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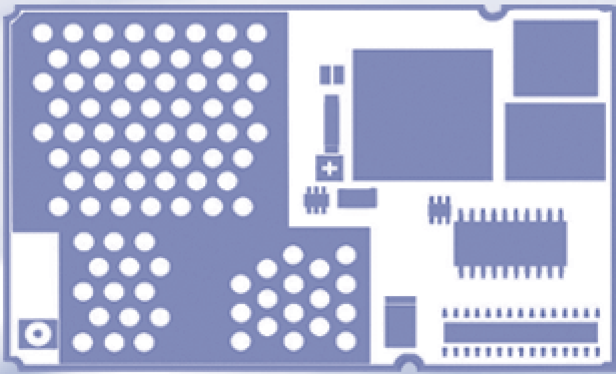

Application Note 26

Power Supply Design for GSM Applications

Siemens Cellular Engine

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1 Introduction

Efficient power supply design is a key issue for any GSM/GPRS application. The purpose of this Application Note is to support system integrators in developing an application layout that minimizes current consumption, reduces the effects of voltage drops and ripples and ensures a reliable product performance.

This document covers the entire range of Siemens Cellular Engines. All examples have been chosen to be generally applicable to most product types. Yet, the diversity of the products implies that, due to hardware or software specific properties, functional differences occur regarding the implementation of features, AT commands and parameters. Therefore, please consult the documents supplied with your module, especially [1] and [3], to make sure whether or not a described feature is supported.

1.1 Related Documents

[1] Hardware Interface Description of your Siemens wireless module
[2] Application Note 07: Li-Ion Batteries in GSM Applications
[3] AT Command Set for your Siemens wireless module

The latest product information and technical documents are ready for download on the Siemens Website or may be obtained from your local dealer or the Siemens Sales department.

To visit the Siemens Website you can use the following link:

http://www.siemens.com/wm

1.2 Terms and Abbreviations

Abbreviation	Meaning
GSM	Global System for Mobile Communication
GPRS	General Packet Radio Service
IC	Integrated Circuit
PCB	Printed Circuit Board
RF	Radio Frequency
USB	Universal Serial Bus
Vbat	Battery Voltage

2 Power Supply Issues

Power supply design for GSM/GPRS modules should be focused on the transmitting mode (dedicated mode), because of the high current consumption during transmission. With this in mind, the following sections sketch the main issues in designing power supply solutions.

2.1 Power Consumption

Due to the maximum RF power levels of approx. 2W the power supply current is modulated at 2A (approx.) pulses of 0.577ms every 4.6ms. During the receive only time period, current GSM call consumption is about 70mA. The current profile is illustrated in Figure 1.

The measured values refer to the GSM 900MHz band at maximum power level (PL 5) with a real 50Ohm load. These values may increase up to 2...3A with an antenna connected depending on its mismatch.

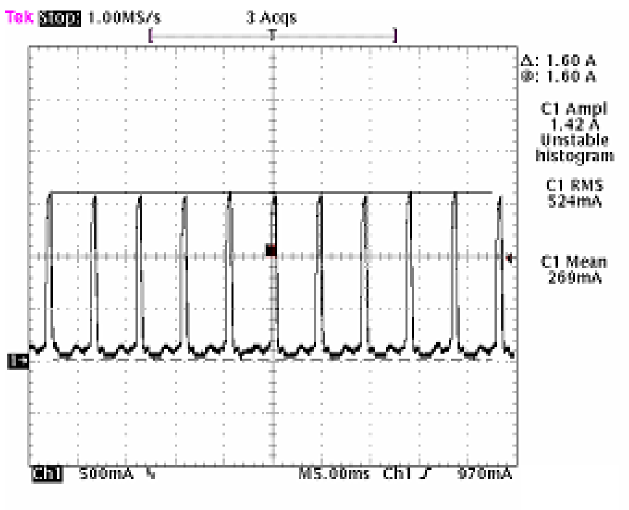

Figure 1: Current at power level 5

During GSM call a GSM module transmits in one timeslot, receives in one or two timeslots and is idle for 5-6 timeslots. In all it transmits for 577 µs and is idle or receiving for 4.03ms.

Taking worst case figures (3A bursts) into account this adds up to an average current consumption of about 440mA for 1Tx timeslot at GSM.

In case the module supports GPRS Class 10, it can transmit two timeslots during one frame (receive only in 3 timeslots). Recalculating the average current consumption for a worst case GPRS Class 10 scenario, this adds up to an average power consumption of 800 mA.

To give you an idea Table 1 lists some current consumption values for the Siemens wireless modules MC45 and TC65.

