## N-channel 650 V-1 $\Omega$-6.4 A TO-220 / TO-220FP Zener-protected SuperMESH ${ }^{\text {TM }}$ Power MOSFET

## Features

| Type | $\mathbf{V}_{\text {DSS }}$ | $\mathbf{R}_{\text {DS(on) }}$ | $\mathbf{I}_{\mathbf{D}}$ | Pw |
| :---: | :---: | :---: | :---: | :---: |
| STP9NK65ZFP | 650 V | $<1.2 \Omega$ | 6.4 A | 125 W |
| STP9NK65Z | 650 V | $<1.2 \Omega$ | 6.4 A | 30 W |

■ Extremely high dv/dt capability
■ $100 \%$ avalanche tested

- Gate charge minimized

■ Very low intrinsic capacitances

- Very good manufacturing repeatability


## Application

■ Switching applications

## Description

The SuperMESH ${ }^{\text {TM }}$ series is obtained through an extreme optimization of ST's well established strip-based PowerMESH ${ }^{\text {TM }}$ layout. In addition to pushing on-resistance significantly down, special care is taken to ensure a very good dv/dt capability for the most demanding applications. Such series complements ST full range of high voltage MOSFETs including revolutionary MDmesh ${ }^{\text {TM }}$ products.


Figure 1. Internal schematic diagram


Table 1. Device summary

| Order codes | Marking | Package | Packaging |
| :---: | :---: | :---: | :---: |
| STP9NK65ZFP | P9NK65ZFP | TO-220FP | Tube |
| STP9NK65Z | P9NK65Z | TO-220 | Tube |

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## Electrical ratings

Table 2. Absolute maximum ratings

| Symbol | Parameter | Value |  | Unit |
| :---: | :---: | :---: | :---: | :---: |
|  |  | TO-220 | TO-220FP |  |
| $\mathrm{V}_{\mathrm{DS}}$ | Drain-source voltage ( $\left.\mathrm{V}_{\mathrm{GS}}=0\right)$ | 650 |  | V |
| $\mathrm{V}_{\mathrm{GS}}$ | Gate- source voltage | $\pm 30$ |  | V |
| $\mathrm{I}_{\mathrm{D}}$ | Drain current (continuous) at $\mathrm{T}_{\mathrm{C}}=25^{\circ} \mathrm{C}$ | 6.4 | $6.4{ }^{(1)}$ | A |
| $\mathrm{I}_{\mathrm{D}}$ | Drain current (continuous) at $\mathrm{T}_{\mathrm{C}}=100^{\circ} \mathrm{C}$ | 4 | $4^{(1)}$ | A |
| $\mathrm{I}_{\mathrm{DM}}{ }^{(2)}$ | Drain current (pulsed) | 25.6 | $25.6{ }^{(1)}$ | A |
| $\mathrm{P}_{\text {TOT }}$ | Total dissipation at $\mathrm{T}_{\mathrm{C}}=25^{\circ} \mathrm{C}$ | 125 | 30 | W |
|  | Derating factor | 1 | 0.24 | W/ ${ }^{\circ} \mathrm{C}$ |
| $\mathrm{V}_{\text {ESD }(\mathrm{G}-\mathrm{S})}$ | Gate source ESD(HBM-C=100 pF, R=1.5 k 2 ) | 4000 |  | V |
| $\mathrm{dv} / \mathrm{dt}{ }^{(3)}$ | Peak diode recovery voltage slope | 4.5 |  | V/ns |
| $\mathrm{V}_{\text {ISO }}$ | Insulation withstand voltage (DC) | - | 2500 | V |
| $\begin{gathered} \mathrm{T}_{\mathrm{j}} \\ \mathrm{~T}_{\mathrm{stg}} \\ \hline \end{gathered}$ | Operating junction temperature Storage temperature | -55 to 150 |  | $\begin{aligned} & { }^{\circ} \mathrm{C} \\ & { }^{\circ} \mathrm{C} \end{aligned}$ |

1. Limited only by maximum temperature allowed
2. Pulse width limited by safe operating area
3. $\mathrm{I}_{\mathrm{SD}} \leq 6.4 \mathrm{~A}$, di/dt $\leq 200 \mathrm{~A} / \mu \mathrm{s}, \mathrm{V}_{\mathrm{DD}} \leq 80 \% \mathrm{~V}_{\text {(BR) }}$ DSS

