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Modelling a Distributed Power System in Saber®

Focused on Power Conversion, Cable Characteristics and Usability of Saber® for Saab Microwave Systems

Master of Science Thesis

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CHALMERS UNIVERSITY OF TECHNOLOGY

Göteborg, Sweden, 2008

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Abstract

There have been two tasks performed in this report. To do an evaluation of the software Saber® from Synopsys Inc, and to design a model of an airborne distributed power system.

By building a simple system from hardware measurements and model it a good start of the project was made, and thereby learning the basics of Saber®. The design was later expanded to be similar to the next generation of distributed power systems. A special interest has been in cables and verification of cable models in Saber®.

The final design is the stepping stone for a continuation of further simulations.

The conclusion is that Saber® is recommended for Saab Microwave Systems and will most likely have a positive effect on the process of developing new products and making changes to existing power systems.

Keywords: Saber, Power distribution system, Airborne Radar, Buck boost converter

Preface

During our time here at Saab Microwave Systems we have received help and input from many directions. For this we would like to thank a couple of people.

First of all we would like to thank Johan Fält who has been our employer, and Torbjörn Thiringer who agreed to be our examiner. They have both brought forth interesting ideas and opinions.

Our supervisors Johan Arvidsson and Bo Nettelblad from Saab Microwave Systems and Andreas Karvonen, Ph.D. student from Chalmers University of Technology, deserves special thanks. They have supported us and answered many questions we have had.

A thank you is also in order for the entire department of DD/MK as they have helped us with various questions in the laboratory and also questions regarding the airborne power system in general.

We would also like to thank Patrik Björklund for allowing us to visit Linköping and for coming with input on Saber® from his experiences. We were also allowed to see the final assembly of the JAS 39 Gripen which was most stimulating.

Martin Larsén was the supervisor of Erik Moreau and his report on Saber® and how it could be used to simulate a motor steering application. He has assisted us by explaining Saber® from Saab Avitronics point of view. We would like to thank him and also Bengt Forsberg for allowing us to visit and discuss the future of Saber in the Saab group.

And last but not least, Frank Lehmann who has taken many hours to explain and guide us in the world of Saber®.

Daniel and Marcus

Göteborg, 2009

List of Symbols

V, v	Voltage	[V]	Volt
I, i	Current	[A]	Ampere
R, r	Resistance	[Ω]	Ohm
C, c	Capacitance	[F]	Farad
L	Inductance	[H]	Henry
η	Efficiency	[-]	-
t	Time	[s]	Second
T	Period	[s]	Second
f	Frequency	[1/s]	Hertz
l	Length	[m]	Meter
A	Cross section area	[m^2]	Square meter
ρ	Electrical resistivity	[Ωm]	Ohm meter

Abbreviations

AC	Alternating Current
CCM	Continuous conduction mode
CPA	Central power architecture
CPU	Central processing unit
DC	Direct current
DIA	Distributed iterative analysis
DMM	Digital multi meter
DCM	Discontinuous conduction mode
DPA	Distributed power architecture
DPS	Distributed power system
EMI	Electromagnetic interference
ESR	Equivalent series resistance
HDD	Hard disk drive
HDL	Hardware description language
IBA	Intermediate bus architecture
IFS	Internal file sharing
MA	Model architect
MAST	HDL used in Saber®
PRM	Pre regulator module
RAM	Random access memory
RMS	Root mean square
SMW	Saab Microwave Systems
VHDL	VHSIC hardware description language
VHDL-AMS	VHDL - analog and mixed signals
VHSIC	Very high speed integrates circuit
ZCS	Zero current switching
ZVS	Zero voltage switching

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1. *Introduction*

1.1 Background

Simulation plays an important role in new products and when upgrading existing systems. To be able to simulate the system behavior before designing gives an advantage and reduces design errors, which can be very expensive. Saab Microwave Systems (SMW) uses simulations to a high degree, mostly on component level to evaluate different parts of the systems.

A necessity is to have a connection between different kinds of signals that can exist in a system, such as mechanical and electronic signals, to simulate the system as a whole.

1.2 Purpose

The purpose of this thesis is to evaluate the Synopsys Inc simulation software called Saber®, to investigate if the program is useful in simulating larger parts or even the complete power system for an airborne radar.

To show this, another purpose is to make a “Top-down” simulation of an airborne radar power system in order for SMW to be able to evaluate various parameters before the final design is done.

1.3 Literature background

There have been two evaluations of Saber® preformed at Saab Technologies. In Jönköping, at Saab Avitronics, there has been a master thesis [1], and in Linköping, at Saab Aerosystems, there has been an employee that has done the evaluation [2]. In both cases the conclusions were to start using Saber®.

No information about any airborne distributed power systems has been found in the general available lists. There are some reports about power systems in ships and applications in hybrid vehicles using Saber® as a simulation tool.

1.4 Method

The “Top-down” modeling was divided into three steps. The purpose of step one and two was to get acquainted with the simulator software, and step three focuses on applying the accumulated knowledge and model an airborne radar power system.

- Step 1

Measurements at an existing Buck-Boost converter were made, and modeled in Saber®. The focus with this first step was to learn and understand how to work with the software.

- Step 2

On this step, the same converter as in Step 1 was used. A small system was built by adding models of cables and loads. Here the focus was on the modeling of an existing system, and making it larger.

- Step 3

Using knowledge from the previous steps, and focus on building a model of an airborne distributed power system.

1.5 Input data

The step 1 and 2 simulations were based on datasheets and the measurements done by the authors of this report.

There is a need that the simulation model functioning like an already existing power system. To be able to get to a comfortable accuracy of the system designed in Saber® it was a necessity to have some type of data to recreate. That data was collected in these three ways.

- Test and verification reports
- Interviews at SMW
- Approximations

To model a complete system with good accuracy would exceed the time for this master thesis. The process of extracting usable data from the reports and designing appropriate models would be a time consuming and not entirely easy task. To decrease the time spent, assumptions have been made to simplify the models and thereby minimize the simulation time.

Much of the data has been based on previous systems, as the new system is still under design and no measurements have been done yet, even if the goal has been a more modern system.

2. *Background theory*

2.1 Distributed power systems

A distributed power system (DPS) is a system that has the loads physically spread, and in addition the loads need different voltages. To be able to make different architectures, a couple of different structures are used as building blocks. The structures are paralleling, cascading, load splitting and source splitting, and are showed in Figure 2.1.

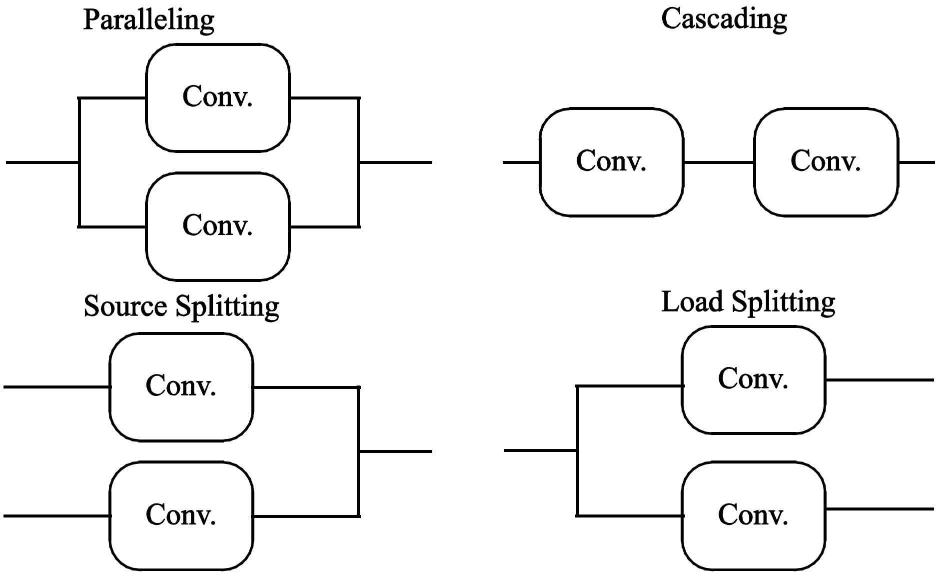

Figure 2.1 Distributed power system structures, Paralleling, Cascading, Load splitting and source splitting

- Paralleling is used to increase the power rating but also to increase the reliability. To be able to have good reliability, the redundancy should be at n+1 units, and thereby increasing the cost of the system.
- Cascading is mostly used in intermediate bus architecture, where a bus voltage is needed.
- Load splitting is used when loads are split physically, as they are in aeroplanes and in large systems.
- Source splitting is mainly used for battery backup but also where two different phases need to be split. [3]

Combinations of these structures build architectures. The most common architectures are presented below.

2.1.1 Centralized power architecture

The centralized power architecture (CPA) was actually the first power system architecture used. It was first used somewhere in between 1980 and 1990 and is based on having a central converter. The central converter distributes the voltage to the loads. The distribution is done with individual wiring. See Figure 2.2.

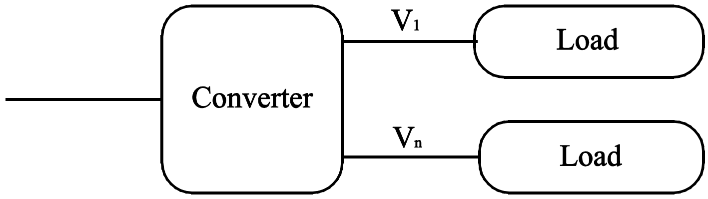

Figure 2.2 Centralized power architecture block diagram

The CPA structure is good for high voltages and low current, since the distribution power losses are proportional to the second power of the current. [3, 4]

2.1.2 Distributed power architecture

The distributed power architecture (DPA) is the development of the CPA. It still has the same kind of centralized power converter, but a point of load (POL) converter is added, see Figure 2.3. The POL converter is added close to the load to minimize the conduction losses, and to improve regulation.

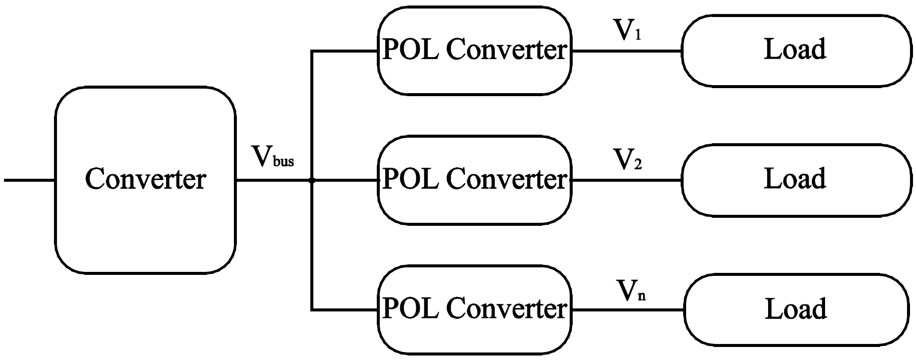

Figure 2.3 Distributed power architecture block diagram

This architecture gives a more stabile load voltage since the POL converter is placed close to the load. The bus voltage can also be higher to minimize the distribution losses. [4, 5]

2.1.3 Intermediate bus architecture

The Intermediate bus architecture (IBA) is based on having a bus voltage distributed to the system loads and the loads are connected via POL converters, see Figure 2.4. Voltages are between 12V and 48V.

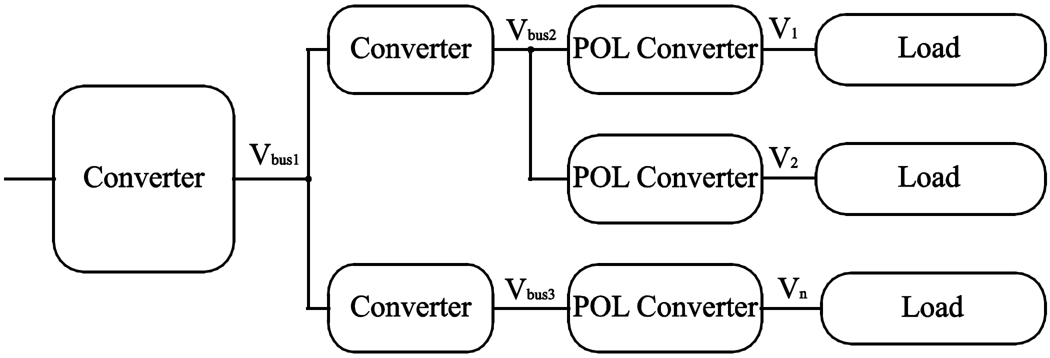

Figure 2.4 Intermediate bus architecture block diagram

To get the most out of the system, the front end converter is galvanically insulated. If that is the case, the POL converters have no need to be galvanically insulated as well, this will result in increasing efficiency. [5, 6]

2.2 Buck boost converter

A converter is an electronic circuit that converts the input DC voltage to a different output DC voltage level, or a DC voltage to an AC voltage

There are different kinds of topologies used depending on input and output voltage. The most common converters are: Step down- (Buck), Step up- (Boost), Buck boost, Forward, Flyback, Cúk, Half bridge and Full bridge converter. [7]

The topology of a Buck boost converter can be seen in Figure 2.5.

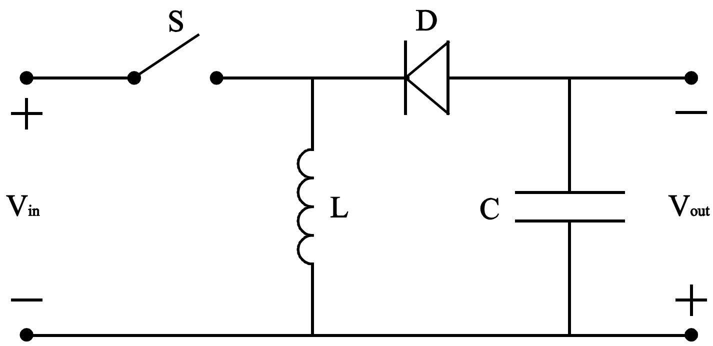

Figure 2.5 Buck boost converter topology

The inductor (L) functions like a battery that is charged and discharged once every switching period.

The capacitance (C) works like a battery, and voltage smoother, and thereby feeding the output while the inductor is charging from the input.

The diode (D) separates the input and the output when the inductor is charging, since the diode is reversed biased.

The task for the switch (S) is to break or connect the connection to the input voltage which makes the inductor to load or unload energy. To drive the switch, there is a feedback loop.

Since there is a switch, there are two possible states; when the switch is on or off.

2.2.1 Switch is ON

The input charges the inductor. The diode is in this state reversed biased and will not conduct any current towards the load. During this time, the capacitor is feeding the output with power. This is illustrated in Figure 2.6.

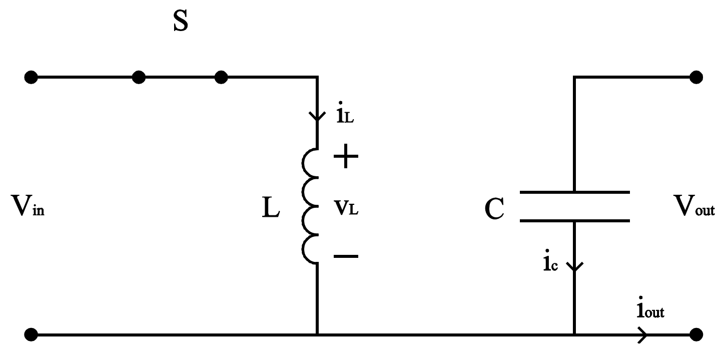

Figure 2.6 Circuitry when the switch is on.

2.2.2 Switch is OFF

Since the inductor is no longer being fed by a voltage, but is still having a current flowing through it. The inductor turns into a voltage source and changes polarity, the diode is now forward biased and starts to conduct. The energy charged in the inductor is being transferred to the capacitor and the output. This can be seen in Figure 2.7

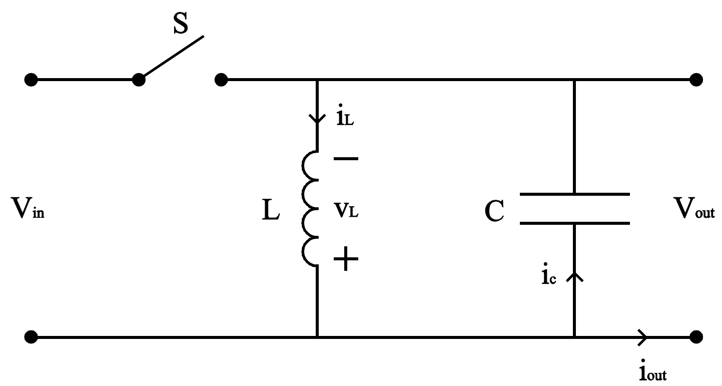

Figure 2.7 Circuitry when the switch is off.

