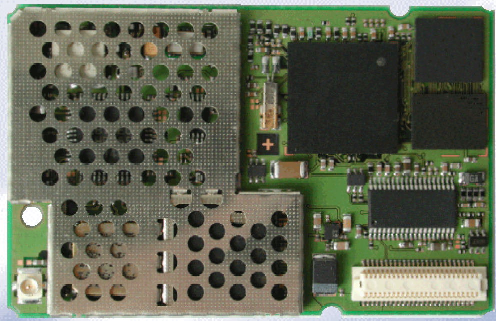
SIEMENS mobile



Application Note 26

Power supply design for GSM applications

Siemens Cellular Engines
Solutions for Innovative Mobile Telecommunications

Version: v01
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Application Note 26:	**Power supply design for GSM applications**
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1 Introduction

An efficient power supply design is one of the key issues for every GSM/GPRS application. The purpose of this application note is to help system integrators to develop an appropriate application layout that minimizes the current consumption, reduces the effect of voltage drops and ripples and ensures reliable product performance.

1.1 Related documents

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

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 Approval considerations

The Siemens GSM modules listed above have been type approved for use with the Siemens reference setup.
When designing a GSM application you are advised to make sure whether or not the final product is standard compliant. This is particularly important for mobile phones, PDAs or other handheld transmitters and receivers incorporating a GSM module. Depending on the individual design, such devices may require additional Type Approval.
Outside of Europe, there may be further international, national or government standards and regulations to be observed for Type Approval.

1.3 Terms and Abbreviations

Abbreviation	Meaning
GSM	Global System for Mobile Communication
PCB	Printed Circuit Board
RF	Radio Frequency
Vbat	Battery Voltage

2 Understanding the problem

2.1 Power consumption

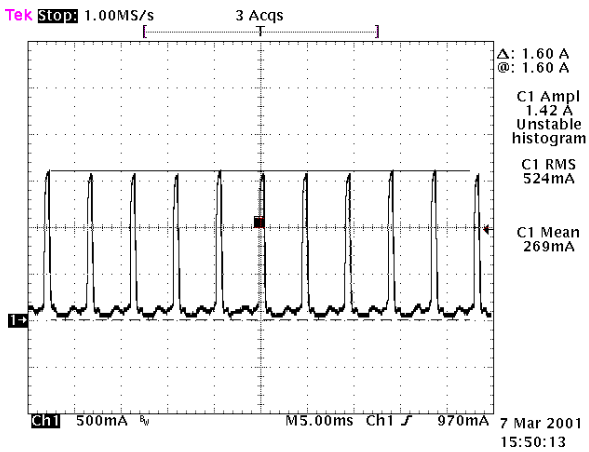
When designing a power supply solution for a GSM/GPRS module, focus must be on transmitting mode (dedicated mode), because of the high current consumption during transmission.

Due to the maximum RF power levels of approx. 2W the power supply current is modulated at 2A (approx.) pulses of 0.577 ms every 4.6 ms. During the receive only time period, current consumption during GSM call is about 70 mA.
The current profile is illustrated in Figure 1 and Figure 2.
The measured values refer to the GSM band 900 MHz at maximum power level (PL 5) with a real 50Ω 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 times this mean transmitting for 577 μs and idle/receiving for 4.03 ms.

Calculating worst case figures (3A bursts) gives an average current consumption that is approx. 440mA.