Table 1: Typical and maximum current consumption of Siemens MC45/TC65

Parameter	Description	Conditions	Min	Typ	Max	Unit
I_{BATT+}	Average supply current	TALK mode: EGSM 900 GSM 1800/1900		300 270	400	mA
		DATA mode: GPRS Class 8, (4 Rx, 1 Tx) EGSM 900 GSM 1800/1900		360 330	460	mA
		DATA mode: GPRS Class 10, (3 Rx, 2 Tx) EGSM 900 GSM 1800/1900		590 540	840	mA
		DATA mode: GPRS Class 12, TC65 only, with reduced power out (1 Rx, 4 Tx) EGSM 900 GSM 1800/1900		810 710	1210 1010	mA
	Peak supply current (during transmission slot every 4.6ms)	Power control level PCL 5		2	3	A

A power supply design for a GSM/GPRS module should be able to deliver 440mA for 1Tx timeslot in average, and also handle very short bursts with current consumption of up to 3A.

2.2 Power Losses and Voltage Drops

Siemens cellular modules are specified to operate with certain voltage supplies. Voltage supplies may instance range from 3.2V to 4.5V as measured on the module's power connector.

When consuming as much as 2…3A peak current, voltage losses due to stray resistances occur. Resistances occur in various parts, but there are three main areas to take into account.

- Impedance/Resistance in the power source
- Resistance on connectors
- Resistance in signal tracks and lines

Assuming that the total resistance in the power supply line is 50mOhm and that the resistance in the ground line is the same, this amounts to a total resistance of 100mOhm (0.1 Ohm). When calculating the voltage drop over the power supply line it is 200mV. To be on the safe side, it should be assumed that the voltage drop during the Tx burst does not exceed 400mV. This means that if the data sheet states a minimum voltage supply for a GSM module of 3.2V, the power supply solution should provide at least 3.6V.

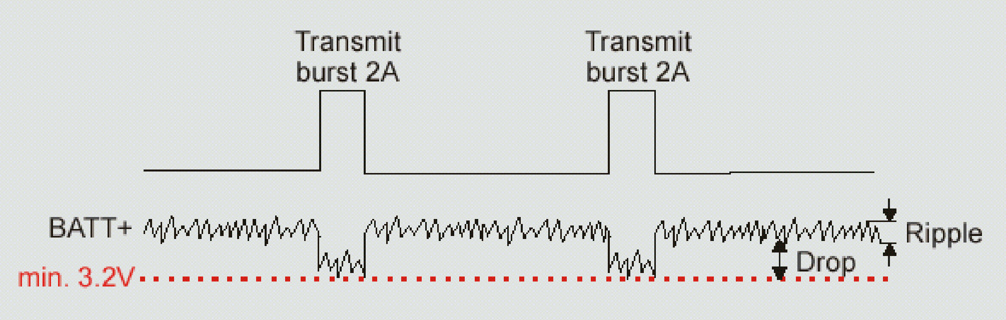

Figure 2: Voltage drop and ripple

2.3 Ripple

Another issue for power supply solutions is supply voltage ripple. Ripple can develop as a result of using a switched power supply circuit or as a result of disturbances caused by bad immunity to what is radiated from the own GSM antenna. Please note that requirements here are far beyond those required to pass standard EMC tests.

A typical requirement for Uripp during a transmit burst would be that the level should not exceed the following values:

- 50mV @ f<200kHz
- 2mV @ f>200kHz

3 Power Supply Solutions

There exists a whole range of possible power supply solutions for GSM/GPRS modules. The most common ones are described in the following sections:

- Linear regulation (see Section 3.1)
- Capacitor supply (see Section 3.2)
- Mix between linear and capacitor supply (see Section 3.3)
- Battery (see Section 3.3.1)
- Switched DC/DC converter (see Section 3.3.2)

NOTE: The values used in the following sections are sample values, mostly for GSM modules. These values will have to be recalculated for any customer-specific power supply solution.

3.1 Linear Regulation

Power supply with linear regulators is easy to design, and the total cost for the components can be low. As seen in Section 2.2 the power supply solution must be able to deliver at least 3A out, which means that it must also get 3A in. If the module's desired supply voltage output voltage is for example 4V and the input voltage is 12V, 12V gets in, and 4V gets out. 8V goes away as heat.

