

## **IGBT for Voltage-Resonant Inverters: GT20N135SRA**

### **Application Note**

#### **Outline:**

Inverter systems with a resonant circuit are widely used for household cooking appliances, including IH rice cookers, tabletop IH cookers, and inverter microwave ovens. These inverter systems are roughly classified into voltage-resonant circuits in which a heating coil and a capacitor are connected in parallel and current-resonant circuits in which they are connected in series, and IGBTs are commonly used as switching devices for both applications.

In October 2019, Toshiba Electronic Devices & Storage began the production of the GT20N135SRA, a 20 A/1350 V IGBT for voltage resonance. We will continue to expand our product portfolio with IGBTs having different current and voltage ratings.

This application note discusses resonant circuits and induction heating and describes the features of the GT20N135SRA compared with those of its current product the GT40RR21.

**This application note is intended merely as a reference. Do not design a final system based on the contents herein.**

**The information contained herein is presented only as guidance for Product use. No responsibility is assumed by TOSHIBA for any infringement of patents or any other intellectual property rights of third parties that may result from the use of Product. No license to any intellectual property right is granted by this document, whether express or implied, by estoppel or otherwise.**

### Table of Contents

|                                                                             |    |
|-----------------------------------------------------------------------------|----|
| Outline: .....                                                              | 1  |
| Table of Contents .....                                                     | 2  |
| 1. Resonant circuits .....                                                  | 4  |
| 1.1. Voltage resonance .....                                                | 4  |
| 1.2. Current resonance .....                                                | 5  |
| 1.3. Induction heating .....                                                | 6  |
| 2. IGBTs for soft-switching applications .....                              | 7  |
| 3. Features of the GT20N135SRA, an IGBT for 220 VAC voltage resonance ..... | 9  |
| 3.1. Reduced collector saturation current.....                              | 9  |
| 3.2. Wide forward-biased safe operating area (FBSOA) .....                  | 10 |
| 3.3. Reduced thermal resistance.....                                        | 11 |
| 3.4. Improved forward characteristics of the body diode.....                | 12 |
| 3.5. Reduced radiated emissions .....                                       | 13 |
| 4. Conclusion.....                                                          | 14 |
| RESTRICTIONS ON PRODUCT USE.....                                            | 15 |

### List of Figures

|                                                                                                              |    |
|--------------------------------------------------------------------------------------------------------------|----|
| Figure 1.1 IGBT application circuit example: Voltage-resonant circuit.....                                   | 4  |
| Figure 1.2 Waveforms of the voltage-resonant circuit.....                                                    | 4  |
| Figure 1.3 Operations of the voltage-resonant circuit .....                                                  | 4  |
| Figure 1.4 IGBT application circuit example: Current-resonant circuit.....                                   | 5  |
| Figure 1.5 Waveforms of the current-resonant circuit .....                                                   | 6  |
| Figure 1.6 Operations of the current-resonant circuit.....                                                   | 6  |
| Figure 1.7 Principle of induction heating .....                                                              | 7  |
| Figure 2.1 Evolution of IGBTs for soft-switching applications .....                                          | 8  |
| Figure 3.1 Comparison of the forward characteristics of the GT20N135SRA and GT40RR21 .....                   | 10 |
| Figure 3.2 Test circuit for emulating inrush current and test results.....                                   | 10 |
| Figure 3.3 Comparison of the safe operating areas of the GT20N135SRA and GT40RR21 .....                      | 11 |
| Figure 3.4 Comparison of the transient thermal resistance of the GT20N135SRA and GT40RR21 .....              | 12 |
| Figure 3.5 Structure of an RC-IGBT and its body diode .....                                                  | 12 |
| Figure 3.6 Comparison of the forward characteristics of the body diode in the GT20N135SRA and GT40RR21 ..... | 13 |
| Figure 3.7 Comparison of the EMI noise of the GT20N135SRA and GT40RR21 (tabletop IH cooker) .....            | 13 |

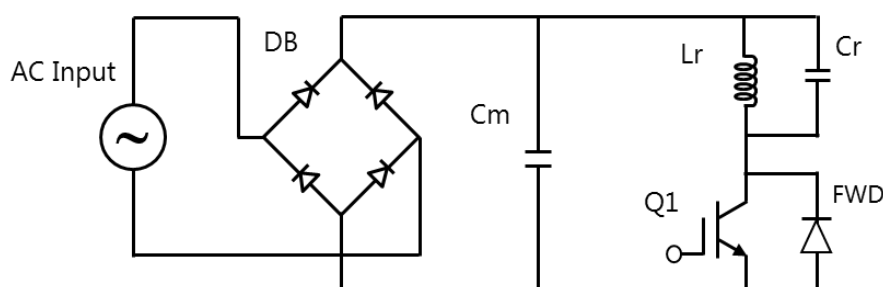
### List of Tables

|                                                                                      |    |
|--------------------------------------------------------------------------------------|----|
| Table 2.1 Lineup of discrete IGBTs for soft-switching applications .....             | 9  |
| Table 3.1 Comparison of the thermal resistance of the GT20N135SRA and GT40RR21 ..... | 11 |

