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Low V_{CEsat} (BISS) transistors and low V_F (MEGA) Schottky rectifiers for DC/DC converters

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Application note

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Keywords	DC/DC converter, BISS, MEGA, MC34063, PBSS5320T, PMEG2020EJ
Abstract	In this paper, we discuss the performance of BISS transistors and MEGA Schottky rectifiers to be used in generic DC/DC converter applications. A corresponding reference design is described.



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1. Introduction

Nowadays, the trend in electronics is towards miniaturization and higher efficiency. Especially handset devices are getting smaller and lighter while performance increases. To get the best efficiency performance of bipolar transistor and diodes, Philips Semiconductors has introduced the low V_{CEsat} transistors and Ultra low V_F Schottky rectifiers to meet the requirements of the market. Philips calls them BISS (Breakthrough In Small Signal) transistors and MEGA (Maximum Efficiency General Application) Schottky rectifiers, due to significant improvements in their characteristics. For more detailed introduction, please refer to AN10116-02, AN10117-01 and AN10230-01.

Thanks to their excellent performance, Philips' low V_{CEsat} (BISS) transistors and MEGA Schottky rectifiers perfectly fit DC/DC-converter applications as pass transistors and diodes. Further, they are also applicable to low voltage fly-back and push-pull converters.

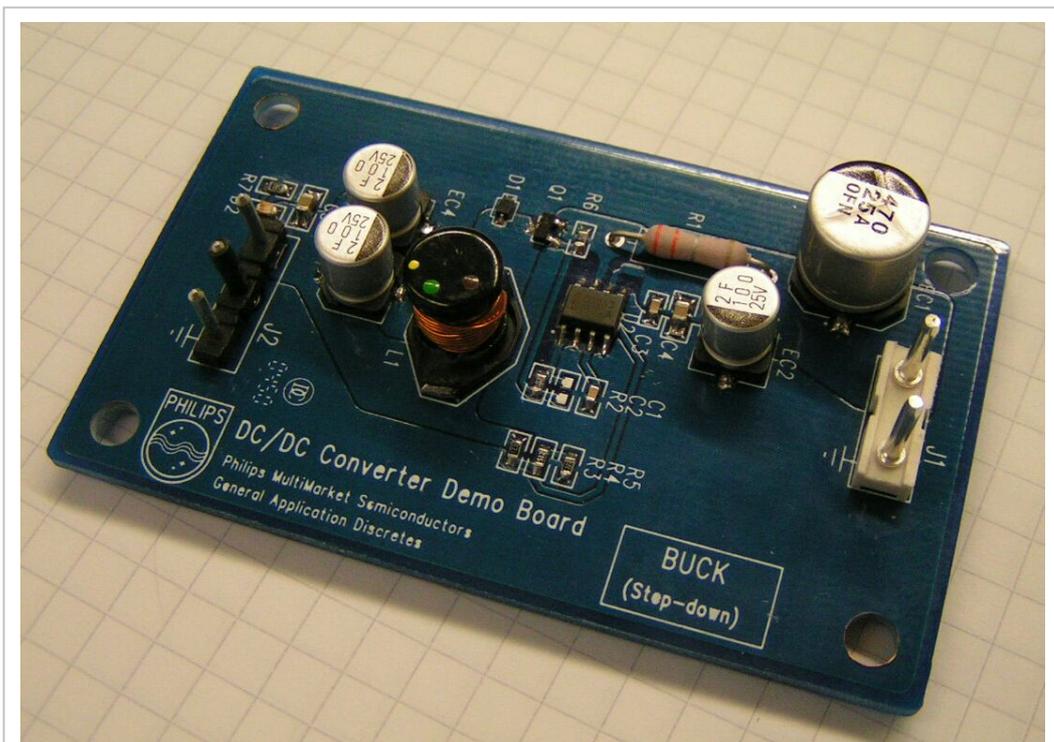


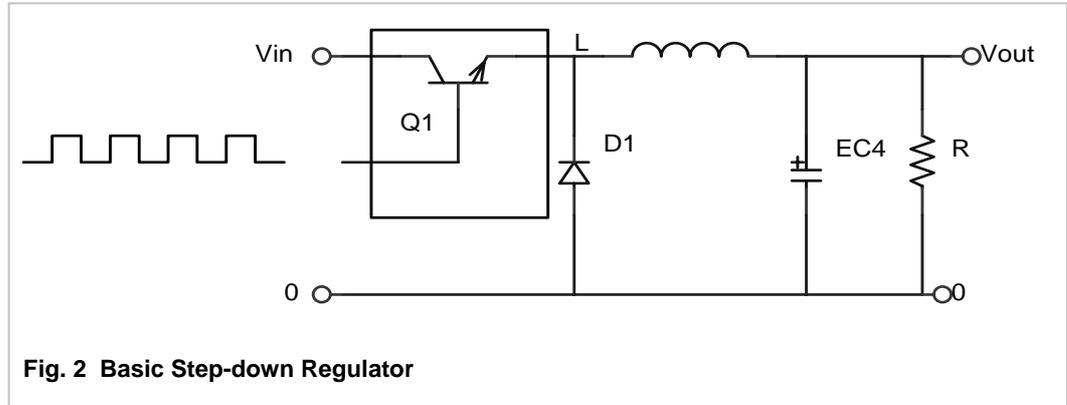
Fig. 1 DC/DC converter demo board with BISS transistors and MEGA Schottky rectifier

DC-DC conversion is one of the fundamental circuit functions in the electronics industry and the DC/DC-converter circuits are increasingly used in almost all electronic devices. The vast variety includes mains driven 3 kW converters as well as very small sized battery driven converters for handheld devices such as PDAs and mobile phones. High efficiency is a must for DC-DC to reduce heat generation, increase battery's lifetime and to protect the environment.