The energy stored in the inductor is finite, and will not be a constant power source. It is depending on the energy stored in the on state, and the length of the on state.

2.2.3 Continuous conduction mode

The first mode introduced is called continuous conduction mode (CCM). The mode is called this because of the current that is constantly flowing through the inductor. In this mode, the power gained in the inductor during the on state is used during the off state of the switch. Some waveforms in the CCM mode are presented in Figure 2.8.

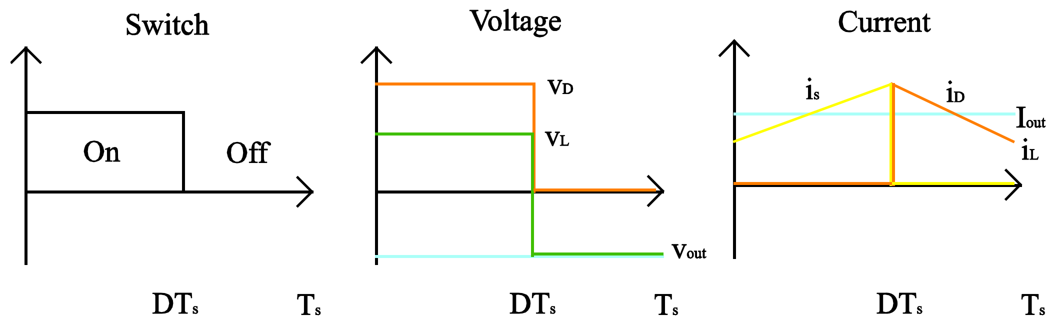

Figure 2.8 Switch, voltage and current waveforms in CCM over one switching period

For the CCM, the transfer function is calculated to be

$$V_{in} DT_s + (-V_{out})(1-D)T_s = 0 \qquad (2.1)$$

, which gives the transfer function

$$\frac{V_{out}}{V_{in}} = \frac{D}{1-D}. \qquad (2.2)$$

The second mode is when the inductor does not carry continuous current. That mode is called discontinuous conduction mode (DCM). In this report CCM will be assumed. The waveform characteristics are presented in Figure 2.9 for comparison purpose to the CCM. For more information about DCM and other converter topologies, see [7]

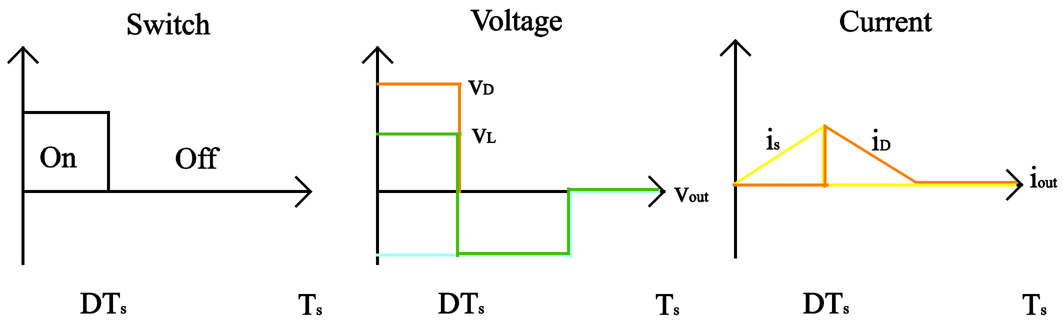

Figure 2.9 Switch, voltage and current waveforms in DCM

2.3 Resonant converters

Resonance is used in different ways in converter design. One application is the load-resonant converter, which is having a resonant load. Another one is the resonant switched converter, which is the type this report is focused on.

The resonant switched converter or soft switched converter as it also is called is made with a resonant circuit around the switch. This resonant circuit makes the current or voltage to alternate. Giving the switch the possibility to switch in a zero voltage or zero current crossing, the switching can be done with low losses. If there is a voltage or current zero switching is design dependent. The two different design types are called zero voltage switched (ZVS) or zero current switched (ZCS) converter.

One of the benefits with resonant switching is the decreased switch loss, which is a large part of the total losses, but it is not just the lower losses that are the benefits, the electromagnetic interference (EMI) is also smaller since the current and voltage derivatives from the switching are smaller. [7]

There are not just benefits, there are some drawbacks too. One obvious drawback is that the component cost gets higher with increasing number of components.

2.4 Cable modeling

Depending on the desired effect of the cable simulation, different models can be used. The most common is the transmission line model, but there are a couple of other models that can be more suitable in special cases. Two different models are chosen to be presented.

- Transmission line
- S-parameters

There are more models that are possible to do, but those two are the only ones handled.

2.4.1 Transmission line model

The simplest form of a cable can be seen as a resistance. Simply inserting a resistance adjusted to simulate the voltage drop over the cable can make an adequate model of the circuit. A formula to calculate the resistance is

$$R = \frac{l \cdot \rho}{A}. \quad (2.3)$$

Resistance is dependent on the length (l), cross section area (A) and the electrical resistivity (ρ) of the material [8].

The nature of the cable however is more complicated. When a current flows through a cable, it will emit a magnetic field around the conductor that induces a voltage. This voltage can be seen as an inductance in series with the resistor, see Figure 2.10.

Figure 2.10: A model of a wire with both real and imaginary parts.

The inductance is dependent on the distance between conductors. When the distance between cables increases, so does the inductance [8].

In order to have a complete model of a cable there are two more parameters to take in consideration, capacitance and conductance. The capacitance is created when charges are built up between the conductors because of voltage variations. The electrons cause an electrical field between the cables or cables to ground. The last parameter is the conductance which is the resistive part of the dielectric element that is surrounding the conductor. The equivalent model over a cable can hereby be set as in Figure 2.11.

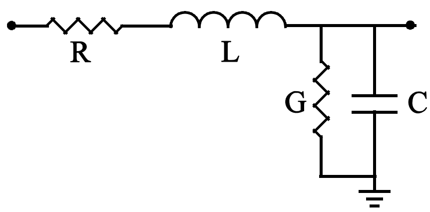

Figure 2.11: Equivalent model of the behaviour for a cable

This design of a cable model gives good model behaviour. This model is also the one used by Saber® in the model of the transmission line. For even better solutions, this model can be put in series to get a distributed capacitance. [9]

2.4.2 Scattering parameter model

Scattering parameters or S-parameters that it often is called are another way of characterizing a cable. This model is mostly used in high frequency applications, were the cable length is shorter than the wavelength of the voltage wave.

The S-parameters are used to model two ports, it means that there are four connection points. For a coaxial cable, this can be the two conductor ends and the two shield ends. For a visualisation see Figure 2.12. There are even possibilities to model multi ports with more conductors, and thereby being able to model DC power cables with two conductors and a shield, which demand three ports.

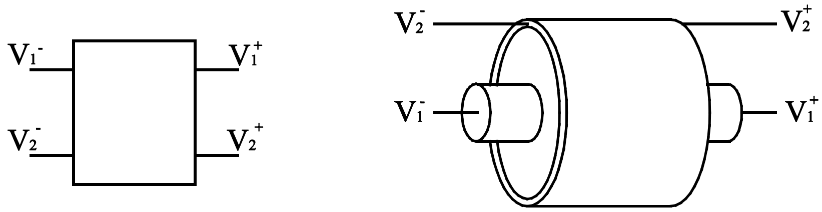

Figure 2.12: A two port model, with reference directions and a corresponding coaxial cable with the S-parameter ports.

Instead of modelling impedances and admittances, the S parameters represent the reflection and transmission of a voltage wave travelling through the cable.

The model in matrix form is

$$\begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix}. \quad (2.4)$$

The different coefficients representation is presented below.

- S11 is the reflection on port one, when port two is adapted.
- S12 is the transmission from port one to port two when port one is adapted.
- S21 is the transmission from port two to port one with port two is adapted.
- S22 is the reflection on port two when port when one is adapted.

When a port is adapted, it means that the characteristic impedance is adapted so that the reflection coefficient is zero.

The reason why this kind of model is presented is because of that Saber® has an S-parameter mode. This makes it a possible model to use and the parameters are quite easy to measure in the lab.

One drawback is that new calculations and measurements need to be done if the length for example has changed. [10]

3. *Saber®*

In this chapter all information about Saber is collected. That is all from background to the different programs and computer power needed.

3.1 History background

Saber® was first introduced to the market in the year of 1986. The thing that makes Saber® to stand out is the mixed technology simulation and the built in programming language MAST. The simulations can for example mix mechanic, electronic and thermal signals to be integrated into the same simulation. Due to this width, there is a large model archive with a wide variety of models, mostly focused on automotive and aerospace applications.

3.2 Saber® software

The Saber® version used for this thesis is A-2007.12-SP2. The program pack consists of a number of different programs which all will be handled later. The arrows in Figure 3.1 represent the interaction between the different programs.

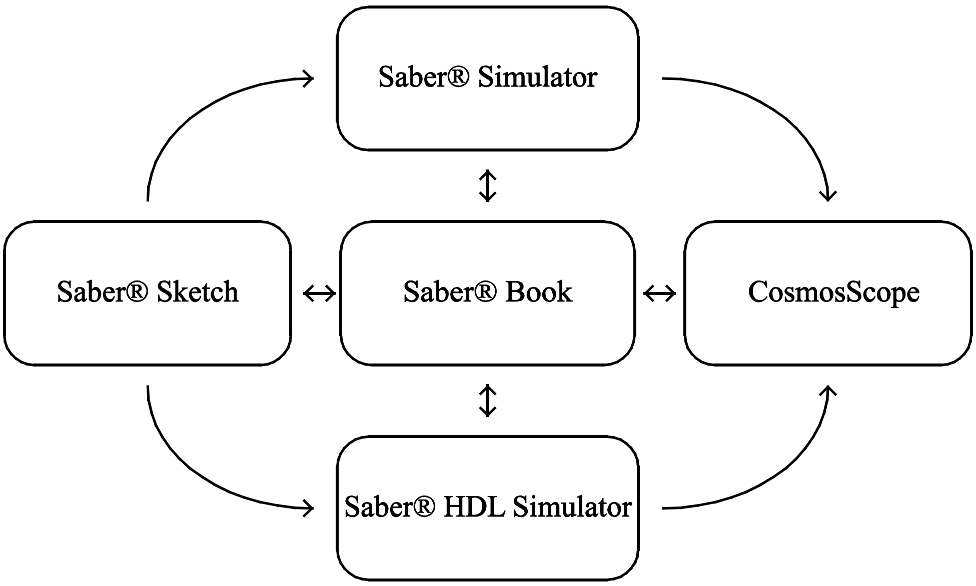

Figure 3.1: Software interaction in Saber®

As can be seen from the Figure 3.1, Saber® Book interacts with all the other programs and functions as a help. What also can be seen is that a design is initiated in Saber® sketch and later evaluated in Saber® simulator or Saber® HDL simulator and finally analyzed in CosmosScope.

3.2.1 Saber® book

Saber® book (see Figure 3.2) is the help program which functions as an online manual for all programs involved in Saber®. There are instructions on how to get started and tutorials on how to simulate and to create different kinds of models. There are also general instructions and some easy exercises for learning how to work with the programs.

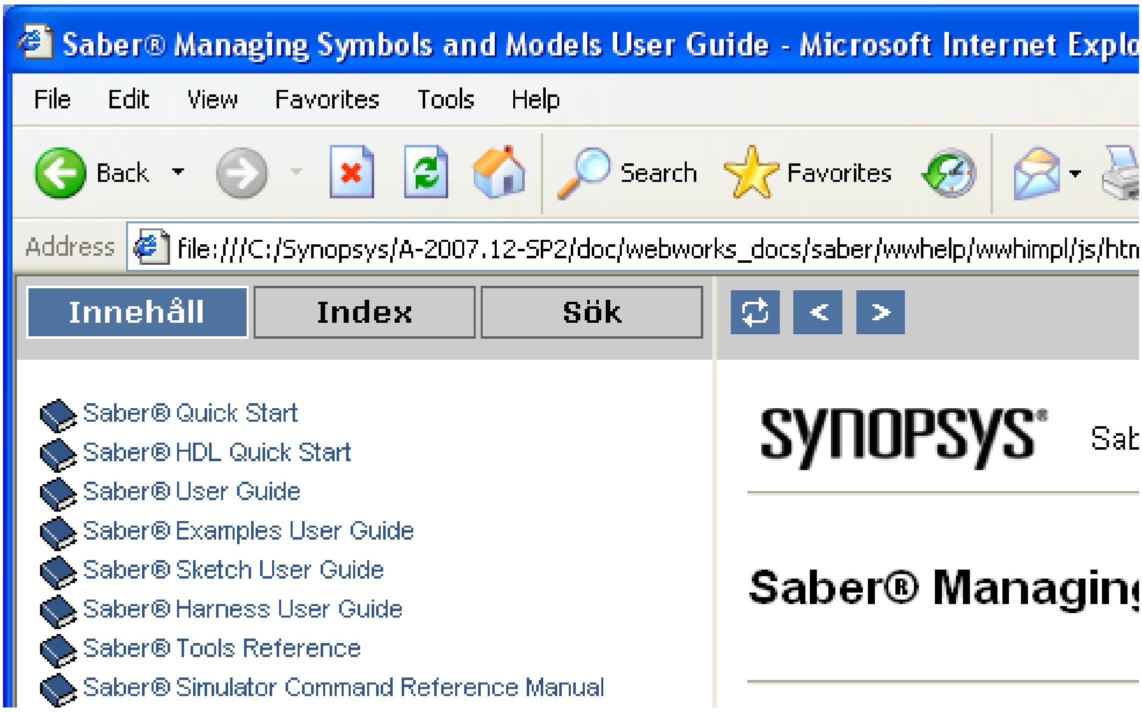

Figure 3.2: Screenshot from Saber® Book

3.2.2 Saber® sketch

Saber® Sketch (see Figure 3.3) is used to design circuits by implementing components and wiring. This is in a way the main software because in this program the design for the schematics are made. It should be noted that it is in the Saber® Sketch that the choice of what kind of analyze that is going to be preformed in the simulator is done. Examples of analyzes are Monte Carlo, Fourier analysis, DC analysis etc.

