Long Live the ~~2N2222~~ EPC7014 Transistor!!

Introduction

The venerable 2N2222 NPN planar bipolar transistor family has had a long run as the premiere rad-hard, small-signal transistor types -- since 1962, to be accurate! But that reign may be close to an end with the introduction by EPC Space of the EPC7014UB n-channel eGAN HEMT transistor. Both the 2N2222 and the EPC7014 are rated for 60V breakdown, however the 2N2222 is rated for 800mA and the EPC7014 is rated for 1A. Both devices are housed in the space-efficient UB package. All other comparisons aside, the EPC7014 has superior radiation performance, easier drive requirements, better saturation characteristics and much faster dynamic characteristics than its bipolar counterpart.

Anything the 2N2222 Can Do, The EPC7014UB Can Do Better!

The recently-introduced EPC7014UB eGaN HEMT transistor fills a void for field-effect devices in the rad-hard product domain. Its characteristics have been optimized for driving loads of less than 1A in a small 3.25mm x 2.74mm footprint (UB) hermetic package, as shown in Figure 1. This transistor, an enhancement-mode field-effect transistor, is also easier to drive than a bipolar transistor. There are a lot of instances where this transistor can be an essential replacement for the 2N2222 style devices.

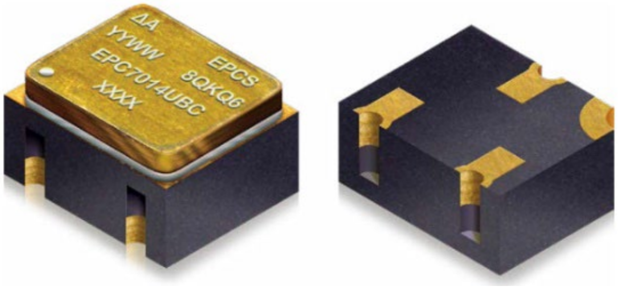

Figure 2. *EPC7014UB Packaging.*

In terms of meaningful electrical performance, the EPC7014 has the 2N2222 beat in the two key aspects: saturation and switching. To compare the saturation performance characteristics of the two devices it is necessary to observe their respective transfer characteristics to determine the saturation point for a given, equal load operating point. This comparison may be performed from the transfer characteristics for the EPC7014 (on the left) and the 2N2222A (on the right) at, for example, a load current of 500mA, as shown following in Figure 3.

