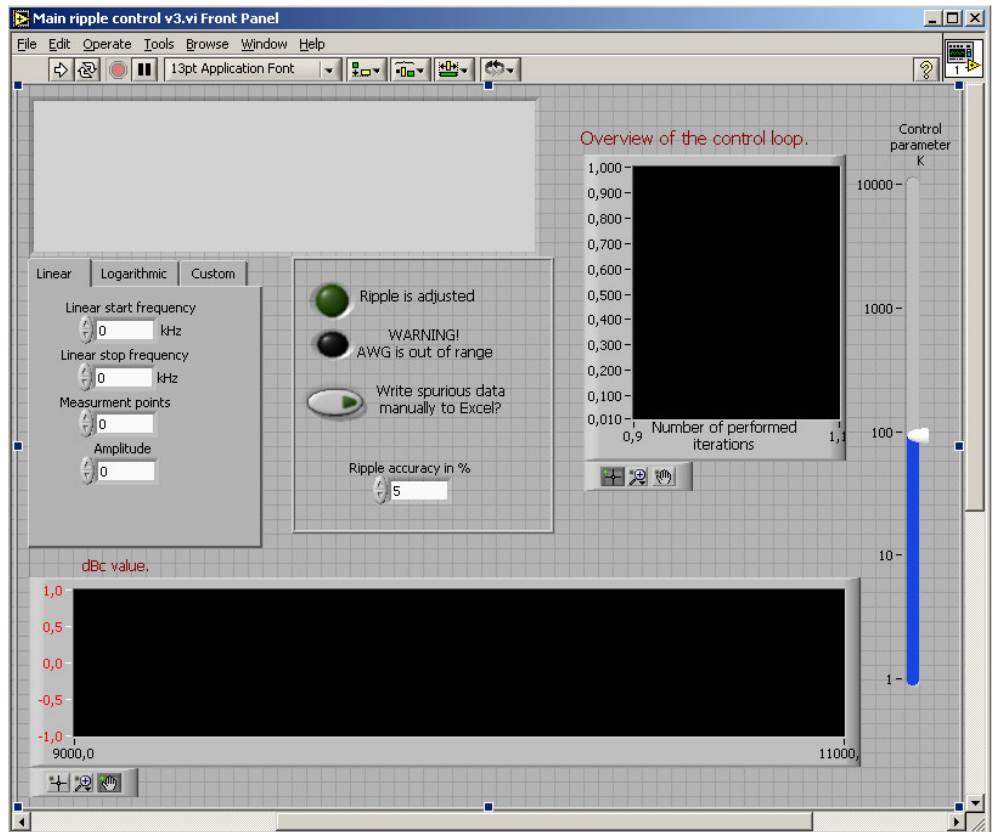The interface of the program will be visible in Figure 8-1.

Figure 8-1 The interface of the AC ripple injection program. For further description of the program, see the manual.

8.3 Automatic adjustment of the spurious level

The other purpose of the programme is to adjust the spurious level comparing to the carrier wave to a certain level, by measuring on the output signal of the power consumer. The programme will after the adjustment inform the user of the applied voltage ripple. If this procedure is repeated for a desired frequency span the tolerated voltage ripple can be plotted. The measured data will be available in an Excel sheet and can easily be plotted by the user.

The user must carefully prepare an automatic measurement if a good and satisfying result should be achieved. There are at least two important things that should be checked before a measurement. At first the noise level must be measured for the actual frequency, the spurious level cannot be below the noise level; preferably the spurious level should be chosen several dB over the noise level. The other important thing is to check how much veil there is around the carrier wave, see Figure 6-4. The program can theoretically be used down to 10kHz but in practise this must be tested before automatic measurements.

The idea behind the program:

- The measurement procedure starts by feeding the program with input data and an Excel sheet is created
- LabVIEW adjusts the chosen spurious amplitude is obtained from the object, the result is stored in the Excel sheet.

- The ripple amplitude is measured and stored in the Excel sheet
- A new frequency is measured and the program repeats itself from point II.

