Integrated Power Semiconductor Components for Power Supplies

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Power semiconductor components of ISOPLUS i4™ series provide features which make them well suited for use in switched mode power supplies (SMPS): Degree of integration is high, operational behaviour can be optimised for high switching frequencies, an integrated isolation leads to low mounting effort, complemented by large creepage and strike distances if required for high voltage. This paper gives an insight in the technology of those components. Their properties are discussed with special regard to SMPS.

1 Circuits of SMPS

Power sections of switched mode power supplies typically consist of a mains rectifier, an inverter stage primary to the transformer and a secondary high frequency rectifier.

Mains rectifier either is a simple non controlled single or possibly three phase circuit as shown in figure 1 (left). If enhanced EMC behaviour is needed as requested by several standards [1] [2], active power factor correction is advantageous, see figure 1 (right) [3].

Figure 1: circuits of three phase rectifier (left) and single phase rectifier with power factor correction (right)

There is a variety of SMPS circuits on primary and secondary side of the high frequency transformer; two examples are displayed in figure 2. Input voltage is U1, output voltage U2 respectively. Both topologies are hard switching, the right circuit uses synchronous rectification [4] to minimise losses at low output voltage.

The exemplary circuits permit to derive several requirements which should be fulfilled by the power electronic components:

- Mains rectifiers should be as rugged as possible to avoid destruction by inrush current at power on or caused by distortions or peaks of mains voltage. Fast and soft switching diodes help to reduce conducted emissions.
- Operational behaviour of the fast switching devices - the chopper D/T of the power factor corrected mains rectifier in figure 1 (right) or the devices in figure 2 - should be adapted to the particular circuit. This includes that transistors being voltage controlled with high frequency should provide a low gate charge to save drive power, or that diodes being hard turned on should switch sufficiently fast.
- Further there are several commutation paths in the fast switching part of the circuit, a minimum parasitic inductance \( L_p \) is required within to avoid transient overvoltage peaks \( U_{ov} = L_p \cdot \frac{d}{dt} \). This should e.g. be considered for the choppers D1/T1, T2/D2 or the common source MOSFETs T3/T4 in figure 2 (right).
- It is necessary to isolate the various circuit elements from each other and towards grounded heatsink. If this isolation is included in the power semiconductor component, assembly of power section is simple.
- Depending on switched voltage levels, large strike and creepage distances may be mandatory between the pins of the component themselves and towards heatsink for safety reasons.
- Further requirements refer to power density, cost etc.

Figure 2: circuits of high frequency sections with inverter, transformer and rectifier

2 Power Semiconductor Technology

2.1 ISOPLUS™ Package

The external outline of the ISOPLUS i4™ component in figure 3 (left and center) is similar to a standard discrete element as frequently used in power supplies. Indeed, length of 21mm and height of 5mm correspond to industry standard TO247 package, while the width of 20mm originates from TO264. The cross sectional view in figure 3 (right) however discloses the differences between conventional discretes and the novel ISOPLUS™ devices:

Their package is based on a direct copper bonded ceramic substrate (DCB). Its upper metallisation can be structured like a printed circuit board with a conductor pattern which will carry the silicon chips, being further electrically connected by wire bonds. This subassembly including a leadframe with up to five pins is finally covered by a molded plastic package. The ceramic sheet within the DCB is thus placed between circuit and heatsink; it fulfills the twofold task to electrically isolate the circuit against ground and to simultaneously transfer heat from the chips to external dissipation.
DCB based packaging proves its worth since years in power semiconductor modules [5]. The first molded discrete type of component by IXYS using DCB has been TO247 style ISOPLUS 247™ [6]; the use of this technology has been expanded to larger ISOPLUS i4™ [7] - this paper deals with - and smaller TO220 style ISOPLUS 220™. ISOPLUS™ devices generally provide the following features:

- Due to the possibility to structure the conductor pattern on the DCB, any circuit can be incorporated as long as enough space for the required current ratings and pins for the circuit are available. This way a high degree of integration can be achieved.
- The denition of pinouts may take into account the aspects to facilitate layout of printed circuit boards and to minimise the area of current loops, thus avoiding parasitic inductance $L_p$.
- Total coupling capacity between the circuit and grounded heatsink is as low as 40pF due to the low dielectric constant $\varepsilon$ of isolating ceramic substrate. This helps to suppress disturbing ow of high frequency displacement current.
- No insulator pad is needed to be applied externally because of the internal ceramic substrate within the devices. Its relatively high thermal conductivity contributes to lower thermal resistances between chip and heatsink than are generally achieved with conventional discretes. Further the significant saving of mounting effort is obvious.
- Creepage distance between pins of the circuit and backside metallisation being in touch with grounded heatsink is 5.5mm wide. Components with high blocking voltages can additionally provide large creepage and strike distances between the respective pins. Figure 4 depicts different versions: Creepage and strike distances between the high voltage terminals of ISOPLUS i4™ single transistor or dual diode package are 7mm or 5.5mm respectively. This is by far more than the some 3.5mm provided by standard TO247/TO264.
- Besides the feature that there is no need to isolate the components externally, those can be mounted with standard processes known from conventional discretes - the leads are soldered into a printed circuit board and the body of the package is clamped to heatsink with some clip.
- Thermal expansion coefficients of silicon chips and DCB ceramic substrates are similar. This leads to a high temperature cycling reliability which is important when power supplies are operated intermittently.

**Figure 3:** top view (left), bottom view (center) and cross section (right) of a five-leaded ISOPLUS i4™ component

**Figure 4:** ISOPLUS i4™ components with five pins (left), three asymmetrical pins for high voltage transistors (center) and three symmetrical pins for high voltage diodes (right)

### 2.2 Transistors, Diodes and Thyristors

ISOPLUS i4™ components as described in the above section 2.1 can be equipped with a variety of power semiconductor chips. This section is intended to give some overview, which kinds of chips are most suitable for the different stages of a SMPS:

- In mains connected rectifier section generally standard rectifier diodes will be used. To optimise EMC behaviour or if input frequency is higher - such as in avionic networks - faster diodes may be advantageous: There are so called fast rectifier diodes and even faster faster recovery epitaxial diodes (FRED), which may also be used as free wheeling diodes for choppers or phaselegs as described below. Further there is the possibility to use thyristors instead of diodes which permits to control inrush current, particularly in supplies with high nominal power or large capacitors in primary side DC link respectively.

Which chips are advantageously chosen for the fast switching parts of SMPS power section - see chopper D/T in figure 1 or transistors and diodes in figure 2 - depends on voltage level and frequency:

Regarding transistors, low applied voltage or high frequency respectively make MOSFETs - as depicted in the above schematics - preferred choice. There are versions with low gate charge to reduce drive power in high frequent operation and versions in trench technology with very low on resistance $R_{DSon}$ for blocking voltages up to some 100V to 200V. If switching losses permit, IGBTs may be used instead, which will sometimes be the case for 600V and more frequently for 1200V devices. It should be taken into account that the inevitable tail current, occuring when an IGBT is turned off, may lead to switching losses although soft switching methods are applied; this effect depends on IGBT technology. BIMOSFET™ devices combine relatively low conduction losses with fast switching behaviour.

For rectification of low voltages on the secondary side of the transformer, being operated at high frequency, Schottky diodes or MOSFETs may be used. The formers are available up to a blocking voltage of some 180V. Devices whose operation is purely based on Schottky effect should be preferred for high frequencies because they exhibit no reverse recovery, which minimises switching losses. MOSFETs may be used instead for synchronous recticatation with even lower conduction losses. If rectified voltage is higher, the aforementioned FREDs are preferred choice. It may be advantageous to series connect them to achieve lower reverse recovery current peaks [8].

FREDs or Schottky diodes will additionally be used as free wheeling diodes in chopper or phase-leg circuits on the primary side of the transformer. In case that the intrinsic reverse diode of a MOSFET would serve as free wheeling current path, care must be taken that it is able to switch sufficiently fast.

### 3 Components for SMPS

The ISOPLUS i4™ components suggested for use in SMPS in the following are manufactured based on the technologies as described in the above section 2. This section gives a survey of their most important ratings and characteristics as some kind of commented excerpt of the respective data sheets.
3.1 Mains Rectifiers

Single and three phase rectifiers can be incorporated in an ISOPLUS i4™ component. Various types and their major ratings of blocking voltage $U_{RRM}$ and DC bridge output current $I_{DAVM90}$ or DC current per switch $I_{TAV90}$ respectively at an elevated case temperature of $T_C = 90 \, ^\circ\text{C}$ are listed in table 1; further a reference to the schematic indicating pinout in fig. 5 and the outline drawing figure 4 is included. Please note that the AC terminals are separated from the DC terminals which facilitates layout of printed circuit board. If required, a combination of thyristor phaselegs of FCC... type may be used to setup a controlled mains rectifier instead of the non controlled bridges of FBO... or FUO... type. FCC..., with terminals 2 and 3 shorted, by the way additionally constitutes a thyristorised AC controller.