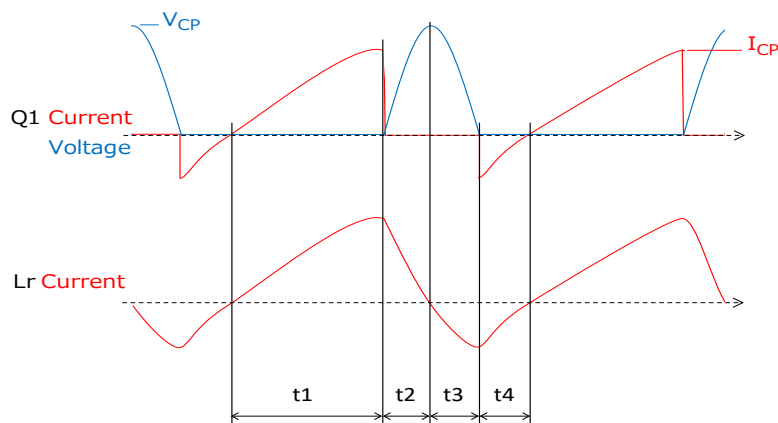
## 1. Resonant circuits

### 1.1. Voltage resonance

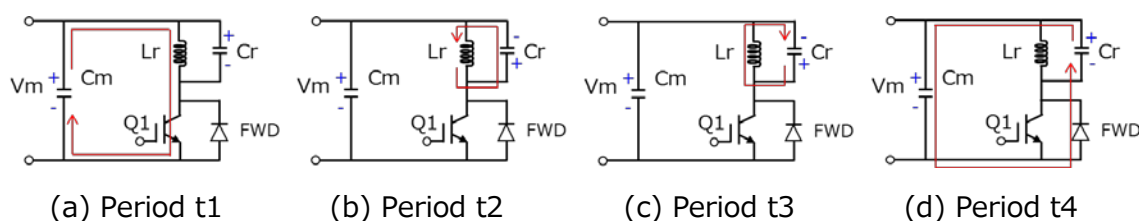
A voltage-resonant circuit is composed of a switching IGBT, a freewheeling diode (FWD), and a parallel LC circuit. It is widely used for IH rice cookers, tabletop IH cookers, inverter microwave ovens, and other applications. Figure 1.1 shows a typical voltage-resonant circuit. In this circuit, an AC input passes through a diode bridge (DB) for full-wave rectification before charging a capacitor ( $C_m$ ). The charged capacitor acts as a source of voltage for a parallel LC circuit consisting of a resonance coil ( $L_r$ ) and a resonance capacitor ( $C_r$ ) as well as for a switching IGBT ( $Q_1$ ) and an FWD. Figure 1.2 shows the voltage and current waveforms applied to  $Q_1$  and the waveform of the current flowing through  $L_r$ . Figure 1.3 shows the circuit operations during periods  $t_1$ ,  $t_2$ ,  $t_3$ , and  $t_4$ .



**Figure 1.1 IGBT application circuit example: Voltage-resonant circuit**



**Figure 1.2 Waveforms of the voltage-resonant circuit**



**Figure 1.3 Operations of the voltage-resonant circuit**

- (a) Q1 turns on, causing current to flow through the closed loop  $C_m(+)-L_r-Q1-C_m(-)$  while increasing linearly:

$$I_{CP} = (V_m / L_r) \cdot t_1$$

During period  $t_1$ , the voltage across  $C_r$  ( $V_{Cr}$ ) is clamped at  $V_m$  (Figure 1.3(a)).

- (b) Q1 turns off, causing  $L_r$  and  $C_r$  to go into resonance. The peak resonance voltage ( $V_{CrP}$ ) is calculated as:

$$V_{CrP} = V_m \cdot t_1 / \sqrt{L_r \cdot C_r}$$

Hence,  $V_{CrP}$  increases in proportion to  $t_1$ , i.e.,  $I_{CP}$ . At this time,  $V_{CP}$  ( $= V_{CrP} + V_m$ ) is applied across Q1 (Figure 1.3(b)).

- (c) The direction of the resonance current generated by the LC circuit ( $L_r$  and  $C_r$ ) reverses, causing the voltage across  $C_r$  to decrease (Figure 1.3(c)).

- (d) The voltage polarity of  $C_r$  reverses. When the voltage across  $C_r$  exceeds  $V_m$ , current begins to flow through  $C_r-C_m-FWD-C_r$  (Figure 1.3(d)).

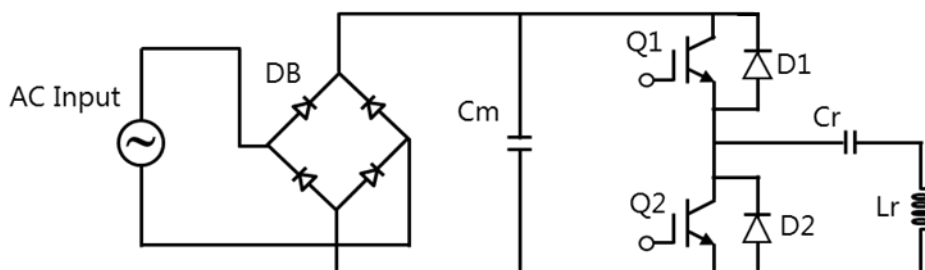
The above steps are repeated.

In the case of voltage resonance, the peak resonance voltage ( $V_{CrP}$ ) is much higher than the peak input AC voltage. Therefore, an IGBT with a  $V_{CES}$  rating of 900 to 1200 V is used when the AC input is 100 VAC whereas an IGBT with a  $V_{CES}$  rating of 1350 to 1800 V is used when the AC input is 220 VAC.

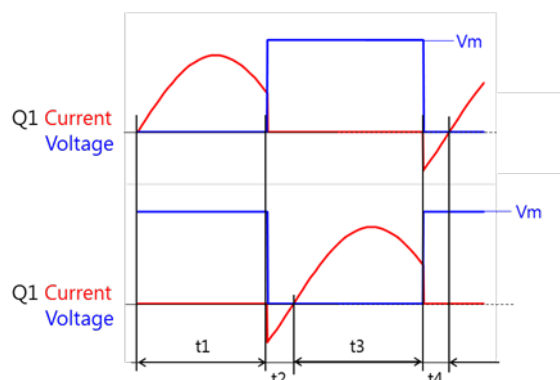
(An IGBT with sufficient voltage rating should be selected according to a margin relative to the applied voltage.)

