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INGENIERO ELÉCTRICO

REALIZATION OF AN INVERTER TO SUPPLY POWER TO A WIRELESS POWER TRANSMISSION SYSTEM

Autor: Karim Kadbey Nasser-Eldine
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Madrid
Agosto 2016

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RESUMEN DEL PROYECTO

Introducción

La transmisión inalámbrica de energía es la transmisión de energía eléctrica desde una fuente de energía a una carga eléctrica sin el uso de soporte físico.

Las técnicas de trasmisión inalámbrica de energía se clasifican en dos categorías, no-radioactiva y radioactiva. En las técnicas no-radioactivas, la energía es típicamente transferida por los campos magnéticos utilizando acoplamiento inductivo entre las bobinas de alambre.

La energía transferida aumenta con la frecuencia y la inductancia mutua entre las bobinas, la cual depende de la geometría de las bobinas y la distancia entre ellas. Una medida ampliamente utilizada para medir la eficiencia de la transmisión de la energía es el coeficiente de acoplamiento. Este parámetro adimensional es igual a la fracción de flujo magnético a través de la bobina transmisora que pasa a través de la bobina receptora.

El coeficiente de acoplamiento, siendo menor cuando más las bobinas están separadas una de la otra, es necesario operar el sistema a una frecuencia relativamente alta para compensar la debilidad de la inductancia mutua. Es entonces posible, al trabajar en la proximidad de la resonancia, transferir una cantidad significativa de energía, y esto con una eficacia adecuada.

Un inversor, siendo un dispositivo de electrónica de potencia que permite el suministro de tensiones alternativas desde una fuente eléctrica de energía de diferente tensión o de diferente frecuencia y siendo un convertidor CC/CA, el objetivo de este proyecto es de realizar un inversor que suministrará energía al sistema de transmisión inalámbrica de energía.

Para llevar a cabo este inversor, vamos a pasar por diferentes etapas. La primera de ellas será la realización de un chopper, la segunda será la realización de un chopper utilizando un circuito integrado (el IR2113), y la última la realización del inversor.

Primer paso: La realización de un chopper

Un chopper es un convertidor estático directo que proporciona una conversión de potencia CC - CC. Es un dispositivo de conmutación que convierte directamente un voltaje fijo de entrada CC en un voltaje variable de salida CC. Un chopper permite obtener un valor específico de voltaje a la salida a partir de una fuente de tensión fluctuante a la entrada, independientemente de la corriente consumida por la carga.

El chopper implementado en este proyecto es el siguiente:

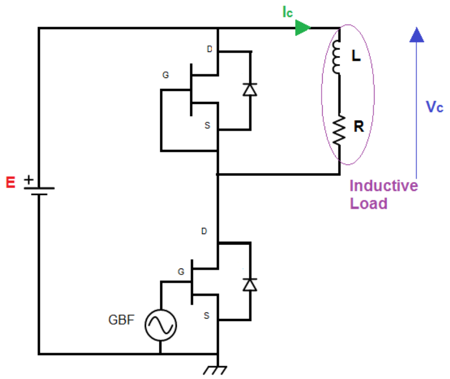


Ilustración 1.a : Esquema del chopper realizado en el proyecto

Los dos transistores actúan como interruptores que conmutan complementariamente y periódicamente en función del valor de la señal de onda cuadrada periódica aplicada por el GBF (Generador de Baja Frecuencia) a la entrada del transistor inferior.

Esta señal de onda cuadrada periódica se caracteriza por el ciclo de trabajo α (con un valor entre 0 y 1) que determina la relación entre un periodo de la señal cuadrada y el estado activo de esta señal durante este período.

Mediante la determinación de α y la frecuencia del GBF, determinamos el periodo de la señal periódica cuadrada aplicada por el GBF a la entrada del transistor inferior y la duración durante la cual la señal está activa durante este período. Cuando la señal de GBF está activa significa que el transistor inferior está cerrado y el transistor de la parte superior (que conmuta de una manera complementaria al inferior) está abierto. Cuando la señal de GBF no está activa significa que el transistor inferior está abierto y el transistor superior (que conmuta complementariamente al inferior) está cerrado.

Mediante la aplicación de un voltaje CC a estos dos transistores, la tensión de salida del chopper debe ser una señal cuadrada periódica con el mismo periodo que la señal aplicada por el GBF con un valor que debe variar entre 0 V y E (E siendo el valor de la fuente de corriente continua aplicada al chopper) y con un valor medio de α.E.