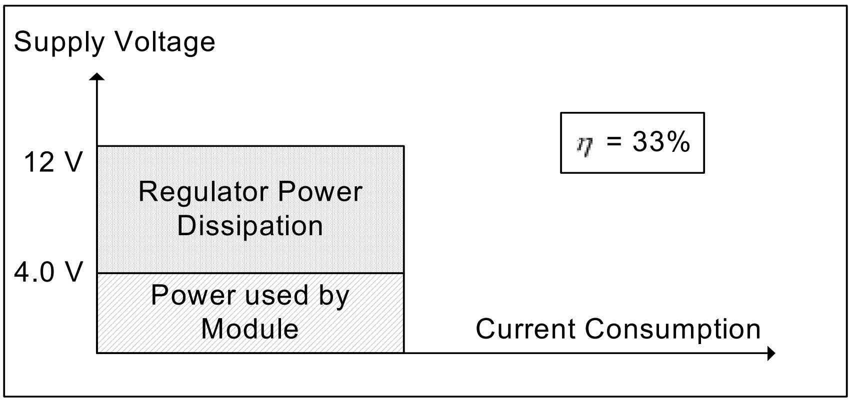

Figure 3: Linear regulation

The advantage of this solution is that there is no big requirement on the input power supply and on the input capacitor. Also, big voltage drops can be filtered by the regulator.

The requirements for the sample circuit are:

	GSM	GPRS 10
Input voltage	12V	12V
Average current	0.44A	0.85A
Peak current	3A	3A
Avg. Power dissipation at regulator IC	3.5W	7W

The peak power dissipation in the circuit is 3A x 8V = $24W_{peak}$, while the heat power is based on the average power consumption. In this case $3.5W_{avg}$ shall disappear as heat.

For small dissipations it is possible that the surface of the IC is enough for cooling. For medium power dissipations the problems can be resolved by having a big copper area on the PCB that can take care of the cooling. For bigger power dissipations extra cooling is necessary. A cooling element as heat sink is often required. The below formula is useful when working with cooling elements.

$$PDmax = \frac{Tjmax - TA}{JC + CS + SA}$$

PDmax = Maximum power dissipation
Tjmax = Maximum IC temperature
TA = Ambient temperature
JC = Junction/case thermal resistance
CS = Case/sink thermal resistance
SA = Sink/ambient thermal resistance

NOTE: Modules are sensitive to heat. If cooling for the module or its housing is insufficient, the module might warm up. If the module gets too hot, it will shut off! This could happen during a long call (long warm up period), if the cooling is not sufficient.

3.2 Capacitor Supply

If the module is integrated on a board with a power supply component that delivers 5V and sufficient current, it is possible to design quite a simple power supply solution for the module.

The appropriate voltage can be achieved by adding one or two diodes in serial with the power supply line. The voltage drop over the diodes will create a suitable voltage for the module.

A big capacitor has to be added, able to supply the module during transmission bursts. The capacitor must be able to deliver up to 3A during 1 burst and must have low ESR values. These requirements translate to the following values:

- ESR values less than 50mOhm
- Ripple current more than 3A
- 4700 – 10 000 µF

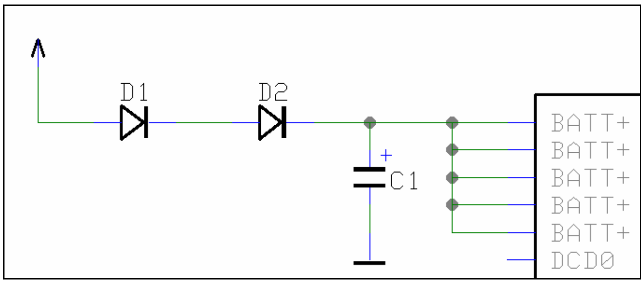

Figure 4: Capacitor supply

3.3 Linear and Capacitor Supply

In a mixed power supply solution there are two components that can supply the module in parallel. These components are usually a big capacitor and a power supply circuit. Such a combination is the easiest and cheapest to realize. Most power supply circuits require a capacitor at the output side in any case.

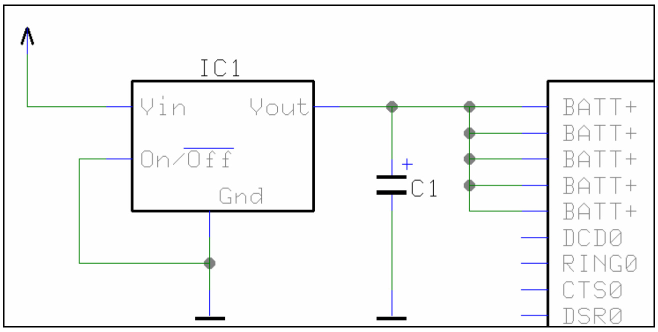

Figure 5: Mixed supply

With this solution power is supplied from both the capacitor and the IC.