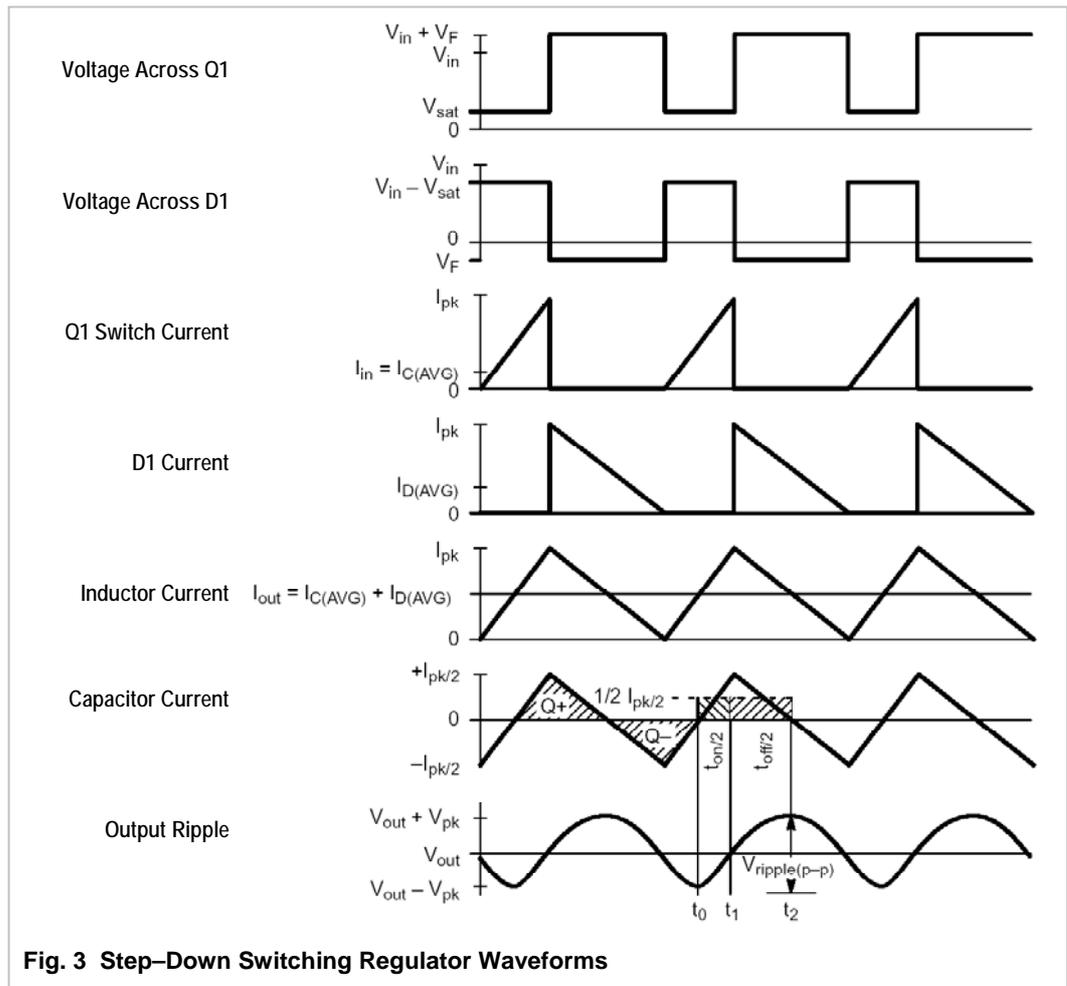
In this paper, the performance will be discussed in detail for BISS transistors and MEGA Schottky rectifiers used in DC/DC-buck (step-down) converter circuits.

2. General description

In the beginning, the principle of DC/DC-converter circuit will be introduced basically. The basic step-down switching regulator as example shown in figure 2. And figure 3 indicates



the switching waveforms for this regulator. Transistor Q1 interrupts the input voltage and provides a variable duty cycle square wave to a simple LC filter. The filter averages the square waves producing a DC output voltage that can be set to any level less than the input by controlling the percent conduction time of Q1 to that of the total switching cycle



time. Generally, the output voltage is available as follows:

$$V_{out} = \frac{(V_{in} - V_{CEsat}) \cdot t_{on} - V_F \cdot t_{off}}{t_{on} + t_{off}} \quad (V_{CEsat} \leq V_{CE})$$

To show the product performance of BISS transistors and MEGA Schottky rectifiers in a DC/DC converter circuit, the MC34063 is selected as the PWM controller because it's a common DC/DC controller is to be implemented and easy to expand for higher output currents with an external transistor. Further, this controller is widely available from many vendors.

The MC34063 contains the primary functions required for DC-to-DC converters. These devices consist of an internal temperature compensated reference, comparator, controlled duty cycle oscillator with an active current limit circuit, driver and high current output switch. With built- in switch transistor, the MC34063 can switch up to 1.5 A current. But for higher output currents or increase of efficiency, an external switch is often used to extend the application range of the device.