The program was verified at the RF card, see chapter 9, the interface of the program will be visible in Figure 8-2.
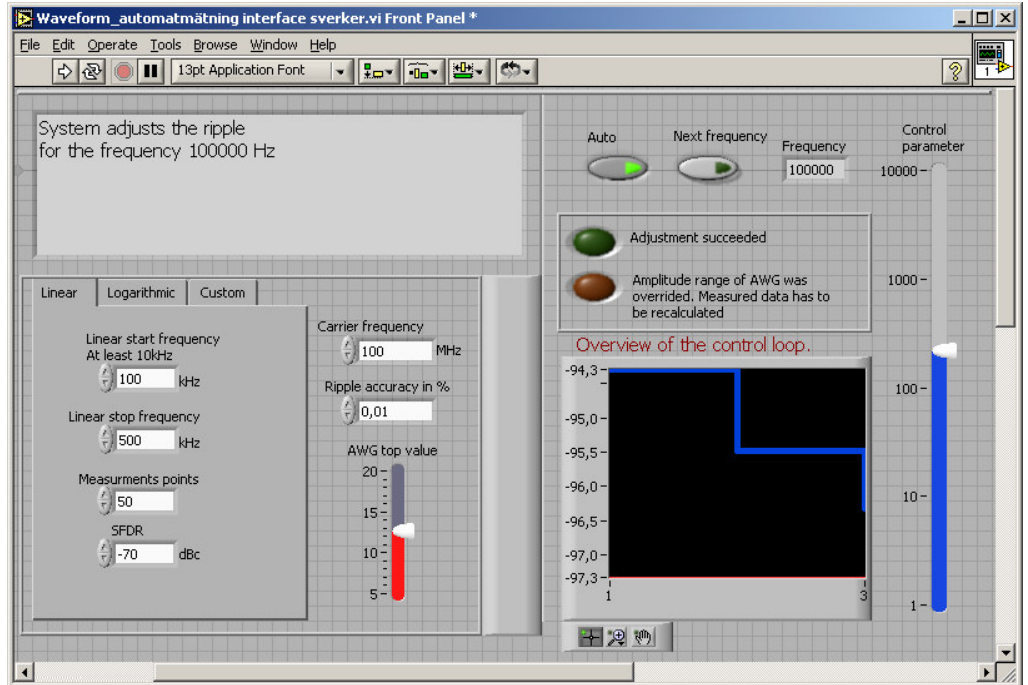
Figure 8-2 The interface of the spurious level adjustment and voltage ripple detection program. For further description of the program, see the manual.

8.4   Impedance measurement

The impedance will be measured in three steps; the voltage, the current and the phase. The user will then have to perform necessarily calculations in order to attain the components in the impedance. The LabVIEW program will make essentially settings of the NA and save the data to a floppy disc as a text file.

The interface of the program is very easy to understand and use. The graphical menu is shown below

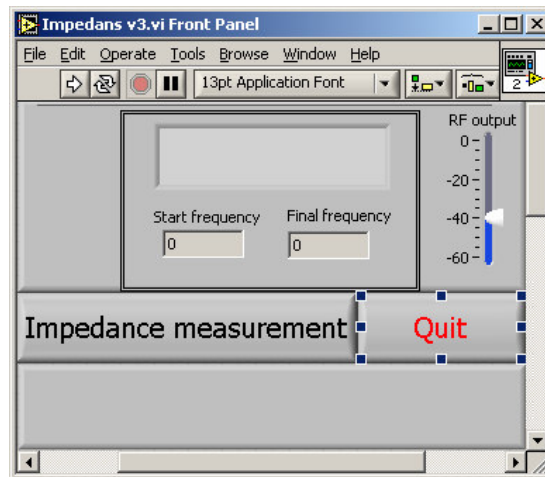Figure 8-3 The interface of the impedance measurement. For further information regarding the program, see the manual.

The basic idea behind the program:

- The voltage window is adjusted and the data is saved to the disc
- The current window is adjusted and the data is saved to the disc
- The phase window is adjusted and the data is saved to the disc

9 A final test performed on a RF card

This measurement is not a verified (non-calibrated instruments were used for example) one but the results should resemble to future verified results.

9.1 The performance of the measurement

The DC/DC-converters are feeding the RF card with different dc voltage levels. It was determined that the dc voltage that should be subjected to a ripple was the 7V level, and accordingly was this level removed from the supply and replaced with the developed measurement equipment.