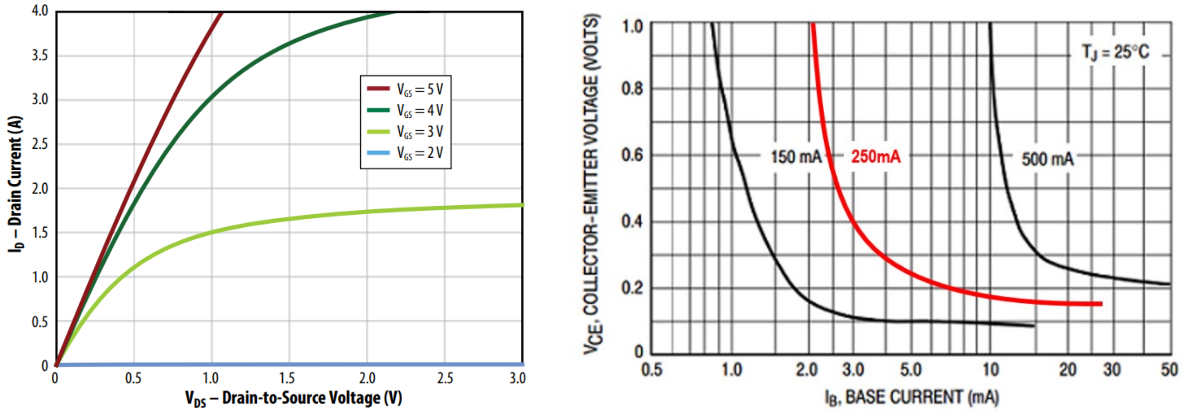

Figure 3. *EPC7014 (l) and 2N2222A (r) Transfer Characteristics.*

It's obvious in Figure 3 that for gate-source potentials of 3V or greater that the drain-source saturation voltage of the EPC7014 with 0.5A of drain current is less than approximately 0.15V. Similarly, with 50mA of base current, the 2N2222A has a collector-emitter saturation voltage of approximately 0.2V for a 0.5A collector current. The two saturation voltages are close to one-another by 0.05V, not a huge difference. But the real difference between the two is the power that the two devices dissipate while saturated: the EPC7014 does not draw gate current of more than 1uA, so the power dissipation of this transistor is Vds(sat) * Id = 0.15 * 0.5 = 75mW. The power dissipation for the 2N2222A is (Vce(sat) * Ic) + (Vbe(sat) * Ib) = (0.2 * 0.5) + (0.6 * 0.05) = 130mW. The saturated power dissipation for the EPC7014 HEMT at the same load operating point is essentially half that of the 2N2222A transistor! This difference is a big deal for the efficiency-minded circuit designer of space circuits.

An LTSpice simulation comparison of the switching performance between the two transistors is shown in Figure 4 (using the 2N2222A) over one switching cycle. Because the 2N2222A is a minority carrier device the switching speeds are characteristically slower than the majority carrier EPC7014 device. This difference is exemplified by the storage time, or the time required to sweep excess charges rom the base-emitter junction at turn-off. It can be seen in Figure 4 that the EPC7014 is at least an order of magnitude faster in terms of rise and fall times, and possesses NO storage time. This means that the AC losses for the EPC7014 will be at least ten times less (and even lower) than those of the 2N2222A! Both devices in Figure 4 are switched at a 250mA drain current from a 25V source, the EPC7014 is provided with a 5V gate pulse signal and a 10 Ohm resistor in series with the gate, and the 2N2222A is operated at a reasonable forced gain of 75 (Ib = 3.3mA, Rb = 1.33kΩ)). The rise and fall times of drive signals are 5ns each.

In Figure 4, the **GREEN** trace is the input signal, the **BLUE** trace is the drain voltage of the EPC7014 and the **RED** trace is the collector voltage of the 2N2222A transistor. When the input signal is low (0V), the devices are OFF. When the input signal is high (5V), the devices are ON.