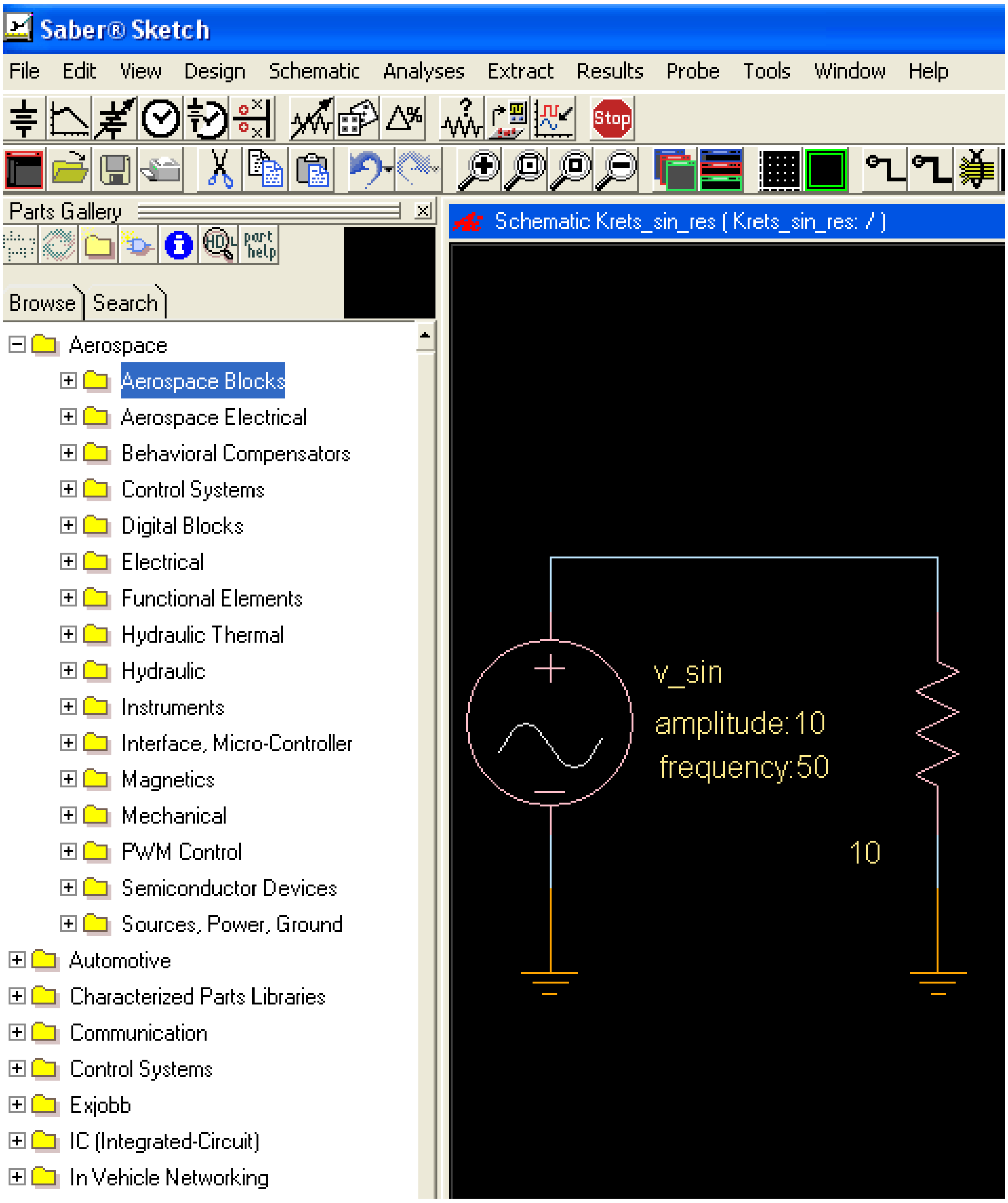

Figure 3.3: Screenshot from Saber® Sketch

3.2.3 Saber® simulator and Saber® HDL simulator

To simulate the designs made in Saber® sketch, a netlist file is made from the sketch file. Depending on which type of simulation used, the netlist file is loaded into Saber® Simulator or Saber® HDL Simulator. The two programs run integrated with Saber® Sketch and run in the background when you chose to make a simulation of a schematic.

There are a number of different simulation methods to choose from. The progress of the simulation is monitored from the control window, were the information on the completed simulation or simulation errors are presented.

The difference between the two simulators is basically that the Saber® HDL Simulator is able to simulate VHDL-AMS components as well as MAST models.

3.2.4 CosmosScope

The results of a simulation can be shown in different ways. One is to use CosmosScope, which is the tool for plotting and making calculations of waveforms. A wide variety of options are available, from plotting a single graph to characterizing values from the waveforms.

Calculations are easily done with the calculator in CosmosScope, and the result can be plotted afterwards. The CosmosScope and calculator layout is shown in Figure 3.4

Another easy way is to plot the results directly in Saber® Sketch with a probe. The probe looks like an oscilloscope illustrating the waveforms from a node in an adjustable window in the design.

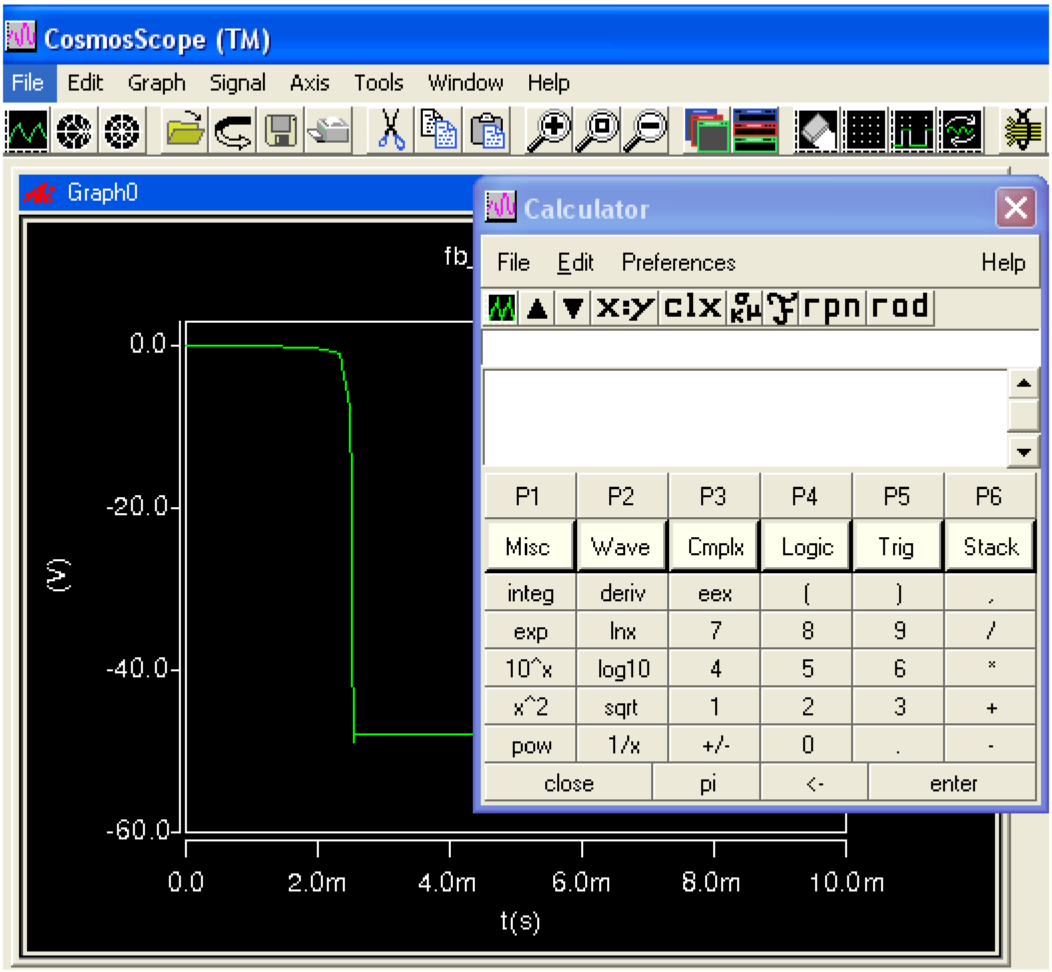

Figure 3.4: Screen shot of CosmosScope with the calculator window open.

3.3 Designing models

3.3.1 MAST

MAST is the analog, mixed technology and mixed signals hardware description language (HDL) used in Saber®. All models are programmed in this language, and are all in ASCII code for easy distribution purposes. There is a possibility to encrypt models for model security.

One way of making a model is to program one. To design a model or template in this way is not one of the simplest tasks for a first time user. When seeking help from existing parts one will find that most of the program code is encrypted. This applies in general to the more advanced models. Interpreting the code is somewhat easier and can provide help when trying to understand the behavior of a model with open code.

3.3.2 Model Architect

Another way to create models is to use Model Architect (MA). This is a program with graphic oriented interface. The program includes various tools (see Figure 3.5) depending on what kind of model that is needed:

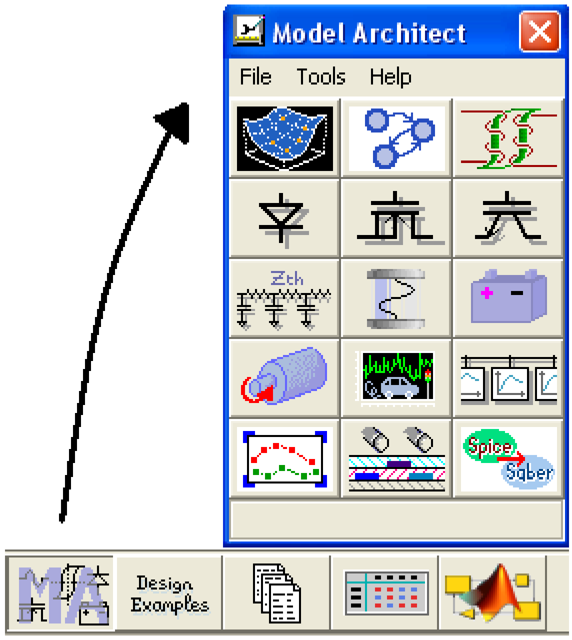

Figure 3.5: Model Architect start window

All different kinds of models which can be done in MA are listed below.

- Table look-up modeling
- Scanned data utility
- Magnetic component characterization
- TxLine Tool
- Diode characterization
- Power MOSFET characterization
- IGBT Level 1 tool
- Thermal characterization
- Fuse characterization
- Battery characterization
- DC PM Motor characterization
- Spice to Saber® converter
- Drive cycle editor
- Load profile editor
- State AMS

The tools used in this thesis report are the State AMS tool, Table look-up tool and TxLine tool. The model tools are described in the report where they are used.

3.4 Computer requirements

In simulating larger systems the calculations needed are often extensive. This requires a computer with a lot of power. The system requirement for a simulation PC is [11]:

- 3 GHz CPU
- 2 GB RAM
- 100GB Hard disk drive (HDD)

Synopsys claims that it can be run on a very simple computer, even a laptop. During this master thesis Saber® was run on a stationary computer with:

- 3GHz Pentium 4 single core
- 3GB RAM
- 80GB HDD

Larger system simulations which will be the case for Saab Microwave Systems are more effectively performed using multi-run simulations. In Saber® this is called distributed iterative analysis (DIA). The simulations are distributed to several computers that will simultaneously run the simulation on two or more cores at the same time. For this purpose the best alternative would be to have computer with a processor that uses multiple cores.

- 2,4GHz Quad-core
- 3GB RAM
- 250GB HDD

This specification would be applicable to Intel and recommended by Synopsys for multi-run simulations. [11].

The multi-run simulations can also be run over a network and hereby using multiple Central Processing Units (CPUs). The problem is that every process requires a Saber® license, but there are special licences that are meant to enable distributed simulations. For more specific information, see [12].

3.5 Simulation time

3.5.1 What affects simulation time?

The complexity of a design is what generally sets the simulation time. This is a simplified answer as there are many parameters that will have an effect. These are a few of them.

- Size
- Number of nonlinear and custom models
- Time step
- Signal selection
- Nodes saved

All these parameters have influence over the simulation time. The first two are directly related to the design and the next three are more related to the simulation technique. To precisely describe the simulation time is almost impossible because the smallest change will effect the time. The size comparison is in Section 3.5.2.

3.5.1.1 Non linear and custom models

The complexity of components can give a heavily increased simulation time, especially if the component is non linear. Non linear components require a smaller time step in order to obtain a good approximation. An example for this type of component that needs a lot of time is the customized transmission line from MA. These model parameters are based on a field solving algorithm. The model itself uses recursive convolution and that has non linear aspects to it. Due to the non linearity, this model has the ability to override the system simulation time step. If the component need a shorter time step than the simulation is set to, it changes it to make it stable.

3.5.1.2 Time step

Setting the time step manually will either increase or decrease simulation time. A shorter time step result in more calculations, and thus more time for the simulation. A larger time step can result in missed transient behaviour.

The experience says that the default, using a flexible time step is recommended in most cases. If there are some specific cases where there are known phenomenon that will occur quickly, a smaller time step in that region is recommended to get the accuracy needed.

3.5.1.3 Signal selection

A good way to lower the simulation time is to choose to do the simulation across (voltage) or through (current) components, instead of both. This means that the simulation does not record all the signals of all components. This lowers simulation time and is generally a good choice when the interest lies in either voltages or currents. It should be noted that all signals are calculated, but only the chosen values are recorded to the HDD.

3.5.1.4 Node selection

Another way of decreasing the simulation time is to specify in which nodes the interesting information is, and just save the information from these nodes. All the nodes will still be calculated, but will not be stored in the plot file.

3.5.2 Simulation time versus size

As mentioned in the previous section, the simulation time is dependent on the size of the design. To visualize this, three designs will be simulated. The simulations are run for 10 seconds and all components are programmed in MAST. All cables are simulated by resistances, thereby avoiding the most time consuming components. Only the voltage signals are recorded

It should be noted that the simulations described in this section are strictly for illustrating what can be expected when it comes to simulation time for larger systems. Simulating a larger system for approximately 10 seconds is something that might be done once to get the systems like a generator to a stable working point. When that is done, the simulation can start from that previous endpoint.

3.5.2.1 Simple circuit

The starting point of the comparison is done with one of the simplest circuits, a voltage source and a resistor. The variable step time is fully utilized since the voltage is constant. The system has no advanced models and therefore the matrix that is setup by Saber® Simulator is solved with a large time step.

3.5.2.2 Small system

Moving from a simple circuit to a small system of the reason says that the time will increase. This is naturally also the case since a few more components have been added. The most significant is the model from the parts gallery of a buck boost converter. The system can be seen in Figure 3.6.

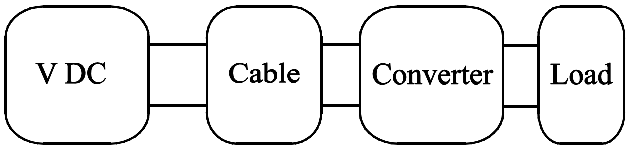

Figure 3.6: Small system consisting of a voltage source, buck-boost converter and a resistive load simulated and evaluated

The small system in Figure 3.6 consists of an ideal voltage source and an average buck-boost converter mentioned above using a purely resistive load. Due to the complexity of the converter, these models increase the simulation time, and forces Saber® simulator to set a smaller time step.

3.5.2.3 Large system

The last system in this comparison is the large system. The procedure in designing the final system is to multiply the previous model. The final model consists of 1 generator, one rectifier, 6 resistive cable models, 96 converters and 96 loads. The biggest time contributors are the rectifier and the generator. The rectifier is a simple design with 6 diodes while the generator is more advanced. The model is taken from the parts gallery in Saber®. The large system can be seen in Figure 3.7 below.

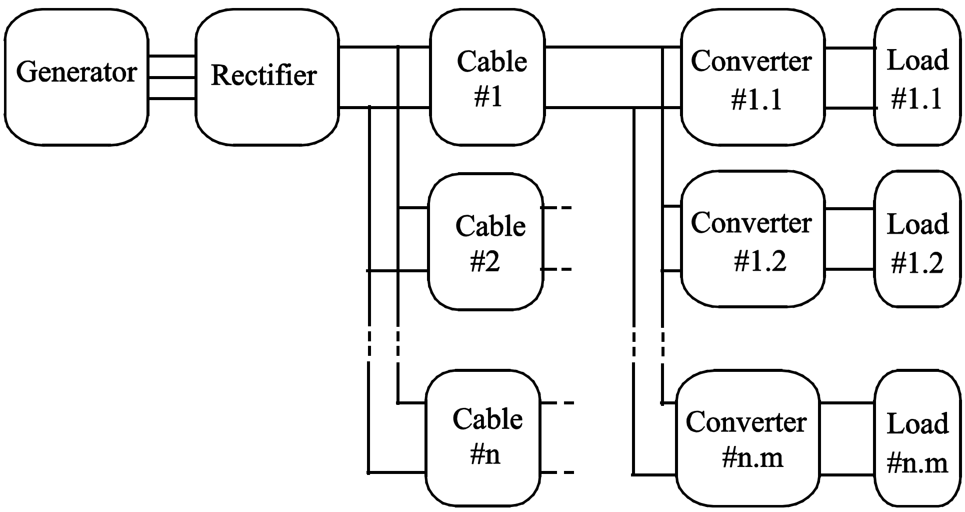

Figure 3.7: Schematics of the simulated larger system

The system is fairly similar to the real power system of airborne radar.

3.5.2.4 Summary of simulation times

The number of variables and components are listed after every simulation. Those are presented in Table 3.1.