### 1.2. Current resonance

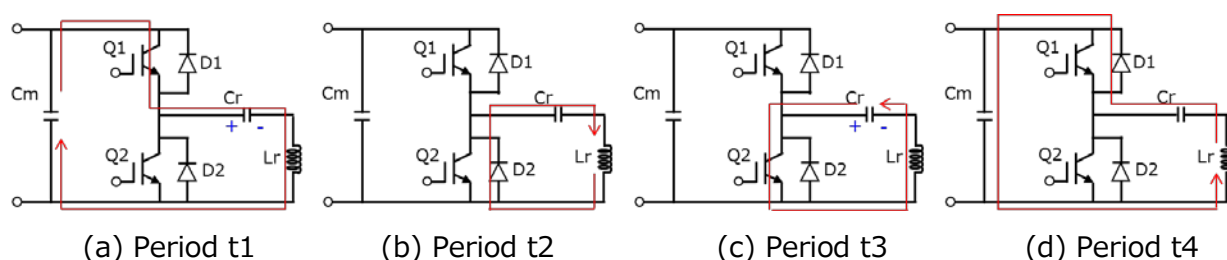
A current-resonant circuit is a series LC or LCR circuit with a half bridge consisting of two switching IGBTs. Figure 1.4 shows a typical current-resonant circuit. In household cooking appliances, the heating coil ( $L_r$ ) is magnetically coupled with a load ( $R$ ). Therefore, a series LCR resonant circuit is equivalently formed. Figure 1.5 shows typical voltage and current waveforms applied to each IGBT. Figure 1.6 shows the circuit operations during period's  $t_1$ ,  $t_2$ ,  $t_3$ , and  $t_4$ .



**Figure 1.4 IGBT application circuit example: Current-resonant circuit**



**Figure 1.5 Waveforms of the current-resonant circuit**



**Figure 1.6 Operations of the current-resonant circuit**

- When Q1 turns on, a resonance current ( $L_r \cdot C_r$ ) flows through the closed loop  $C_m(+)-Q1-Cr-Lr-Cm(-)$ , charging Cr (Figure 1.6(a)).
- After Q1 turns off, Cr is charged by current flowing through  $Lr-D2-Cr-Lr$  (Figure 1.6(b)).
- Q2 turns on, with the collector-emitter voltage clamped at roughly -1 V (i.e.,  $V_F$  of D2). This is called zero-voltage switching (ZVS). Therefore, a resonance current flows through the closed loop  $Cr(+)-Q2-Lr-Cr(-)$  (Figure 1.6(c)).
- When Q2 turns off, a freewheeling current flows through  $Lr-Cr-D1-Cm-Lr$ , causing the collector-emitter voltage of Q1 to be clamped at roughly -1 V (i.e.,  $V_F$  of D1). This leads to the next zero-voltage switching of Q1 (Figure 1.6(d)).

The above steps are repeated.

In the case of current resonance, the voltage applied to the switching IGBTs is equal to the sum of the peak input AC voltage and the spike voltage that appears during the turn-off of the switching IGBTs. Therefore, IGBTs with a  $V_{CES}$  rating of 600 to 650 V are used when the AC input is 220 VAC.

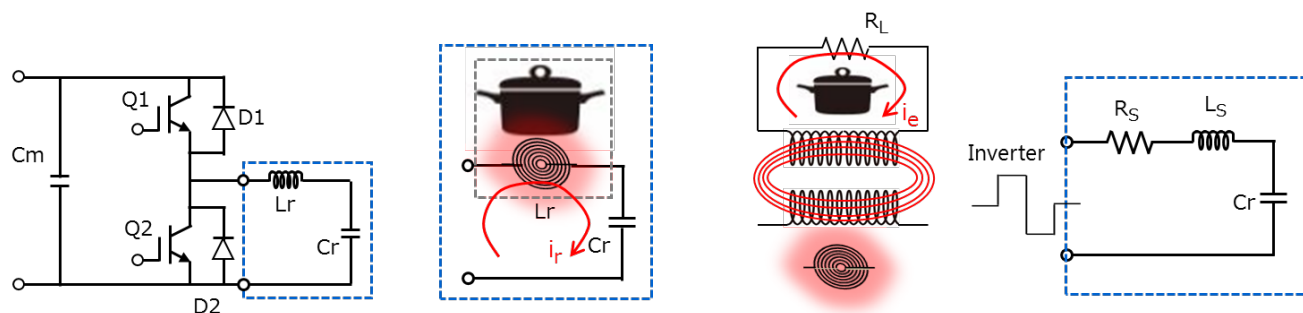
(In the case of household cooking appliances, current resonance is commonly used for applications that need to control higher electric power than voltage resonance applications or require high-frequency switching. Therefore, there are not many current resonance applications with an input of 100 VAC.)

### 1.3. Induction heating

IH rice cookers and tabletop IH cookers use induction heating to convert electricity into heat.

Figure 1.7 illustrates the principle of induction heating. Figure 1.7(a) shows a current-resonant circuit using an IGBT pair. Figure 1.7(b) illustrates a heating coil ( $L_r$ ) and a pot heated by the current flowing through  $L_r$ . Figure 1.7(c) shows that when current flows through a heating coil, a magnetic field is formed around the coil. The alternating magnetic field generates electric currents inside the pot called eddy currents ( $i_e$ ), which produce Joule heat ( $i_e^2 \cdot R_L$ ) because of the surface resistance of the pot.

Therefore, the resonant circuit of Figure 1.7(a) can be considered equivalent to the LCR resonant circuit consisting of  $L_s$ ,  $C_r$ , and  $R_s$  that operates from an output from an inverter circuit (AC) (Figure 1.7(d)). ( $L_s$  and  $R_s$  are equivalent inductance and resistance as seen from the heating coil, respectively.)



(a) Current-resonant circuit

(b) Heating coil and pot

(c) Eddy currents in a pot

(d) Equivalent circuit for resonant circuit

**Figure 1.7 Principle of induction heating**

The equivalent resistance ( $R_s$ ) depends on the material of the pot. Magnetic substances such as iron and magnetic stainless steel have high  $R_s$  whereas non-magnetic substances such as aluminum and copper have low  $R_s$ .  $R_s$  increases as frequency increases. Therefore, when a non-magnetic pot is used as a load, it is necessary to increase frequency in order to increase  $R_s$  and thereby the amount of Joule heat generated.

In induction cooking appliances for magnetic cookware (iron and magnetic stainless steel), the resonant frequency is generally set to 20 to 30 kHz for both voltage and current resonance. Many all-metal models that also work with non-magnetic cookware (aluminum and copper) use a current-resonant circuit with a resonant frequency of 80 to 100 kHz.