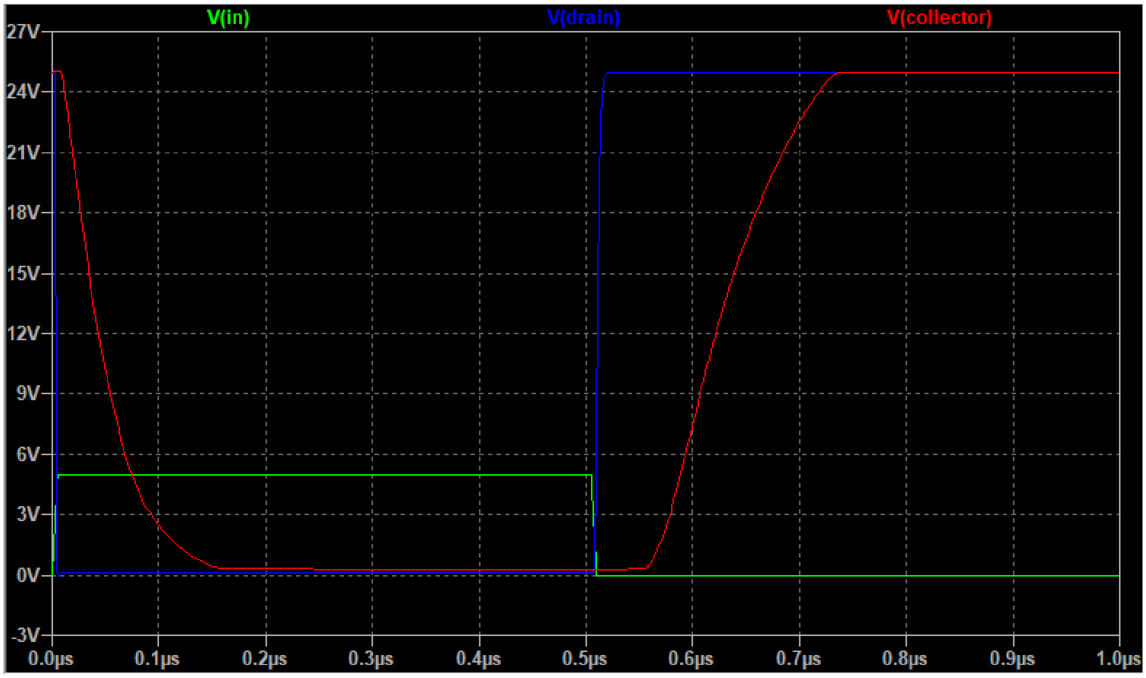

Figure 4. *EPC7014 (l) and 2N2222A (r) Switching Characteristics.*

Applications

It is often convenient to have so-called "glue" or spot logic available to accommodate circuit modifications such that firmware changes need not be made in an existing programmable device (FPGA, etc.), or that valuable I/O pins may be conserved for other critical usage when a small design change is required to be implemented.

Additionally, in many design requirements it is also desirable to have a high-speed, highly-efficient saturated switch, such as in DC-DC conversion.

It is also noteworthy that unlike most available logic gates/functions, the EPC7014 can directly drive a load without additional buffering. As such, the overall complexity of driving a high(er) current load can be reduced using this device. Accordingly, loads of up to 40W, with proper component de-ratings, may be driven by the EPC7014 in the application examples to follow. For inductive loads, it is always recommended/required that a "catch" diode be placed across the load to prevent destructive voltage spikes/transients from damaging the EPC7014.

The following application examples demonstrate the versatility of the EPC7014:

a.) Logic Inverter.

Figure 5 demonstrates the EPC7014 as a simple inverter. Obviously Figure 5 is not rocket science! But the EPC7014 makes driving a load much easier than using a similarly-rated bipolar transistor, where accommodating the variation in current gain with temperature and radiation is always a design concern. A key feature of the EPC7014 is the fact that the gate voltage is directly compatible with 3V logic and unlike the bipolar 2N2222, the gate input leakage current remains low when ON or OFF, typically less than one microampere.

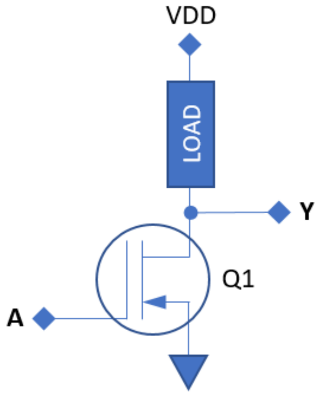

Figure 5. *EPC7014 Inverter (A=High, Y = Low, Load=ON).*

b.) NORing Function.

Figure 6 illustrates a simple, rad-hard, 2-input NORing function using two EPC7014 devices.

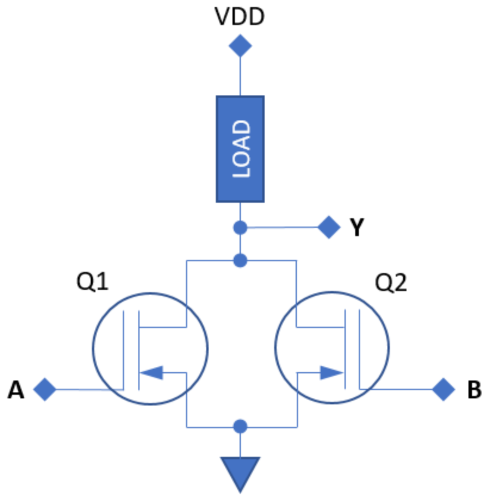

Figure 6. *EPC7014 ORing Function (A or B=High, Y = Low, Load=ON).*

c.) NAND-ing Function.

Figure 7 shows a simple 2-input, rad-had NAND-ing function using two EPC7014 devices and a Schottky diode. The diode is necessary to guarantee that transistor Q2 remains OFF when VDD is greater than 5V. For VDD levels less than or equal to 5V, diode D1 may be omitted.