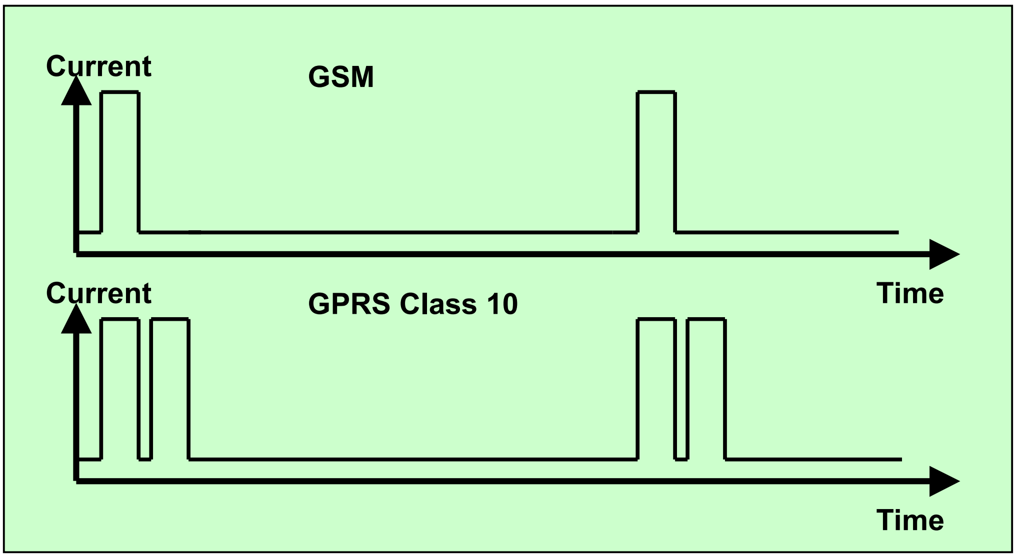


Figure 2: GSM/GPRS bursts

A power supply design must be able to deliver 440 mA in average, and also handle very short bursts with current consumption of up to 3 A.

If the module supports GPRS Class 10, it can transmit two timeslots during one frame (receive only in 4 timeslots). Recalculating average current consumption during worst case for GPRS Class 10, gives an average power consumption of 800 mA.

For example, the Siemens MC45 is a GPRS Class 10 module. To give you an idea Table 1 shows the current consumption of MC45. The entire table can be found in the MC45 Hardware Interface Description.

Table 1: Typical and maximum current consumption of Siemens MC45

Parameter	Description	Conditions		Min	Typ	Max	Unit
I_{BATT+}	Average supply current	POWER DOWN mode			50	100	µA
		SLEEP mode	@ DRX = 6		3		mA
		IDLE mode	EGSM 900		15		mA
			GSM 1800/1900		15		
		TALK mode	EGSM 900		300 4)	400	mA
			GSM 1800/1900		270 4)		
		IDLE GPRS	EGSM 900		15		mA
			GSM 1800/1900		15		
		DATA mode GPRS, (4 Rx, 1 Tx)	EGSM 900		360 4)	460	mA
			GSM 1800/1900		330 4)		

Parameter	Description	Conditions	Min	Typ	Max	Unit
		DATA mode GPRS, (3 Rx, 2 Tx) EGSM 900		590 4)	840	mA
		GSM 1800/1900		540 4)		
	Peak supply current (during transmission slot every 4.6ms)	Power control level PCL 5		2	3	A

2.2 Power losses and voltage drops

A Siemens GSM module is specified to operate with a certain voltage supply. It can for instance reach from 3.2V to 4.5V, measured on the GSM module power connector.
When consuming as much as 2…3A peak current, voltage losses due to stray resistances will occur. Resistances exist on different places, but there are mainly three parts to look out for.

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

Assume that the total resistance in the power supply line is 50 mOhms. Also assume that the resistance in the ground line is the same. It gives a total resistance of 100 mOhms (0.1 Ohm). When calculating the voltage drop over the power supply line it will be 200 mV.
To be on the safe side always assume that the voltage drop during the Tx burst shall not exeed 400 mV, which means that if the data sheet says that minimum voltage supply for a GSM module is 3.2V, the power supply design shall not give less than 3.6V.