## 2. IGBTs for soft-switching applications

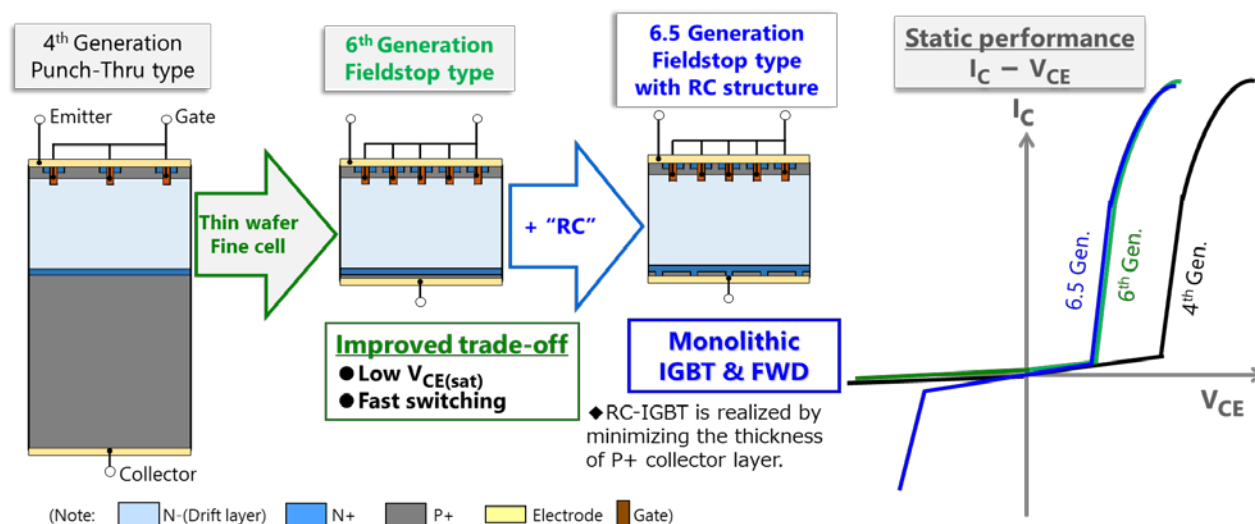
Toshiba Electronic Devices & Storage has continually improved the performance of IGBTs for soft-switching applications that are used for voltage and current resonance.

The 4<sup>th</sup> and earlier generations of our IGBTs were manufactured with punch-through (PT) technology using thick wafers. The 5<sup>th</sup> and 6<sup>th</sup> generations are also PT IGBTs, but are fabricated using thin wafers to achieve better forward and switching characteristics. At present, the 6<sup>th</sup> generation is the mainstay product. (IGBTs with a thin PT structure are called field stop (FS) IGBTs.)

Since field stop IGBTs have a very thin P collector layer (called a transparent P collector

layer), an N layer can easily be formed in the collector layer. Leveraging this characteristic, we have also developed reverse-conducting IGBTs (RC-IGBTs), which are now available for mass production.

Figure 2.1 shows the structures of different generations of IGBTs and their typical static characteristics.



**Figure 2.1 Evolution of IGBTs for soft-switching applications**

The new additions to our product portfolio include 1350 V and 1100 V RC-IGBTs for voltage resonance fabricated using the newly designed 6.5 generation process that provides various features (highlighted in red in Table 2.1). In October 2019, we began the production of the GT20N135SRA, a 20 A / 1350 V RC-IGBT for medium-power applications with an input of 220 VAC. We will also develop high-current RC-IGBTs and 1100 V RC-IGBTs for voltage resonance suitable for 100 VAC applications.

Toshiba Electronic Devices & Storage is manufacturing and developing IGBTs for various soft-switching applications, as shown in Table 2.1.

Accompanying the release of the GT20N135SRA, we have modified the part naming conventions for IGBTs to make it easier to grasp their ratings, packages, and applications. Major changes are as follows:

1. Current rating: Indicates DC collector current at 100°C (Previously, the part number mainly indicated DC collector current at room temperature.)
2. Package: Indicates package type using an alphabetical letter (N: TO-247) (Previously, the part number did not contain any character that indicates a package type.)
3. Voltage rating: Indicates one-tenth of the rated voltage (135  $\Rightarrow$  1350 V) (Previously, an alphabetic notation was used.)
4. Other: Indicates applications, an internal structure, and a process generation (SRA: RC-IGBT for soft-switching applications, 6.5 generation)



Table 2.1 Lineup of discrete IGBTs for soft-switching applications

| V <sub>CES</sub> | IGBTs for 100 VAC voltage resonance |                            |                          | IGBTs for 220 VAC voltage resonance |                            |                          | IGBTs for current resonance                  |
|------------------|-------------------------------------|----------------------------|--------------------------|-------------------------------------|----------------------------|--------------------------|----------------------------------------------|
|                  | Small Capacity (≤ 1100 W)           | Medium Capacity (≤ 1250 W) | High Capacity (≤ 1400 W) | Small Capacity (≤ 1900 W)           | Medium Capacity (≤ 2200 W) | High Capacity (≤ 2400 W) |                                              |
| 600 V            |                                     |                            |                          |                                     |                            |                          | GT40J322<br>GT50J341<br>GT50JR21<br>GT50JR22 |
| 900 V            | GT50MR21                            |                            |                          |                                     |                            |                          |                                              |
| 1000 V           |                                     | GT50N322A                  | GT50N324                 |                                     |                            |                          |                                              |
| 1050 V           | GT50NR21                            |                            |                          |                                     |                            |                          |                                              |
| 1100 V           |                                     | GT60PR21<br>S1PA6(*)       | S1PA7(*)                 |                                     |                            |                          |                                              |
| 1200 V           | GT40QR21                            |                            |                          | GT40QR21                            |                            |                          |                                              |
| 1350 V           |                                     |                            |                          | GT40RR21                            | GT20N135SRA                | S1PA5(*)                 |                                              |
| 1800 V           |                                     |                            |                          | GT40WR21                            |                            |                          |                                              |

(Black: 4<sup>th</sup> Gen., Green: 6<sup>th</sup> Gen., Blue: 6.5 Gen., Red: Under development or new)

(\*: S1PA\* is a prototype name being used at the development stage. It will be replaced by a formal part number when the device becomes available for mass production.)