Aplicamos al circuito una tensión continua de valor E = 30V y ajustamos el GBF para tener un ciclo de trabajo igual a ½ y una frecuencia de 50 kHz.

Obtenemos así una señal de salida cuadrada y periódica (de período T= 20μs) a través de la carga inductiva de un valor eficaz de Vc = 22.3V y un valor medio de < v > = 14.6V. Así, podemos observar que los resultados obtenidos corresponden a los esperados.

Segundo paso: La realización del chopper usando el IR2113

La función del IR2113 es emitir dos señales de onda cuadrada complementarias en su salida, sobre la base de una señal de entrada emitida por el GBF. De esta manera, seremos capaces de dirigir los dos transistores del chopper para obtener resultados similares en la salida del chopper con el montaje del chopper con el IR2113 como hemos obtenido con el montaje del chopper sin el IR2113.

El chopper implementado en este proyecto mediante el IR2113 es el siguiente:

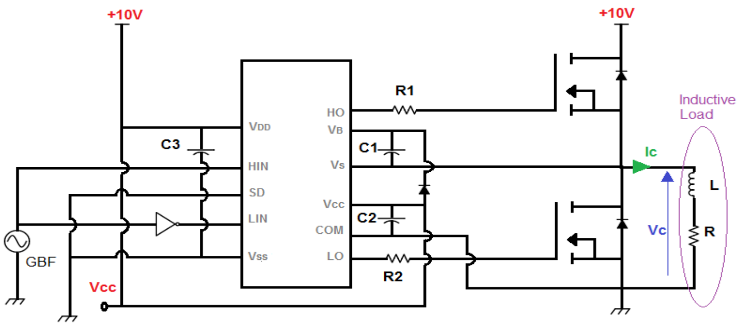


Ilustración 2.a : Esquema del chopper realizado usando el IR2113

Aplicamos al circuito una tensión continua de 10 V y ajustamos el GBF para tener un ciclo de trabajo igual a ½ y una frecuencia de 50 kHz.

Como hemos mencionado anteriormente, debemos tener salidas similares a los obtenidos con el montaje del chopper sin el IR2113 a través de la carga inductiva (similares y no las mismas porque estamos aplicando un valor de tensión continua diferente al circuito y estamos utilizando una diferente valor de la resistencia de la carga inductiva) como el IR2113 está controlando los dos transistores.

Por lo tanto, la tensión de salida del chopper debe ser una señal cuadrada periódica que varía entre 0V y E (E siendo el valor de la fuente de corriente continua aplicada al chopper) con el mismo período que la señal aplicada por el GBF y con un valor medio de α.E.

De hecho, se obtiene una señal de tensión de salida cuadrada y periódica (de período T = 20 µs) a través de la carga inductiva con aproximadamente un valor medio de <v> = 5V y un valor eficaz igual a Vc = 7.28V. Los resultados obtenidos corresponden a los esperados.

Tercer paso: El montaje final: El inversor

Un inversor es un dispositivo electrónico capaz de convertir energía eléctrica en forma continua en energía en forma alternativa de cualquier frecuencia. El inversor es un convertidor estático CC/CA.

El inversor realizado en este proyecto es un inversor autónomo de tensión, un inversor capaz de suministrar energía alternativa a partir de una fuente de tensión continua a una carga inductiva.

El inversor autónomo realizado en este proyecto es un inversor autónomo de tensión de medio puente capacitivo:

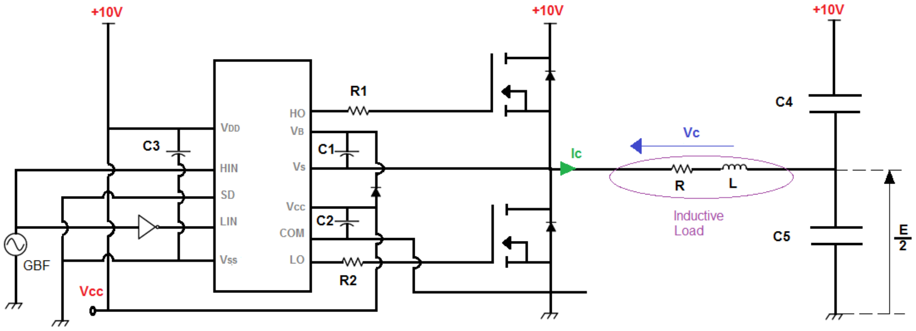


Ilustración 3.a : Esquema del inversor realizado en este proyecto

El GBF emite la señal de entrada del IR2113 que a su vez emite dos señales complementarias en su salida para el control de los dos transistores del inversor.