Apart from feeding the RF card the 7V converter also feeds the other DC/DC-converters in the power supply. To put the converter into its normal working position, the 7V converter should have been loaded with the same current, as it would have been if it had been connected to the card. This was however not done in this measurement. There is therefore a change from the normal conditions when the DC/DC converter is feeding all loads. This change was considered to have no impact on the final result.

This measurement was performed automatically with the developed LabVIEW program. However it was made with non-calibrated instruments and only a few test points were verified manually. The measurement was however repeated a few times and similar results were achieved.

9.1.1 Problems which aroused, when performing the measurement

The spuriouses as well as the carrier frequency were varying quite a lot in amplitude, the average factor for the SA was chosen to three. For a more verifying measurement a suggestion is to increase the average factor. Two different measurements were performed, one when the voltage ripple was measured from the box just as intended and one measurement when the ripple was measured with soldered coaxial cable right on the card. The second measurement was preformed to increase the accuracy of the result.

A slightly different result was obtained when changing the cables. This should be noted and checked before a final verifying measurement is performed.

9.2 Discussions regarding the results

The requirement for the spuriouses of the RF card is that, the sum of the spuriouses should be less than -57dBc. The LabVIEW program that has been developed is not able to perform such measurement. It was therefore approximated that the dBc value to the maximum spurious should be chosen to -60dBc.

The measurement was performed for dBc values of 50 and the linearity was verified and utilized. In the figure it is clear that the margins are very high for this specific measurement. When studying the levels on the Y-axis it turned out that it is the card that is resistance to conducted disturbances. The card might however have less margins when applying radiated emission in forms of spuriouses. That requirement data could however be complemented with radiated susceptibility data.

Mapping chart for the RF card and the output voltage
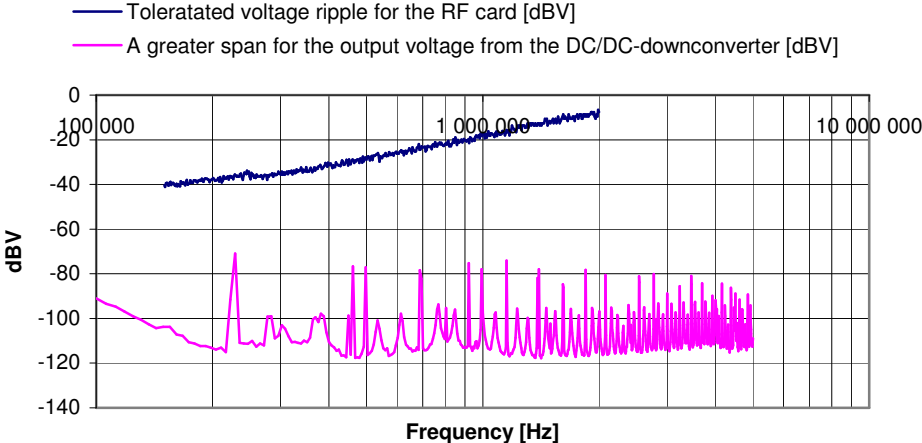
Figure 9-1 The figure above shows the results for the measurement performed on the RF card. The greater span output voltage has a different setting comparing to the smaller ones. The effect from the spikes are spread to its surrounding for the greater span and the noise level therefore looks greater. The spikes are however just as high for both of the measurements. Notice that the amplitude of the spikes remains at a constant level and also the great margin to the requirements.

10 Discussions and consequences of the suggested measurement set-up

Some thought regarding the methods and further upgrades of the measurement system will be discussed, as well as results.

10.1 Discussions regarding the methods

This project was from the beginning about developing a measurement routine for measuring how power ripple affects the spurious levels. It was decided to conform the requirements for the power supply to the requirements for the RF signal. This routine would be a more accurate one, comparing to the methods used nowadays. Today a standard peak to peak voltage is used as a limit line in a figure of the output signal in the time domain. This limit line cannot be translated to the developed DC/DC converter limit line in this project. If there are other requirements than the SFDR requirements, these requirements should be inserted into the same chart. When looking at the highest requirements for the whole frequency span, one single final limit line is obtained.