### 3. Features of the GT20N135SRA, an IGBT for 220 VAC voltage resonance

The newly developed 20 A/1350 V GT20N135SRA provides various advantages over the previous equivalent device, the GT40RR21, and is easier to use for 220 VAC voltage resonance applications. (The new part naming scheme indicates the rated DC collector current at 100 °C.) The following subsections describe the advantages of the GT20N135SRA in comparison with the GT40RR21.

#### 3.1. Reduced collector saturation current

In the voltage-resonant circuit shown in Figure 1.1, the voltages across C<sub>m</sub> and C<sub>r</sub> are usually equal when Q1 turns on. The turn-on current (i<sub>c</sub>) of Q1 is expressed as  $i_c = (V_m/L_r) \cdot t$ , which increases linearly over time (t) after turn-on. Therefore, large turn-on current does not flow to Q1. (V<sub>m</sub>: Voltage charged across C<sub>m</sub>)

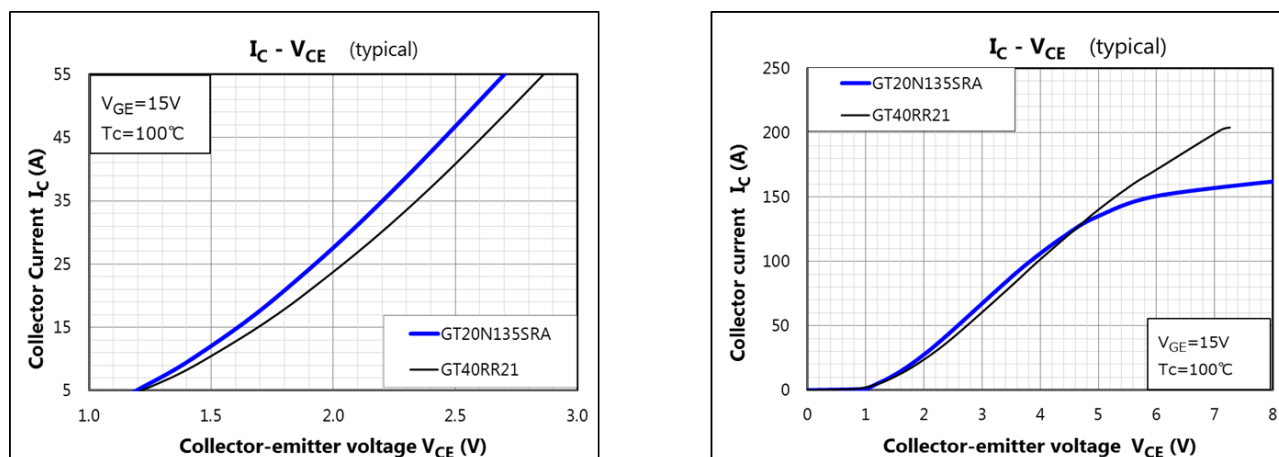
However, if Q1 turns on when the charged voltage of C<sub>r</sub> is lower than that of C<sub>m</sub> (e.g., at system power-on), a short-circuit current flows through C<sub>m</sub>(+)–C<sub>r</sub>–Q1–C<sub>m</sub>(-). This current can be reduced in two ways: 1) using a circuit control technique called soft start and 2) reducing the current-carrying capability of the switching device used.

As shown in Figure 3.1(a), the GT20N135SRA exhibits lower collector-emitter voltage (V<sub>CE</sub>) than the GT40RR21 in the current region in which they are typically used (i.e., the load current region) and therefore causes less conduction loss. In addition, the collector saturation current (I<sub>C(sat)</sub>) of the GT20N135SRA is as low as roughly 150 A at 100°C as shown in Figure 3.1(b).

This helps reduce short-circuit current. Figure 3.2(b) and Figure 3.2(c) show the test results.

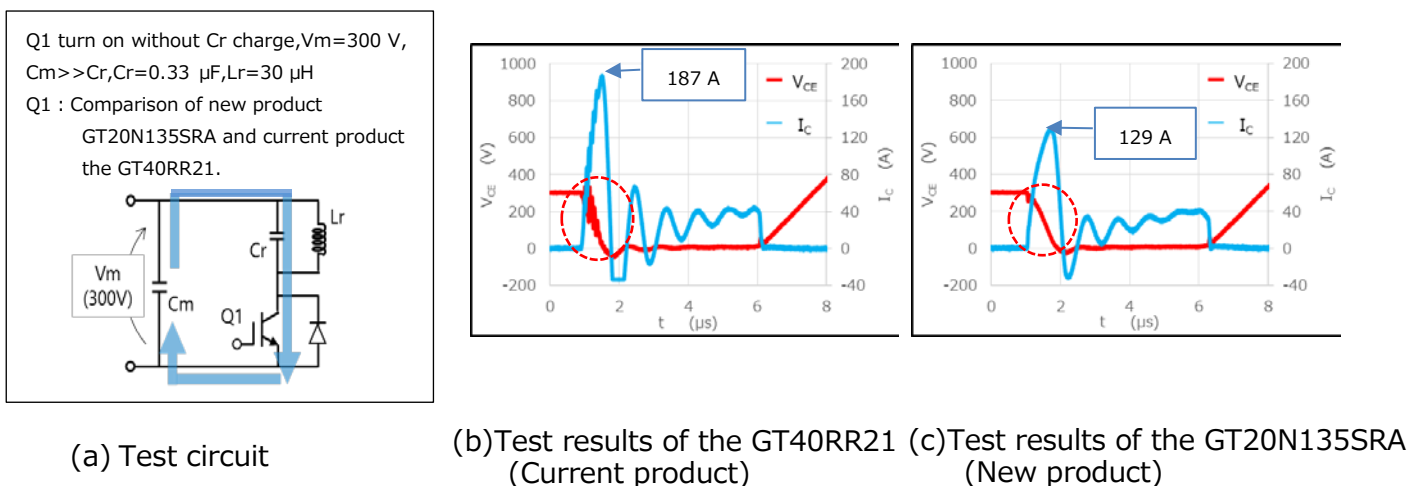
As can be seen from these figures, the GT20N135SRA helps reduce short-circuit current at power-on because of the reduced collector saturation current ( $I_{C(sat)}$ ) (129 A as against 187 A of the GT40RR21). IGBTs are susceptible to oscillation in the short-circuit state. The GT40RR21 exhibits this tendency as highlighted by the dashed red circle in Figure 3.2(b). In contrast, the GT20N135SRA helps suppress oscillation as indicated by the dashed red circle in Figure 3.2(c).