Mediante el ajuste del GBF para tener un ciclo de trabajo igual a ½, la señal que el GBF emitirá al IR2113 será la mitad de su período activa y la otra mitad inactiva. Esto conduce a un control simétrico de los transistores. Por lo tanto, debemos tener una señal de tensión alternativa, cuadrada y periódica (de periodo T = 1/50 = 20 µs) que varía entre -5V y + 5V con un valor eficaz igual a + 5V a través de la carga inductiva.

En efecto, se obtiene una tensión alternativa, cuadrada y periódica (de periodo T = 1/50 = 20 µs) a través de la carga inductiva que varía entre aproximadamente -5 V y + 5 V (el valor eficaz siendo igual a + 5.38V), lo que corresponde aproximadamente a lo esperado.

Conclusión

Hemos realizado en este proyecto un inversor que permite el suministro de tensiones alternativas a partir de una fuente de tensión en CC, de diferente voltaje y distinta frecuencia.

El coeficiente de acoplamiento, una medida de la eficiencia de la transmisión de energía por campos magnéticos utilizando el acoplamiento inductivo entre las bobinas de alambre, es menos cuanto más las bobinas están separadas una de la otra. Mediante el uso de un inversor para generar tensiones alternativas, a partir de una fuente de tensión en CC de diferente voltaje y distinta frecuencia, a la bobina transmisora del sistema de transmisión de energía inalámbrica, podemos trabajar de esta manera en la proximidad de la resonancia y transferir una energía significativa con la eficiencia adecuada.

Hemos sido capaces de crear un sistema capaz de proporcionar una señal de tensión alternativa y cuadrada de amplitud y frecuencia deseadas a partir de una fuente de tensión en CC. Para poder lograr esto, se utilizó un control simétrico para ambos transistores del inversor.

Aplicando el principio de modulación por ancho de pulsos (PMW) al inversor, tendremos una señal de tensión alternativa sinusoidal en su salida en lugar de tener una señal de tensión alternativa cuadrada en su salida; que puede ser más interesante en algunos otros casos.

ABSTRACT

Introduction

Wireless power transfer is the transmission of electrical energy from a power source to an electrical load without the use of physical support.

Wireless power techniques fall into two categories, non-radiative and radiative. In non-radiative techniques, power is typically transferred by magnetic fields using inductive coupling between coils of wire.

The power transferred increases with frequency and the mutual inductance between the coils, which depends on their geometry and the distance between them. A widely used measure of efficiency of the transmission of energy is the coupling coefficient. This dimensionless parameter is equal to the fraction of magnetic flux through the transmitter coil that passes through the receiving coil.

The coupling coefficient being lower the more the coils are separated from one another, it is necessary to operate the system at a relatively high frequency to compensate for the weakness of the mutual inductance. It is then possible, by working in the vicinity of the resonance, to transfer a significant energy, and this with a proper efficiency.

An inverter being a device of power electronics which enables the supply of alternating voltages from an electric source of energy of different voltage or different frequency and being a DC/AC converter, the purpose of this project is to realize an inverter that will supply power to the wireless power transmission system.

To realize this inverter, we are going to go through different steps. The first one will be the realization of a chopper, the second one will be the realization of a chopper using an integrated circuit (the IR2113), and the last one the realization of an inverter.

First step: Realization of the chopper

A chopper is a static direct converter providing a DC-DC power conversion. It is a switching device that directly converts fixed DC input voltage into a variable DC output voltage. A chopper enables to obtain a specific value of output voltage data from a fluctuating voltage source regardless of the current drawn by the load.

The chopper implemented in this project is the following:

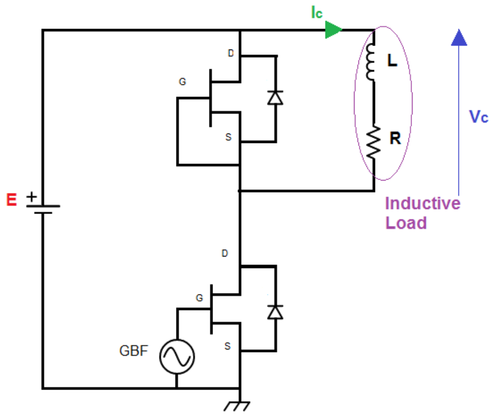


Figure 1.b : Schematic of the chopper realized in this project

The two transistors act as switches that switch complementarily and periodically depending on the value of the periodic square wave signal applied by the function generator (GBF in figure 1.b) at the entrance of the lower transistor.