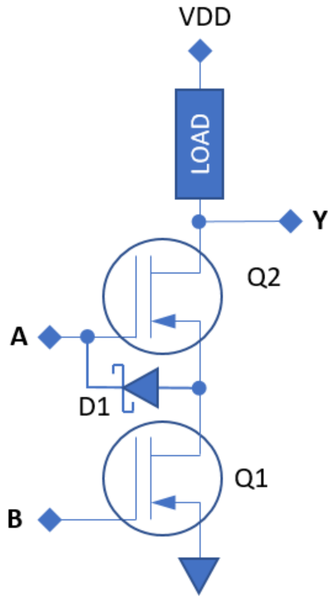

Figure 7. *EPC7014 NANDing Function (A and B=High, Y = Low, Load=ON).*

d.) Set/Reset Flip-Flop.

Figure 8 details a Set/Reset Flip-Flop function utilizing two EPC7014 devices, a Zener diode (D1), an “initialization” capacitor (CR) and three biasing resistors. Capacitor CR provides a useful function in that at power-up it holds the reset input low and ensures that the load is in the OFF state. The operation of the circuit in all other respects is identical to an integrated flip-flop: pulling the Sbar (Set) input low turns the load ON, while pulling the Rbar (Reset) input low turns the load OFF; and if both Sbar and Rbar are open, the load remains in the previous state until Set or Reset. In either the Set or Reset condition the load is latched to that state until Set or Reset is asserted.

If the load is low-voltage (≤ 5Vdc) then VDD may be connected to Vlog and D1 may be eliminated.

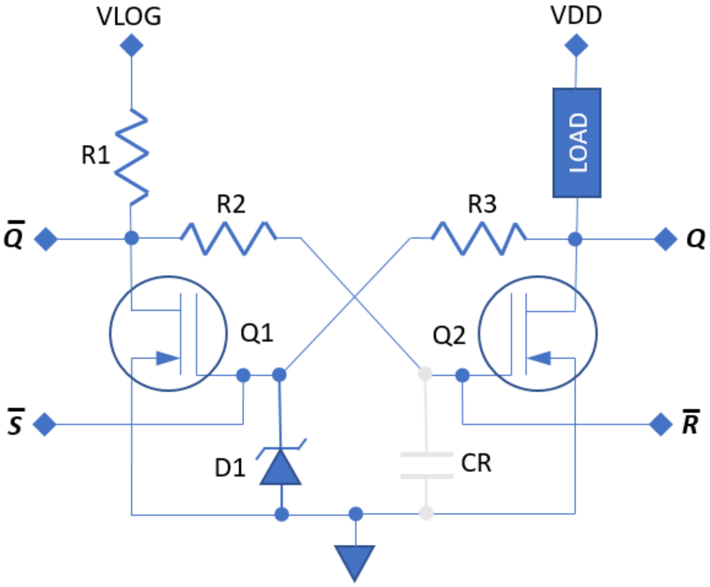

Figure 8. *EPC7014 S-R Flip-Flop Function (Sbar=Low, Load=ON; Rbar=Low, Load=OFF, Sbar and Rbar=Open, Load in Previous State).*

e.) DC Constant Current Source.

The EPC7014UB may be configured as a wide-compliance voltage DC current source, as shown in Figure 6. The servo feedback loop consisting of U1, Q1, R4, R5, R6 and C1 regulates the voltage across resistor R6 based on the voltage at the junction of R2 and R3. This voltage is then translated into a constant current via R6. This current, the source current of Q1 is also the drain current in Q1, and it is provided to the load. The voltage at the junction of R2 and R3 (V_{ref}) is:

$$V_{ref} = V(D1) * R2 / (R2 + R3) \quad (Vdc)$$

And the constant drain current (I_D) is given by:

$$I_D = V_{ref} / R6$$

It is recommended that the magnitude of V_{ref} be kept as low as possible to increase the compliance range of the current source for the load with respect to the supply voltage, VDD. It is also recommended that the bias potential for the circuit, VBIAS, be 5.5Vdc or less to ensure that the gate of Q1 is never voltage-overstressed.