	Simple Circuit	Small system	Large system
Analog variables	3	25	2133
Digital variables	0	3	288
Components and subsystems	3	20	1759
Non Linear components	0	5	488
Simulation Time	1 ms	15 ms	2h 40 min

Table 3.1: Simulation time based on number of variables in a system

The conclusion from this is that the simulation time is heavily dependent on the number of non linear components. As can be seen in the large system, it took almost three hours to simulate the system which is a long time during development of the design.

3.6 Saber® used at Saab

In this section there is a short description of where Saber® is used in Saab Technologies and why.

Today, there are only one license shared between Saab Avitronics in Jönköping and Saab Aerosystems in Linköping, and an evaluation license for this thesis.

3.6.1 Saab Avitronics, Jönköping

The procedure involving the purchase of Saber® resembles the one currently in progress at Saab Microwave Systems. There has been a master thesis [1] during the spring of 2008 and was the first contact with Saber® for Saab Avitronics in Jönköping. The evaluation came out positive and a license for using Saber® was bought. But so far it has only been used to a limited extent and is not incorporated into the work process.

Erik Moreau who wrote the master thesis [1], is not an employee at Saab. His knowledge was passed on to Martin Larsén, his supervisor, and he is one of the few Saber® users at Saab Avitronics. To keep the knowledge about Saber® in the company, Erik left three fully functional models that in some respect have served as training objects. There are a few persons able to work in Saber® today.

The reason to start to use Saber® was that it was a costumer demand, and because of that no other kind of was considered.

Saab Avitronics vision for Saber® is to model smaller parts of systems. And to provide costumer demanded models. [13]

3.6.2 Saab Aerosystems, Linköping

Here the procedure of purchase was that a employee, Patrik Björklund, evaluated Saber® and initiated the cooperation with Avitronics in Jönköping.

Today there are currently two people that are able to use Saber®, but the use has been low.

The reason why Saber® is used is that it is a requirement of Saber® models from costumers.

Their vision with the software is to have some sort of verified and validated model as a reference, to be able to locate possible problems when changing design parts. Patrik would also welcome a closer cooperation between the departments using Saber® and especially in the field of electric power engineering.[2]

3.6.3 Saab Microwave Systems, Göteborg

SMW is in the position where Avitronics in Jönköping was last year. This Masters thesis is the first contact with Saber®, and knowledge need to be passed on to others.

The authors are the only people that have used the program

The reason and vision of the program is to have a “Top-down” simulation of a complete power distribution system, and to be able to see design problems in an early stage of the design process when changes are done to it.

SMW has a belief in that this program can do the things that are expected of it. And thus, a continuation of this master thesis is planed and will start in 2009.

4 Cable Modeling and Measurements

4.1 Long Cable

As the purpose is to have a complete system and that involves having the cables implemented in the simulation. The choice fell on making a measurement having a 100 meter cable.

The cable chosen was found in the laboratory at SMW. It is a Radox 155 with 1.5 mm^2 cross section area, and 30 strands. More specifications from the cable can be seen in Appendix A2.1

4.1.1 Measurements

4.1.1.1 Initial measurements

The measurement was done with a pulsed current load. The load was switching between 1A and 2 A and then back again to 1 A, with a slew rate of 0.125 Ampere per microsecond. The time between the switching was long enough for the oscillations to damp out. The test was done at a 10 V. The measurement setup can be seen in Figure 4.1.

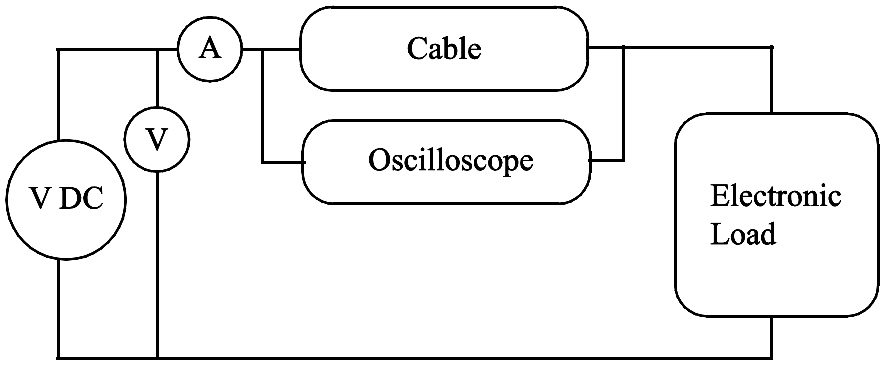

Figure 4.1 Cable measurement setup

To be sure that the result originates from the cable, and that the converter would not interfere, the converter was removed from this test. By removing the converter, the results were clearer and the assumptions for choosing cable models in Saber® that could be used were made easier. In Figure 4.2 the voltage over the cable can be seen.

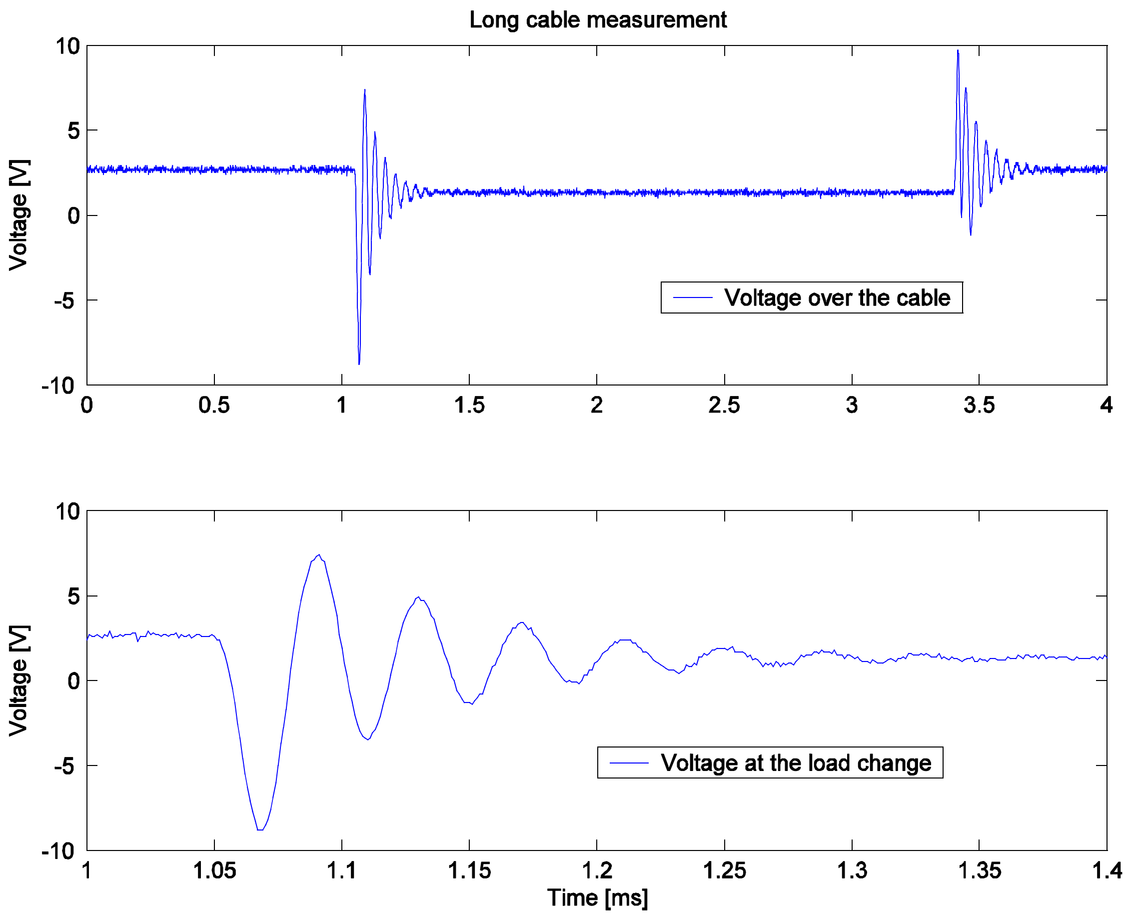

Figure 4.2 Long cable voltage measurement during a 2A to 1A pulsed load, and then back to 1A.

From Figure 4.2 approximations of the oscillating frequencies can be made. Taking the value of the period time from the zoomed waveform in Figure 4.2 gives the frequency, 25 kHz.

To have some start values for the modeling of the cable, a digital LCR meter was used to measure capacitance and inductance. The measuring frequency on the LCR meter was either 20Hz or 1 kHz. The 1 kHz are closest to the oscillations that can be seen in the Figure 4.2, so that is the setting used. The values in total for the cable of 100 meters are:

- L= 128uH
- C=51.6uF
- R=1.84Ω

As the results from the digital LCR meter proved to be inadequate when trying to model the cable in Saber® new measurements were done. These were carried out both at Chalmers by the authors under supervision of Andreas Karvonen but also by Lennart Kruse, a consultant at SMW. Measurement results are illustrated in Appendix A3.

The LCR measurement result for the capacitance is not reliable since the cable has no shield. The reason for that is because it is hard to actually say what is measured when doing a capacitance measurement between two ends of a cable. When there is no shield the measurements of inductance and capacitance are case specific depending on positioning in the room.

4.1.1.2 Further measurements

The test done was measuring the inductance and capacitance on a piece of the cable. The cable used was the same kind of cable that was used in the long cable measurement.

The cable was measured in three lengths, 0.5 meter, 1meter and 1.5 meters. The idea of doing the test in three lengths was to be able to remove the connection effects.

The inductance was measured in two different ways, for each length. The first was with the cable twisted against itself. The other test was with the cable parts as wide apart as possible.

4.1.2 Modeling

Saber® has got a lot of different cable models for different applications and approaches. To get some kind of idea of the strengths and weaknesses, a straight forward trial and error process was used. In acquiring a model of a cable suitable for simulating the system three models were tested.

- Simple wire
- Transmission line
- Building a cable in Model Architect

4.1.2.1 Simple Wire Model

This model is programmed in VHDL-AMS and therefore the Saber® HDL Simulator has to be used. This is often a problem when simulating, because the simulations are often not as stable as simulations done purely in the MAST language.

Examples of input parameters to the model are cross section area, length, thermal conductivity etc.

The model is basically represented by a resistance and then various parameters to determine how that resistance changes with temperature. A breakdown of the cable due to temperature can also be simulated.

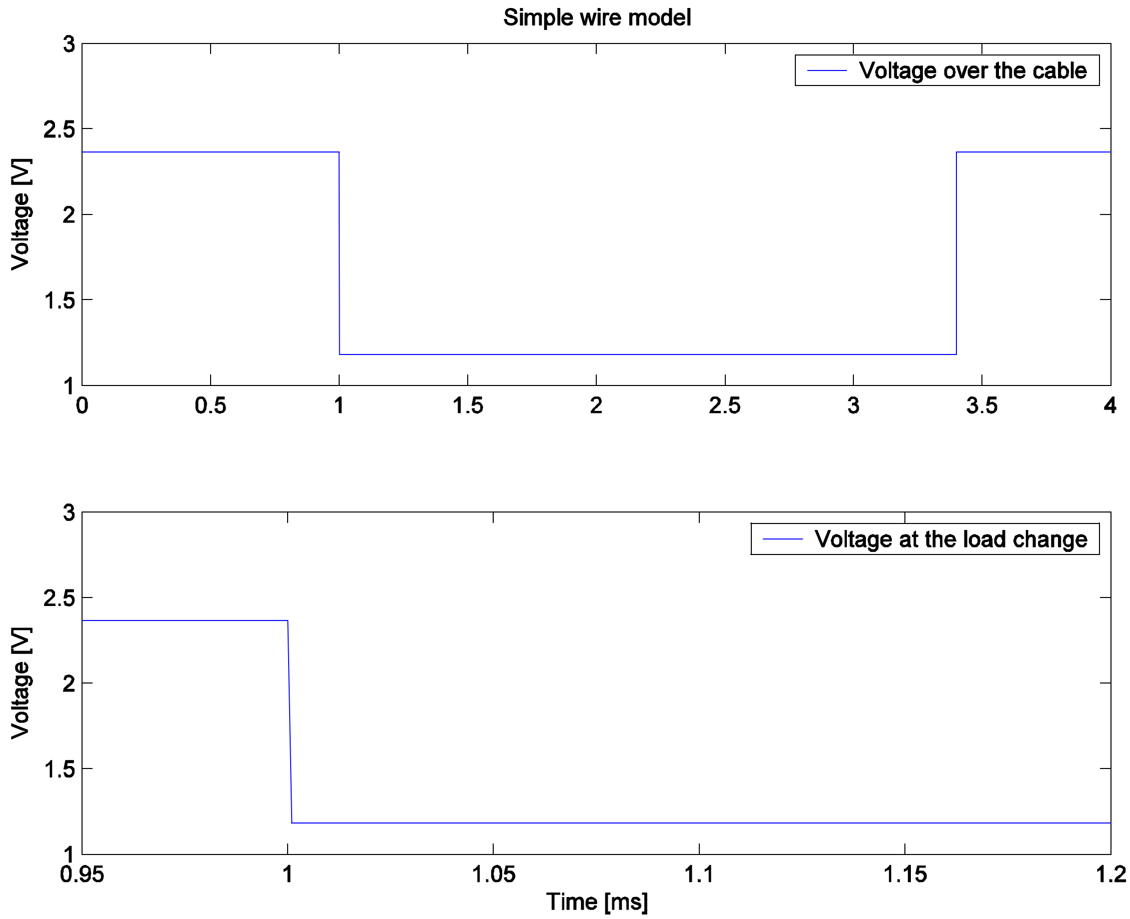

Figure 4.3 Simple wire model simulation, 1 – 2A pulsed current load

4.1.2.2 Transmission line

This model is programmed in MAST language, and is in this case relatively simple since the model needs the LCR values. They were inserted in per meter and are then multiplied with the length specified. This makes alterations in length a small problem as that means only changing one parameter.

The result from this model is better than the first, which can be seen in the simulation in Figure 4.4.

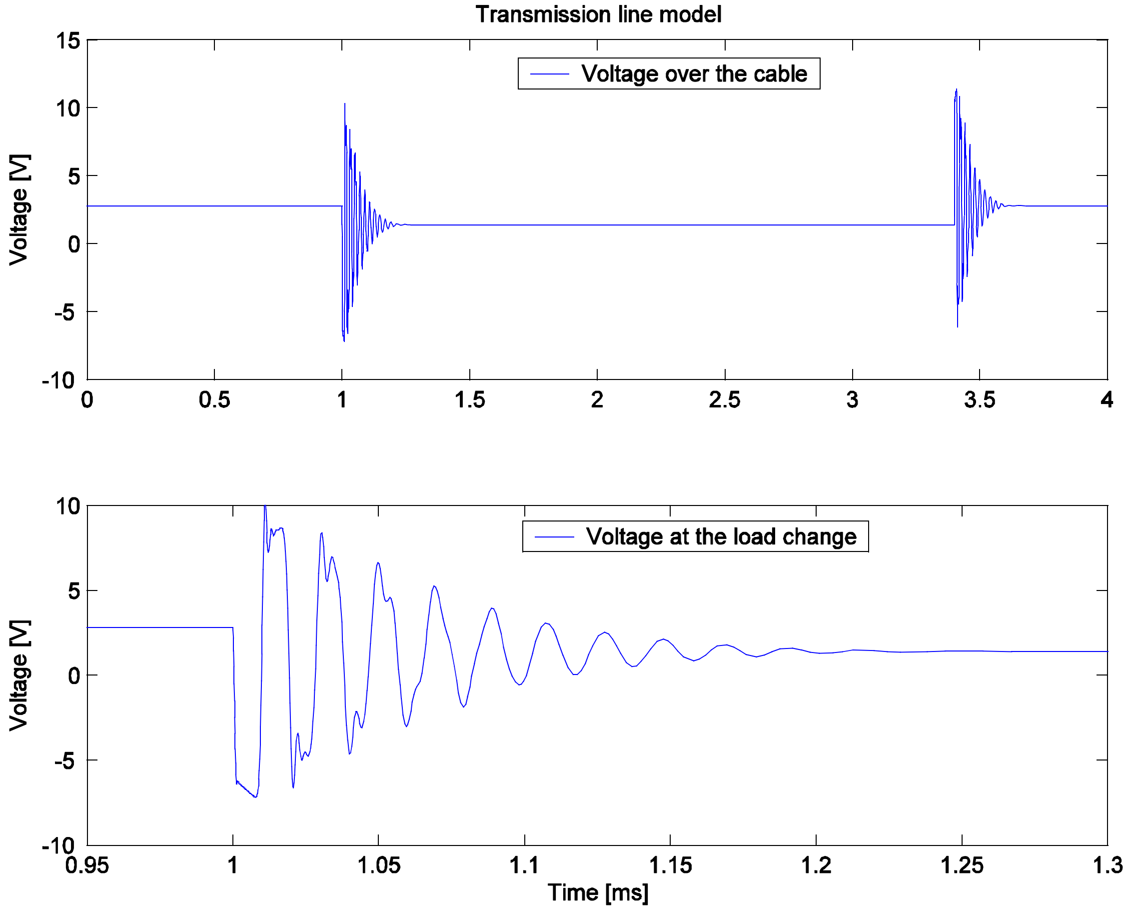

Figure 4.4 Transmission line model simulation, 1 – 2A pulsed current load

An approximation of the oscillating frequency on the modeled waveform can also be applied to Figure 4.4. This gave a frequency of 52 kHz.