This periodic square wave signal is characterized by the duty cycle α (value between 0 and 1) that determines the relationship between a period of the square signal and the active state of this signal during this period.

By determining α and the frequency of the function generator, we determine the period of the square periodic signal applied by the function generator at the entrance of the lower transistor and the duration during which the signal is active during this period. When the function generator signal is active it means that the bottom transistor is closed and the transistor of the top (which switches in a complementary manner to the lower one) is open. When the function generator signal is not active it means that the bottom transistor is open and the top transistor (which switches in a complementary manner to the lower one) is closed.

By applying a DC voltage to these two transistors, the output voltage of the chopper should be a periodic square signal with the same period as the signal applied by the function generator with a value that should vary between 0V and E (E being the value of the DC source applied to the chopper) and with an average value of α.E.

We apply to the circuit a DC voltage of E=30V and we adjust the function generator to have a duty ratio equal to ½ and a frequency of 50 kHz.

We thus obtain a square and periodic (of period 20µs) output voltage signal across the inductive load with an rms value of Vc=22.3V and an average value of <v>=14.6V. We can thereby notice that the results obtained correspond to the ones expected.

Second Step: Realization of the chopper using the IR2113

The IR2113 function is to issue two complementary square wave signals at its output, on the basis of an input signal emitted by the function generator. Thereby, we will be able to direct the two transistors of the chopper so that to obtain similar results on the output of the chopper with the electric assembly of the chopper with the IR2113 as we obtained with the electric assembly of the chopper without the IR2113

The chopper implemented in this project using the IR2113 is the following:

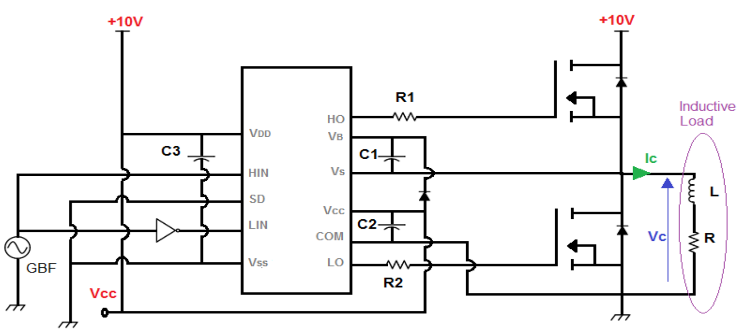


Figure 2.b : Schematic of the chopper using the IR2113

We apply to the circuit a DC voltage of 10V and we adjust the function generator (GBF in figure 2.b) to have a duty ratio equal to ½ and a frequency of 50 kHz.

As we mentioned earlier, we should have similar outputs to the ones obtained with the electric assembly of the chopper without the IR2113 across the inductive load (similar and not the same as we are applying different DC voltage value to the circuit and we are using a different resistance value for the inductive load) since the IR2113 is controlling the two transistors.

Therefore, the output voltage of the chopper should be a periodic square signal that varies between 0V and E (E being the value of the DC source applied to the chopper) with the same period as the signal applied by the function generator and with an average value of α.E.

As a matter of fact, we obtain a square and periodic (of period T=20 µs) output voltage signal across the inductive load with approximately an average value of <v>= 5V and an rms value equal to Vc=7.28V. The results obtained correspond to the ones expected.

Third step: The final assembly: The inverter

An inverter is an electronic device capable of converting electrical energy in continuous form into energy in an alternative form of any frequency. The inverter is a DC/AC static converter.

The inverter realized in this project is an autonomous voltage inverter, an inverter capable of supplying alternative energy from a continuous voltage source to an inductive load.

The autonomous inverter realized in this project is an autonomous capacitor half-bridge voltage inverter:

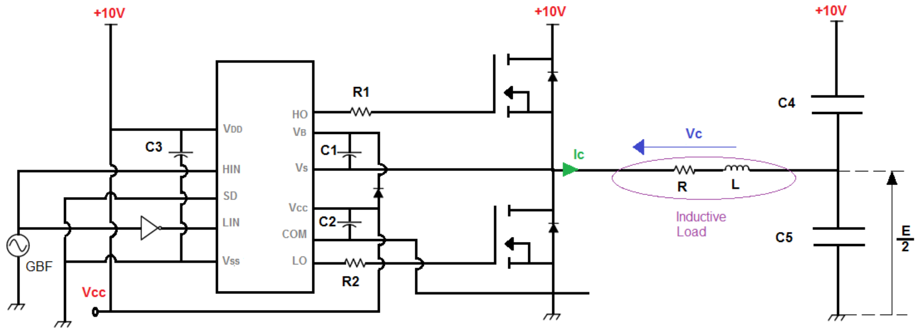


Figure 3.b : Schematic of the inverter realized in this project

The function generator (GBF in figure 3.b) emits the input signal of the IR2113 which will in turn emit two complementary signals at its output to control the two transistors of the inverter.