In the circuit, components R5 and C1 perform frequency compensation for the feedback loop and resistor R4 may be necessary to ensure that the operational amplifier U1 remains stable driving the capacitive load represented by the C_{iss} of Q1. This resistor will have a value between 0 and 33 Ohms. Finally, it essential that amplifier U1 be a rail-to-rail input and output type.

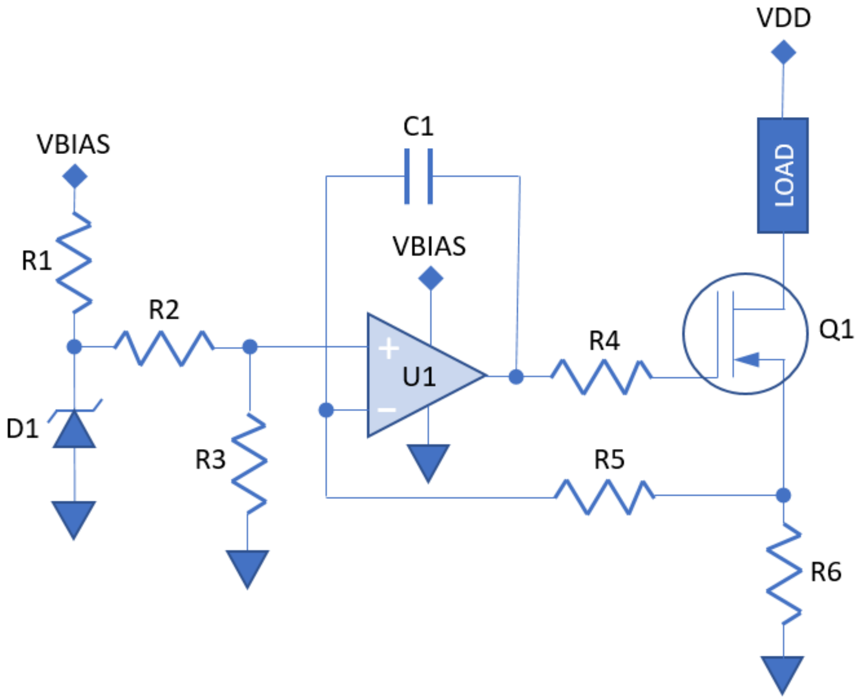

Figure 9. *EPC7014 Wide-Compliance Constant Current Source.*

f.) Pulsed Current Source.

The circuit of Figure 9 may be modified as a pulsed current source with the addition of a second EPC7014UB HEMT, as shown in Figure 10. The circuit in Figure 10 exactly as that shown in Figure 9 except that when logic input A of Q2 is low, current flows in the load and when input A is high, zero current flows in the load. Exclusive of transistors Q1 and Q2, the speed at which the current turns ON and OFF can be controlled by the bandwidth of amplifier U1. Such a circuit is useful when creating a amplitude-controlled, pulsed current source for a laser diode, such as that may be employed in LIDAR applications for either time-of-flight ranging or point mapping for collision avoidance.