During this work we have seen that measurements of this type are not performed nowadays. In the future it might be necessary to perform these kinds of measurements. This conclusion can be taken after studying of the technical evolution when the margins are getting smaller and the technics are becoming more sensitive. If this evolution is continuing, these measurements will definitely be necessary. These measurements might also play a part when developing more cost efficient products. During the measurement of the RF card it turned out that the margins were too great regarding conducted emission.

This measurement method requires a consumer, but when the project starts and the first specifications are set there might not be any available consumer. The output signal from the DC/DC converter could be loaded with an approximated consumer load and the levels from of the output signal could carefully be studied. The RF requirements must be taken into account when the first prototype is ready and a DC/DC converter limit line can be measured. If the requirements for the DC/DC converter are greater than the previous stated specifications, an updating must be done and the greater demands must be met by the power supply as well.

In the end all developments of new products are about profits and the intention is therefore that when the stated specifications are verified with measurements, some profit could be made. If the power supply fulfills the requirements with great margins, the amount of components can be decreased. Or if it does not fulfill the requirements, a profit will be made when reducing future errors. However caution has although has to be taken, developing an optimal solution will take time and the time might be more expensive then using some extra components.

10.2 Discussions regarding the LabVIEW

The interface has been developed in order to make such a logic program as possible. It works satisfyingly but knowledge regarding the consumer is necessary as has been pointed out in previous chapters. The LabVIEW program, which only adjusts the voltage ripple can be very useful when using linearity relations. This program must be used for the lower frequencies as well as if spurious harmonics want to be measured. The other program could be run just as many times as the users wishes. If repeating the measurement several times a more accurate result will be obtained. It might however be necessary to check some of the measurement points manually.

10.3 Developments in order to increase the usage of the set-up

Some developments might be necessary in order to upgrade the equipment. The injection card could be optimized for special applications. The exciting card is designed to inject a ripple to a load, which requires a constant dc-current. This solution might not be sufficient if the load for example requires a pulsed current. This due to, that there are no capacitors that can deliver this current when the transformer fails.

To be able to increase the ripple frequency some components must be replaced with more frequency stiff ones, or more current must be injected. The high frequency transformer is sufficient up to 40MHz but for higher frequencies, some further investigations may be performed to guarantee its performance as well as the rest of the system.

10.4 The Six Sigma approach and an evaluation of the CTQ-parameters

The central strategy for the Six Sigma method; DMAIC-tool was used. The task of the project was defined followed by measurements, analyses and improvements. The improvements lead to further measurements and analyses until the task was fulfilled satisfyingly.

The CTQ-parameters, which were stated, are quite measurable ones. We are satisfied with the LabVIEW program. The priority has been to have a program that works and not one that has neither a nice graphic design nor a good program technique. The equipment has been working fine. An improvement, which could have been done is to purchase the impedance measurement probes for the spectrum analyser instrument. The timetable has been followed; the project is going to be ready in time. The applied ripple voltage is pure and we have developed a LabVIEW program that adjusts the amplitude of the signal to a desired value. The performances of the measurements are very good. They are reliable as far as we are concerned. Repeated measurements with the LabVIEW program has resulted in the same result. These measurements have also been verified manually. To sum up the CTQ parameters have been fulfilled.

11 Further work within the area, which can be performed

Apart from upgrading the system, some other work should be done.

11.1 Necessary work to be done, before using the method and measurement system as a reference system

Firstly, the whole measurement set-up must be verified and calibrated. Some of the instruments were not calibrated nowadays. More verifying measurements must be performed before the measurement system could be truly trusted.

A discussion with the consumer's designers is definitely needed. The requirements for the RF signal must be stated carefully.

The whole measurement procedure must also be standardised, if it should be used on a common basis. The original thought is that this method should be a part of the process when developing further DC/DC converters. This method should then be well known both for the consumers and the power supply designers.

11.2 Impedance measurements

The impedance measurements have to be verified further. Passive measurements have been quite successful. Unfortunately has measurements on impedances while feeding them with a DC current failed. This would have been advantageous since most of the input impedances of the consumers will change while being fed by a DC current.