By adjusting the function generator to have a duty ratio equal to ½, the signal that the function generator will emit to the IR2113 will be half of its period active and the other half inactive. This leads to a symmetric control of the transistors. Therefore, we should have a square, periodic (of period T = $\frac{1}{50}$ = 20 µs) and alternating voltage signal that varies between -5V and +5V across the inductive load with an rms value equal to +5V.

Indeed, we obtain a square, periodic (of period T = $\frac{1}{50}$ = 20 µs) and alternating voltage signal across the inductive load that varies between approximately -5 V and + 5 V (the rms value being equal to +5.38V) which approximately corresponds to what we expected.

Conclusion

We realized in this project an inverter which enables the supply of alternating voltages from a DC voltage source of different voltage and different frequency.

The coupling coefficient, a measure of efficiency of the transmission of energy by magnetic fields using inductive coupling between coils of wire, is lower the more the coils are separated from one another. By using an inverter to generate alternating voltages, from a DC voltage source of different voltage and different frequency, to the transmitter coil of the wireless power transmission system, we can thereby work in the vicinity of the resonance and transfer a significant energy with proper efficiency.

We were able to create a system capable of providing an alternating square voltage signal of desired amplitude and desired frequency from a DC source. To be able to achieve this, we used a symmetric control for both transistors of the power inverter.

By applying the principle of pulse width modulation PWM to the inverter, we will have an alternating sinusoid voltage signal at its output instead of having an alternating square voltage signal at its output; which might be more interesting in some other cases.

Introduction

Wireless power transfer is the transmission of electrical energy from a power source to an electrical load without the use of physical support. Wireless transmission is useful to power electrical devices in cases where interconnecting wires are inconvenient, hazardous, or are not possible.

Wireless power techniques fall into two categories, non-radiative and radiative. In non-radiative techniques, power is typically transferred by magnetic fields using inductive coupling between coils of wire. Applications of this type include, for example, electric toothbrush chargers and smartcards. A current focus is to develop wireless systems to charge mobile and handheld computing devices such as cellphones, digital music players and portable computers without being tethered to a wall plug.

In inductive coupling, power is transferred between coils of wire by a magnetic field. The transmitter and receiver coils together form a transformer. An alternating current (AC) through the transmitter coil (L1) creates an oscillating magnetic field (B) by Ampere's law. The magnetic field passes through the receiving coil (L2), where it induces an alternating EMF (voltage) by Faraday's law of induction, which creates an AC current in the receiver.

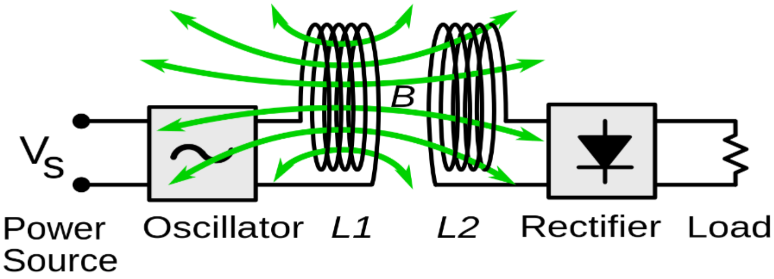


Figure 4 : Generic block diagram of an inductive wireless power system

The induced alternating current may either drive the load directly, or be rectified to direct current (DC) by a rectifier in the receiver, which drives the load. A few systems, such as electric toothbrush charging stands, work at 50/60 Hz so AC mains current is applied directly to the transmitter coil, but in most systems an electronic oscillator generates a higher frequency AC current which drives the coil, because transmission efficiency improves with frequency. Oscillators designed to produce a high-power AC output from a DC supply are usually called inverters.

Inductive coupling is the oldest and most widely used wireless power technology, and virtually the only one so far which is used in commercial products.