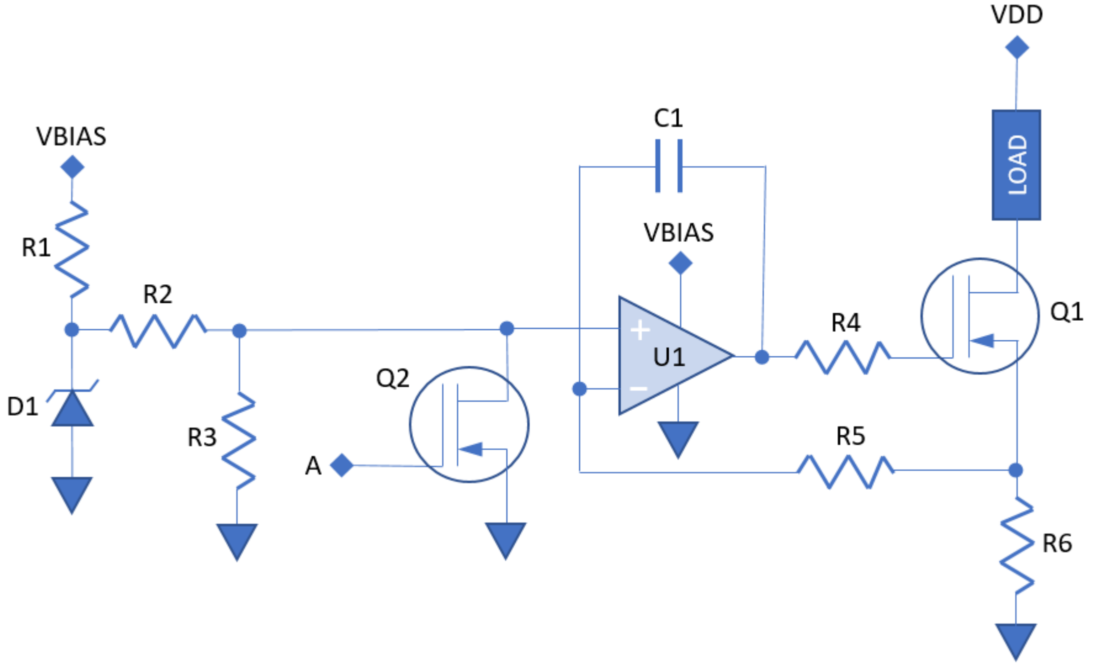

Figure 10. *EPC7014UB Pulsed Current Source.*

g.) Non-Isolated Boost Converter.

The EPC7014 also makes an ideal high-speed switch for a low power boost converter. Based on its ratings this transistor will allow for up to 30W of load power, useful for “spot” regulation that occupies minimum area on a PCB. In Figure 10, the logic input A of Q1 is a PWM signal whose duty cycle, D, is t_{on} / T, where t_{on} is the on time and T is the period of the signal.

The output voltage Vout, is related to the supply voltage, VDD, and the duty cycle, D, by:

$$Vout = VDD * (1/ (1 - D)) \quad (Vdc)$$

The signal at logic input “A” may be generated by a PWM voltage regulation controller or an FPGA that includes analog signal processing to sense the output voltage and provide a frequency compensated, stabilized PWM signal. Due to its low input capacitance and fast switching speed the EPC7014UB allows switching speeds of over 2MHz, which provides for greatly reduced sizes of filter components L1 and C1.

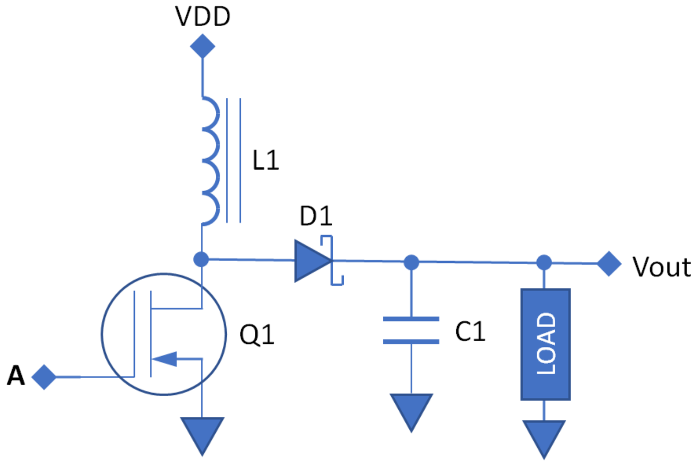

Figure 10. *EPC7014UB Non-Isolated Boost Converter.*

h.) Isolated Forward Converter.