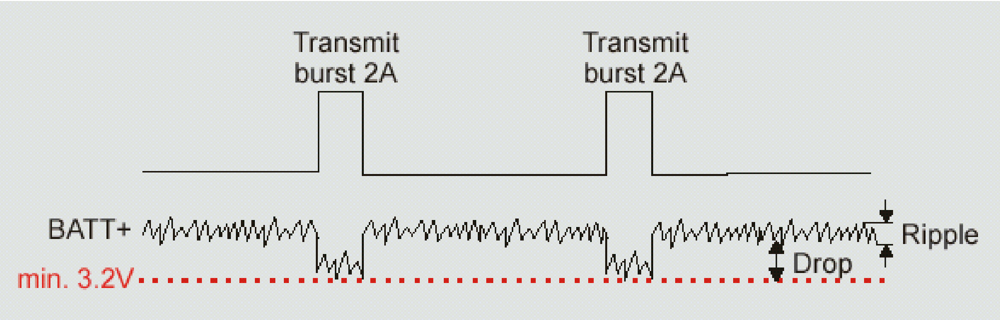


Figure 3: Voltage drop and ripple

2.3 Ripple

Another source for problems with the power supply design can be ripple on the supply voltage. Ripple can come from using a switched power supply circuit, or from disturbances caused by bad immunity to what is radiated from the own GSM antenna.
Please note that requirements here are far beyond what is required to pass “normal” EMC test.
A typical requirement for Uripp during a transmit burst is that the level shall not exceed:

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

3 Power supply design

There are some different design alternatives available for GSM/GPRS module power supply solutions. The most common are described in the following section, and they are:

- Linear regulation (Section 3.1)
- Capacitor supply (Section 3.2)
- Mix between linear and capacitor supply (Section 3.3)
- Battery (Section 3.4)
- Switched DC/DC converter (Section 3.5)

Note:
The following examples are only for GSM. If using GPRS class 10 modules (for instance MC45), all values must be recalculated.

3.1 Linear regulation

Power supply with linear regulators is easy to design, and the total cost for the components can be low. If the desired output voltage is 4V and the input voltage is 12V, 12V gets in, and 4V gets out. 8V goes away as heat.

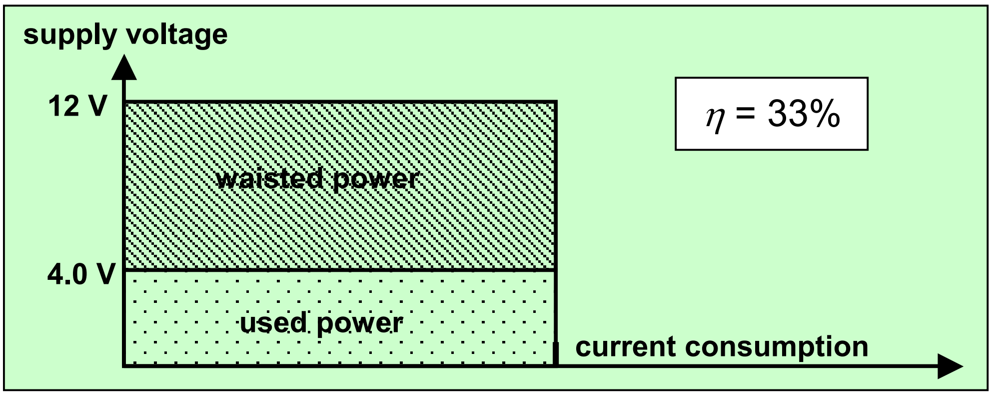


Figure 4: Linear regulation

The power supply design must be able to deliver at least 3A out. It means that it must also get 3A in.

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 this sample circuit will be:

	GSM	GPRS
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 will then be 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 it is necessary with extra cooling.

A cooling element for heat sinking is often required. Here is a formula that is useful when working with cooling element.

$$PD\max = \frac{Tj\max - TA}{JC + CS + SA}$$

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:
GSM modules are sensitive to heat. If the cooling is not good enough, the GSM module might get warmed up. If the GSM module gets warm enough 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 GSM/GPRS module shall be integrated on a board that already has a power supply part, which for instance delivers 5V and a lot of current, it is possible to do a really simple power supply design for the GSM/GPRS module.