4.1.2.3 Model Architect – TxLine tool

The model is created in Model Architect (MA), using the TxLine tool.

To design a model in MA, a two dimensional graphical interface is used. To design a cable one uses different layers with different dielectric characteristics, ground, number of conductors, size, position relative ground etc. When the cable is designed, the two dimensional picture is converted into MAST code by a field solver algorithm.

The model can take in consideration the effects of higher frequencies and how that affects the behavior, for example skin effect. This option can be switched on or off in the model in Saber® sketch. The result of the simulation is illustrated in Figure 4.5.

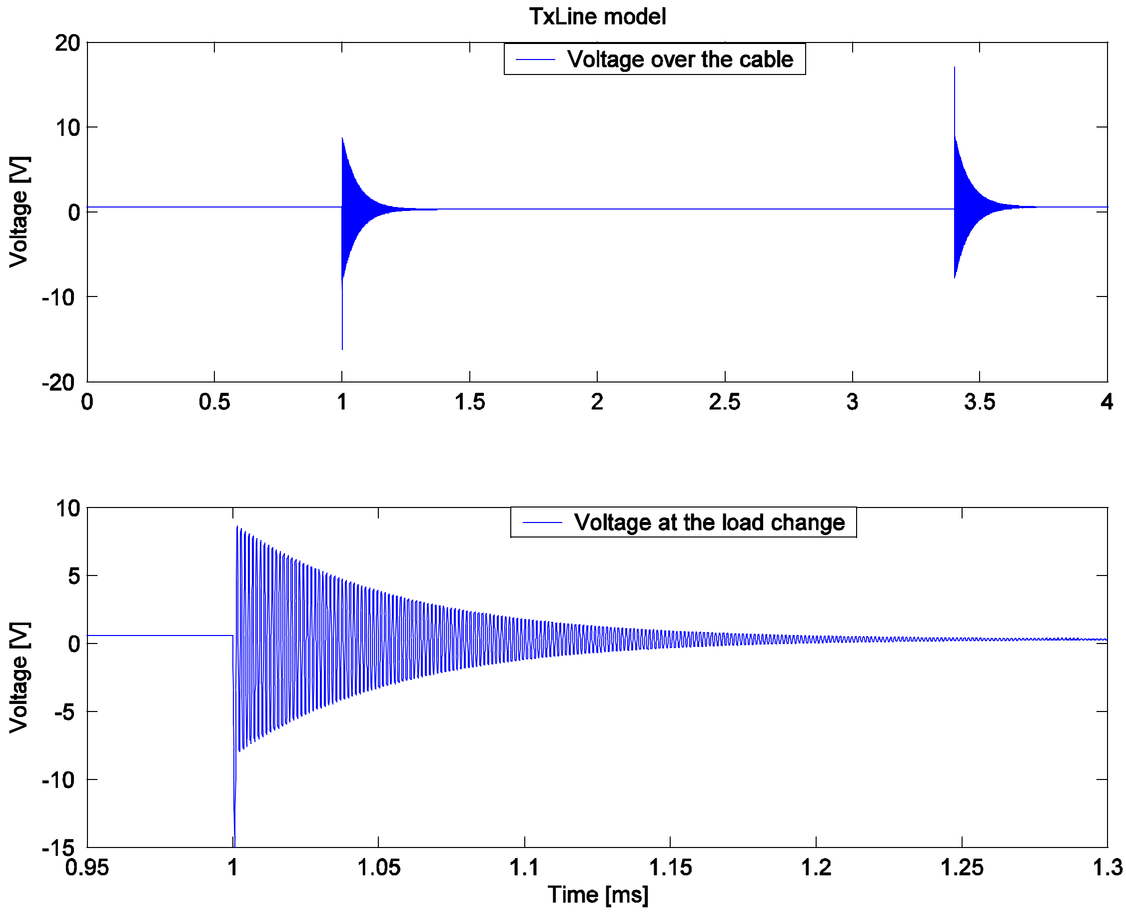

Figure 4.5 TxLine tool model simulation 1-2A pulsed current load

The oscillating frequency from Figure 4.5 is approximated to 770 kHz. The overshoot is similar to that of the measured values.

4.1.2.4 Cable Model Comparison and Evaluation

The simple wire model in Figure 4.3 is not interesting for the purpose of the simulations that are to be done. Simply because the modeling is focused on the oscillations, and those are not handled in the model.

Going on with a comparison between the other models, the Transmission line and TxLine are shown in Figure 4.4 and Figure 4.5. These are similar to the measurement, but there are some differences in voltage level and oscillation frequency. The transmission line has got in comparison, a right oscillation frequency, but the TxLine tool has got a more correct wave shape.

In the modeling of the transmission line model, the parameters were values measured from the actual cable at the test. This means that the connection point losses were integrated into the model. This is because the measurement instrument has roughly the same losses in its connection to the wire as the measurement set up has. The transient spikes or overshoots (see Figure 4.4) that occur when the load is changed (see Figure 4.2) are not visible from this model.

The conclusion from this is that both cable models are of interest in the future. The choice of which model to choose is based on what kind of parameters that are present. If the geometrical cable is known it is possible to draw it in Model Architect, and if the inductance resistance and capacitance per meter is known, the transmission line model is preferred. A difficulty is that in the TxLine tool a geometrical ground level must be set. This might not always be applicable and therefore calls for an approximation.

4.2 Coaxial cable

A discussion regarding how important the capacitance value was and how accurate it needs to be inspired the idea of making another comparison. The cable chosen for this was a RG174/U coaxial cable from Bedea in Germany, for datasheet see Appendix A2.2. The coaxial cable has a shield and that makes a homogenous electrical field around the inner conductor which makes the capacitance easy to measure.

4.2.1 Measurements

The measurements were carried out at Chalmers under supervision of Andreas Karvonen. The parameters were the same as for the long cable but the values must be seen as more reliable due to the shield.

The complete results from the measurements can be seen in Appendix A4. The chosen frequencies where measurements were done were at 100 kHz and at 1 MHz due to the oscillation of the results at lower values of the frequency. Figure 4.6 shows the test setup.

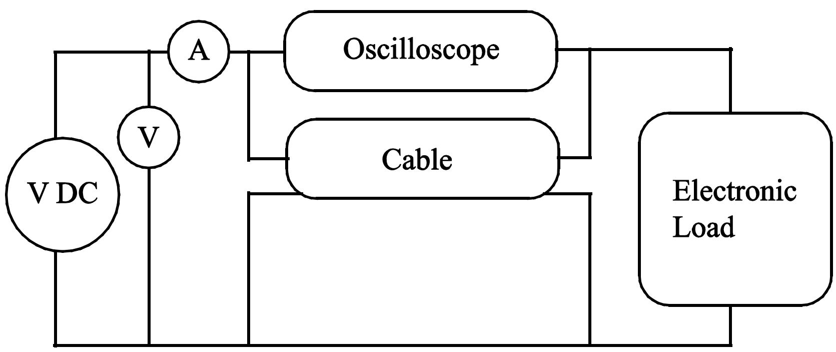

Figure 4.6: The test setup for the coaxial cable measurement with the shield at both end connected to the minus pole of the DC power supply.

The coaxial cable measurement setup was in a similar way to that of the long cable. This was done to measure the cable during a pulsed load case. As seen in Figure 4.6 the test setup was the same except for that the shield to the cable that was connected to the reference of the minus pole of the DC voltage source. This was done so that there was

10V between the inner and outer conductor. The measurement result when the current shifted between 2A and 1A can be seen in Figure 4.7.

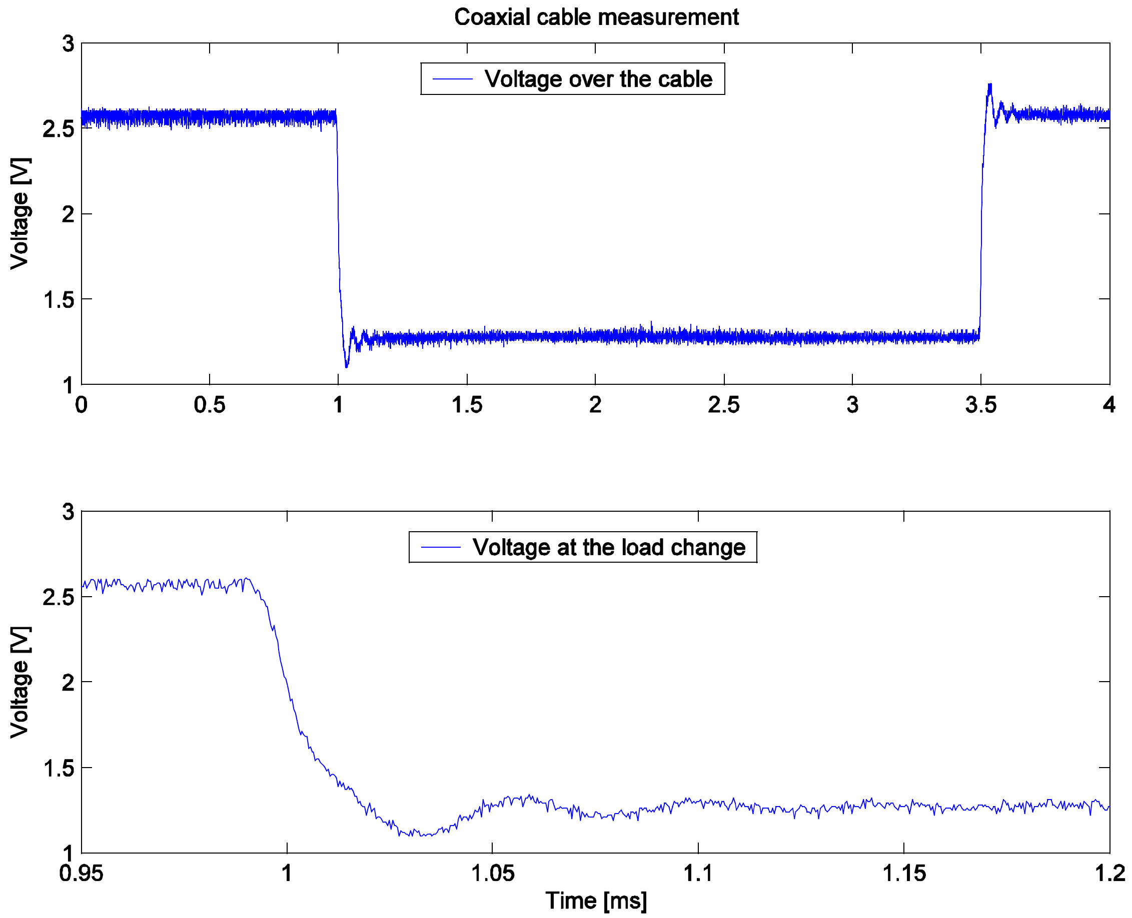

Figure 4.7: The voltage over a coaxial cable during the switching with a pulsed load. The top graph is during 4 milliseconds, and the bottom one is zoomed from 0.95milliseconds to 1.2 milliseconds.

The cable as can be seen is substantially less influenced by the inductance which is mainly dependent upon the shield. The oscillation frequency is calculated to 22 kHz by approximations from the Figure 4.7.

4.2.2 Modeling

To have some sort of verification that Saber® is able to simulate the reality, the values for the coaxial cable were used in Saber®. These tests were more or less concentrated on if the models are correct, and how accurate the input needs to be to get a fairly good simulation result.

A similar comparison as with the more simple wire was conducted. The wire was simulated using different alternatives provided in Saber® with the exception of a model especially designed for coaxial cables. The results from these models are illustrated below.

4.2.2.1 Transmission line model

The model is based on what can be seen in Figure 2.11 and the number of segments that is to be used when calculating the cable can be set as a parameter. Having this model simulating a coaxial cable is under the assumption that the ground reference in the model is the shield. The simulation is done in Figure 4.8 and as before the load is a current source alternating between 1A and 2A.

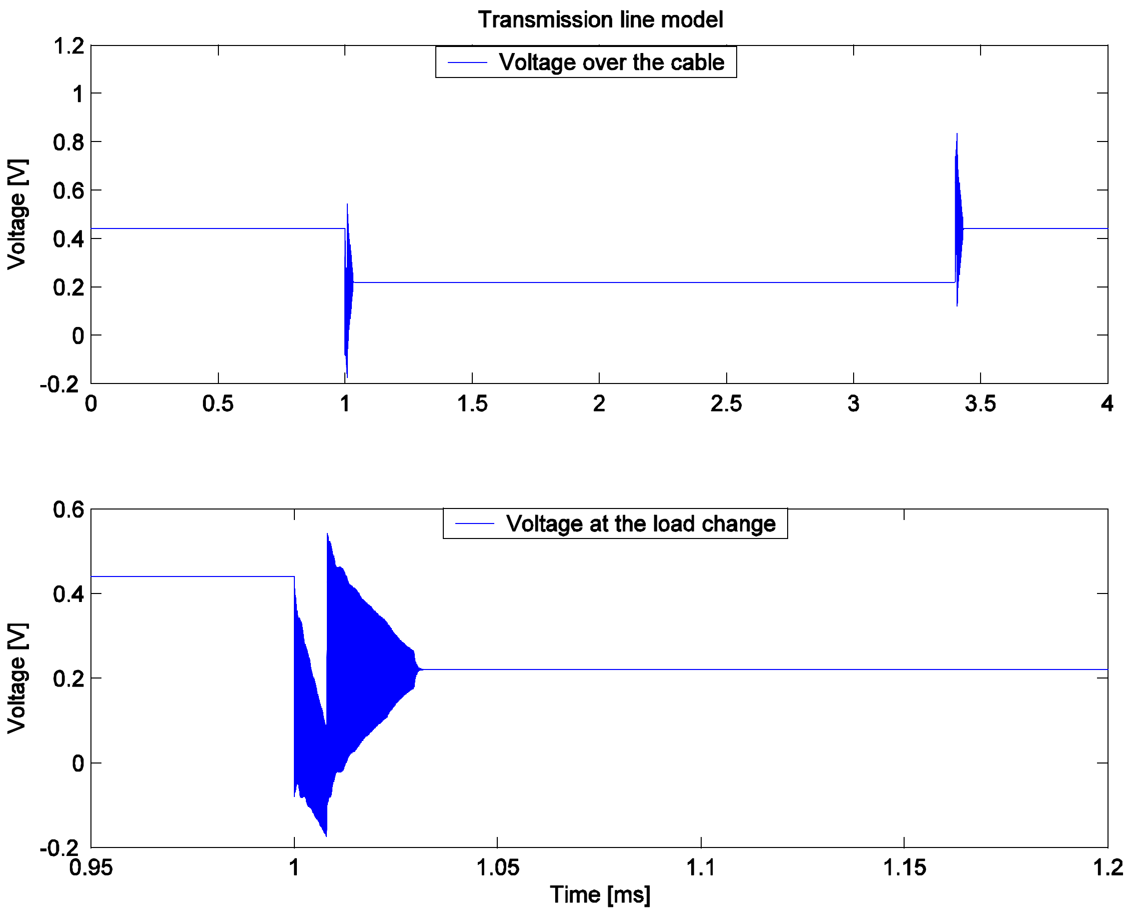

Figure 4.8: The voltage over a coaxial cable with a pulsed current load. Top graph shows the 4 milliseconds, and the bottom one is zoomed between 0.95milliseconds and 1.2 milliseconds.