3. Typical BUCK (Step-down) circuit with MC34063 and conduction loss on passing transistor(s)

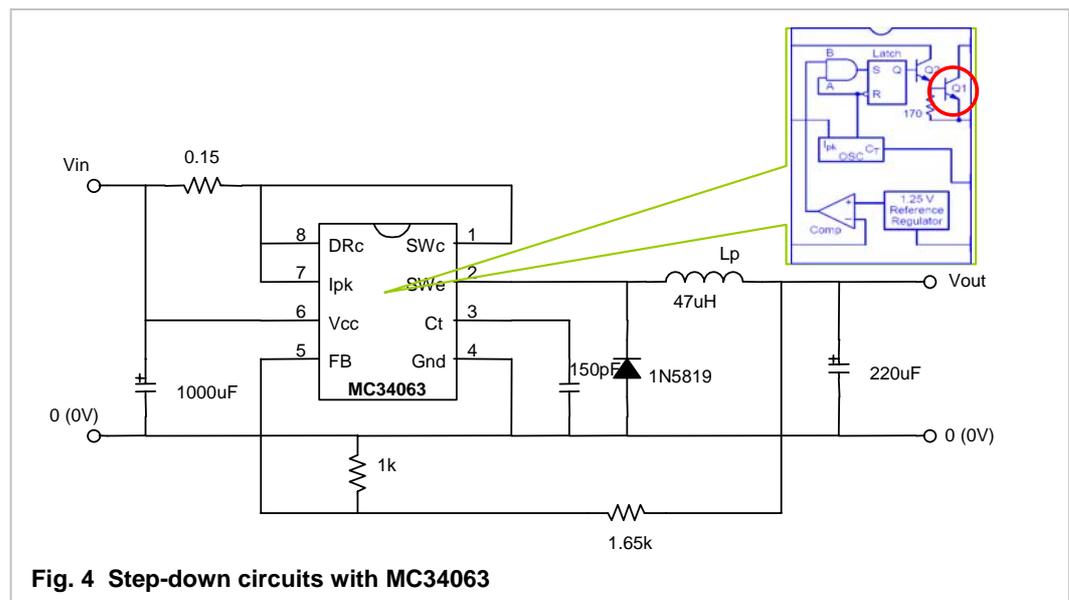
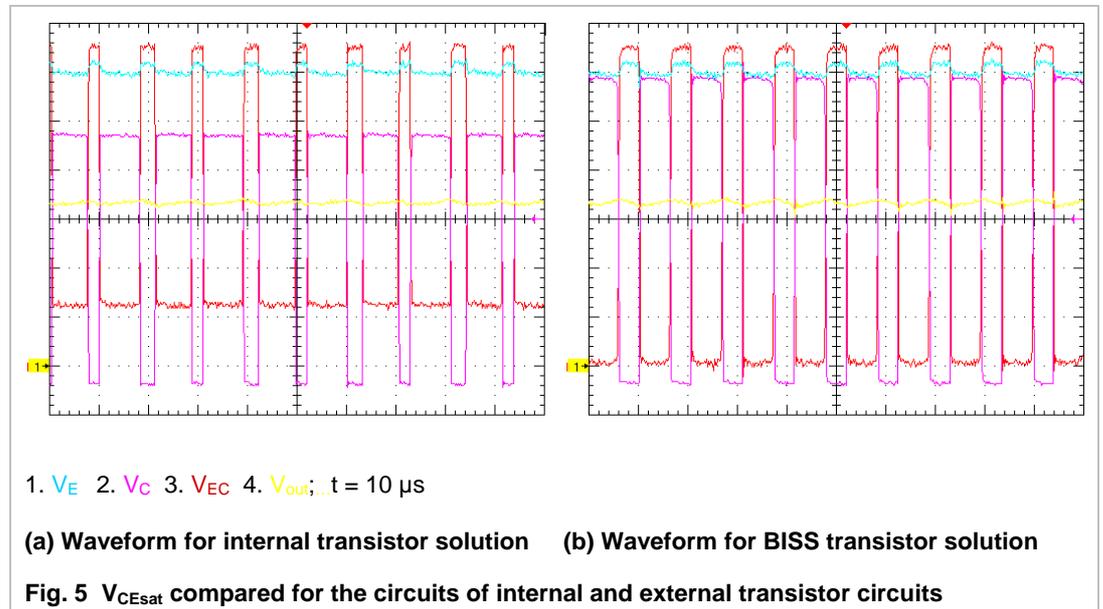


Fig. 4 Step-down circuits with MC34063

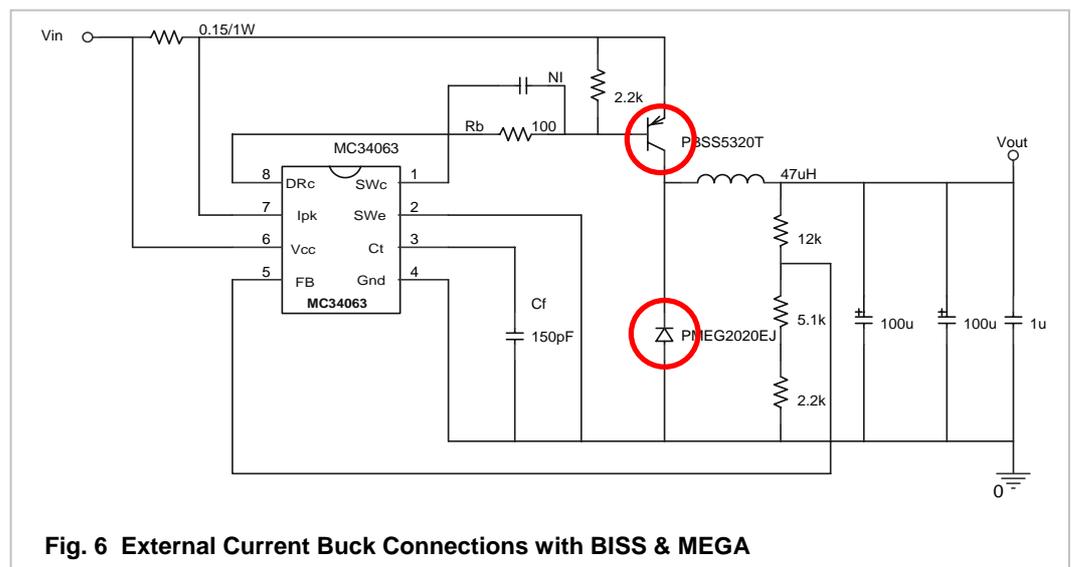
For the basic MC34063 application, the internal switch transistor Q1 is used as high side pass transistor as shown in figure 4 of the circuit and MC34063 block diagram. For example, given input voltage +6 V, output voltage +3.3 V with average output current 600 mA, customers usually complain that the conversion efficiency is poor and the controller is very hot so that thermalization becomes a major issue for the designers. (The converter doesn't operate with 5 V input voltage using the internal transistor.) The worse thing is that sometimes the controllers are stop working because of too high temperature. For further investigation, we can find a high V_{CE} drop voltage on the internal transistor Q1 shown in figure 4. Though the external resistors can be modified to adjust the saturation level of Q1, but a drop of over 1V still can be observed between the collector and emitter when Q1 is open, the figure 5 (a) reveals that, the value there is around 1.3 V. So $V_{CE}=1.3$ V is given here. Under such a condition, the power dissipation

of the transistor when it's conduct can be calculated by $P_Q = V_{CE} \times I_C$. But with the same collector current (I_C), if the V_{CE} is made to drop to a very low level, say 100 mV as shown in figure 5(b), the heat that generates on the transistor will be reduced dramatically and the conversion efficiency can also increase a lot. This objective can be achieved by using Philips low V_{CEsat} (BISS) transistors.