The right voltage can be accomplished 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 GSM/GPRS module.
A big capacitor must be added, that is able to supply the GSM/GPRS module during the transmission burst.
The requirements for the capacitor is:

- Must be able to deliver 3A during 1 burst
- Must have low ESR value

In clear values those requirements can be translated to:

- ESR values less than 50 mOhm
- Ripple current more than 3000mA
- 4700 – 10 000 μF

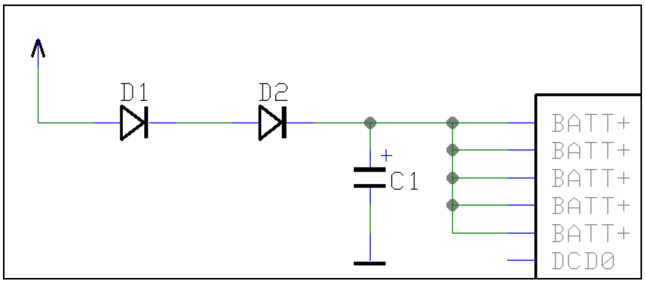


Figure 5: Capacitor supply

Note:
In the circuit diagram above a resistor shall be added in parallel with the capacitor. It's necessary for discharging the capacitor when the GSM/GPRS module is switched off.

3.3 Mix between linear and capacitor supply

In a mixed design there are two parts that can supply the GSM module in parallel. Those parts are often a big capacitor and a power supply circuit. This is the most common design, booth from the fact that it is easiest and cheapest, and from the fact that most power supply circuits anyhow require a capacitor at the output side.

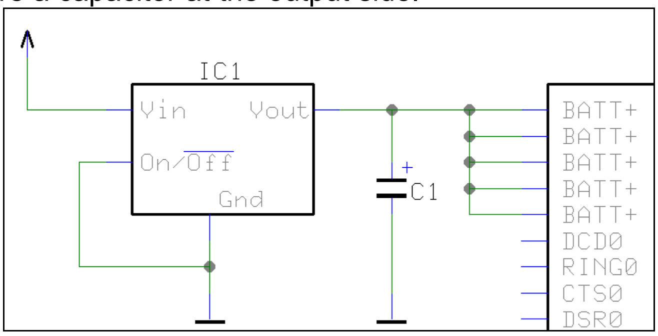


Figure 6: Mixed supply

With this design power is supplied from both the capacitor and the IC. Let's take some examples:

3.3.1 Sample with low current regulator IC

The average power consumption of a GSM module is max. 440 mA, and the peak consumption is max 3A during the Tx burst which can be 1 x or 2 x 577 μs.
If the IC can deliver 500mA, it will cover the total need for power supply, but it will not be able to handle the current peak. The current peak must instead be delivered from the capacitor. The capacitor must be able to deliver 2.5A (3A – 500mA) for 1 x or 2 x 577μs.
This is a sufficient solution, but what requirements will that give for the capacitor?

Focus shall be on finding a capacitor with low ESR, and with high ripple current. In general the higher the rated voltage the better are ESR and ripple current.

Let's do a rough assumption:
It's assumed that the resistance in the power supply feeding line together with the ESR

resistance of the capacitor is 50 mOhm. 50 mOhm @3A means 150mV drop of the module. Let's assume that the IC is a zero resistance current source. The power supply IC shall deliver 0.5A, the capacitor shall deliver the remaining 2.5A. The maximum voltage drop shall be 400mV.

In this example 2.5A is supplied from the capacitor. Since this is something that will done 217 times every second, it must considered as ripple current.

Requirements for the capacitor is:

- Ripple current 2.5A
- Rated voltage >6V (general rule: the higher the rated voltage - the better is the ESR).
- A lot of μF

The needed capacitance can be calculated with the formula:

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

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

If calculating the capacitance we will get:
C = 2.5A x 577μs / 250mV = 5770μF

This is a worst case scenario with bad antenna and strict power restriction by the regulator chip. In practice we can live with 4700 - 7200 μF for GSM. For GPRS class 10 you have to double the value.