From Figure 4.8 the oscillating frequency from the area where the voltage is dampened is approximately 7,7MHz. The switching time between the two current levels is set to 8us and that explains the behavior from 1ms to 1.008ms. This also applies for Figure 4.9 and is the same as in the measurement setup.

4.2.2.2 Coaxial cable model

This model was taken from the parts gallery and applies especially to coaxial cables. The parameters that are set are for example the radius of the inner conductor and the radius of the outer conductor. The results for the simulation can be seen in Figure 4.9.

These relatively simple parameters gave a model that has a general appearance as in the measurements in Figure 4.7.

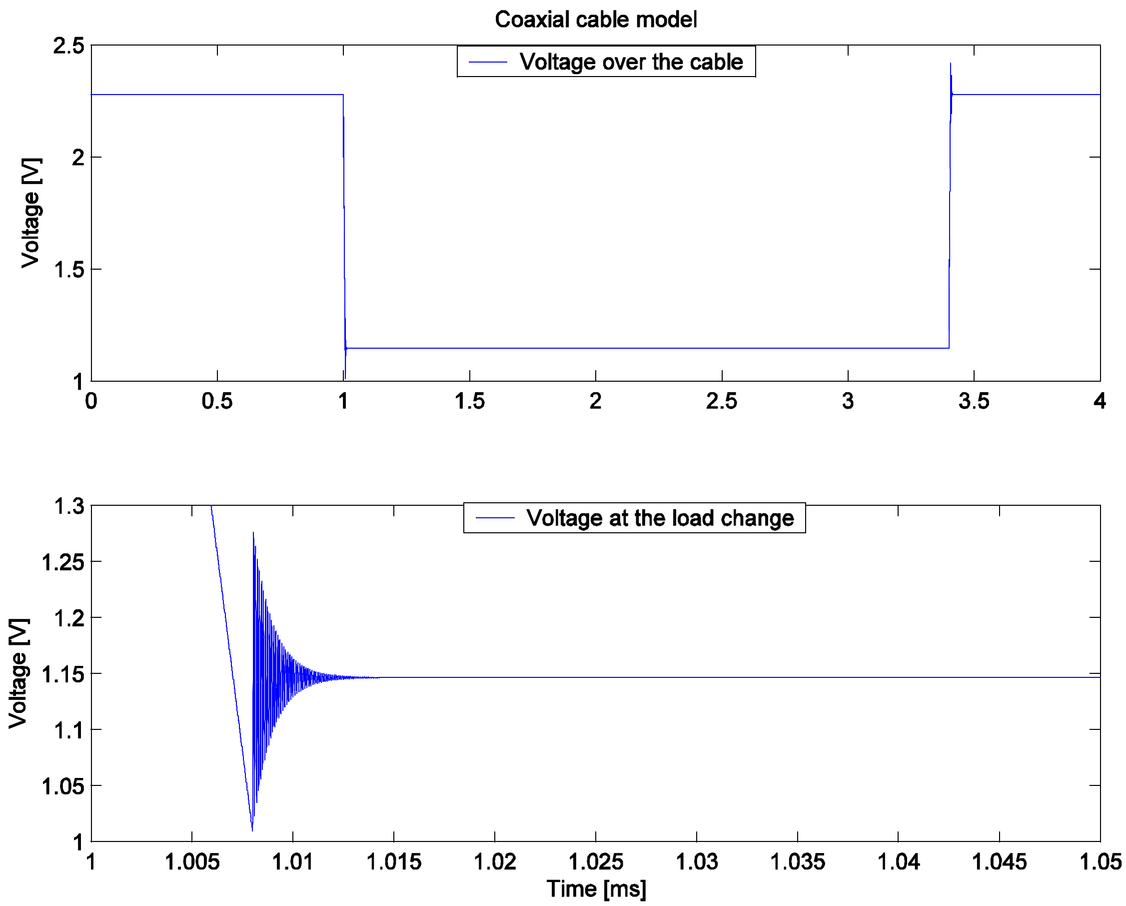

Figure 4.9: Voltage over the coaxial cable model during a pulsed load. Top graph shows 4 milliseconds, and the bottom graph is zoomed from 1 millisecond to 1.05 milliseconds.

The oscillating frequency is calculated to 10MHz which is substantially high. There is also a likely source of error as the values were taken from the figure.

4.2.2.3 Model Architect – TxLine tool

The same tool as was used for the long cable modeling. When using it to model a coaxial cable a new problem is presented as there is no possibility to have a ground reference that is not a straight plane. This constitutes a problem and basically renders the model unusable for this application.

Attempts were made of using it with approximations but no results worth mentioning were created.

4.2.2.4 Cable model comparison and evaluation

The best results were obtained using the coaxial cable model provided by Saber®s parts library. There is still the problem with the high oscillating frequency but in general they show resemblance.

Comparing the simulations results from Figure 4.8 and Figure 4.9 to the results of the measurement done in Figure 4.7, the Coaxial model must be seen as the best model for the coaxial cable.

5. *Converter modeling and measurements*

This chapter contains measurements and modeling of the converter. The converter used to do the measurements on was a Vicor power product. The measurement object is a Pre- Regulator Module (PRM) in Figure 5.1 is a ZVS Buck boost converter.

The converter was put on an evaluation board with model number P048F048T12AL-CB. [14]

The PRM was chosen because that it has potential to be included into the next version of ERIEYE®. The PRM is specially made to create a controlled distribution voltage to power downstream in a distributed power system.

Figure 5.1: VI chip PRM component case, [14]

5.1 Measurement setup

A general measurement setup was used for the measurements done in the laboratory. This is shown below in Figure 5.2.

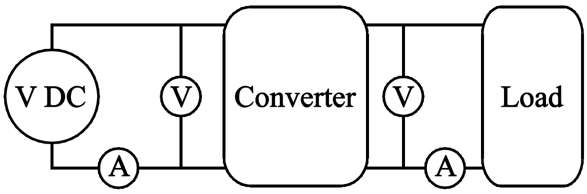

Figure 5.2: Block diagram of the hardware setup

The ampere meters and volt meters are the same type of instrument, Fluke 87. To monitor the voltage ripple and switching periods, an oscilloscope was connected to the output voltage.

The load was an electronic load. The electronic load was chosen because of the easy way of setting the load to a specific current.

5.1.1 Measurement influences

One must be aware that measured signals can have interference from a number of different sources. When analyzing the measured data it is important to have that in mind.

Regarding the wiring from the DC source and to the load there are some things to think about. To minimize losses and antenna phenomena the shorter cables used the better. Another thing was to twist the cables to make the emitted magnetic field as well as the sensitivity towards imposed magnetic fields smaller.

To get the galvanic insulation between the oscilloscope and the main power grid ground, a full transformer was used to power the oscilloscope. This is done to be sure of that the oscilloscope ground is free of noise.

5.1.2 Measurement accuracy

Different measurement devices have got different tolerances in precision. And even different precision depending on which range the measured voltage or current is in. The precision is given from the manufacturer and are presented in the device datasheet. For the fluke 87 datasheet see [15].

5.2 Converter component values

Even when using a "Top-down" approach to the simulations, values on different component values are needed to get the right characterization of the converter. For instance the inductor, capacitor and duty cycle are parameters that will affect the behavior of the converter.

To be able to have some sort of entry, an assumption of about 2A of averaged output current, and a current ripple of about 30%.

The calculations were done using MatLab 6.5.1. The .m file can be seen in the appendix.

- L = 24.8 uH
- C = 2.6 uF
- D = 0.4961

5.3 Averaged converter model

To get the simulation times down to an acceptable level, some simplifications need to be done. Especially when the system contains several converters, the time required for simulating the design would be extensive. To minimize this, an averaged model from the Saber® part gallery was used. The difference is, when Saber® is running the simulation is that it uses one mathematical algorithm for the converter instead of using one algorithm for each component.

There are three different models of Buck boost converters in the Saber® parts gallery. All of them are averaged models and has more or less the same inputs.

The simplifications in the averaged converter compared to a regular one are:

- Fixed frequency
- Variable duty cycle
- No switching ripple

The model chosen includes the switch, the diode and the Pulse Width Modulator (PWM).

Parts that are not included are the feedback and the inductor which are needed to have a fully working converter.

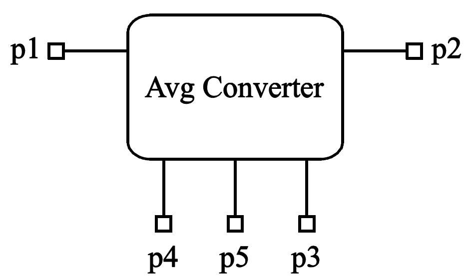

Figure 5.2 Averaged buck boost model in Saber®

The different pins have the input or output of:

- P1: Input voltage
- P2: Output voltage
- P3. Inductor connection (the inductor is not included in the model)
- P4: Voltage control
- P5: Current control (not used in this application)

5.4 Feedback loop design

To be able to create a converter that looks like the measured one, a feedback loop had to be created. The first attempt was to build a P regulator that took the output voltage and divided it down to the desired Duty ratio. This was a fairly good approximation for the specific case, assuming constant input voltages. But it did not work as a feedback, more like a steady state duty converter. So the feedback was rebuilt and to handle even input voltage changes. To handle this better, a PI regulator was chosen to be focused on. The finished PI regulator can be seen in Figure 5.3.

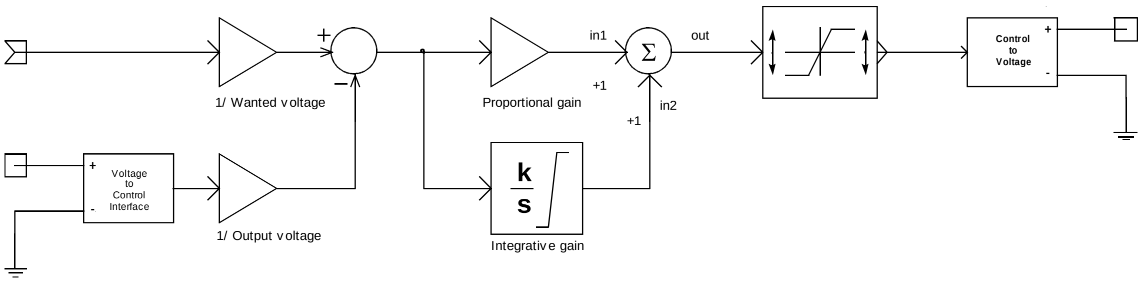

Figure 5.3 PI regulated feedback design

To build a PI regulator was a lot trickier than it seemed in the planning stage. At first the feedback was a poor approximation of the measured one. A problem that was found and solved was that the components were too ideal. Equivalent series resistance (ESR) was added to the capacitance and winding resistance for the inductor. The bandwidth of the system then got larger, and that made the converter feedback to act faster in a stable mode.

5.5 Efficiency

That the choice fell on efficiency as one of the parameters is not a coincidence. The parameter is often one of the more documented ones and this applies to the chosen VI-chip.

The efficiency is a dimensionless number measured for each unit. It is measured in steady state operation and is a relatively simple parameter to measure which makes it a good choice for building a first custom model in Saber®.

In datasheets for the VI-chip the efficiency is presented as a function of output current and input voltage. This makes for a solid ground for verification of measured values, simulated values and given values from datasheets.

5.5.1 How to calculate the efficiency

To calculate the efficiency the parameters needed are input and output voltage and currents, all in Root mean square (RMS). The correct formula for the efficiency is

$$\eta = \frac{\int_0^T u_{out} i_{out} \, dt}{\int_0^T u_{in} i_{in} \, dt} \approx \frac{U_{out} I_{out}}{U_{in} I_{in}} , \qquad (5.1)$$

where the RMS values can be used in a simplification of the formula.

To get to the efficiency values listed in the datasheets a very precise work is needed. Those are often measured at the most convenient temperatures often even with soldered connection points. This is done to get the very best result possible

5.5.2 Measurement

The measurements were taken at different input voltages to compare with the component datasheet. The different efficiencies are shown in Figure 5.4 compared with the datasheet values.

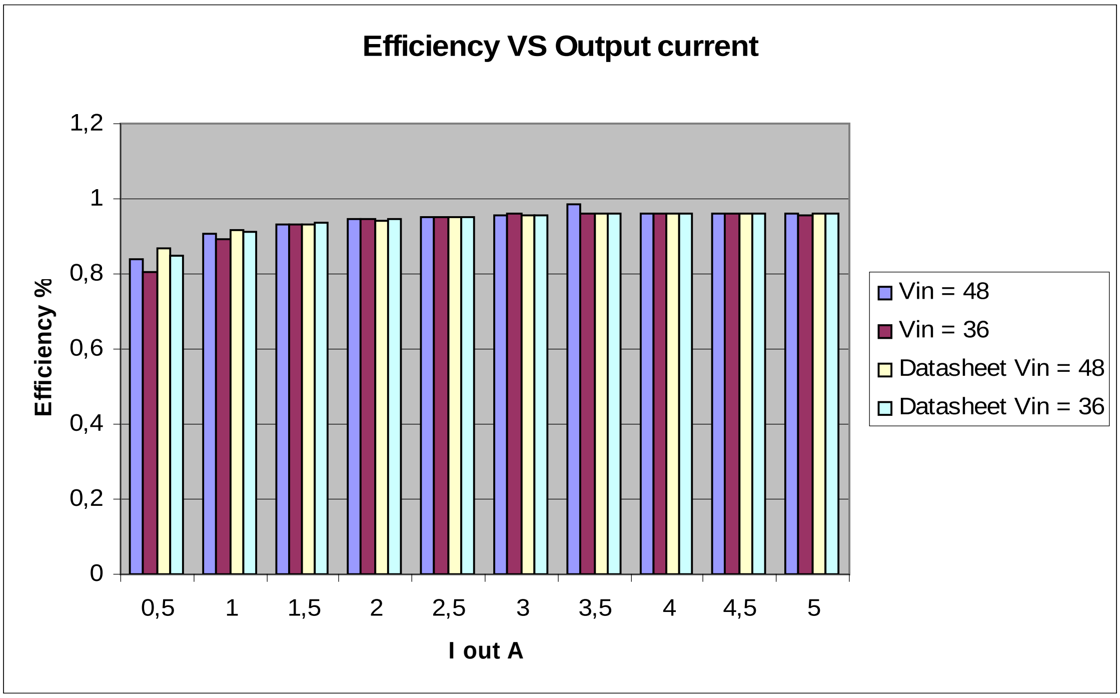

Figure 5.4: Efficiency versus output current

Having the datasheet values makes it easy to verify the result. Having those verified enables a good modeling of a converter.

5.5.3 Modeling

The converter model does not handle switching and the converter that was measured on, uses ZVS. To get the same losses, an efficiency model was built.

The idea is to model a leakage current in the inductor and thereby setting the efficiency that way.

This model was made in MA using the State AMS tool, and has two states, on and off state. The starting state is the off state. This state gives the output condition.

- $I_{leak} = 0$

To change to the other state one of the state change conditions have to be met. The state change conditions to change from off to on state is the following

- $V_{in} > 0$
- $I_{in} > 0$
- $\eta > 0$
- $I_{leak} > 0$

When changed to the on state the output conditions change to that of Equation 5.2.

$$I_{leak} = \frac{V_{out} \cdot I_{out}}{\eta \cdot V_{in}} - I_{in} \qquad (5.2)$$

To change back to the initial stage, there is one condition set, and that is that

- $V_{in} \cdot \eta = 0$

The η values in this model are taken from the measurements in section 5.5.2, which are put into a look-up table.

So far only the equations are presented. For the input and outputs, see Figure 5.5 below.