4. External current buck connections based on MC34063

To increase efficiency and to avoid malfunction of the circuit, figure 6 shows a modified schematic with an external pass transistor. As show in Figure 5 (b) V_{CEsat} is only about 100 mV when the transistor conducts. Here, one BISS transistor PBSS5320T is used as example. For the Schottky rectifier, the PMEG2020EJ is selected.



The PBSS5320T is a 20 V low V_{CEsat} PNP transistor in the SOT23 package, with a high collector current capability up to 2 A continuous current. The transistor also has a high current gain at least 150 at $I_C = 2$ A.

The PMEG2020EJ is a 20 V, 2 A very low V_F (MEGA) Schottky rectifier in the SOD323F package. Compared with standard Schottky diode, 1N5819 for example, the PMEG2020EJ provides a higher continuous forward current, lower forward voltage and features a much smaller package. Low V_{CEsat} and low V_F enable to offer transistors and Schottky rectifiers with small packages, thus enabling the designer to shrink its circuit.

5. Efficiency improvement using the external low V_{CEsat} (BISS) transistor PBSS5320T

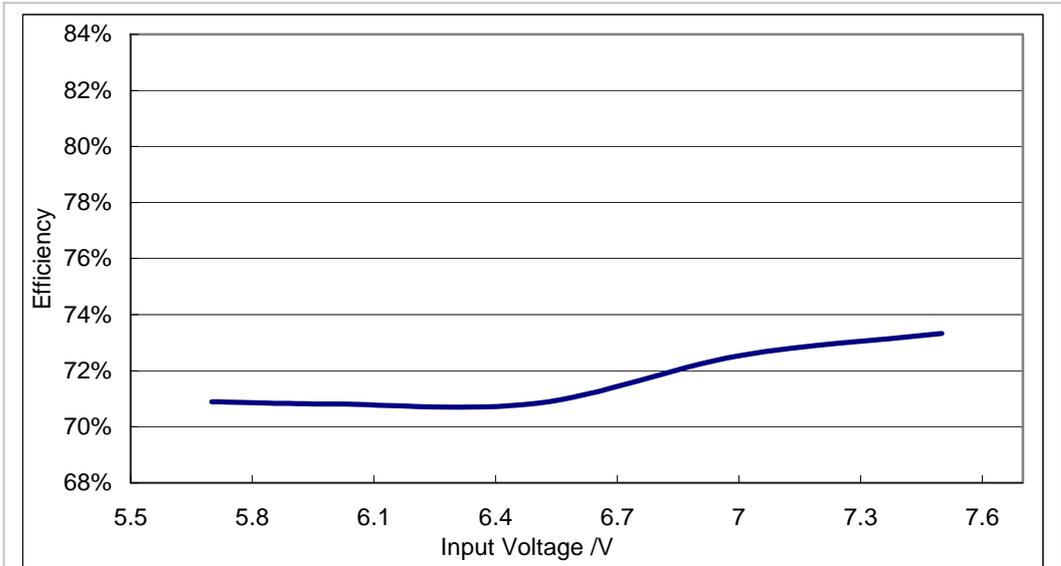


Fig. 7 Conversion efficiency with internal transistor for different input voltage
($V_{out} = 3.3\text{ V}$, $I_{out} = 600\text{ mA}$)

Here we will compare the conversion efficiency of the two different configuration circuits.

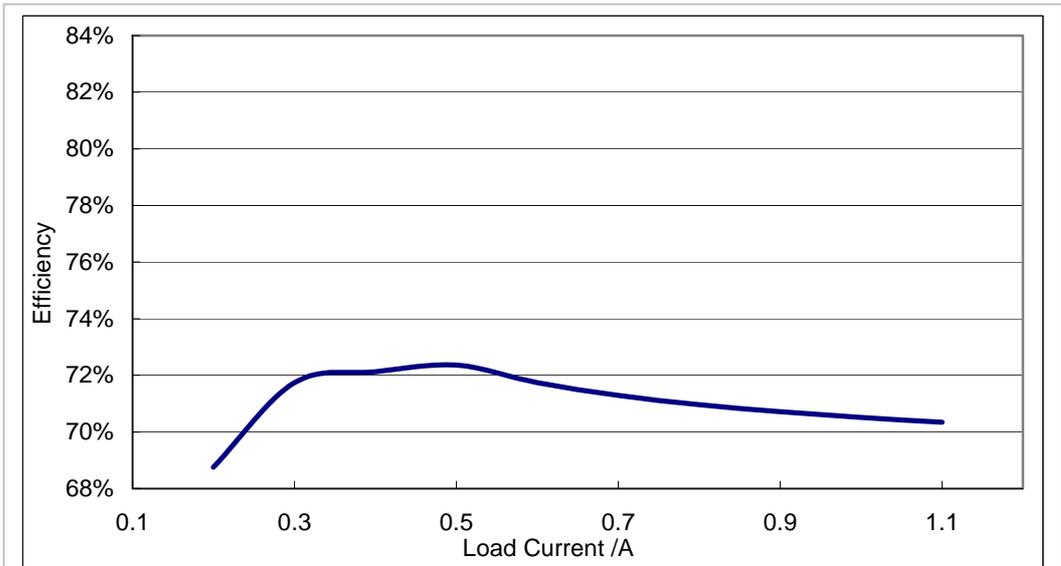


Fig. 8 Conversion efficiency with internal transistor for different output current
($V_{in} = 6\text{ V}$, $V_{out} = 3.3\text{ V}$)

Figure 7 shows the efficiency on circuit with internal pass transistor with the increasing input voltage. In this picture the voltage range from 5.7 V to 7.5 V is selected because only in this range, the circuit keeps the output voltage constant and the operation