Note:
A capacitor drops its capacity after ageing and when temperature gets low. Check the datasheet for remaining capacitance at low temperature if the product is likely to work in low temperatures.
It's normally a good idea to compensating for ageing and low temperatures by choosing a capacitor with higher values than required.

It's often easier to meet the requirements by adding two or more capacitors in parallel.

This capacitor will dissipate power depending on ripple current an ESR every 8th time slot:
$P = I^2 \times R / 8 = 39mW$

This power will additionally heat up the capacitor.

3.3.2 Sample with higher current regulator IC

In the example above there was a need for a big capacitor. To be able to use a smaller capacitor, the IC must deliver higher current. Let's take one more example.

In this example the IC can deliver 2.5A. It means that the ripple current over the capacitor will be 0.5A. What about the ESR value then?
Let's do a rough assumption:
Let's assume that the IC is a zero resistance current source. The capacitor shall deliver 0.5A. Even with a ESR of 300mOhms a maximum voltage drop of 150mV will occur. The capacitance can be calculated like this

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)

If calculating the capacitance we will get:
C = 0.5A x 577μs / 250mV = 1154μF

In practice we can live with 470 - 1000 μF for GSM. For GPRS class 10 at least 2200μF are recommended in this sample.

3.4 Battery

When using a LiIon battery the battery must be able to deliver all necessary power peaks to the GSM/GPRS module. For that the battery must be connected directly to the module.
For charging and choosing the right battery there are separate application notes available for those issues.

Note:
See also Siemens application notes:
- WM_AN_07_Use_of_Li+_Batteries.pdf

3.5 Switched DC/DC converter

A switched DC/DC converter is very often used when there are requirements for small footprint and high efficiency. Linear regulation if input voltage can be up to 40V and output voltage only is 4V means a lot of heat and need for cooling. This problem can be resolved by using a switched DC/DC converter that creates (almost) no heat at all.
There are instead a lot of other things to consider 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, other)
- Which operation modes to use (PWM, Hysteretic, other)
- Switching frequency
- Required efficiency
- Cost/size

- Post filtering
- Layout

It’s not possible to cover all those issues completely in an application note, but some guidelines are given here.

The first thing to decide is: what is most important with the DC/DC design?
Must it be small?
Must it be cheap?
Must it have a high efficiency (often required if the unit shall be included in a battery operated system)?
Must the primary line be isolated from the secondary line in the DC/DC converter?

There are DC/DC controllers available on the market with integrated switch (like 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. It decides how fast the switcher shall react on voltages 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 works with frequencies from 50 kHz to 150kHz, but there are other frequencies available. When doing an own design it’s fully possible to work with switch frequencies up to 1 MHz, and even higher.
In a switcher circuit design there is (almost) always an inductor included. There is a limit for how high frequencies that is useful to use in an inductor design, especially if the inductor has a core.
There are also disadvantages with working with high frequencies. Switchers creates ripple on the supply voltage. This ripple **must** be minimized on the power supply line to the GSM/GPRS module. **It is a risk for GSM specification violation, especially for higher DC/DC switch frequencies**.

There are normally no EMC tests for frequencies below 150 kHz, which means that with a switcher frequency that is 48 kHz, even the third overtone will be below the limit.

If the requirement is a small, inexpensive design, you should go for higher frequencies, but be prepared for more troubles.

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.