3.3.1 Example with Low Current Regulator IC

The average power consumption of a GSM module is 440mA, while the peak consumption is max. 3A during the Tx burst, which can be 1 x or 2 x 577µs.

In this example the IC delivers 500mA and covers the average power supply needs. However, it is not able to handle current peaks. Current peaks must instead be handled by the capacitor. The capacitor should be able to deliver 2.5A (3A – 500mA) for 1 x or 2 x 577µs. It should also have low ESR and high ripple current. The higher the rated voltage is the better are as a rule ESR and ripple current.

The resistance in the power supply feeding line together with the ESR resistance of the capacitor is 50mOhm. 50mOhm @3A mean a 150mV voltage drop of the module. The IC is a zero resistance current source. The power supply IC delivers 0.5A, the capacitor the remaining 2.5A. The maximum voltage drop is 400mV.

Since the Tx burst frequency is 217Hz, it can be considered as ripple current. The required capacitance can be calculated using the formula:

$$C = Q/U = (I \times \Delta t)/(\Delta U)$$

C = capacitance (Farad)
Δt = discharge time (here: 577µs)
Q = charge
ΔU = voltage change (here: max. 250mV)
I = current (here: 2.5A)

With the sample values this results in:

$$C = 2.5A \times 577\mu s / 250mV = 5770\mu F$$

The above example is a worst case scenario with bad antenna matching and strict power restriction by the regulator chip. In practice 4700…7200 µF are enough for GSM; for GPRS class 10 the values will have to be doubled.

NOTE: A capacitor loses its capacity through ageing or low temperatures. If the product is likely to operate in low temperatures, check the datasheet for remaining capacitance at low temperatures. It is also a good idea to compensate for ageing and low temperatures by choosing a capacitor with higher values than required. Often it is easier to meet the requirements by adding two or more capacitors in parallel.

These capacitors will dissipate power depending on ripple current and ESR; power that will additionally heat up the capacitor:

$$P = I^2 \times R / 8 = 39\text{mW}$$

3.3.2 Example with High Current Regulator IC

In the previous example there was a need for a big capacitor. To be able to use a smaller capacitor, the IC must deliver higher currents.

In this example the IC can deliver 2.5A. It means that the ripple current over the capacitor is 0.5A.

Assuming the IC is a zero resistance current source the capacitor delivers 0.5A. Even with an ESR of 300mOhm a maximum voltage drop of 150mV occurs. The required capacitance can be calculated as follows:

$$C = Q / U = (I \times \Delta t) / (\Delta U)$$

C = capacitance (Farad)
Δt = discharge time (here: 577µs)
Q = charge
ΔU = voltage change (here: max. 400mV-150mV=250mV)
I = current (here: 3A-2.5A=0.5A)

With the sample values this results in:

$$C = 0.5\text{A} \times 577\mu\text{s} / 250\text{mV} = 1154\mu\text{F}$$

In practice 470…1000 µF are enough for GSM, for GPRS class 10 at least 2200µF are recommended.

3.4 Battery

Using a Li-Ion battery, the battery must be able to deliver all necessary power peaks to the module. Therefore, the battery should be connected directly to the module.

For charging and choosing the correct battery see the separate application note on Li-Ion batteries in GSM applications [2].

3.5 Switched DC/DC Converter

A switched DC/DC converter is very often used when there are requirements for a small footprint, high efficiency and little heat dissipation. Linear regulation often leads to undesirable heat dissipation that needs to be speeded by a heat sink. This problem can be resolved by using a switched DC/DC converter that creates (almost) no heat at all.

However, there are a number of issues to take into account when working with switched DC/DC converters: Shall the DC/DC converter be isolated, which design typology is the best to use (boost, buck, fly back, or other), which operation modes is best employed (PWM, hysteretic, other), switching frequency, required efficiency, cost/size, post filtering as well as layout.

Not all of these issues can be covered in an application note, but some guidelines may be given here.

There are DC/DC controllers available on the market with an integrated switch (like the simple switcher series from National), and they are often easier to design with then DC/DC controllers with external switch.

When working with switched regulation the switching frequency is very important as it decides how fast the switcher reacts on voltage drops (together with the filter in the error amplifier) on the load (in this case, the GSM/GPRS module). The switching frequency is also important for the choice of components around the switcher circuit. Higher frequency means smaller (and cheaper) components.

Integrated switcher circuits typically work with frequencies from 50kHz to 1MHz. There are disadvantages operating with high frequencies. A switcher creates ripple on the supply voltage. This ripple **must** be minimized on the power supply line to the GSM/GPRS module. Otherwise, there may be the risk of violating the GSM transmitter modulation spectrum and therefore application approval, especially at higher DC/DC switch frequencies.