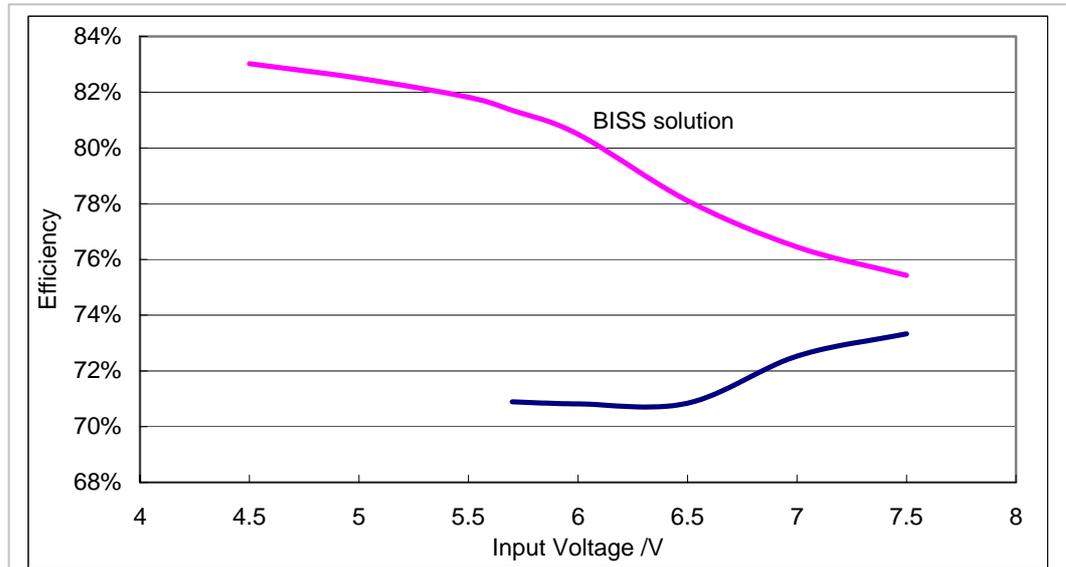


Fig. 9 Conversion efficiency with external transistor for different input voltage
 ($V_{out} = 3.3\text{ V}$, $I_{out} = 600\text{ mA}$)

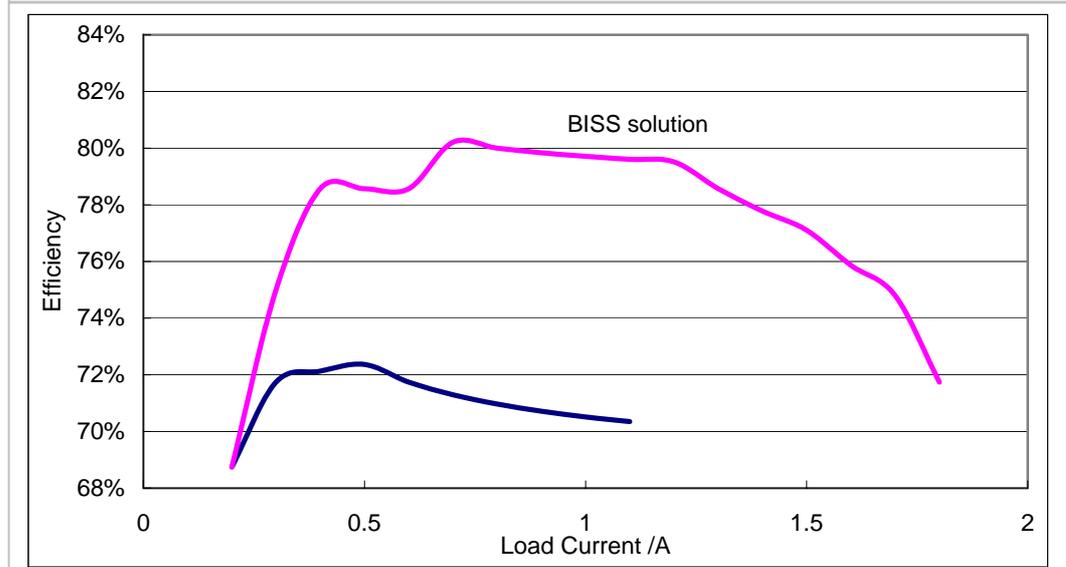


Fig. 10 Conversion efficiency with external transistor for different output current
 ($V_{in} = 6\text{ V}$, $V_{out} = 3.3\text{ V}$)

frequency stable. (Output is kept at $V_{out} = 3.3\text{ V}$, $I_{out} = 600\text{ mA}$ with $f = 90\text{ kHz}$). In the figure, the conversion efficiency is around 70 – 73 % and the efficiency has slight improvement with increasing V_{in} because more effective voltage can reach the inductor. The best conversion efficiency is around 72 % for load currents between 300 mA and 500 mA (fig. 8).

In comparison, figure 9 shows the efficiency of the circuit with the external BISS transistor PBSS5320T. When the input voltage increases, the conversion efficiency of

the BISS & MEGA solution drops because the switching loss is increasing (The voltage rising while the V_{CE} keeps the same slew rate, so longer is switching time). Another reason for the decrease in efficiency is that the duty cycle of the transistor decrease while the duty cycle of the MEGA Schottky rectifier increases. But for the voltage range from 5 to 7.5 V, the efficiency is higher than the internal switch transistor solution.

And figure 10 shows the conversion efficiency of the circuit with varying output current. For the higher output current (>500 mA), the efficiency improves by nearly 10 % using an external BISS transistor. At the same time, the other benefit is that with the PBSS5320T, the circuit has the capability to handle a much higher load current up to 1.8 A. The minimum input voltage can now be less than 5 V.