In addition, the non-repetitive peak collector current ( $I_{CSM}$ ), which provides a measure of short-circuit current at power-on, is rated at 220 A ( $t < 3 \mu s$ ).



(a) Forward voltage drop in the load current region (b) Collector saturation current characteristics

**Figure 3.1 Comparison of the forward characteristics of the GT20N135SRA and GT40RR21**



(a) Test circuit

(b) Test results of the GT40RR21  
(Current product)

(c) Test results of the GT20N135SRA  
(New product)

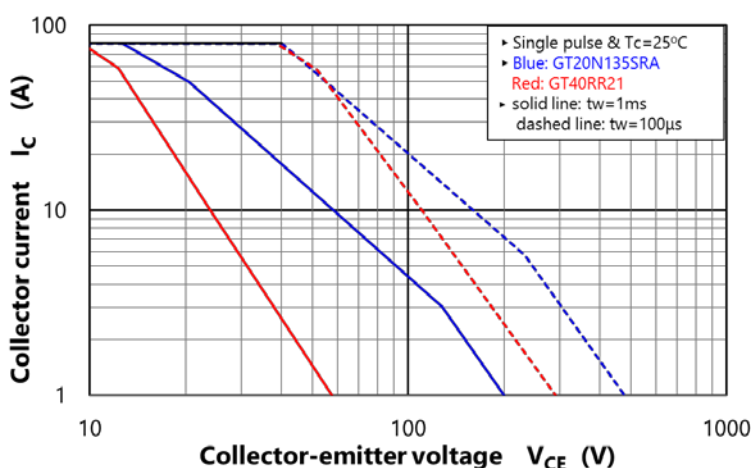
**Figure 3.2 Test circuit for emulating inrush current and test results**

### 3.2. Wide forward-biased safe operating area (FBSOA)

Although the GT20N135SRA and GT40RR21 have almost the same pellet size, the GT20N135SRA provides a much wider safe operating area because of the optimized pellet design (e.g., layout and longitudinal design). Figure 3.3 shows the guaranteed forward-biased safe operating areas (FBSOAs) of these IGBTs at pulse widths of 1 ms and 100  $\mu s$ .

As the collector-emitter voltage ( $V_{CE}$ ) increases, the difference in the maximum permissible collector current between the two devices increases. The FBSOA plots indicate that, at voltage higher than 100 V, the GT20N135SRA tolerates more than double the collector current

compared with the GT40RR21.



**Figure 3.3 Comparison of the safe operating areas of the GT20N135SRA and GT40RR21**

### 3.3. Reduced thermal resistance

As described above, the GT20N135SRA provides a wider FBSOA than the GT40RR21 because of the optimized pellet design. In addition, the GT20N135SRA exhibits an improvement in thermal resistance characteristics. Table 3.1 shows the junction-case thermal resistance ( $R_{th(j-c)}$ ) of these IGBTs, and Figure 3.4 shows their transient junction-case thermal impedance ( $r_{th(j-c)}$ ) curves.

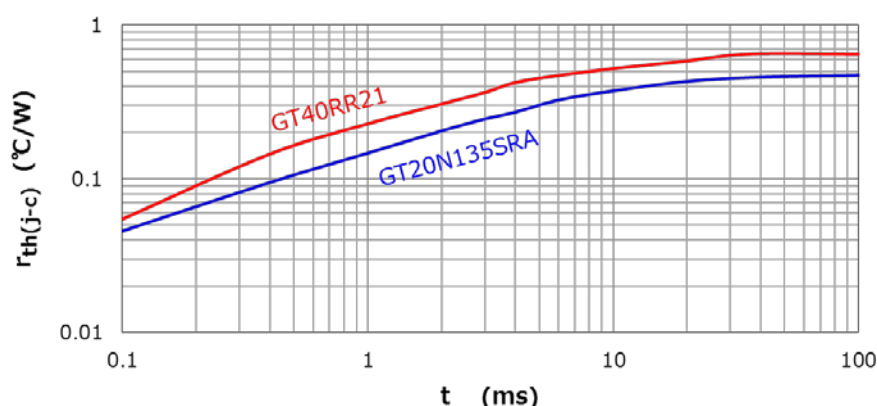
The GT20N135SRA provides a thermal resistance 0.17 °C/W lower than the GT40RR21 and 25 to 30% lower transient thermal resistance in the time region between 0.1 and 100 ms.

Therefore, the junction temperature ( $T_j$ ) of the GT20N135SRA rises less than that of the GT40RR21 under the same power dissipation and heat dissipation conditions.

Suppose, for example, these IGBTs dissipate an average of 35 W when incorporated in tabletop IH cookers. Then, the difference between the junction and case temperatures ( $\Delta T_{j(c)}$ ) for the GT20N135SRA is roughly 6 °C less than that for the GT40RR21. Therefore, the GT20N135SRA provides more flexibility in thermal design. (There will be a greater difference when a transient temperature rise at peak power is taken into consideration.)