Normally there are no EMC tests for frequencies below 150kHz. This means that with a switcher frequency of 48kHz, even the third overtone is below the limit. But this third overtone can be modulated in the GSM switching spectrum, if the ripple value is too high. This point should be considered, even if the risk of a GSM spectrum violation is much smaller than at high switching frequencies.

If a small, inexpensive design is required, it should be realized with higher frequencies, but the mentioned issues need to be taken into account.

NOTE: Keep in mind that around a DC/DC switch (specially the coil) there are magnetic fields, which can create disturbances to other electronic circuits. This might be the case if the coil is placed close or under / over the RF part of the GSM module.

4 Design Considerations

As already mentioned above the switch frequency from a switched DC/DC converter might cause violation on the GSM transmitter's modulation spectrum.

If the unit has to be able to work with input voltages such 30…40V it may be inconvenient to work with linear regulation.

If you are not sure how to design a switched DC/DC converter that does not cause any trouble for the GSM module, and linear regulation is not suitable for your design, the following ideas might be helpful.

4.1 Post Filtering

With post filtering an extra inductor and an extra capacitor are added after the components included in the DC/DC design.

The dimensions of these extra components depend on how well filtered the output power from the DC/DC switch is. It might be enough to use a small inductor of 1uH. The inductor must of course be able to handle the current (2…3A) and it should not have too much resistance so as not to create too big a voltage drop.

A switched DC/DC regulator has a feedback line from the output side that is used by the circuit to regulate the output voltage. It would be nice, if the feedback line could be taken from the output of the extra LC filter. The regulator could then compensate for the voltage drop over the second inductor as well. In most cases this is not possible. An LC filter creates a phase shift. The regulation IC expects this phase shift from the ordinary output filter. By adding an extra phase shift in the feedback line, it's likely to add malfunction of the regulation IC.

However, the output capacitor in the extra LC filter can be calculated according to what was previously mentioned in this application note.

4.2 Double Regulation

A second way of solving the problem is to use double regulation. A switched DC/DC converter can be used to convert input voltage >6V to for instance 5V. As a second step a linear regulator can be used to convert 5V to 4V, which can be a suitable voltage level for a GSM module. A linear regulator with a drop out voltage less then 1V must be chosen.

The advantage with this design is a post filtering effect that lowers the DC/DC converter's typical output ripple. The disadvantage is the cost and size for having two regulators on board.

4.3 Input Voltage Filter

When working with power supply circuits it is important not to forget about the input voltage side. The input voltage side depends on the input voltage source and the operational environment. A typical design example is:

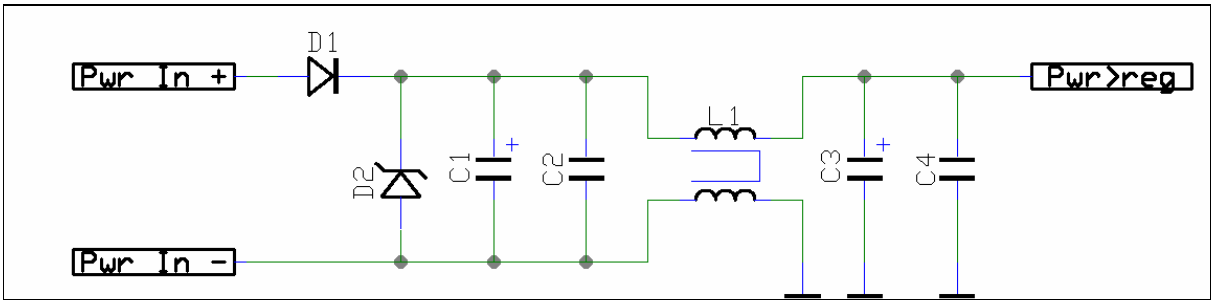

Figure 6: Input filter

- D1 protects for reverse polarity connections.
- D2 is a transil and protects over voltage spikes. It could also be a varistor, placed before the D1.
- L1 is a common mode choke that reduces the high frequencies coming into the circuit (from the power cable) and going out from the circuit (from switching regulator, causes cable radiation).
- C1 is a big capacitor that adds a delay function for potential spikes. Also, in combination with C2, it forces high frequency signals to be common for the plus and minus lines. C1 and C2 are often not included in designs.
- C3 and C4 are the “main” capacitors in the input voltage filter.

C1 and C4 are usually in the range of 47µF to 470µF. C2 and C3 are usually in the range of 1nF to 100nF.