6. About the switching loss of BISS transistor

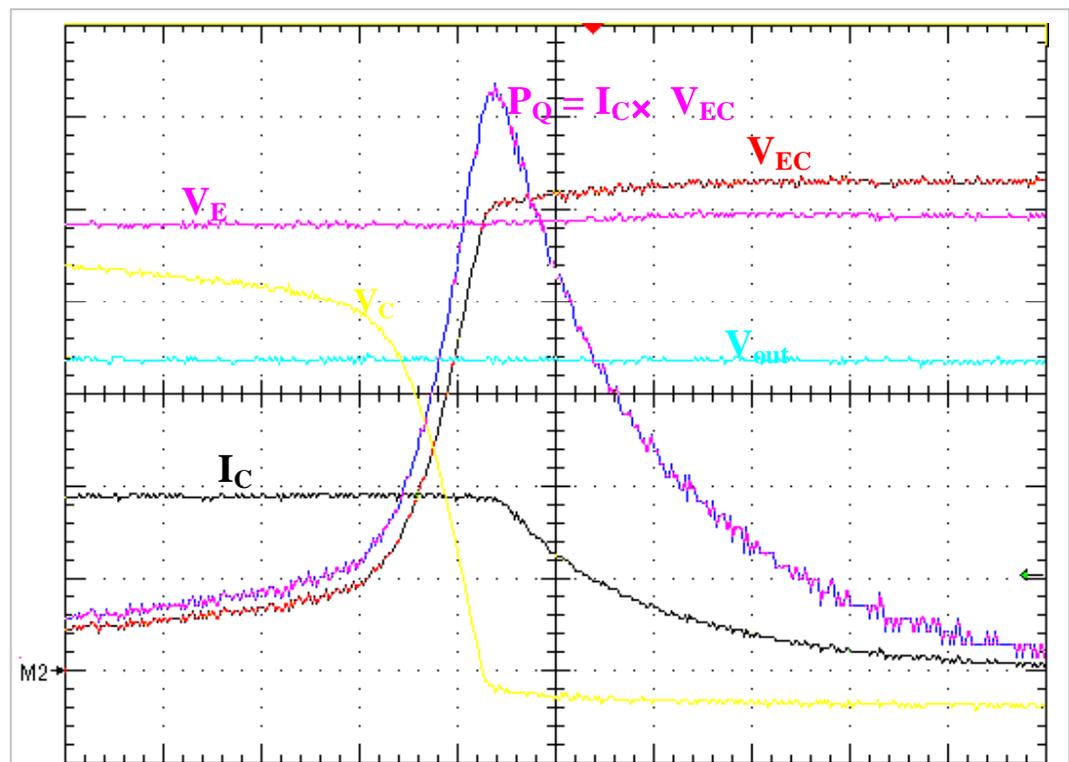


Fig. 11 Example of switching loss on BISS (P_Q)

As mentioned above, with BISS transistors, the V_{CE} drops to a very low level, but sometimes the efficiency's improvement doesn't as what we have expected. The main reason is because of the switching loss of the BISS transistors. The loss is due to the base and collector charge phenomena in bipolar transistors. Now these losses become the main power dissipation on the transistors. Figure 11 shows an example of the loss when the transistor is switch off. In the Figure, the power loss on the transistor is shown in purple. The peak value is up to 9.55 W in the example (configuration: $V_{in} = 5$ V, $V_{out} = 3.3$ V, $I_{out} = 1.5$ A). From the waveform, we can find the change of V_{CE} and I_C when the transistor is switch off. V_{CE} is already rising from V_{CEsat} to V_{CC} while I_C is still flowing due to the inductor. Unfortunately, the rising and falling edges are not sharp. With the

equation $P_Q = V_{CE} \times I_C$, the switching power loss occur. Sometimes, the average switching loss can be even higher than the R_{CEsat} loss. Based on the above discussion, the designer must have this loss in consideration when the operation frequency comes to a high level.

7. BISS & MEGA solution for high load current application

Based on the above analysis, BISS are best suited for DC/DC converter applications:

1. For output currents above the 1.5 A peak current of the MC34063.
2. For improved conversion efficiency.
3. For low operation frequency (<100 kHz).

The reference board contains the PBSS5320T with a high collector current capability of up to 2 A continuous current and 3 A peak current in SOT23. The PMEG2020EJ features up to 2 A continuous forward current in SOD323F (SC-90). Other BISS transistors and MEGA Schottky rectifiers can be used to adopt the design to the actual needs.

The circuit is pre-set to evaluate $V_{in} = 5\text{ V}$, $V_{out} = 3.3\text{ V}$, $f = 60\text{ kHz}$, $I_B = 35\text{ mA}$. The schematic is still as shown in figure 6.

Figure 12-14 show the conversion efficiency with different configurations.

1. With different operation frequency

As shown in figure 12, the efficiency will drop about 2 % - 5 % if the frequency is changed from 60 kHz to 90 kHz. And the BISS transistor is easier to be damaged under high load current. It also can be seen as another illustration of the switching loss because there will be more switch times with higher frequency.

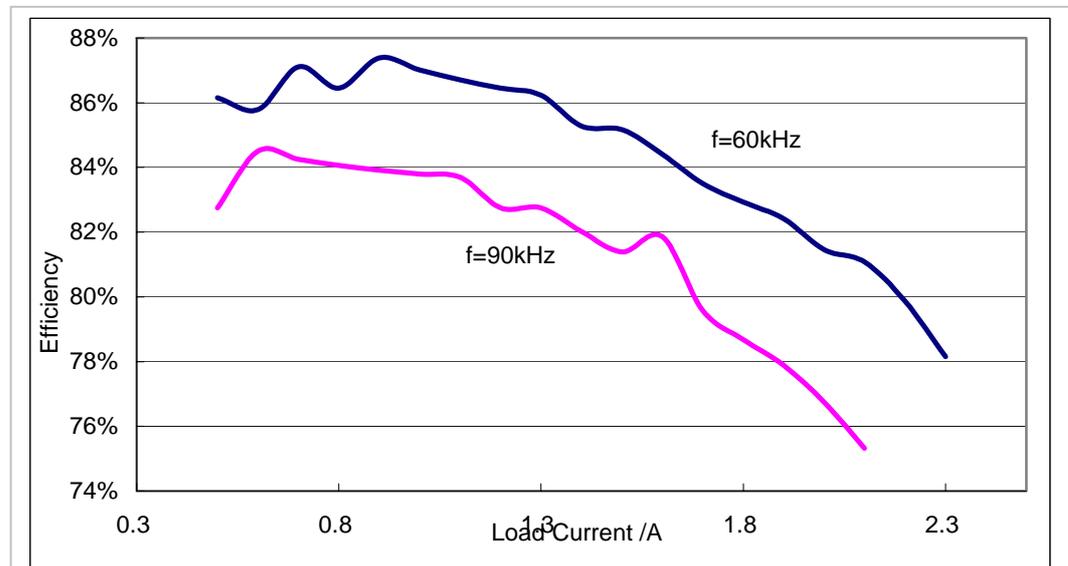


Fig. 12 Conversion efficiency with 60 kHz and 90 kHz switch frequency
 ($V_{in} = 5\text{ V}$, $V_{out} = 3.3\text{ V}$)

2. For different input voltage

The conversion efficiency drops with increasing supply voltage, as shown in figure 13.