Another system, called GNAT has also been tested for this application but no satisfying results have been obtained.

12 A summary of the measurement procedure

In order to summarise the measurement procedure some figures, which will be describing the procedure will be presented in this chapter. This measurement will transfer the requirements on the consumer, regarding spuriouses, to the power supply.

12.1 Analyse the measurement object and measure the spuriouses

Since it sometimes might be impossible to measure the spuriouses accordingly to the SFDR requirement curve, the spuriouses should be measured as close as possible to this requirement curve. The ripple should be applied for different frequencies and the spuriouses for each frequency should be recorded as well as the applied voltage ripple. For automatically performed measurements it is very important to analyse, which spurious levels that are practically measurable, see Figure 12-1.
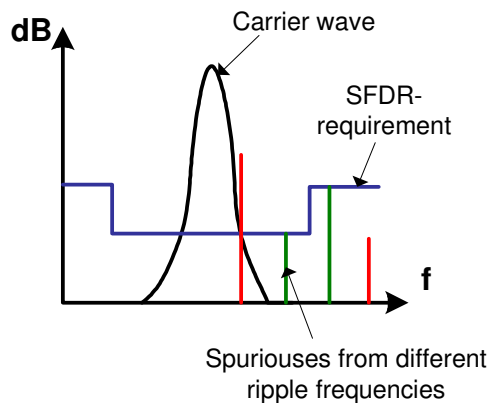

Figure 12-1 The spurioses should be measured as close as possible to the SFDR requirement curve.

12.2 Detect the applied voltage ripple

The applied voltage ripple could be presented in a graph, see Figure 12-2.
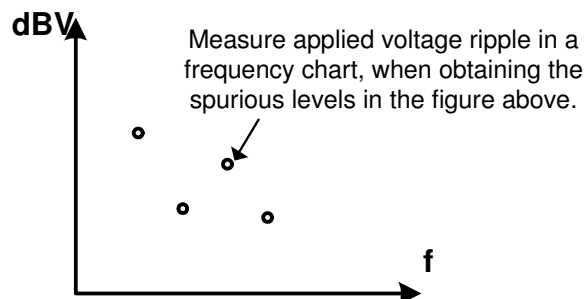

Figure 12-2 Insert the applied voltage ripple amplitude in a graph.

If the spurioses have been measured at the SFDR requirement curve, the applied voltage ripple will correspond to the DC/DC converter limit line directly and no adjustment is needed.

12.3 Investigating if there is a relation between applied voltage ripple and spurious levels

If it is impossible to measure she spurious levels accordingly to SFDR requirement curve a relation between the applied voltage ripple and spurious levels should be investigated. It has for some objects been stated that the relation is equal to 1:1, see Equation 12-1, if this relation is true it will result in Equation 12-2. But this relation must be studied further before making a final conclusion regarding the relation.

Equation 12-1

$$\frac{\Delta Spurious \ [dBV]}{\Delta Ripple \ [dBV]} \approx 1$$

Equation 12-2

$$Tolerated \ ripple[dBV] = Applied \ ripple[dBV] + SFDR[dBV] - Spurious[dBV]$$

The tolerated applied voltage ripple can be recalculated for each frequency, when knowing the SFDR requirements and the measured values. This will result in a DC/DC converter requirement line, so called DC/DC converter limit line, see Figure 12-3.
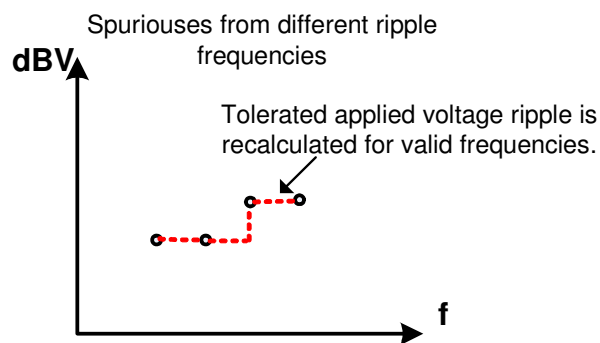

Figure 12-3 When recalculating the applied voltage ripple to the tolerated one.