The power transferred increases with frequency and the mutual inductance between the coils, which depends on their geometry and the distance between them. A widely used measure of efficiency of the transmission of energy is the coupling coefficient. This dimensionless parameter is equal to the fraction of magnetic flux through L1 that passes through L2. If the two coils are on the same axis and close together, all the magnetic flux from L1 passes through L2, and efficiency approaches 100%. The greater the separation between the coils, the more of the magnetic field from the first coil misses the second, and the lower the efficiency is, approaching zero at large separations.

The coupling coefficient being lower the more the coils are separated from one another, it is necessary to operate the system at a relatively high frequency to compensate for the weakness of the mutual inductance. It is then possible, by working in the vicinity of the resonance, to transfer a significant energy, and this with a proper efficiency.

An inverter being a device of power electronics which enables the supply of alternating voltages from an electric source of energy of different tension or different frequency and being a DC/ AC converter, the purpose of this project is to realize an inverter that will supply power to the wireless power transmission system.

To realize this inverter, we are going to go through different steps. The first one will be the realization of a chopper and the last one the realization of an inverter.

Chapter I: The Chopper

In this part of the project, we are interested in achieving a chopper as a first step in the realization of the power inverter that will feed the wireless power transmission system. Similarly, we can thereby make sure that the MOS transistors that we are going to select for the whole process will not heat.

1. Definition of a Chopper

A chopper is a static direct converter providing a DC-DC power conversion. It is a switching device that directly converts fixed DC input voltage into a variable DC output voltage. A chopper allows to modulate the energy exchanged between a DC source (e.g. a battery) and a DC load (e.g. an inductive load).

Choppers allow adaptation in voltage and in current of the source and the load. They enable to obtain a specific value of output voltage data from a fluctuating voltage source regardless of the current drawn by the load.

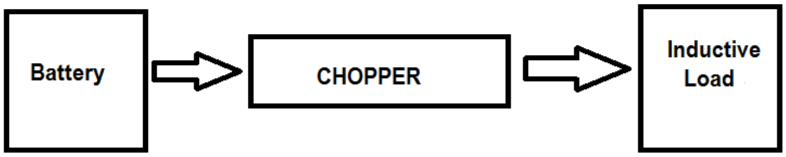


Figure 5 : Adaptation of the source and the load through the chopper

2. Principle of the chopper

The principle of operation of a chopper is based on chopping the voltage or the current of the source by playing periodically (period T) on the duration of the connection (α duty cycle) of this source with the load.

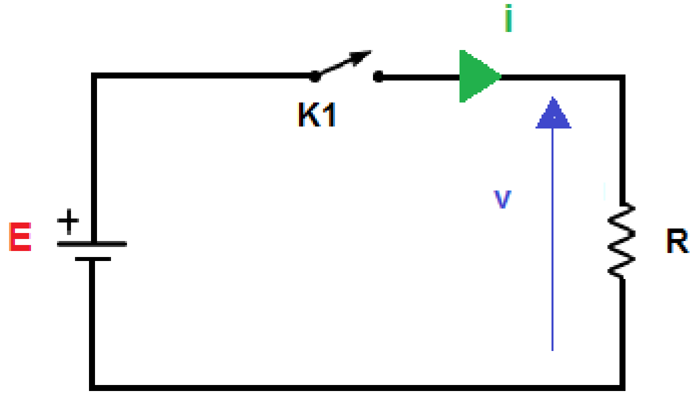


Figure 6 : Schematic of a chopper

Switching or chopping frequency: $f = \frac{1}{T}$

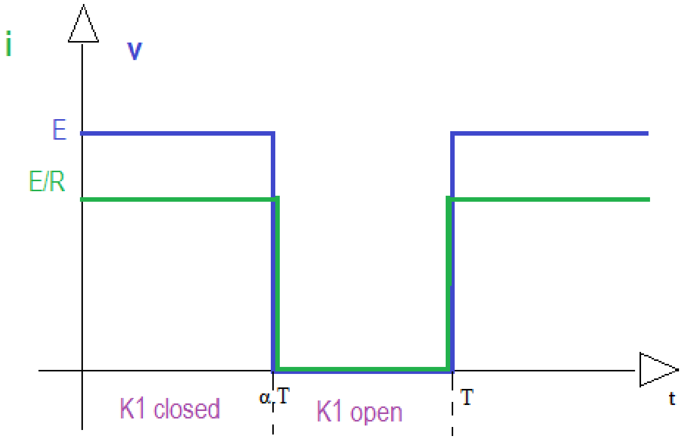


Figure 7 : Voltage and current across the load

Where $f = \frac{1}{T}$: switching frequency of the switch (switching or chopping frequency);

α: duty cycle of the command;

Average load voltage: <v> = α.E.