The rectifiers in table 1 are intended for use with mains frequency. Further rectifiers suitable for higher operating frequency - or a superior EMC behaviour regarding low conducted emissions when connected to mains - are described in section 3.3.

Table 1: mains rectifiers

<table>
<thead>
<tr>
<th>type designation</th>
<th>circuit</th>
<th>blocking voltage</th>
<th>current capability</th>
<th>pinout/outline g.</th>
</tr>
</thead>
<tbody>
<tr>
<td>FBO16-12N</td>
<td>single phase mains rect</td>
<td>$U_{RRM} = 1200V$</td>
<td>$I_{DAVM90} = 22A$</td>
<td>5 (left)/4 (left)</td>
</tr>
<tr>
<td>FBO40-12N</td>
<td>single phase mains rect.</td>
<td>$U_{RRM} = 1200V$</td>
<td>$I_{DAVM90} = 40A$</td>
<td>5 (left)/4 (left)</td>
</tr>
<tr>
<td>FUO22-12N</td>
<td>three phase mains rect.</td>
<td>$U_{RRM} = 1200V$</td>
<td>$I_{DAVM90} = 27A$</td>
<td>5 (2nd left)/4 (left)</td>
</tr>
<tr>
<td>FCC21-12io</td>
<td>thyristor phaseleg</td>
<td>$U_{RRM} = 1200V$</td>
<td>$I_{TAV90} = 20A$</td>
<td>5 (right)/4 (left)</td>
</tr>
</tbody>
</table>

3.2 Single Transistors, Choppers and Phaselegs for High Frequency Inverters

Table 2 lists a variety of fast transistor switches in several configurations, sorted by blocking voltage. Indicated voltage and current ratings refer to each switch corresponding to the description in section 3.1, circuit and pinout are listed in the same way as above. The devices can be differently classified according to the considerations in section 2:

- classification by topology:
  - Single switches are the most simple circuit. Those devices make use of the feature, that ISOPLUS i4™ package can provide large strike and creepage distances. Please note that the gate and source or emitter terminals are close together, while the high voltage difference occurs between them and most far drain or collector terminal.
  - Choppers or phaselegs have a higher degree of integration. This is useful to increase power density. It further helps to minimise parasitic inductances in the commutation path $L_P$ as explained and thus contributes to a good operational behaviour. Again, pinout facilitates the layout of the printed circuit board: Pins assigned to each other - like the control terminals gate and source or emitter - are placed neighbouring each other.
  - Finally the topology of common source dual MOSFET is suitable for use either in high frequency inverter sections - see figure 2 (left) - or in synchronous rectifiers - see fig. 2 (right). Features of those devices correspond to choppers’ and phaselegs’.

- classification by chip technology:
  - There are several versions of MOSFETs: The low voltage device FMM150-0075P is a trench MOSFET, while the other types use planar MOSFET technology. Out of those, FMD21-05QC and FDM21-05QC are optimised for low gate charge.
  - Further, there are several versions of IGBTs for higher blocking voltages.
  - BIMOSFET™s reach comparable blocking voltages above the typical ratings of MOSFETs.
  - The free wheeling diodes of choppers or IGBT phaselegs are either FREDs or even consist of a series connection of two FREDs to optimise switching behaviour as depicted in the circuit diagrams figure 6.

Table 2: fast single switches, choppers and phaselegs, sorted by blocking voltage