3.6 Input voltage filter

When working with power supply circuits it's important to not forget about the input voltage side. What is required on the input voltage side is dependent on the input voltage source, and in which environment the design shall operate. Here is a typical design example given:

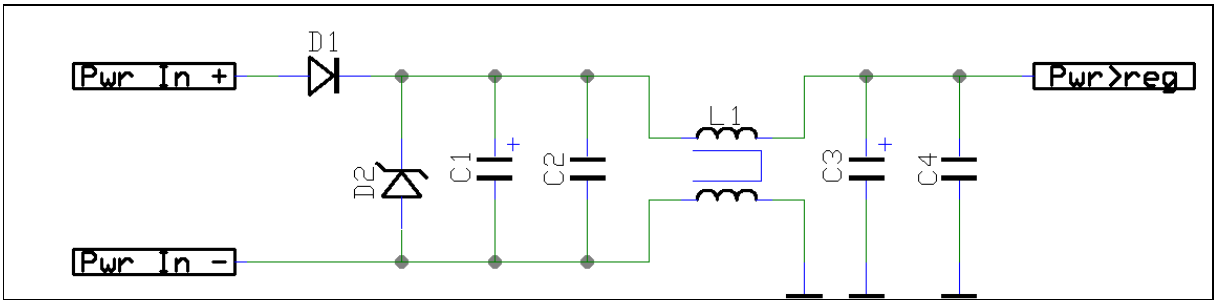


Figure 7: Input filter

In this design D1 shall protect for reverse polarity connections. D2 is a transil and shall protect for over voltage spikes.
L1 is a common mode choke that reduces high frequencies signals.
C1 is a big capacitor that adds a delay function for potential spikes, but also in combination with C2 forces high frequency signals to be common for the plus and minus lines. C1 and C2 are often left out from designs.
C3 and C4 are the "main" capacitors in the input voltage filter.

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

The value of C4 is however highly dependent of the regulation design, since C4 (maybe in parallel with an other capacitor) is the input capacitor of the power regulation circuit. Voltage drop on the regulation output side because of to transmission bursts will also be seen on the regulation input side. It's important to reduce the voltage drop even on the regulation input side, since they will be seen also on the power input feeding line (Pwr In +), and might cause problems during EMC tests (cable radiation).

4 Layout guidelines

4.1 General guidelines

The PCB layout is very critical in a power supply design, and shall be considered as one of the most important components in the design.
A PCB strip line shall be seen as a resistance, and can also be seen as an inductance.

The resistance for a strip line can be calculated with the formula:
Resistivity x length / area

where
resistivity = the resistance for copper, which is 0,017 μOhm x m @ 20 degrees
length = is the length of the leader
area = width x copper thickness

Let's take one example.
Let's assume that the strip line on the PCB is 0,5 mm wide, and 100 mm long. A common thickness for copper is 0,035mm.

The resistance for this leader can then be calculated to:
R = 0,017 x 0,1 m / (0,5 x 0,035) mm^2
R= 0,0017 / 0,0175 = 0,097 Ohm

The resistance in this leader is almost 100 mOhm, which absolutely is enough to have influence on the power supply line.

Let's take one more example.
Let's assume that the strip line on the PCB is 2 mm wide, and 20 mm long.

The resistance for this leader can then be calculated to:
R = 0,017 x 0,02 m / (2 x 0,035) mm^2
R= 0,00034 / 0,07 = 0,005 Ohm

In this example the resistance is 5 mOhm, which is neglect able.

The conclusion of this 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.

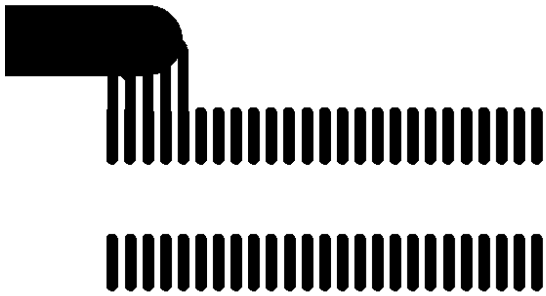


Figure 8: Power feeding line

Here is an example of how a power supply line on the PCB can look like. It's a wide line, but with short narrow lines to each soldering pad to a MC45 connector. A wide line across all power supply lines will destroy the solderbility.

As previous mentioned a strip line could also be seen as an inductor.