3. Adaptation to an inductive load / Series chopper (Buck)

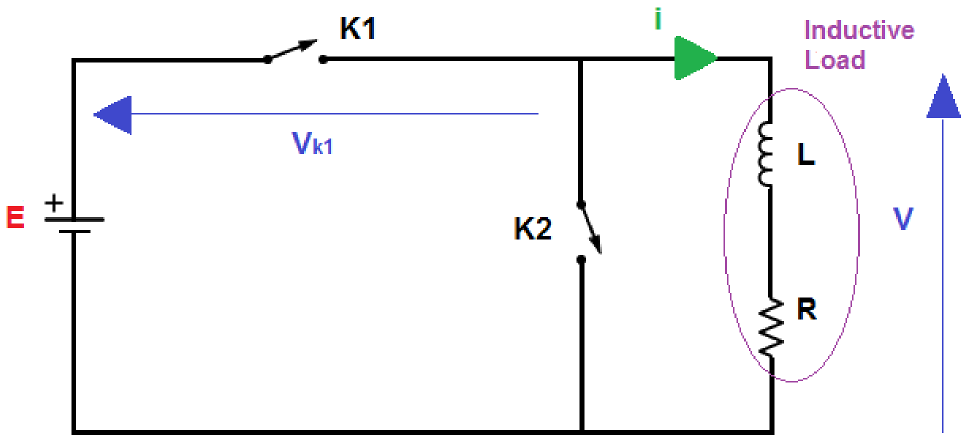


Figure 8 : Schematic of a chopper with an inductive load

The changes of states of the switches K1 and K2 are complementary and periodic (of period T):

- From 0 to α.T: K1 is closed and K2 is open.

  $E = L.\left(\frac{di}{dt}\right) + R.i$

  The intensity i increases, the source supplies energy to the load.

- From α.T to T: K2 is closed and K1 is open.

  $0 = L.\left(\frac{di}{dt}\right) + R.i$

  The intensity i decreases, freewheeling phase.

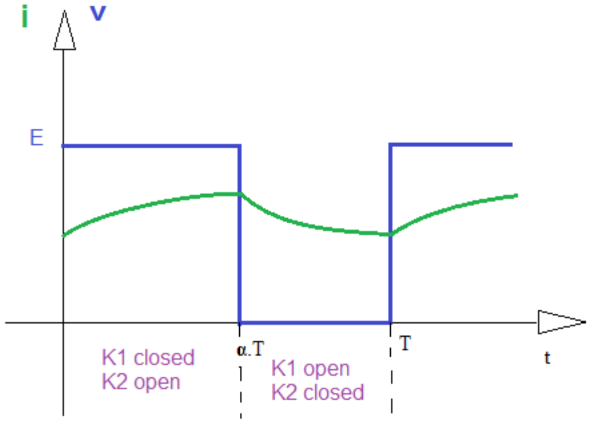


Figure 9 : Voltage and current across the inductive load

Where f = $\frac{1}{T}$: switching frequency of the switch (switching or chopping frequency);

α: duty cycle of the command;

Average load voltage <v> = α .E.

Note :

- Switch K1 is used to chop the voltage. At the opening of the switch K1, closing the switch K2 is essential not to have a discontinuity of the current in the inductive load.
- The current is never cancelled in the load.
- The series chopper is called buck chopper because for $0 < \alpha < 1$, the output voltage is lower than the initial voltage:

  $<v> = \alpha.E < E$
- Why do we put the switch K2?

  $V_{k1} = E - R.i - L.\left(\frac{di}{dt}\right)$

  If i = 0 at once (instantaneously), we will have L $\left(\frac{di}{dt}\right)$ = infinite and therefore, there will be an over-voltage across the switch when opened (arc phenomenon) and thus, this will lead to the destruction of the component K1.

  Therefore, we add the switch K2 to solve the problem of sudden power cut (i = 0).