The circuit in Figure 11 describes the power stage for an isolated forward converter with resonant transformer reset. In the circuit, transformer T1 is the primary-to-secondary power transformer with the ratio of N primary turns to each secondary turn. HEMT Q1 acts as the primary-side power switch. Diode D1 is the ON time energy transfer element in the secondary circuit that provides current to the load during the ON time of Q1, and diode D2 is the OFF time element that "catches" the current flowing in L1 and provides a path for the current in L1 to circulate to the load. Elements L1 and C1 form a 2nd order L-C filter that attenuates the VDD/N voltage signal that appears at the transformer's secondary during the ON time. The result is that a DC voltage is provided to the load at Vout. Capacitor Cres is the resonance capacitor for the reset of the transformer's primary winding. The capacitor Cres and the primary inductance, Lp, of T1 resonate during the OFF time of Q1 and when properly chosen provide the primary voltage required to reset transformer (V(Lp) * ton) = (-V(Lp) * toff) and prevent the magnetic core of T1 from saturating.

There are of course, other transformer reset techniques to prevent core saturation. The resonant reset technique was chosen for this example because it is the least complex and requires the least number of components to implement.

In Figure 11, the logic input A of Q1 is a PWM signal whose duty cycle, D, is t_{on} / T, where t_{on} is the on time and T is the period of the signal.

The output voltage Vout, is related to the supply voltage, VDD, and the duty cycle, D, by:

$$Vout = (VDD / N) * D \quad (Vdc)$$

The same regulation control techniques as suggested for the boost converter in Figure 10 may be utilized for this converter type.

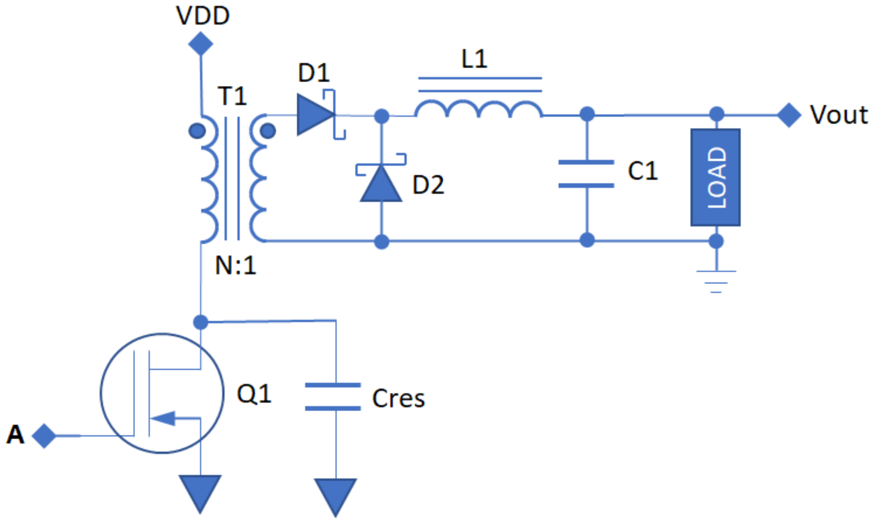

Figure 11. *EPC7014 Isolated Forward Converter (w/Resonant Transformer Reset).*

i.) Other Applications.

There are literally as many applications for the EPC7014UB as there are for the 2N2222 except those that rely on the Vbe of the bipolar transistor for its behavior as a “reference” potential with its die temperature (i.e. Vbe(T)). Exclusive of those applications, there are certainly many thousands of applications where the EPC7014UB can replace and outperform the 2N2222 transistor. The only limits are the imaginations of our designer customers.

Summary

Certainly, the 2N2222 NPN transistor family has had a long run as the go-to, rad hard, small-signal switch or amplifier of choice in space applications. But with the development and availability of EPC Space’s EPC7014UB n-channel eGaN HEMT device, the circuit designer for space products is provided with a viable, rock-solid, rad hard alternative. Accordingly, the EPC7104UB will satisfy the performance demands of most applications where the 2N2222 would be or is chosen. As a result, that designer will be rewarded with better saturation characteristics (meaning higher efficiency), simpler drive requirements and much faster switching speeds. We believe it won’t be a long time before the “UB” in EPC7014UB means **U**biquitous and **B**etter to the space community.

References

EPC7014UB Data Sheet

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