## Table 3. Thermal data

| Symbol | Parameter | Value |  | Unit |
| :---: | :--- | :---: | :---: | :---: |
|  |  | TO-220 | TO-220FP |  |
| Rthj-case | Thermal resistance junction-case max | 1 | 4.2 | ${ }^{\circ} \mathrm{C} / \mathrm{W}$ |
| Rthj-amb | Thermal resistance junction-ambient max | 62.5 |  | ${ }^{\circ} \mathrm{C} / \mathrm{W}$ |
| $\mathrm{T}_{I}$ | Maximum lead temperature for soldering purpose | 300 |  | ${ }^{\circ} \mathrm{C}$ |

Table 4. Avalanche characteristics

| Symbol | Parameter | Value | Unit |
| :---: | :--- | :---: | :---: |
| $\mathrm{I}_{\mathrm{AR}}$ | Avalanche current, repetitive or not-repetitive <br> (pulse width limited by Tj Max) | 6.4 | A |
| $\mathrm{E}_{\mathrm{AS}}$ | Single pulse avalanche energy <br> (starting $\left.\mathrm{T}_{\mathrm{j}}=25^{\circ} \mathrm{C}, \mathrm{I}_{\mathrm{D}}=\mathrm{I}_{\mathrm{AR}}, \mathrm{V}_{\mathrm{DD}}=50 \mathrm{~V}\right)$ | 200 | mJ |

## 2 Electrical characteristics

( $\mathrm{T}_{\text {CASE }}=25^{\circ} \mathrm{C}$ unless otherwise specified)
Table 5. On/off states

| Symbol | Parameter | Test conditions | Min. | Typ. | Max. | Unit |
| :---: | :--- | :--- | :---: | :---: | :---: | :---: |
| $\mathrm{V}_{(\mathrm{BR}) \mathrm{DSS}}$ | Drain-source <br> breakdown voltage | $\mathrm{I}_{\mathrm{D}}=1 \mathrm{~mA}, \mathrm{~V}_{\mathrm{GS}}=0$ | 650 |  |  | V |
| $\mathrm{I}_{\mathrm{DSS}}$ | Zero gate voltage <br> drain current $\left(\mathrm{V}_{\mathrm{GS}}=0\right)$ | $\mathrm{V}_{\mathrm{DS}}=$ Max rating <br> $\mathrm{V}_{\mathrm{DS}}=$ Max rating, $@ 125^{\circ} \mathrm{C}$ |  |  | 1 | $\mu \mathrm{~A}$ |
| $\mathrm{I}_{\mathrm{GSS}}$ | Gate-body leakage <br> current $\left(\mathrm{V}_{\mathrm{DS}}=0\right)$ | $\mathrm{V}_{\mathrm{GS}}= \pm 20 \mathrm{~V}$ |  |  | $\pm 10$ | $\mu \mathrm{~A}$ |
| $\mathrm{~V}_{\mathrm{GS} \text { (th) }}$ | Gate threshold voltage | $\mathrm{V}_{\mathrm{DS}}=\mathrm{V}_{\mathrm{GS}}, \mathrm{I}_{\mathrm{D}}=100 \mu \mathrm{~A}$ | 3 | 3.75 | 4.5 | V |
| $\mathrm{R}_{\mathrm{DS} \text { (on) }}$ | Static drain-source on <br> resistance | $\mathrm{V}_{\mathrm{GS}}=10 \mathrm{~V}, \mathrm{I}_{\mathrm{D}}=3.2 \mathrm{~A}$ |  | 1 | 1.2 | $\Omega$ |