**Table 3.1 Comparison of the thermal resistance of the GT20N135SRA and GT40RR21**

| Part Number | Thermal Resistance, $R_{th(j-c)}$<br>max |
|-------------|------------------------------------------|
| GT20N135SRA | <b>0.48 °C/W</b>                         |
| GT40RR21    | <b>0.65 °C/W</b>                         |

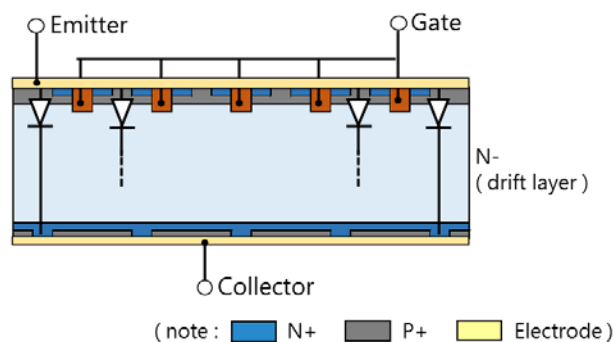


**Figure 3.4 Comparison of the transient thermal resistance of the GT20N135SRA and GT40RR21**

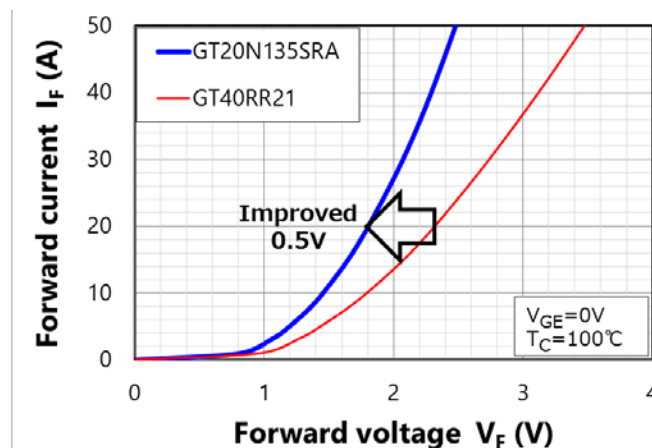
### 3.4. Improved forward characteristics of the body diode

Figure 3.5 illustrates the structure of the RC-IGBT used in the GT20N135SRA. In the RC-IGBT, a body diode is formed in the N layer in the transparent P collector layer. The forward characteristics of the body diode vary greatly, depending on the location of the N layer of the collector electrode, its area, and other factors.

In the GT20N135SRA, the design of the N layer is optimized to reduce the forward voltage drop ( $V_F$ ) of the body diode. Therefore, the GT20N135SRA provides considerably lower  $V_F$  than the GT40RR21, as shown in Figure 3.6 (0.5 V lower at an  $I_F = 20$  A).



**Figure 3.5 Structure of an RC-IGBT and its body diode**



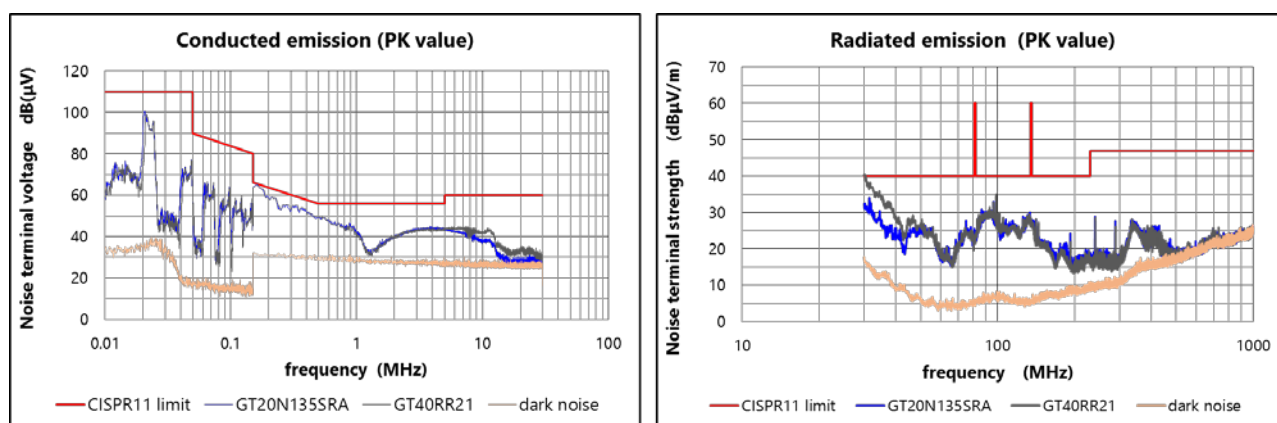
**Figure 3.6 Comparison of the forward characteristics of the body diode in the GT20N135SRA and GT40RR21**

### 3.5. Reduced radiated emissions

Electromagnetic compatibility (EMC) is regulated in many countries. The Comité International Spécial des Perturbations Radioélectriques (CISPR; English: International Special Committee on Radio Interference) provides major EMC standards. EMC depends on two factors: electromagnetic interference (EMI) and electromagnetic susceptibility (EMS). EMI is categorized into conducted emissions that travel through power supply lines and land patterns and radiated emissions that are radiated through the air as radio waves.

Figure 3.7 shows the results of measurement of conducted and radiated emissions from commercially available 220 VAC tabletop IH cookers incorporating the GT20N135SRA and GT40RR21. The magnitude of conducted emissions mainly depends on the designs of printed circuit boards (PCBs) and filters in the IH cooker and is almost unaffected by the IGBT used. In contrast, the magnitude of radiated emissions differs by roughly 10 dB at 30 MHz between the GT20N135SRA and GT40RR21. Therefore, the GT20N135SRA provides a greater margin relative to the EMI limit specified by the CISPR standard. One of the causes of this difference is a difference in the turn-off operation between the GT20N135SRA and GT40RR21. To reduce radiated emissions, a large gate resistor (RG) is generally inserted to slow the turn-off of the IGBT at the expense of an increased turn-off loss.

When compared under the same gate drive conditions, the GT20N135SRA generates less radiated emissions than the GT40RR21. Therefore, the GT20N135SRA provides a better trade-off between the power dissipation of an IGBT and a reduction in the system EMI level, reducing the burden of system design engineers.