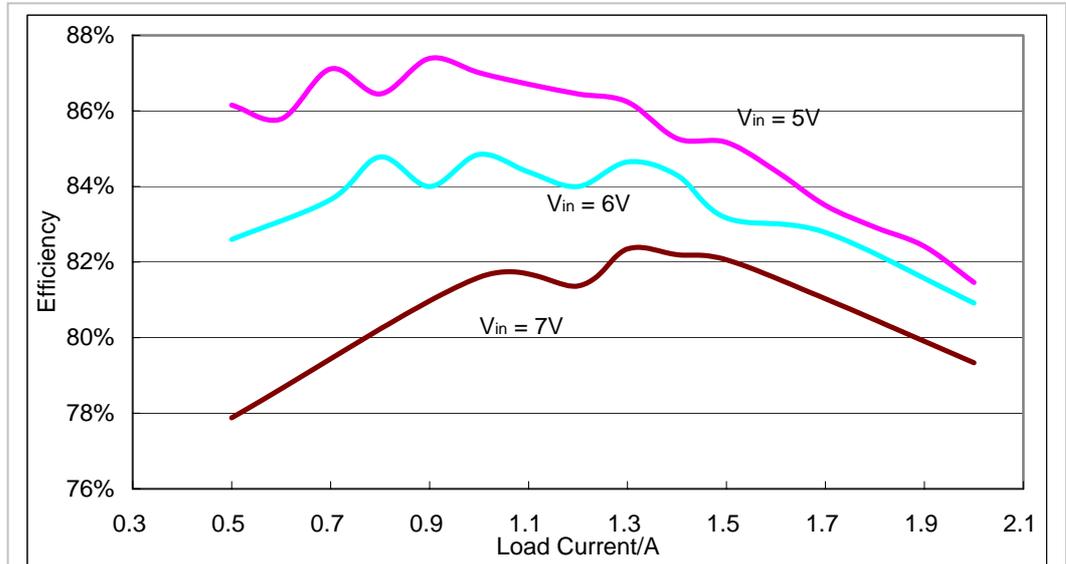


Fig. 13 Conversion efficiency with different input voltage ($V_{out} = 3.3 V$, $f = 60 kHz$)

3. For different transistor base current

We change the value of R_b to modify the transistor's base current. It will define the BISS transistor's working area. For the same collector current, a too high base current makes the transistor working in deep saturation area resulting in low V_{CEsat} and in an increasing storage time, while a too small base current increases V_{CEsat}

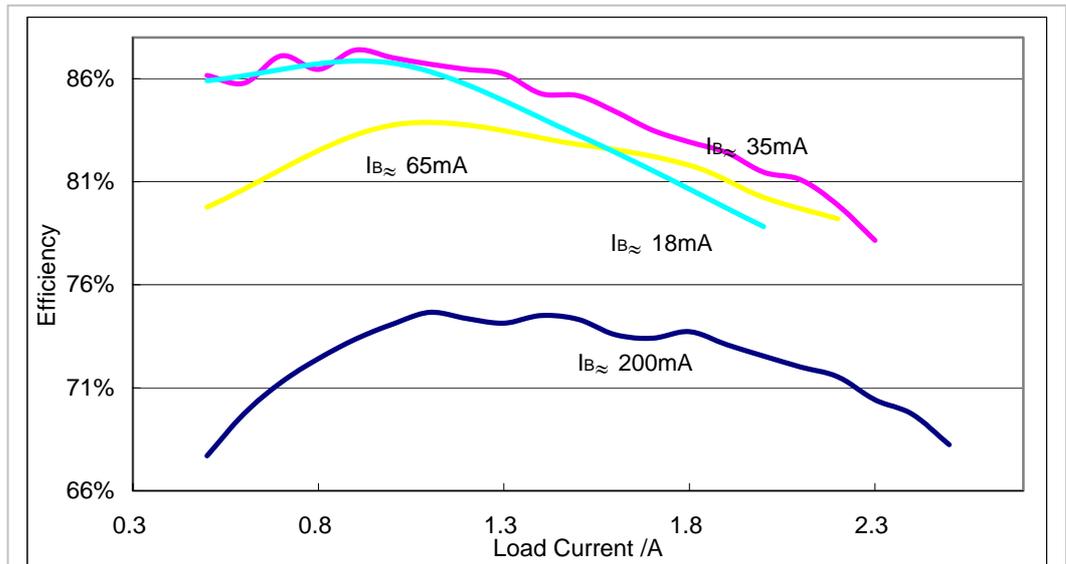


Fig. 14 Conversion efficiency with different BISS transistor base current ($V_{in} = 5 V$, $V_{out} = 3.3 V$, $f = 60 kHz$)



So the base current needs to be balanced for a minimum power loss. From figure 14, we got the best I_B is about 35 mA in this application.

8. Tips for the BISS transistors application in the circuits

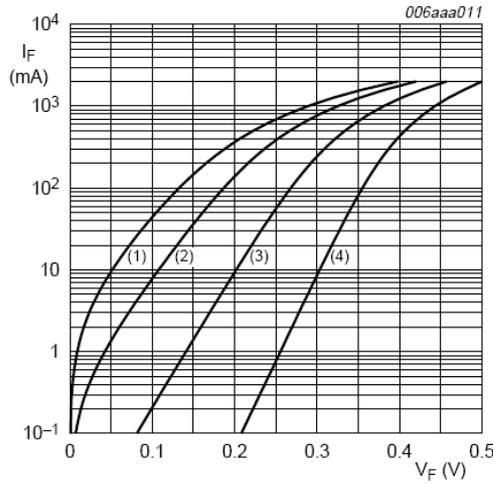
Below are some tips how to implement BISS transistors and MEGA Schottky rectifiers in DC/DC-converter circuits.

1. Fine-tune the base current of the BISS. It's important to define the BISS transistor's working area (Saturation/Deep saturation/linear operation). In this application, designer should assure that the BISS transistor is working in the saturation area to make use of the low V_{CEsat} performance. Increase of base current must be taken into consideration along with higher power dissipation longer storage time and thus operating frequency limitations with deeper saturation.
2. Efficiency increases with decreasing operation frequency. However, at lower frequencies, inductance and capacitance values increase to keep the output voltage ripple low.