<table>
<thead>
<tr>
<th>type designation</th>
<th>circuit</th>
<th>blocking voltage</th>
<th>current capability</th>
<th>pinout/outline g.</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMM150-0075P</td>
<td>trench MOSFET phaseleg</td>
<td>$U_{DSS} = 75V$</td>
<td>$I_{D90} = 120A$</td>
<td>6 (2nd right)/4 (left)</td>
</tr>
<tr>
<td>FMM75-01F</td>
<td>MOSFET phaseleg</td>
<td>$U_{DSS} = 100V$</td>
<td>$I_{D90} = 50A$</td>
<td>6 (2nd right)/4 (left)</td>
</tr>
<tr>
<td>FMD75-01F</td>
<td>common source MOSFETs</td>
<td>$U_{DSS} = 100V$</td>
<td>$I_{D90} = 50A$</td>
<td>6 (right)/4 (left)</td>
</tr>
<tr>
<td>FMD21-05QC</td>
<td>MOSFET boost chopper</td>
<td>$U_{DSS} = 500V$</td>
<td>$I_{D90} = 15A$</td>
<td>6 (2nd left)/4 (left)</td>
</tr>
<tr>
<td>FDM21-05QC</td>
<td>MOSFET buck chopper</td>
<td>$U_{DSS} = 500V$</td>
<td>$I_{D90} = 15A$</td>
<td>6 (3rd left)/4 (left)</td>
</tr>
<tr>
<td>FID35-06C</td>
<td>IGBT boost chopper</td>
<td>$U_{CES} = 600V$</td>
<td>$I_{C90} = 25A$</td>
<td>6 (left)/4 (left)</td>
</tr>
<tr>
<td>IXFF24N100</td>
<td>single MOSFET</td>
<td>$U_{CES} = 1000V$</td>
<td>$I_{C90} = 15A$</td>
<td>7 (right)/4 (center)</td>
</tr>
<tr>
<td>FII50-12E</td>
<td>IGBT phaseleg</td>
<td>$U_{CES} = 1200V$</td>
<td>$I_{C90} = 32A$</td>
<td>6 (3rd right)/4 (left)</td>
</tr>
<tr>
<td>IXBF9N160G</td>
<td>single BiMOSFET</td>
<td>$U_{CES} = 1600V$</td>
<td>$I_{C90} = 4A$</td>
<td>7 (left)/4 (center)</td>
</tr>
<tr>
<td>IXBF40N160</td>
<td>single BiMOSFET</td>
<td>$U_{CES} = 1600V$</td>
<td>$I_{C90} = 16A$</td>
<td>7 (left)/4 (center)</td>
</tr>
<tr>
<td>IXLF19N250A</td>
<td>single IGBT</td>
<td>$U_{CES} = 2500V$</td>
<td>$I_{C90} = 19A$</td>
<td>7 (left)/4 (center)</td>
</tr>
</tbody>
</table>
Table 3: high frequency output rectifiers, sorted by blocking voltage

<table>
<thead>
<tr>
<th>type designation</th>
<th>circuit</th>
<th>blocking voltage</th>
<th>current capability</th>
<th>pinout/outline.g.</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSS100-008A</td>
<td>dual Schottky</td>
<td>$U_{PRM} = 80V$</td>
<td>$I_{FADM90} = 90A$</td>
<td>5 (2nd right)/4 (right)</td>
</tr>
<tr>
<td>FBE22-06N1</td>
<td>FRED single phase rect.</td>
<td>$U_{PRM} = 600V$</td>
<td>$I_{DADM90} = 20A$</td>
<td>5 (left)/4 (left)</td>
</tr>
<tr>
<td>FUE30-12N1</td>
<td>FRED three phase rect.</td>
<td>$U_{PRM} = 1200V$</td>
<td>$I_{DADM90} = 30A$</td>
<td>5 (2nd left)/4 (left)</td>
</tr>
<tr>
<td>DSEE55-24N1F</td>
<td>dual FRED</td>
<td>$U_{PRM} = 1200V$</td>
<td>$I_{FADM90} = 55A$</td>
<td>5 (2nd right)/4 (right)</td>
</tr>
</tbody>
</table>

Figure 6: pinout of choppers and phaselegs

Figure 7: pinout of high voltage single switches

3.3 High Frequency Output Rectifiers

While the rectifiers described in section 3.1 are suitable for operation at mains frequency of typically 50Hz or 60Hz, switching behaviour of the devices under question in this section qualifies them for high frequency rectification, e.g. in secondary rectifiers of SMPS. The voltage ratings given in table 3 again refer to each switch, the DC current ratings $I_{DADM90}$ to the bridge or $I_{FADM90}$ to each diode at elevated case temperature of $T_C = 90 \, ^\circ C$. Pinouts and circuits of the single and three phase bridges of FBE... and FUE... type are the same as known from mains rectifiers; the dual diodes of FSS... and DSEE... type again provide large strike and creepage distances between the pins. This is particularly useful for high voltage DSEE... FRED which will be used for SMPS with high output voltages. FSS... Schottky diode instead is suitable for output rectification at low voltage levels. If synchronous rectification is preferred, a common source MOSFET as mentioned in section 3.2 would be suitable.

4 Conclusion

Chip and packaging technology of isolated power semiconductor components belonging to ISOPLUS i4™ series have been described. The resulting properties of those devices make them suitable for use in advanced designs of switched mode power supplies. All stages of conversion - input rectifier, optional power factor corrector, high frequency inverter and rectifier - can be equipped with matched types of devices. Their high degree of integration leads to high power density of the SMPS and low mounting cost, further enhanced operational behaviour and reliability can be achieved. Thus ISOPLUS i4™ components may contribute to an advantageous evolution of power supply technology.

References

[1] IEC61000-3-2
[2] IEC61000-3-4