The C4 value depends to a great degree on the regulation design, since C4 (maybe in parallel with another capacitor) is the input capacitor of the power regulation circuit. Voltage drops on the regulation output side because of transmission bursts are noticed on the regulation input side. It is important to reduce the voltage drops even on the regulation input side, since they are noticed on the power input feeding line (Pwr In +), and might cause problems during EMC tests (cable radiation).

4.4 Reduced Resistance between Battery and Module

Generally, the power lines of the PCB tracks connecting the module with the battery should be as short and low resistant as possible.

To minimize the effect of voltage drops (max. 400m), you can decrease the GND resistance by using additional ground connections from the module to the customer application. This can be done by using a screw or spring contact and as well via soldering on the battery contact pads (not for all GSM engines).

5 Layout Guidelines

5.1 General Guidelines

The PCB layout is very critical in a power supply design, and should be considered as one of the most important design issues. A PCB strip line has to be viewed as a resistance as well as an inductance. The resistance for a strip line can be calculated with the formula:

Resistivity x Length / Area

Resistivity	The resistance for copper, which is 0,017µOhm x m @ 20 degrees
Length	The length of the leader
Area	Width x copper thickness

Examples:

In this first example the strip line on the PCB is 0,5mm wide, 100mm long and has a 0,035mm copper thickness. The resistance can be calculated as:

$R = 0{,}017 \times 0{,}1m / (0{,}5 \times 0{,}035)mm^2$
$R = 0{,}0017 / 0{,}0175 = 0{,}097$ Ohm

The resistance in this leader is almost 100mOhm; more than enough to have an influence on the power supply line.

In the second example the strip line on the PCB is 2mm wide, and 20mm long. The resistance can be is calculated as:

$R = 0{,}017 \times 0{,}02\ m / (2 \times 0{,}035)\ mm^2$
$R = 0{,}00034 / 0{,}07 = 0{,}005$ Ohm

The resistance is 5mOhm, which is almost neglectable.

The conclusion from these examples is obvious. The leader from the power supply IC and/or capacitor shall be as short and wide as possible.

NOTE: In the examples above it is assumed that the copper thickness on the PCB is 35µm. Normal values of copper thickness can be from 15µm to 50µm. If the copper thickness had been 15µm instead of 35µm in the examples above, the resistance had been 2,3 times higher.

The figure below shows a power supply line on the PCB. It is a wide line, but with short narrow lines to each soldering pad to a module's connector. A wide line across all power supply lines will decrease the solderability.

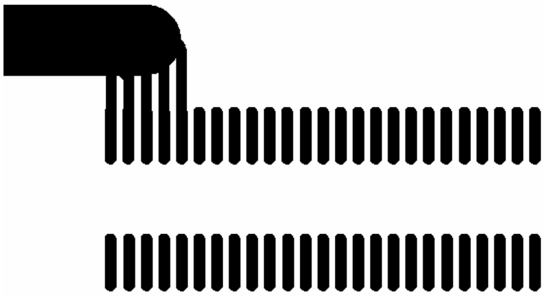

Figure 7: Power feeding line

As previous mentioned a strip line could also be seen as an inductor. In the figure below the power supply-feeding line is placed in parallel with a microphone line. If those lines are seen as inductors they can be viewed as a transformer. The efficiency of the transformer is not really very good. So, if the small line were a data line, it might not have any impact. But since it is a microphone line, some problems can arise from this kind of design.

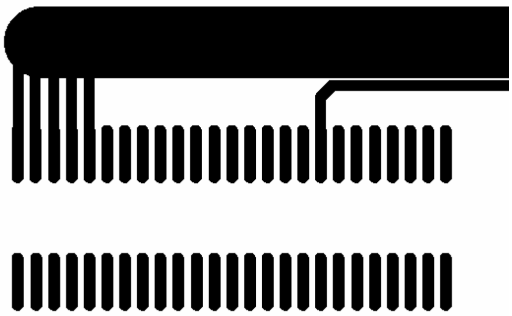

Figure 8: Inductance of power feeding line

5.2 Guidelines for DC/DC Converters

When working with switched DC/DC converters there are some special issues to consider for PCB layouts. Guidelines can very often be found in the data sheet for the IC, but here are some general hints:

- Place the inductor as close as possible to the switch.
- Place the freewheeling diode (or second switch) on the line between the switch and the inductor.
- Place the output capacitor as close as possible to the inductor.
- Place the input capacitor as close as possible to the switch.
- Keep all lines to the components mentioned above as short and thick as possible.
- Consider the block consisting of switch, inductor, free-wheeling diode, and input and output capacitors as a source of disturbance signals, and keep it as far away from micro controller, audio blocks and other parts that can easily be interfered.