12.4 Add the output voltage of the power supply to the DC/DC converter limit line

Since the DC/DC converter limit line describes the requirement for each frequency the output voltage from the power supply should be measured with a SA. The power supply should be loaded with the consumer's load, see Figure 12-4. The margins could be studied and other design parameters could be further analysed, for example if the placement of the switching frequency is optimal.
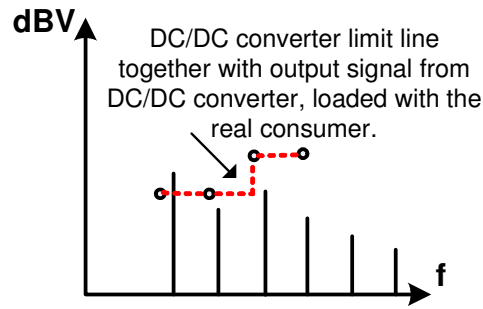
Figure 12-4 The output voltage from the power supply and the DC/DC converter limit line. The margins could for example be studied here.

If there are other consumers that are being fed from the same power supply, the requirements from these products could be added to the same graph and a final DC/DC converter limit line could be obtained. Other requirements based on other parameters could also be inserted into the same figure graph.

12.5   If no consumer is available

It is quite common that the consumer is designed at the same time as the power supply. It could therefore be useful to design an approximated load of the input impedance of the consumer, see Figure 12-5.
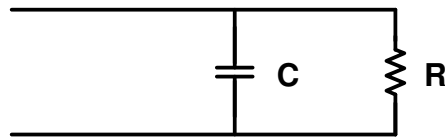

Figure 12-5 The impedance could be designed and used when designing the power supply.

The power supply could be loaded with the designed impedance. It has in this project been studied that a RC-circuit will result in lower spikes in the frequency domain, comparing to an ordinary resistance. The levels could be studied and some analyses could be performed.

13 References and list of literature

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7. ELFA53 2005

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10. Manual till Power CELL och dess program

Interviewed people:

Torbjörn Thiringer 2005-10-18

Robert Carlsson 2005-10-18

14 Appendix including a manual to the LabVIEW

14.1 Calculations for the ferrite transformer using the values stated in 5.5.3

$$f_{lowest,ferrite} = \frac{1}{(1 \cdot 1,54 \cdot 10^{-4} \cdot 0,2 * 4)} = 8116 Hz$$

Without airgap:

$$L_{magnetisation} = 4\pi \cdot 10^{-7} \cdot 1600 \cdot \frac{1{,}54 \cdot 10^{-4}}{14{,}4 \cdot 10^{-2}} = 2{,}2\,\mu H$$

$$\Delta i = \frac{1{,}54 \cdot 10^{-4} \cdot 1 \cdot 0{,}2}{2{,}1 \cdot 10^{-6}} = 14\,A$$

With airgap:

$$\mu_e = \frac{\mu_i}{1 + \dfrac{G}{l_e} \cdot \mu_i}$$

G = Length of the airgap

$$\mu_e = \frac{1600}{1 + \dfrac{0{,}0005}{14{,}4 \cdot 10^{-2}} \cdot 1600} = 244$$

$$L_{magnetisation,\ air\ gap} = 4\pi \cdot 10^{-7} \cdot 244 \cdot \frac{1{,}54 \cdot 10^{-4}}{14{,}4 \cdot 10^{-2}} = 0{,}33\,\mu H$$

$$\Delta i = \frac{1{,}54 \cdot 10^{-4} \cdot 1 \cdot 0{,}2}{0{,}33 \cdot 10^{-6}} = 93{,}3\,A$$

14.2   List of instruments and measure objects

RF generator – Synthezised signal generator HP 8663A

RF generator LO – Signal generator HP 8560 A

Power supply – Delta Elektronika SM7020-D

Spectrum analyzer – HP Network/Spectrum/Impedance – Analyser 4395 A

Network analyzer - HP Network/Spectrum/Impedance – Analyser 4395 A

Waveform generator – TTi Arbitary Waveform Generator TGA 1242

RF cards

Evaluation board downconverter WJ CV11X Single branch downconverter

DC/DC converters

AC Ripple Injection Box (ARIB)