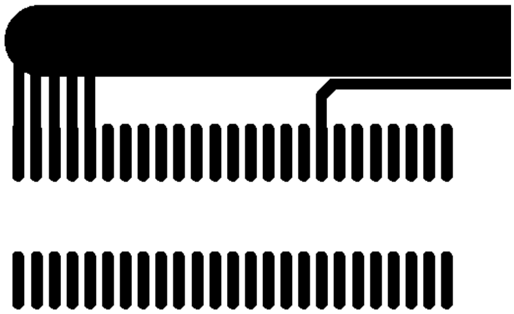


Figure 9: Inductance of power feeding line

In the example above the power supply-feeding line is placed in parallel with a microphone line. If those lines are seen as inductors it can be understood that this is a transformer. The efficiency of the transformer is not good, so if the small line had been a data line it might not have had any impact, but since it is a microphone line, which means small signal line, big troubles can be expected from this kind of design.

4.2 Guidelines for DC/DC converters

When working with switched DC/DC converters there are some special points to consider for the PCB layout. 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 as possible.

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. Both ground lines must however be connected in one single point, such that different potentials for the two grounds cannot occur.

5 Design considerations

As previous mentioned in this document the switch frequency from a switched DC/DC converter might cause violation on the modulation spectrum of the GSM transmitter.

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

So, if you are insecure about how to design a switched DC/DC converter that don't cause any trouble for the GSM module, and linear regulation is not suitable in your design, what can you do?

Here are two ideas of how to solve the problem.

5.1 Post filtering

The post filtering idea is to add an extra inductor and an extra capacitor after the components included in the DC/DC design.
The dimensions of those components are dependent of how well filtered the output power from the DC/DC switch is, but it might e enough with a small inductor of 1uH.
The inductor must of course be able to handle the current (2…3A), and it can't have too much resistance so it creates a voltage drop that is too big.

A switched DC/DC regulator has a feedback line from the output side, which is used by the circuit to regulate the output voltage. Wouldn't it 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.
This is in most cases not possible. A 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.

The output capacitor in the extra LC filter can be calculated according to what is said previous in this application note.

5.2 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 DCDC converter typical output ripple. The disadvantage is the cost and size for having two regulators on board.

5.3 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. 400mV recommended), 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).

6 Reference design

6.1 USB linear regulation

This reference design is aimed for 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 voltage specification

Parameter	Min	Max
Supply Voltage [V]	4.75	5.25
Current limitation [mA]	500	

A 500mA power supply is enough for GSM modules, but it's 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 lower power port does not deliver enough with power for a GSM/GPRS application.

6.1.1 Simple Design

The design below 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.