It is sometimes recommended to run the ground lines to the power section separately from other ground lines. This is to prevent the high current in the output circuit to influence the regulating circuit. However, both ground lines must be connected in one single point to ensure that the potentials for the two grounds cannot differ.

6 Current Limitation by AT Command

The latest module generation provides users with the possibility to reduce the maximum RF output power and hence the maximum required peak supply current. This can be achieved using the AT^SCFG command. Please refer to the ATC specification of your Siemens wireless module for more information [3].

7 Reference Design

7.1 USB Linear Regulation

This reference design is aimed at USB equipment, but can be used for all cases with similar requirements. According to USB specification (revision 2.0 Chapter 7.3.2) power supply from a high power port is:

Table 2: USB Host / powered Hub voltage specification

Parameter	Min	Max
Supply Voltage at USB port [V]	4.75	5.25
Supply Voltage at end of USB cable [V]	4.625	5.125
Current limitation [mA]	500	

A power supply of 500mA is enough for GSM modules, but not enough for GPRS class 10 modules. This reference design is therefore only suitable for GSM and GPRS class 8 modules. For designs with GPRS class 10 modules a battery supply with battery charging current from USB or another additional power supply is recommended.

NOTE: According to the USB specification there is also a low power port. A low power port does not deliver enough power for a GSM/GPRS application. Also, there is a voltage loss on the USB connection cable under maximum load. It is defined as 250mV (125mV each in Vusb and Vgnd). The user should include this fact in a calculation.

7.1.1 Simple Design

The below design is based on a low cost linear regulator. Since available current is limited by the USB power source, and the input capacitance is limited by the USB specification, a large capacitor has been placed between the linear regulator and the GSM/GPRS module to take care of the peak current during transmission bursts.

Output voltage is set to approximately 4.1V by resistors R1 and R2. The design is high frequency decoupled by C2, C4 and C5. J1 is a USB connector.

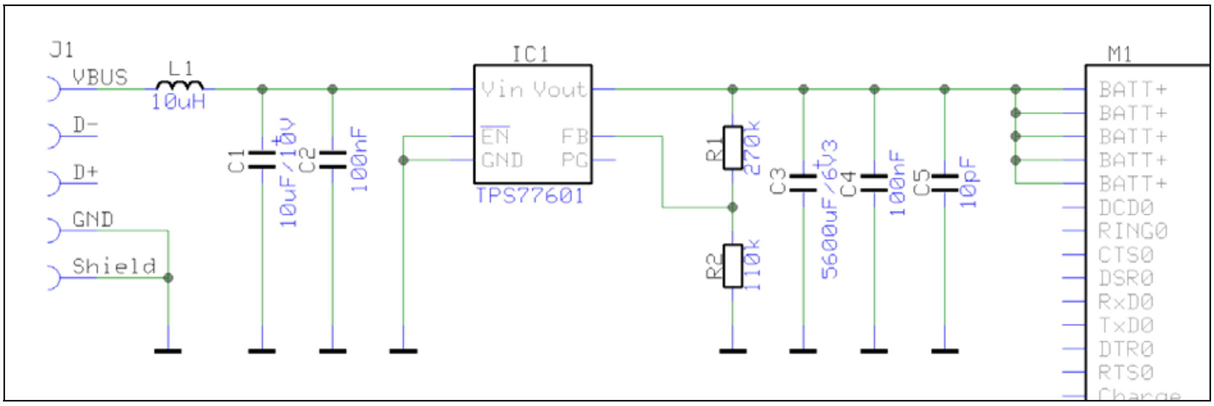

Figure 9: USB power supply 1

Table 3: Component list

Ref.	Order Number	Description	Manufacturer	Size
C1	B45196H2106K109	Capacitor, tantalum 10V/10µF	Epcos	3216
C2	std	Capacitor 100nF		0603
C3	6.3ZL5600M16X20	Capacitor, electrolytic 6.3V/ 5600µF	Rubycon	16x20
C4	std	Capacitor 100nF		0603
C5	std	Capacitor 10pF		0603
L1	LPC4045*TED100K	Inductor, 10µH/1020mA	Koa	4045
R1	std	Resistor, 270k		0603
R2	std	Resistor, 110k		0603
IC1	TPS77601	Low noise, low drop linear regulator	TI	TSSOP20
J1		USB connector		
M1		GSM module	Siemens	

Requirements for key components are:

IC1:

Input voltage:	4.75 – 5.25V
Output current:	500mA
Output voltage:	Adjustable 3.4 – 4.5V
Drop out voltage:	Less than 1V

C1:

Input voltage:	7.5V
Capacitance:	6.8 – 10 µF

C3:

Input voltage:	6.3V
Capacitance:	3600 – 7200 µF
Ripple current:	2.5A
ESR:	Less than 60mOhm

NOTE: The TPS77601 (IC1) is available in SO8 and TSSOP20 Power pad package. It is strongly recommended to use the TSSOP20 Power pad version because of power dissipation. See the linear regulator data sheet for more information.