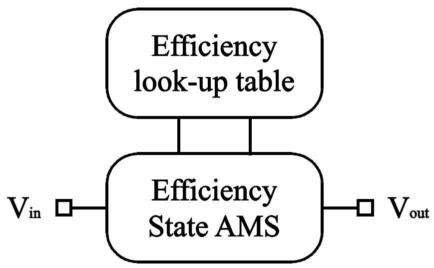

Figure 5.5 State AMS and a look up table to model efficiency in the converter

5.6 Output voltage ripple

The output voltage ripple says quite a bit of the converter function. For example if the load is known the current ripple can be calculated, and from that the value of the inductance. This makes it a good parameter to measure and model.

5.6.1 Measurement

The ripple from the converter was measured with an oscilloscope. The output voltage ripple is highly dependent on the load connected. The ripple is shown in Figure 5.6.

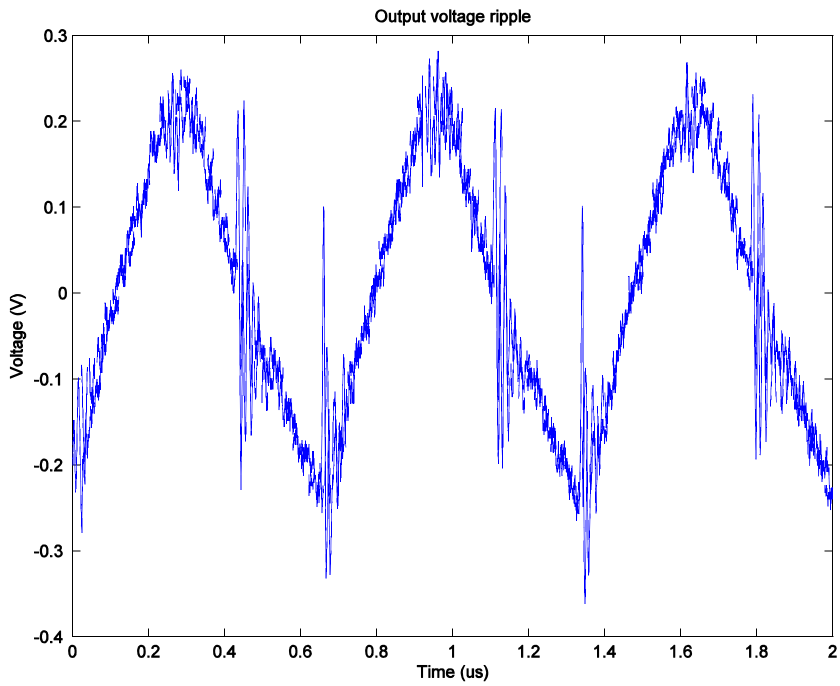

Figure 5.6: Output voltage ripple at 3.5A load, full bandwidth

Even if there is a good result from the measurement, this kind of data cannot be modelled using the converter model chosen. This is based on that the converter averaged as mentioned above. The solution to the problem would be to make a bottom up model which will include switching. This falls outside the Master thesis and a model of this will not be done.

5.7 Final converter model

The final version of our converter model can be seen in Figure 5.7

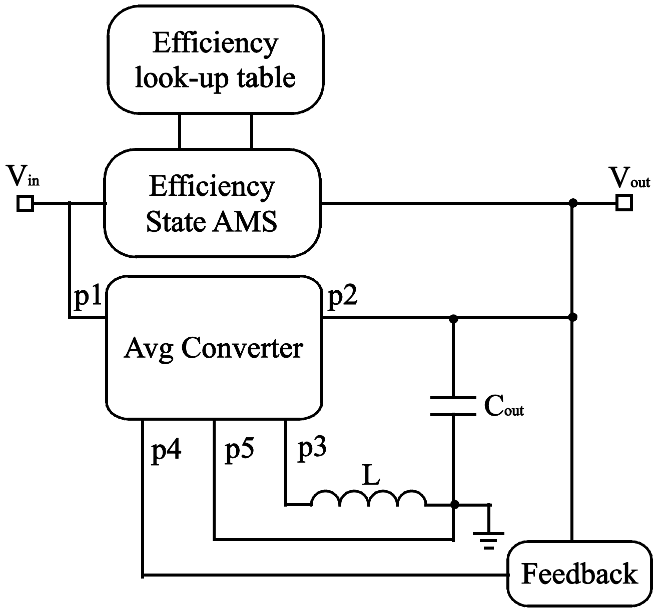

Figure 5.7: Converter block diagram

As seen in the Figure 5.7, the model of the converter consists of an averaged converter model, feedback loop, State AMS model and a table look-up for the efficiency.

This converter model simulates the reality pretty good since the efficiency measurements were done and put into a look up table.

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6. *Airborne power system simulation*

To get a complete power system some more components are needed. One of those things is the generator, which often is case specific. Today there are at least three different generators used for different models of ERIEYE®, since it is used on different aircrafts.

The aeroplane used for simulations is the Saab 2000. It is a turboprop aircraft, fitted with 3 generators in total, one generator on each wing in the engine, and one auxiliary power unit (APU) inside the aircraft. The electric power from the APU is not used by the radar, and will not be dealt with during this simulation.

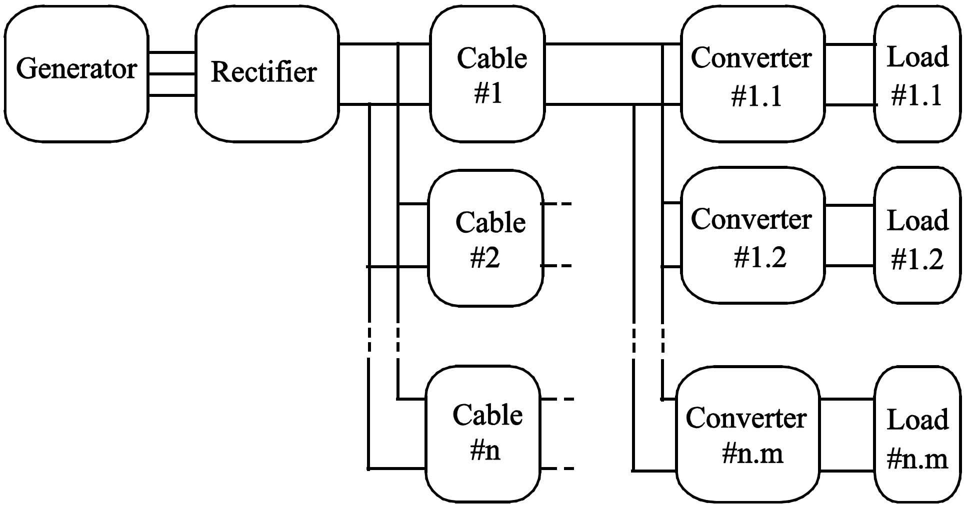

Figure 6.1 Block diagram of the complete power system

In line with the purpose of evaluating the program Saber® the main focus has been to do the simulation on a system with roughly the same size as it will be when completed, in order to evaluate Saber®s ability to do simulations on this scale.

6.1 Method

When building a large system, it is best to advance in small steps. This is done to keep track of problems easier, and to solve those quicker. In general the total design progress was managed like this. Note that each bulletin was divided into even smaller steps.

- First the converter was modeled, including feedback.
- The next step was to get the power from a generator. Beginning at a DC generator and not an AC generator since a rectifier needs to be implemented during the same time, and small steps were taken.
- When the generator was functioning, a step backwards was taken and the pulsed load was tested. When everything was working, all parts were connected together.
- The DC generator was then replaced by a model of an AC generator
- When a whole system was working, the cables and wiring were built into the model.

In order to evaluate Saber® the focus was on having the design resembling that of the plan for the next system in size and complexity. When the system was the same size and it was shown that Saber® was capable of handling such a large system the focus shifted to verify the design to such a high degree as possible.

6.2 Additional models

In order to have a complete system simulation some more models than the converter are needed. Having a full simulation includes having the mechanical connection from the propellers to the generator and hereby achieving the mechanical to electrical connection, but also the rectification and the load are modeled.

6.2.1 Generator

6.2.2.1 Input data

The data found on the generators operating at the right and left engines shows the specifications:

- 115/200 V AC
- 45 kVA
- Brushless and variable frequency
- 11400 RPM (380Hz) to 18172 RPM (606Hz)
- Power factor 0.85

More information was asked for, but was never delivered due to security issues. This was a large drawback, since the mechanical dynamics has a large influence on the system.

6.2.2.2 Modeling

There are several generator models possible to use when simulating, all with different strengths and weaknesses. There are also the difficulties of understanding the model, which includes to use the right domain and to choose the correct pins.

From all models a brushless permanent magnet synchronous machine was chosen. This model can operate both as a motor and generator depending on the input to the model. But it seemed to be the easiest model to work with, and results could be reached fast.

Input parameters for the model was: motor inertia, number of poles, Back EMF, line to line winding inductance and resistance. Since no input was given for these parameters, some guesses were made.

6.2.2 Rectifier

As the output from the generator is a three phase ac voltage, a rectifier is needed to invert the output to DC voltage. The rectifier was designed with the simplest setup of ideal diodes, and an output filter, to filter the voltage waveform. Showed in Figure 6.2

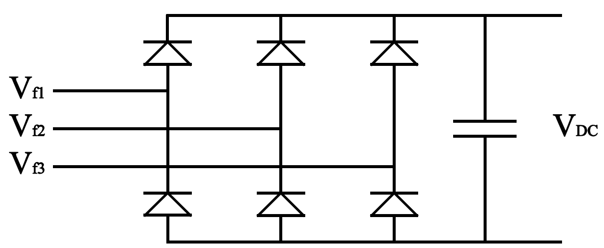

Figure 6.2 Full bridge rectifier with an output capacitor.

6.2.3 Load

The physical load is the antenna which transmits a pulsed radar wave. The power of the pulse is taken from a capacitor bank. And this bank is fed by the converters. Between the capacitor bank and the converter is a linear regulator that regulates the current flow. This current is approximated to a constant current. See Figure 6.3.

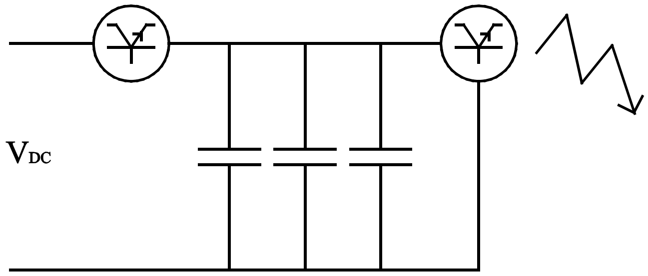

Figure 6.3 Approximate radar wave transmission circuit

But when the radar is not used, and the capacitor bank is discharged and the load drops to zero. And then when the radar activates again, the load pulses up to max load almost immediately.

The load is expressed in a lookup table, and can very simply be imported from an Excel file. A specification table can also be filed in directly in Saber®.

6.4 System evaluation

The outcome of this project was not as planed. Initially the plan was to build a model of a system that is already flying and that there have been measurements on. But instead of that, the system was redirected towards the next generation of airborne power systems for Saab Microwave Systems. The decision to change focus was taken during the transition from step two. It was a conscious choice that fitted better with the evaluation purpose for this master thesis from Saabs point of view. It must be mentioned that this fell in well with the authors.

The system meant to be simulated resembles the system in step two to a high. There are no measurements or any realizations of this system yet. To have a somewhat reliable simulation it is assumed that the generator for the system is that of a Saab 2000 propeller aircraft. This will not likely be the case in reality.

Due to the lack of experience the design of a system came to a halt sooner then expected and the original goals were not quite met.

7. Discussion

7.1 Realization

The initial time plan that first was planned was not followed as expected. The project was more like a pilot project with no specific ending. Since no one had any experience of Saber®, and thereby nobody knew what Saber® was capable off.

Basically the method by doing small steps throughout the project was followed really well. There were some problems that made the time fly faster than calculated.

One of the problems that made the time plan to fail was to determine the abstraction level the design. A design can be made in so many ways. For example a converter can be built with discrete components, using a State AMS model or by simply modifying an existing model. This results in that sometimes the problem is simply to choose the best solution. And for this, experience is needed, and since the authors do not have a lot of experience the choices were not correct all the time.

This has meant that a lot of time has been spent on exploring different possibilities. This was time consuming, but increased the knowledge about Saber®

In the early stage of the master thesis, delimitations were set not to go into the programming and customizations of models. The hypothesis was that this would take an extensive amount of time just to be able to understand. Having the “Top-Down” method meant that this was a reasonable assumption to make. And it was probably a good delimitation to have, since the models would probably have been too detailed. This was however a thing that held us back in terms of results for the system.

7.2 Evaluation

7.2.1 Measurements

In general regarding measurements, there could be more planning done before testing. There were a few times that retesting were needed. This could have saved some time, and this is a thing that will be considered in future test done by the authors.

7.2.1.1 Cables

The long cable measurements were somewhat of a disappointment. If some background checking would have been done before testing, it would have been obvious that the placement and positioning of the cable are of great importance, and another cable with more specs and shield would have been chosen at start. It can be argued however this was a useful experience to see the limitations. Anyway it has been a useful insight for the authors to try to see the difficulties that can occur, and that the planning before doing measurements is important.

When looking closer at the simulated oscillation frequencies for the single conductor wire, it is obvious that they are too fast for all the models created. The oscillation frequencies are approximated from the corresponding figure, and are:

- TxLine model = 770kHz
- Transmission line model = 52kHz

This should be compared with the frequency of the measured cable which is:

- Long cable measured value = 25kHz

This confirms the transmission line model as the best choice when modelling a simple cable. The measured values are better, since the TxLine model has the drawback of having to place the ground plane close to the conductor.

But going over to the coaxial cable, where the capacitance and inductance were easier to measure. It shows that the frequencies of the two models used have a lot higher frequencies than the measurement.

- Transmission line model = 7,7MHz
- Coaxial cable model = 10MHz

As the period times are getting lower, the sampling frequency is getting closer and closer, which gives a lower accuracy in approximating the oscillating frequency. It however gives a fair picture of the frequency and that it is quite far from the measured value of the coaxial cable.

- Coaxial cable measured value = 22kHz

Comparing the measurements done, it shows that they are quite similar. The difference between the two cables measurements is 3 kHz. The modelled frequencies are a lot higher than the measured ones. The probable cause is that the electronic load has a lot of inductive and capacitive effects on the circuit, which lowers the switching frequency. The switching frequency can be calculated by

$$\omega = \sqrt{\frac{1}{LC}} \,. \qquad (7.1)$$

With a capacitive load, the total circuit capacitance would get higher and thereby lowering the resonance frequency.

Another place that can add capacitive and inductive effects are the connections. But this has probably a smaller effect, but it will have effect.

This would mean that the simulations are probably correct, or in the close neighbourhood of it anyway. To continue this investigation a better test setup would be needed, or the capacitive effect from the electronic load would have to be investigated.

7.2.1.2 Converter measurements

The measurements on efficiency as seen in Figure 5.4 are very much alike to the values taken from the datasheet. There are small variations especially in the measurements involving lower currents.

These are accredited to the measurement set up as it becomes more vitale when having lower currents. Lower currents are affected by cable resistance and outside influence to a higher degree.

7.2.2 System simulation

7.2.2.1 Small system simulation

With the first two steps completed some reflections could be made. The first impression of Saber® is that it is a very powerful tool when simulating. It is relatively easy to use if the user has some experience in other simulating programs.

Going over to evaluate the simulation of the converter, the consequence of using an average model taken from the parts library, it quickly became clear that the results never could become perfect. A fairly good model of the hardware was however created. It has a clear resemblance to the hardware and has a custom made feedback where the efficiency are modelled

A problem that took quite long time to solve was that the transient response of the feedback was very slow, and when efforts were made to make it faster the feedback turned into an unstable mode, probably with heavy oscillation. This is just a guess, because of that the equation in the software model had no solution.

The fault for this was later found to be ideal components. Not giving ESR to the output capacitor and winding resistance to the inductor made the bandwidth of the feedback to get very low, and easily get unstable. This is now solved, and the feedback is behaving as wanted.

One clear limitation on modelling the converter has been the delimitation of not programming a custom model. Also the “Top-Down” approach has meant that the simplified models had to be used. This is not negative as it gives a good ground for further work, improving existing parts of the design.

7.2.2.2 Airborne power system simulation

The results do not resemble that of a real system to a degree that is needed to make any conclusions. The system as a whole must be improved in terms of resemblance to the power system of the airborne radar.