Table 6. Dynamic

| Symbol | Parameter | Test conditions | Min. | Typ. | Max. | Unit |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathrm{gfs}^{(1)}$ | Forward transconductance | $\mathrm{V}_{\mathrm{DS}}=15 \mathrm{~V}, \mathrm{I}_{\mathrm{D}}=3.2 \mathrm{~A}$ |  | 6 |  | S |
| $\begin{aligned} & \mathrm{C}_{\text {iss }} \\ & \mathrm{C}_{\mathrm{oss}} \\ & \mathrm{C}_{\mathrm{rss}} \end{aligned}$ | Input capacitance Output capacitance Reverse transfer capacitance | $\begin{aligned} & \mathrm{V}_{\mathrm{DS}}=25 \mathrm{~V}, \mathrm{f}=1 \mathrm{MHz}, \\ & \mathrm{~V}_{\mathrm{GS}}=0 \end{aligned}$ |  | $\begin{gathered} 1145 \\ 130 \\ 28 \end{gathered}$ |  | pF <br> pF <br> pF |
| $\mathrm{Cossseq}^{(2)}$. | Equivalent output capacitance | $\mathrm{V}_{\mathrm{GS}}=0, \mathrm{~V}_{\mathrm{DS}}=0$ to 400 V |  | 55 |  | pF |
| $\begin{aligned} & \mathrm{Q}_{\mathrm{g}} \\ & \mathrm{Q}_{\mathrm{gs}} \\ & \mathrm{Q}_{\mathrm{gd}} \end{aligned}$ | Total gate charge Gate-source charge Gate-drain charge | $\begin{aligned} & \mathrm{V}_{\mathrm{DD}}=520 \mathrm{~V}, \mathrm{I}_{\mathrm{D}}=6.4 \mathrm{~A}, \\ & \mathrm{~V}_{\mathrm{GS}}=10 \mathrm{~V} \\ & \text { (see Figure 18) } \end{aligned}$ |  | $\begin{gathered} 41 \\ 7.5 \\ 22 \end{gathered}$ |  | $\begin{aligned} & \mathrm{nC} \\ & \mathrm{nC} \\ & \mathrm{nC} \end{aligned}$ |

1. Pulsed: pulse duration $=300 \mu \mathrm{~s}$, duty cycle $1.5 \%$
2. $\mathrm{C}_{\text {oss eq. }}$ is defined as a constant equivalent capacitance giving the same charging time as $\mathrm{C}_{\text {oss }}$ when $\mathrm{V}_{\mathrm{DS}}$ increases from 0 to $80 \% V_{\text {DSS }}$

Table 7. Switching times

| Symbol | Parameter | Test conditions | Min. | Typ. | Max. | Unit |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\begin{gathered} \mathrm{t}_{\mathrm{d}(\mathrm{on})} \\ \mathrm{t}_{\mathrm{r}} \end{gathered}$ | Turn-on delay time Rise time | $\begin{aligned} & \mathrm{V}_{\mathrm{DD}}=325 \mathrm{~V}, \mathrm{I}_{\mathrm{D}}=3.2 \mathrm{~A} \\ & \mathrm{R}_{\mathrm{G}}=4.7 \Omega \mathrm{~V}_{\mathrm{GS}}=10 \mathrm{~V} \\ & \text { (see Figure 17) } \end{aligned}$ |  | $\begin{aligned} & 20 \\ & 12 \end{aligned}$ |  | $\begin{aligned} & \mathrm{ns} \\ & \mathrm{~ns} \end{aligned}$ |
| $\begin{aligned} & \mathrm{t}_{\mathrm{d}(\text { off })} \\ & \mathrm{t}_{\mathrm{f}} \end{aligned}$ | Turn-off delay time Fall time | $\begin{aligned} & \mathrm{V}_{\mathrm{DD}}=325 \mathrm{~V}, \mathrm{I}_{\mathrm{D}}=3.2 \mathrm{~A} \\ & \mathrm{R}_{\mathrm{G}}=4.7 \Omega \mathrm{~V}_{\mathrm{GS}}=10 \mathrm{~V} \\ & (\text { See Figure 17) } \end{aligned}$ |  | $\begin{aligned} & 45 \\ & 15 \end{aligned}$ |  | $\begin{aligned} & \mathrm{ns} \\ & \mathrm{~ns} \end{aligned}$ |