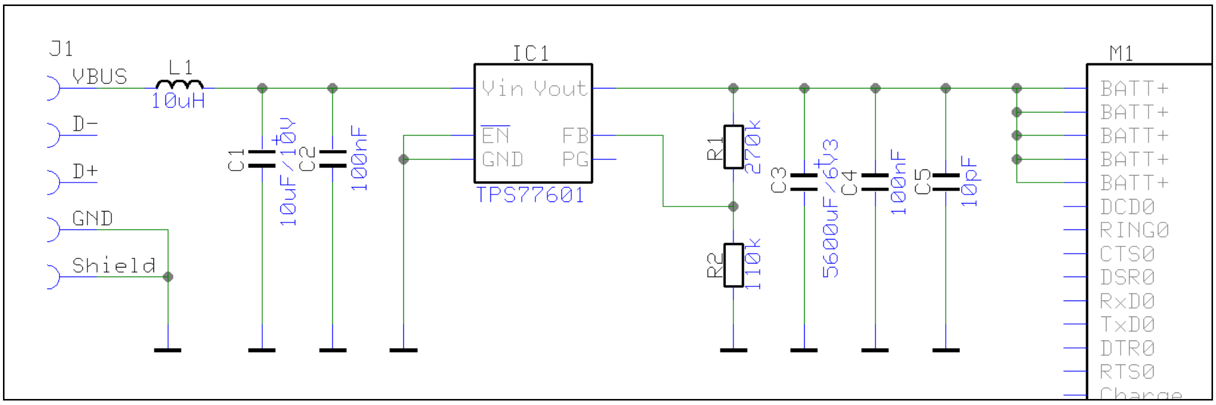


Figure 10: USB power supply 1

Table 3: Component list

Ref	PN	Description	MFG	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

Note1:
The TPS77601 is available in SO8 and TSSOP20 Power pad package. It's strongly recommended to use the TSSOP20 Power pad version because of power dissipation.
See the linear regulator data sheet for more information.

Note2:
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 milliohms.

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 bigger will become the problem with the Inrush current. That means the smaller is the range of supported PC's.

6.1.2 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 supply 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 it's minimum operating level. This problem must be solved by limiting the inrush current during the power up phase.

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

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

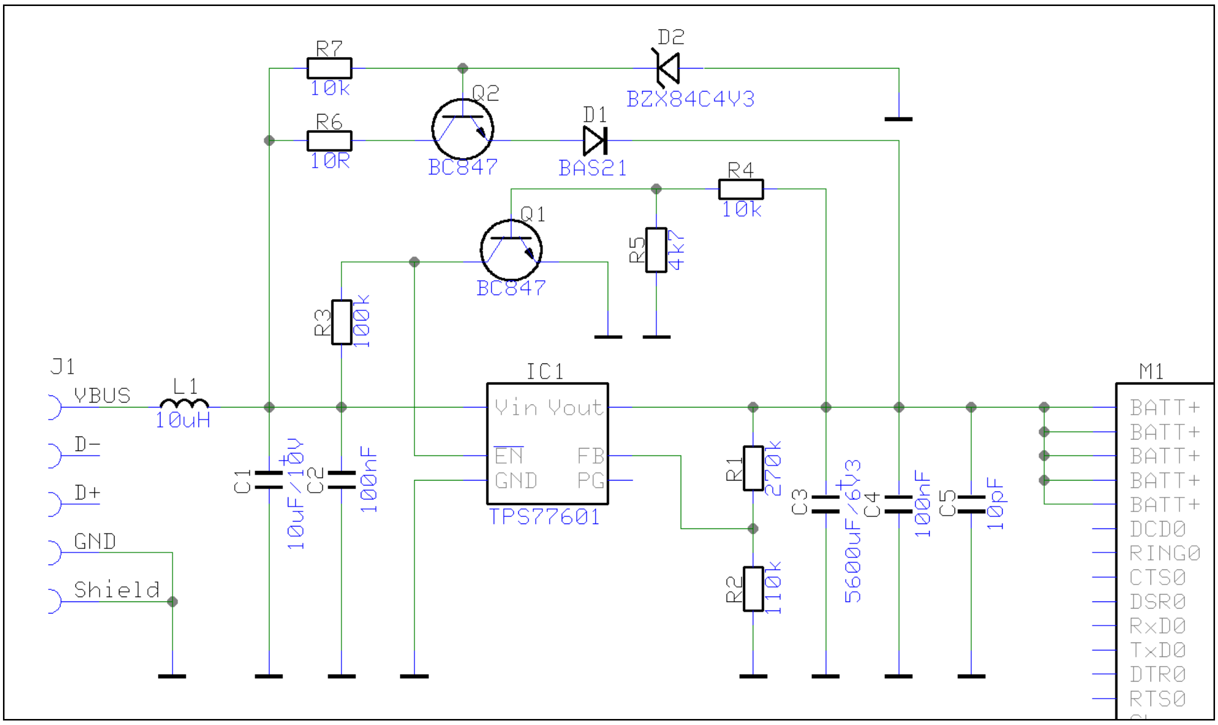


Figure 11: USB power supply 2

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. When the right voltage level is reached Q1 will set the enable pin of IC1 to a low status, which will switch on IC1.

This is one example of how the in-rush current to C3 can be limited.