One of the delimitations of not programming and building customized models is one of the causes for the deviations from the meant to be simulated system. This delimitation has however resulted in a more complete system that could test Saber® as a program in a better way given the time for the master thesis.

7.2.3 Saber® software

In this chapter, some pros and cons are listed, regarding the software, and help and support from Synopsys Inc.

7.2.3.1 Modeling

For a novice user results can be achieved relatively fast using the already existing models. These however are almost always inadequate because they are not adaptable enough. The underlying mathematical algorithms that control the behavior of the model cannot be altered without altering the programming and the programming are most often encrypted.

Otherwise, the models in Saber® are generally good. There is just a surprisingly lack of model information. Often you have to guess what kind of input that is needed.

There are a lot of models as well. That is because of the fact that mixed signals need individual models to be handled separately. This can lead to confusion.

Sometimes the program chooses to switch itself off during simulation. This does not happen all the time, and when the program is restarted it often works fine. The reason for this fault is unknown to the authors.

It is generally important due to simulation time to have a design optimized for the analyses preformed. Otherwise the simulation often takes a fair amount of time and the size of the plot file becomes substantial.

7.2.3.2 Simulating

The default is that the simulator uses a variable time step when simulating. The time step can be set with a maximum or a minimum value. But if the smallest time step is larger than needed this will affect the result.

When one simulation is finished, one can choose to start from the finish point of the last simulation. This feature is very usable, especially when there are for example generators that need to get to the work point before the simulation of the system can begin.

Another thing that is possible to do is to choose which signals, and which nodes that are going to be saved into the plot file, and in that way save time and disk space.

There are a lot of different analyses that can be performed of a design. Transient, Monte Carlo, small signal AC, and Fourier are examples on analyses that can be done. The analyses are run separately, and which to use is chosen in Saber® sketch.

7.2.3.3 Visualization of waveforms

To use CosmosScope as visualization tool for graphs made in the simulator is easy and intuitive. There is a calculator were you can do mathematical calculations with the waveforms and plot the results.

Different waveforms are easily moved between graphs with a “drag and drop” operation. Exporting graphs is easy as well, and can be done to several different file formats. In sketch there is a probe function. It works like an oscilloscope window appears in the sketch environment and with one or two arrows to measure differences in the system.

7.2.3.4 Error messages

How well the errors are presented by the program determines much of its user friendliness. If the cause of the error is easy to understand by looking at the error message the error itself is easily corrected. This can be a major time saver in designing.

In Saber® this is done in a fairly good way. For a first time user it is not completely simple to understand since the information about the error is rather complex. In the message you have a detailed presentation as to what has gone wrong. It resembles the error message that exists in a programming language and with a bit of experience you get a good felling as to what has gone wrong.

The error is mostly described in such a way that you can follow from the initial error and then trace it down through the hierarchy of the program or simulation to find the cause of the problem. There are however glitches as for example when something goes wrong in the initial point calculations.

If this happens it is very difficult to locate the error that might be an unconnected wire or connection point. Perhaps marking the floating point red in the design or likewise would help. It should be pointed out that a manual for interpreting errors that occur would be helpful. Frank Lehmann commented on the suggestion and said that it is often difficult to point to a certain place where the error has occurred. This kind of error interpreting comes with experience.

7.2.3.5 Help and support

When using such a high tech program as Saber®, it is important to have access to support. The nature of Saber® is such that a person working for a support department needs to have a good insight into the program but also and this is very important, have an overall knowledge of the schematic simulated. The guidance the authors had was from Frank Lehmann, an employee at Synopsys Inc. He has been of great help and answered a lot of questions. Having the same person to contact has helped, as he has been familiar with our goals and tasks.

During this master thesis most contact with support has been via email, WebEx meetings and phone conversations. WebEx is an online tool to conduct web meetings and enables the possibility to see the other person's desktops. Although skeptical in the beginning, WebEx has been an excellent way to have fast, flexible and educational support for Saber®.

The regular way to seek help would be to use the Solvnet web portal. This is a web based forum for Saber® users. Among other things it is here you can download the newest version of Saber®. But also application notes, tutorials and a question forum are included. This is good, but the feeling the authors got is that there is a need for more expertise to help with specific cases.

In some aspect it has been hard to have an objective assessment of the support since the people involved in this master thesis have been aware that one of its major purposes has been to see if Saber® is a program for SMW in the future. Anyhow, the people working with technical support for Saber® seem to have a good knowledge of electrical engineering and were very helpful.

7.3 Proposed further work

7.3.1 Improving system models

Further work can be done in improving models by customizing them. It should be noted that in most cases the customization would not mean to build more advanced models but rather having less advanced models. This would especially make the results from a “Top-Down” simulation approach much better.

The generator which is just mentioned in this report is also a component to model. This is quite a large thing to do, and this might not be a thing for SMW to do, but instead the manufacturers of the generator. But a model of the generator is most important if a good simulation result is wanted.

7.3.2 Creating a model of an existing airborne power system

Having done a more thorough simulation of a complete system many of the problems faced can be simulated and therefore time and money can be gained. Removing the limitation of not programming and building customized models and then concentrating on building and improving one part of the design would enable more precise simulations.

When having one part of the system verified and setting up simulations using approximations for the rest of the system this would enable more interesting simulations as problem areas could be targeted. This was also confirmed by Frank Lehmann.

It is our firm belief that this would be the way to go. Having the system simulated as a whole would require a great amount of time. The alternative would be to simulate the system to a steady state and having it set as a starting point. This would also lead to an acceptable simulation time as only the interesting course of events would be included.

7.3.3 Cable change simulations

Aspects that could be simulated are for example the possibility of having aluminium wiring instead of copper wiring to reduce the weight. Another problem mentioned is the fact that the lengths of the cables need to be changed when having the system installed on another aircraft. This would not be a problem to make the alterations needed in Saber® and do simulations of the new design.

An aspect of cable modelling that might be worth having a look at is the modelling of connection points. As explained many of the results in this master thesis could probably be greatly improved by considering the effect of connection points and adding them to the simulation.

7.3.4 Model handling at Saab Technologies

Further investigations should be done into the recommendations given in this master thesis for suggestions to a common system for storing models. This could also include setting up routines for simulations done in Saber® and how the licenses could have a maximum degree of utilization.

Another area that would be interesting is the ability of Saber® to have models from MatLab and Simulink integrated into the Saber® design.

7.4 Recommendations

The feeling for us about Saber® is that it is a good program that fits the wanted functions of SMW. It is intuitive and easy to get started. But to get to a deeper level of simulation quite a bit of knowledge are needed about the program.

That is why we recommend SMW to have a few employees that specialises in Saber®. Those people should work as administrators as well, administrating the SMW model library, model structure, naming etc.

Thesis projects are as in this case good to build a basic knowledge but must not be over extended. The basic knowledge is gained at a relatively low price for the company and can then be passed on. When the simulations come to a more advanced level, it is however important that the program is used on a more professional level by employees of the company.

As we see it, SMW should go all the way with Saber® or leave it and try to find another program that can do the same kind of simulations. The license costs for this program are high, and it would not be economical to proceed slowly.

To get a good start it would be good if the financing would be at a department level, and put in the budget as a separate post, this to keep the cost from the projects and thereby making the use of Saber® more valuable.

7.4.1 Cooperation within the Saab group

When visiting the departments Saab Avitronics, Jönköping and Saab Aerosystems, Linköping we have actively pressed on the need for cooperation. It is our firm belief that all parties have everything to gain on such an exchanging experience. Even if it seems like the vision with Saber® differs somewhat, there are help to be found in the other companies, if not in Saber® applications, so in electric power engineering in general.

The most valuable thing we can see now is to go together and have some educational courses which could be held by Synopsys with participants from all three departments. This would not only be cost efficient, but also make cooperation more natural.

To get a more strong cooperation, some structural changes are needed. One of the things is to get a file sharing system for Saab Technologies. Maybe a program like the one used at SMW which is IFS. That would be an excellent way of sharing models.

Another thing to think about is a way to handle models, and versions of a model. Most likely there are a couple of complexity levels needed for each component, and this should be standardized as soon as possible, even model revision numbering could be handled.

8. *Conclusions*

One of the conclusions drawn in this master thesis is that Saber® probably would be of use for the simulations expected by Saab Microwave Systems.

When it comes to the results it is concluded that a higher insight into Saber® must be attained in order to have simulations that can be used for foreseeing results of changes in the system.

It is also concluded that a deeper cooperation between different companies inside the Saab group would benefit all parties. This cooperation would not only apply to Saber® related information but also documents and documentation in general.

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A Appendix

A1 Buck-Boost calculations in MatLab 6.5

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                                          %
%              Buck Boost parameter calculations           %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

Vin = 48;                         % Input voltage
Vd=0.75;                          % Diode Forward voltage drop
Vut = 48+Vd;                      % Output voltage
SF = 1450000;                     % Switch frequency
Ts = 1 / SF;                      % Switch period
R = 13                            % load
dVut = 0.2;                       % Output voltage ripple
i = 2.2;                          % Averaged current
di = 0.3 * i;                     % Current ripple
dt = D * Ts;                      % T on for the switch


D = (Vin/Vut) / (1 + Vin/Vut)     % Duty
C = (Vut * D * Ts) / (R * dVut)   % output capacitor
L = Vin / (di/dt)                 % Inductor value
```

A2 Datasheets

A2.1 Hüber Sühne, Radox 155, Connection lead

General properties:

Excellent high temperature, low temperature, ozone and weathering resistance, flame retardant, soldering iron resistant, easy to strip and process, compatible to all common resins and varnishes, flexible.

Applications:

For protected and fixed installation inside electrical equipment, especially suitable for the connection of motor windings, switchboards, magnets and transformers.

Technical data:

Temperature range	-55 to 155 [ºC]
Cross section, nominal	1.5 [mm^2]
Conductor construction	30 x 0.25 [n x mmØ]
Conductor diameter, maximum	1.55 [mm]
Core diameter (D)	2.7 ± 0.10 [mm]
R_{20} IEC 228, max	13.7 Ω
Weight	1.9 [kg/100m]
Nominal voltage	600/1000 [V]
Test voltage	3500 [V]
Minimum bending radius	3 x D

Information taken from Hüber Suhne webpage, and written approval for publishing the data has been given.

A2.2 Bedea, RG174/u, Coaxial cable

Type

Specification			M17/119
Product number	PVC		1089
Structure			
Innerconductor	Ø dia (mm)		StCub, 7x0.16
Insulation	Ø dia (mm)		LD-PE, 1.52
Outer conductor			CuGvz
Sheating Ø dia (mm)			2.8
Color			black
Electrical properties			
Characteristic impedance	(Ω)		50 ± 2
Attenuation	(dB/100m)	1Mhz	2.9
		10MHz	9.5
		20MHz	13.5
		50MHz	21.6
Velocity ratio	v/c		0.66
DC resistance	(Ω/km)	inner cond.	306
		outer cond.	54
Operating voltage	max (V)		1100
Mechanical properties			
Min bending radius	(mm)		15
Weight approx.	(kg/km)		12
Temperature range	(ºC)		-25 / +70
Heat combustion	kWh/m		0.05

Information from Bedea, “RG-Cables for highest demands” catalog.

A3 Inductance and Capacitance Measurement Tables

A3.1 Radox 155 measurement results

Hüber Suhne, Radox 155

Length = 0.5 m	*100 kHz*	*1 MHz*
Twisted cable from center to the ends		
Series inductance	174.7 n	169 n
Cable formed like a circle		
Series inductance	475 n	462 n

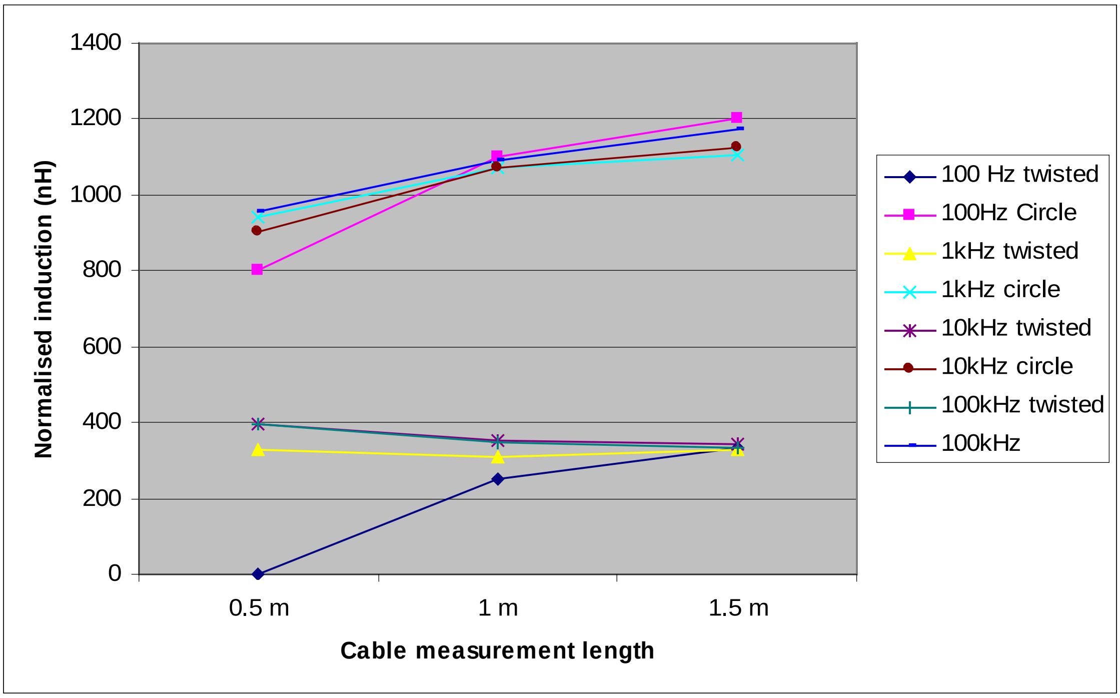
Hüber Suhne, Radox 155

Length = 1 m	*100 kHz*	*1 MHz*
Twisted cable from center to the ends		
Series inductance	350 n	311 n
Cable formed like a circle		
Series inductance	1.035 u	996 n

Hüber Suhne, Radox 155

Length = 1.5 m	*100 kHz*	*1 MHz*
Twisted cable from center to the ends		
Series inductance	586 n	500 n
Cable formed like a circle		
Series inductance	1.551 u	1.490 u

Inductance per meter calculated from the measurements above. This gives some sort of maximum and minimum values of the inductance.



A3.2 Radox 155 measurement data,

These measurements are made by Lennart Kruse.

Inductance measurement at 25mAac					
	100 Hz	1 kHz	10 kHz	100 kHz	
Cable	Twisted from the center to the ends. (nH)				R (mOhm)
0.5 m	Resonance	165	197	198	6,55
1m	250	310	352	347	13,2
1.5m	500	490	511	497	19,71
Cable	Formed like a circle. (nH)				
0.5 m	400	470	452	477	
1 m	1100	1070	1070	1090	
1.5 m	1800	1660	1690	1760	

A3.3 Coaxial cable measurement results

The measurements are done at Chalmers by the authors, under the supervision of Andreas Karvonen.

Bedea coaxial cable, RG174/U

Length = 4.55 m	*100 kHz*	*1 MHz*
Capacitance, conductor to shield, open end		
Parallel capacitance	453 pF	456 pF
Series capacitance	453 pF	456 pF
Inductance, conductor to conductor		
Series inductance	6.0 uH	5.25 uH
Series resistance	1.7 Ω	3.45 Ω
Parallel inductance	7.2 uH	5.3 uH
Parallel resistance	10 Ω	316 Ω
Inductance, shield to shield		
Series inductance	3.85 uH	3.85 uH
Series resistance	187 Ω	267 Ω
Parallel inductance	3.90 uH	3.85 uH
Parallel resistance	31.5 Ω	2k Ω
Inductance, conductor to shield, shorted end		
Series inductance	2.15 uH	1.375 uH
Series resistance	1.84 Ω	3.5 Ω
Parallel inductance	6.15 uH	1.6 uH
Parallel resistance	2.85 Ω	24.6 Ω