Table 8. Source drain diode

| Symbol | Parameter | Test conditions | Min. | Typ. | Max. | Unit |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\underset{\mathrm{I}_{\mathrm{SDM}}{ }^{(1)}}{\mathrm{I}_{\mathrm{SD}}}$ | Source-drain current <br> Source-drain current (pulsed) |  |  |  | $\begin{gathered} \hline 6.4 \\ 25.6 \end{gathered}$ | $\begin{aligned} & \mathrm{A} \\ & \mathrm{~A} \end{aligned}$ |
| $\mathrm{V}_{\mathrm{SD}}{ }^{(2)}$ | Forward on voltage | $\mathrm{I}_{\mathrm{SD}}=6.4 \mathrm{~A}, \mathrm{~V}_{\mathrm{GS}}=0$ |  |  | 1.6 | V |
| $\mathrm{t}_{\mathrm{rr}}$ <br> $Q_{r r}$ <br> $I_{\text {RRM }}$ | Reverse recovery time Reverse recovery charge Reverse recovery current | $\begin{aligned} & \mathrm{I}_{\mathrm{SD}}=6.4 \mathrm{~A}, \\ & \text { di/dt }=100 \mathrm{~A} / \mu \mathrm{s} \\ & \mathrm{~V}_{\mathrm{DD}}=50 \mathrm{~V}, \mathrm{~T}_{\mathrm{j}}=150^{\circ} \mathrm{C} \\ & \text { (see Figure 19) } \end{aligned}$ |  | $\begin{gathered} 400 \\ 2600 \\ 13 \end{gathered}$ |  | $\begin{gathered} \mathrm{ns} \\ \mathrm{nC} \\ \mathrm{~A} \end{gathered}$ |

1. Pulse width limited by safe operating area.
2. Pulsed: Pulse duration $=300 \mu \mathrm{~s}$, duty cycle $1.5 \%$

Table 9. Gate-source zener diode

| Symbol | Parameter | Test conditions | Min. | Typ. | Max. | Unit |
| :---: | :---: | :--- | :---: | :---: | :---: | :---: |
| BV $_{\text {GSO }^{(1)}}{ }^{(1)}$ | Gate-source breakdown voltage | Igs $= \pm 1 \mathrm{~mA}$ <br> (open drain) | 30 |  |  | V |

1. The built-in back-to-back Zener diodes have specifically been designed to enhance not only the device's ESD capability, but also to make them safely absorb possible voltage transients that may occasionally be applied from gate to source. In this respect the Zener voltage is appropriate to achieve an efficient and cost-effective intervention to protect the device's integrity. These integrated Zener diodes thus avoid the usage of external components.

### 2.1 Electrical characteristics (curves)

Figure 2. Safe operating area for TO-220


Figure 4. Safe operating area for TO-220FP

Figure 3. Thermal impedance for TO-220


Figure 5. Thermal impedance for TO-220FP


Figure 6. Output characteristics


Figure 7. Transfer characteristics


Figure 8. Transconductance
Figure 9. Static drain-source on resistance


Figure 10. Gate charge vs gate-source voltage Figure 11. Capacitance variations


Figure 12. Normalized gate threshold voltage vs temperature


Figure 13. Normalized on resistance vs temperature


Figure 14. Source-drain diode forward characteristics


Figure 15. Normalized $\mathrm{BV}_{\text {DSS }}$ vs temperature


Figure 16. Maximum avalanche energy vs temperature


## 3 Test circuits

Figure 17. Switching times test circuit for resistive load

Figure 18. Gate charge test circuit


Figure 19. Test circuit for inductive load switching and diode recovery times


Figure 21. Unclamped inductive waveform

Figure 20. Unclamped Inductive load test circuit


Figure 22. Switching time waveform

|  |  |
| :---: | :---: |
|  |  |

## 4 Package mechanical data

In order to meet environmental requirements, ST offers these devices in ECOPACK® packages. These packages have a Lead-free second level interconnect. The category of second level interconnect is marked on the package and on the inner box label, in compliance with JEDEC Standard JESD97. The maximum ratings related to soldering conditions are also marked on the inner box label. ECOPACK is an ST trademark. ECOPACK specifications are available at: www.st.com