9. Conclusion

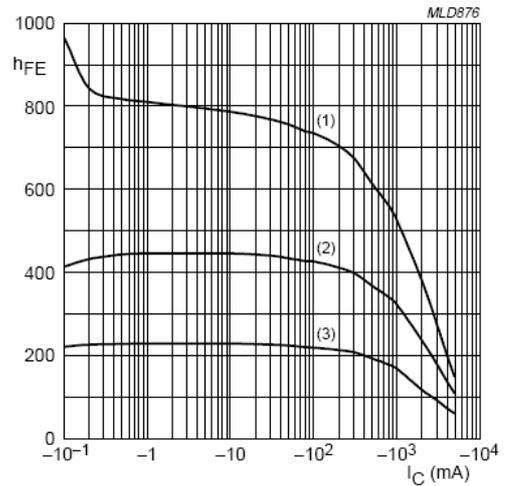
Low V_{CEsat} (BISS) transistors and low V_F (MEGA) Schottky rectifiers are excellent choices to build an efficient low cost DC/DC converter. Due to technology improvements, these devices are very small and easy to be mounted due to the use of standard packages. Together with a simple controller like the MC34063 one can build a very cost effective, high performing DC/DC converter. Using a BISS transistor widens the application area of the controller circuit by expanding the output current capability and lowering the required input voltage.

10. Annex



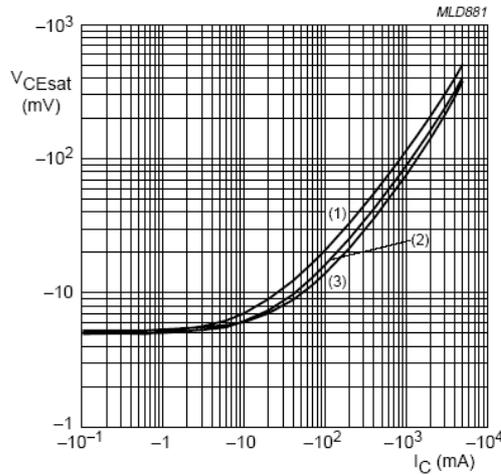
- (1) $T_{amb} = 125\text{ }^{\circ}\text{C}$.
- (2) $T_{amb} = 85\text{ }^{\circ}\text{C}$.
- (3) $T_{amb} = 25\text{ }^{\circ}\text{C}$.
- (4) $T_{amb} = -40\text{ }^{\circ}\text{C}$.

Fig. 15 PMEG2020EJ forward current (I_F) as a function of forward voltage (V_F); typical values.



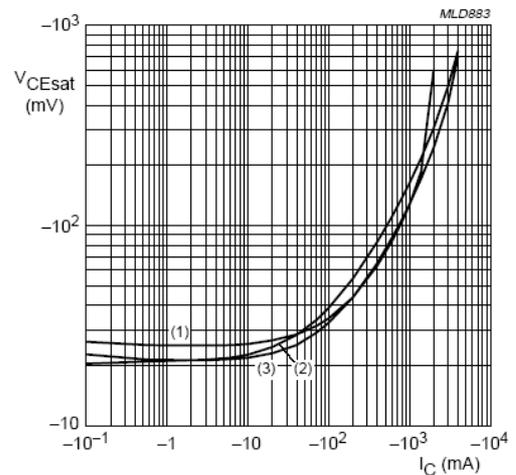
- $V_{CE} = -2\text{ V}$.
- (1) $T_{amb} = 150\text{ }^{\circ}\text{C}$.
 - (2) $T_{amb} = 25\text{ }^{\circ}\text{C}$.
 - (3) $T_{amb} = -55\text{ }^{\circ}\text{C}$.

Fig. 16 PBSS5320T DC current gain (h_{FE}) as a function of collector current (I_C); typical values.



- $I_C/I_B = 20$.
- (1) $T_{amb} = 150\text{ }^{\circ}\text{C}$.
 - (2) $T_{amb} = 25\text{ }^{\circ}\text{C}$.
 - (3) $T_{amb} = -55\text{ }^{\circ}\text{C}$.

Fig. 17 PBSS5320T Collector-emitter saturation voltage (V_{CEsat}) as a function of collector current (I_C); typical values.



- $I_C/I_B = 100$.
- (1) $T_{amb} = 150\text{ }^{\circ}\text{C}$.
 - (2) $T_{amb} = 25\text{ }^{\circ}\text{C}$.
 - (3) $T_{amb} = -55\text{ }^{\circ}\text{C}$.

Fig. 18 PBSS5320T Collector-emitter saturation voltage (V_{CEsat}) as a function of collector current (I_C); typical values.

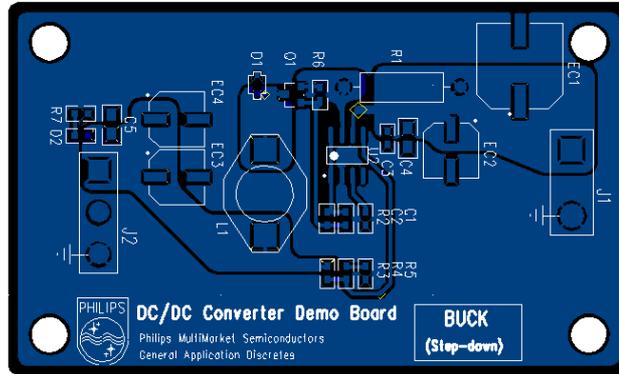


Fig. 18: Reference design layout

Bill of Material (BOM) for the demo board

Items	Part Reference	Value	Qty	Vendor	Vendor Number	Remark
1	R5, R6	2.2 k	2			
2	R2, R7	100	2			
3	R3	12 k	1			
4	R4	5.1 k	1			
5	C1	150 p	1			NPO
6	C3	0.1 u	1			
7	C4, C5	1 u	2			
8	EC2, EC3, EC4	100 u	3			Low ESR
9	EC1	470 u	1			
10	L1	47 u / 220 u	1	Coilcraft	DO3340-473	
11	D2	LED	1			
12	Q1	PBSS5320T	1	Philips	PBSS5320T	
13	D1	PMEG2020EJ	1	Philips	PMEG2020EJ	
14	U2	MC34063	1			
15	R1	0.15	1			1 W
16	J1		1			
17	J2		1			

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