NOTE: The big capacitor C3 can be replaced by two or more smaller capacitors in parallel. It's important to keep control over the total ESR values when having capacitor in parallel. It should be in the range of tens of mOhm.

In practice the amount of necessary capacitance can be decreased if C1 gets the bigger capacitance while the linear regulator delivers the peak currents. But the bigger the capacitor C1 the worse the problem with inrush current and the smaller the range of supported PC's becomes.

SIEMENS

7.1.2 Design with Inrush Current Reduction

When a USB unit is plugged into the network, it has a certain amount of capacitance between VBUS and ground (C1). In addition, the regulator supplies current to it's output capacitor (C3) as soon as power is applied. Consequently there could be a surge of current into the device, which might pull the VBUS below its minimum operating level. This problem must be solved by limiting the inrush current during the power up phase.

According to the USB specification the maximum load that can be placed at the downstream end of a USB cable is 10mF in parallel with 44Ohm resistance. For this reason C1 shall not be larger than 10mF.

With the above design (see Section 7.1.1) inrush current to C3 might be a problem. The problem can be handled by charging C3 to a certain level before IC1 is enabled.

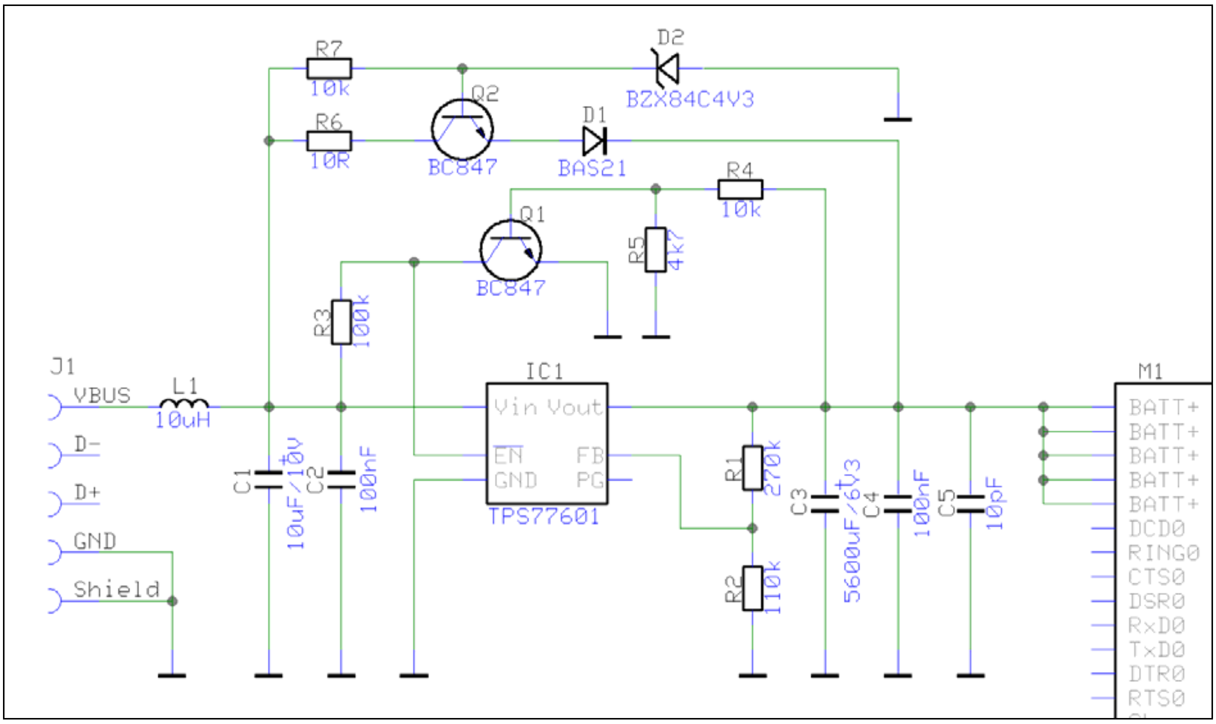

Figure 10: USB power supply 2

In the design above IC1 is disabled immediately after power up, because of pull-up resistor R3. C3 will be charged through current setting resistor R6, Q2 and D1 to a voltage level decided by D2. As soon as the appropriate voltage level is reached, Q1 will set the enable pin of IC1 to a low status. That switches on IC1.