| Dim | mm |  |  | inch |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Min | Typ | Max | Min | Typ | Max |
| A | 4.40 |  | 4.60 | 0.173 |  | 0.181 |
| b | 0.61 |  | 0.88 | 0.024 |  | 0.034 |
| b1 | 1.14 |  | 1.70 | 0.044 |  | 0.066 |
| c | 0.49 |  | 0.70 | 0.019 |  | 0.027 |
| D | 15.25 |  | 15.75 | 0.6 |  | 0.62 |
| D1 |  | 1.27 |  |  | 0.050 |  |
| E | 10 |  | 10.40 | 0.393 |  | 0.409 |
| e | 2.40 |  | 2.70 | 0.094 |  | 0.106 |
| e1 | 4.95 |  | 5.15 | 0.194 |  | 0.202 |
| F | 1.23 |  | 1.32 | 0.048 |  | 0.256 |
| H1 | 6.20 |  | 6.60 | 0.244 |  | 0.107 |
| J1 | 2.40 |  | 2.72 | 0.094 |  | 0.154 |
| L1 | 13 |  | 14 | 0.511 |  |  |
| L20 | 3.50 |  | 3.93 | 0.137 |  | 0.645 |
| L30 |  | 16.40 |  |  | 1.137 |  |
| $\varnothing P$ |  | 28.90 |  |  |  | 0.116 |
| Q | 3.75 |  | 3.85 | 0.147 |  |  |



POA OO15988_P

## TO-220FP MECHANICAL DATA

| DIM. | mm. |  |  | inch |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | MIN. | TYP | MAX. | MIN. | TYP. | MAX. |
| A | 4.4 |  | 4.6 | 0.173 |  | 0.181 |
| B | 2.5 |  | 2.7 | 0.098 |  | 0.106 |
| D | 2.5 |  | 2.75 | 0.098 |  | 0.108 |
| E | 0.45 |  | 0.7 | 0.017 |  | 0.027 |
| F | 0.75 |  | 1 | 0.030 |  | 0.039 |
| F1 | 1.15 |  | 1.7 | 0.045 |  | 0.067 |
| F2 | 1.15 |  | 1.7 | 0.045 |  | 0.067 |
| G | 4.95 |  | 5.2 | 0.195 |  | 0.204 |
| G1 | 2.4 |  | 2.7 | 0.094 |  | 0.106 |
| H | 10 |  | 10.4 | 0.393 |  | 0.409 |
| L2 |  |  | 30.6 | 1.126 |  | 0.204 |
| L3 | 28.6 |  | 10.6 | .0385 |  | 0.417 |
| L4 | 9.8 |  | 3.6 | 0.114 |  | 0.141 |
| L5 | 2.9 |  | 16.4 | 0.626 |  | 0.645 |
| L6 | 15.9 |  | 9.3 | 0.354 |  | 0.366 |
| L7 | 9 |  | 3.2 | 0.118 |  | 0.126 |
| $\varnothing$ | 3 |  |  |  |  |  |



TO-220FP(040Y) MECHANICAL DATA

| DIM. | mm. |  |  | inch |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | MIN. | TYP | MAX. | MIN. | TYP. | MAX. |
| A | 4.4 |  | 4.6 | 0.173 |  | 0.181 |
| B | 2.5 |  | 2.7 | 0.009 |  | 0.106 |
| C | 1 |  | 1.4 | 0.039 |  | 0.055 |
| D | 2.4 |  | 2.75 | 0.094 |  | 0.108 |
| E | 0.4 |  | 0.7 | 0.015 |  | 0.027 |
| F | 0.75 |  | 1 | 0.029 |  | 0.039 |
| F1 | 1.15 |  | 1.7 | 0.045 |  | 0.215 |
| G | 4.68 |  | 5.48 | 0.184 |  | 0.111 |
| G1 | 2.24 |  | 2.84 | 0.088 |  | 0.409 |
| H | 10 |  | 10.4 | 0.393 |  | 0.755 |
| L1 | 18.4 |  |  | 16.2 | 0.724 |  |
| L2 |  |  |  |  | 0.629 | 0.633 |
| L4 | 15.3 |  |  | 16.4 | 0.625 |  |
| L5 |  |  | 9.4 | 0.354 |  | 0.665 |
| L6 | 15.9 |  |  | 53.6 | 0.885 |  |
| L7 | 9 |  | 5.4 | 0.181 |  | 0.362 |
| L8 | 22.5 |  | 3.29 | 0.090 |  | 0.129 |
| M | 4.6 |  |  |  | 0.019 |  |
| N | 2.29 |  |  |  |  |  |
| Dia | 3 |  |  |  |  |  |
| R | 0.5 |  |  |  |  |  |

(

## 5 Revision history

Table 10. Document revision history

| Date | Revision | Changes |
| :---: | :---: | :--- |
| $11-$ Sep-2006 | 2 | Complete version |
| $19-$ Dec-2007 | 3 | The document has been reformatted |

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