(a) Results of conducted emission measurements (b) Results of radiated emission measurements

**Figure 3.7 Comparison of the EMI noise of the GT20N135SRA and GT40RR21 (tabletop IH cooker)**

## **4. Conclusion**

Toshiba's GT20N135SRA RC-IGBT is designed as a switching device for a voltage-resonant circuit for 220 VAC IH rice cookers, tabletop IH cookers, and inverter microwave ovens, and other cooking appliances. The GT20N135SRA provides various advantages over conventional devices, including 1) reduced short-circuit current at power-on because of the reduced collector saturation current, 2) a wider forward-biased safe operating area, 3) a reduced rise in junction temperature because of the reduced thermal resistance, 4) improved forward characteristics of the body diode, and 5) reduced radiated emissions.

Following the GT20N135SRA RC-IGBT for 220 VAC voltage resonance, we will develop high-current RC-IGBTs as well as 1100 V RC-IGBTs for 100 VAC voltage resonance.

## RESTRICTIONS ON PRODUCT USE

Toshiba Corporation and its subsidiaries and affiliates are collectively referred to as "TOSHIBA". Hardware, software and systems described in this document are collectively referred to as "Product".

- TOSHIBA reserves the right to make changes to the information in this document and related Product without notice.
- This document and any information herein may not be reproduced without prior written permission from TOSHIBA. Even with TOSHIBA's written permission, reproduction is permissible only if reproduction is without alteration/omission.
- Though TOSHIBA works continually to improve Product's quality and reliability, Product can malfunction or fail. Customers are responsible for complying with safety standards and for providing adequate designs and safeguards for their hardware, software and systems which minimize risk and avoid situations in which a malfunction or failure of Product could cause loss of human life, bodily injury or damage to property, including data loss or corruption. Before customers use the Product, create designs including the Product, or incorporate the Product into their own applications, customers must also refer to and comply with (a) the latest versions of all relevant TOSHIBA information, including without limitation, this document, the specifications, the data sheets and application notes for Product and the precautions and conditions set forth in the "TOSHIBA Semiconductor Reliability Handbook" and (b) the instructions for the application with which the Product will be used with or for. Customers are solely responsible for all aspects of their own product design or applications, including but not limited to (a) determining the appropriateness of the use of this Product in such design or applications; (b) evaluating and determining the applicability of any information contained in this document, or in charts, diagrams, programs, algorithms, sample application circuits, or any other referenced documents; and (c) validating all operating parameters for such designs and applications. **TOSHIBA ASSUMES NO LIABILITY FOR CUSTOMERS' PRODUCT DESIGN OR APPLICATIONS.**
- **PRODUCT IS NEITHER INTENDED NOR WARRANTED FOR USE IN EQUIPMENTS OR SYSTEMS THAT REQUIRE EXTRAORDINARILY HIGH LEVELS OF QUALITY AND/OR RELIABILITY, AND/OR A MALFUNCTION OR FAILURE OF WHICH MAY CAUSE LOSS OF HUMAN LIFE, BODILY INJURY, SERIOUS PROPERTY DAMAGE AND/OR SERIOUS PUBLIC IMPACT ("UNINTENDED USE").** Except for specific applications as expressly stated in this document, Unintended Use includes, without limitation, equipment used in nuclear facilities, equipment used in the aerospace industry, lifesaving and/or life supporting medical equipment, equipment used for automobiles, trains, ships and other transportation, traffic signaling equipment, equipment used to control combustions or explosions, safety devices, elevators and escalators, and devices related to power plant. **IF YOU USE PRODUCT FOR UNINTENDED USE, TOSHIBA ASSUMES NO LIABILITY FOR PRODUCT.** For details, please contact your TOSHIBA sales representative or contact us via our website.
- Do not disassemble, analyze, reverse-engineer, alter, modify, translate or copy Product, whether in whole or in part.
- Product shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable laws or regulations.
- The information contained herein is presented only as guidance for Product use. No responsibility is assumed by TOSHIBA for any infringement of patents or any other intellectual property rights of third parties that may result from the use of Product. No license to any intellectual property right is granted by this document, whether express or implied, by estoppel or otherwise.
- **ABSENT A WRITTEN SIGNED AGREEMENT, EXCEPT AS PROVIDED IN THE RELEVANT TERMS AND CONDITIONS OF SALE FOR PRODUCT, AND TO THE MAXIMUM EXTENT ALLOWABLE BY LAW, TOSHIBA (1) ASSUMES NO LIABILITY WHATSOEVER, INCLUDING WITHOUT LIMITATION, INDIRECT, CONSEQUENTIAL, SPECIAL, OR INCIDENTAL DAMAGES OR LOSS, INCLUDING WITHOUT LIMITATION, LOSS OF PROFITS, LOSS OF OPPORTUNITIES, BUSINESS INTERRUPTION AND LOSS OF DATA, AND (2) DISCLAIMS ANY AND ALL EXPRESS OR IMPLIED WARRANTIES AND CONDITIONS RELATED TO SALE, USE OF PRODUCT, OR INFORMATION, INCLUDING WARRANTIES OR CONDITIONS OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, ACCURACY OF INFORMATION, OR NONINFRINGEMENT.**
- Do not use or otherwise make available Product or related software or technology for any military purposes, including without limitation, for the design, development, use, stockpiling or manufacturing of nuclear, chemical, or biological weapons or missile technology products (mass destruction weapons). Product and related software and technology may be controlled under the applicable export laws and regulations including, without limitation, the Japanese Foreign Exchange and Foreign Trade Law and the U.S. Export Administration Regulations. Export and re-export of Product or related software or technology are strictly prohibited except in compliance with all applicable export laws and regulations.
- Please contact your TOSHIBA sales representative for details as to environmental matters such as the RoHS compatibility of Product. Please use Product in compliance with all applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive. **TOSHIBA ASSUMES NO LIABILITY FOR DAMAGES OR LOSSES OCCURRING AS A RESULT OF NONCOMPLIANCE WITH APPLICABLE LAWS AND REGULATIONS.**