4. Chopper implemented in this project

a. *Electric Assembly*

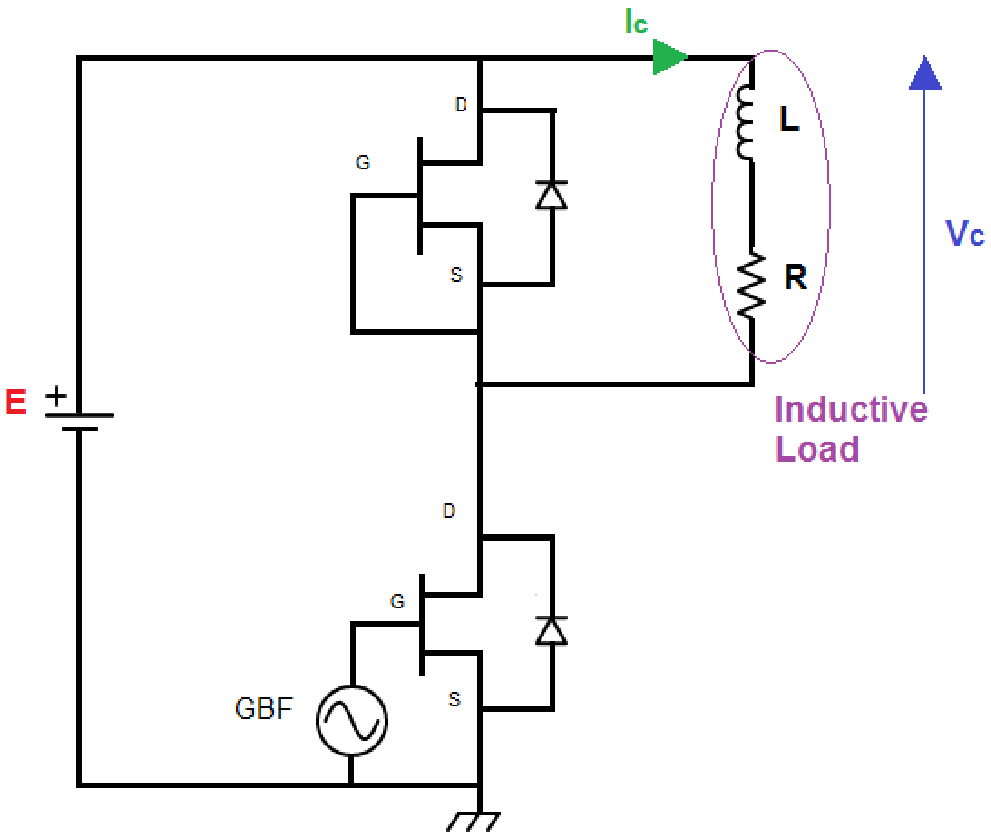


Figure 10 : Schematic of the chopper realized in this project

b. *Components used*

To be able to realize this assembly, we needed:

- 1 breadboard;
- 2 transistors MOS SMP60N06-18 (Data sheet in the annex);
- 1 function generator (GBF in figure 7): Frequency = 50 kHz and V = 15V;
- 1 DC source E;
- 1 inductive load;
- 1 oscilloscope.

5. Function generator and expected results

The two transistors act as switches that switch complementarily and periodically (as described in point 3) depending on the value of the periodic square wave signal applied by the function generator at the entrance of the lower transistor.

This periodic square wave signal is characterized by the duty cycle α (value between 0 and 1) that determines the relationship between a period of the square signal and the active state of this signal during this period.

By determining α and the frequency of the function generator, we determine the period of the square periodic signal applied by the function generator at the entrance of the lower transistor and the duration during which the signal is active during this period. When the function generator signal is active it means that the bottom transistor is closed and the transistor of the top (which switches in a complementary manner to the lower one) is open. When the function generator signal is not active it means that the bottom transistor is open and the top transistor (which switches in a complementary manner to the lower one) is closed.

By applying a DC voltage to these two transistors, the output voltage of the chopper should be a periodic square signal with the same period as the signal applied by the function generator with a value that should vary between 0V and E (E being the value of the DC source applied to the chopper) and with an average value of α.E.

We apply to the circuit a DC voltage of E=30V value and we adjust the function generator to have a duty ratio equal to ½ and a frequency of 50 kHz.

The expected results are:

- A square and periodic (of period $T = \frac{1}{50} = 20\ \mu s$) output voltage signal from the chopper (signal across the inductive load) that varies between 0V and 30V;
- An average voltage across the inductive load of value: $<v> = \alpha.E = \frac{30}{2} = 15V$and an rms voltage across the inductive load of value: $Vc = 30\ (\sqrt{½}) = 21.2V$;

- The shape of the intensity curve of the inductive load must be close to the shape of the intensity curve of the inductive load that is theoretically drawn in point 3 of this chapter (Figure 6).

6. Obtained results

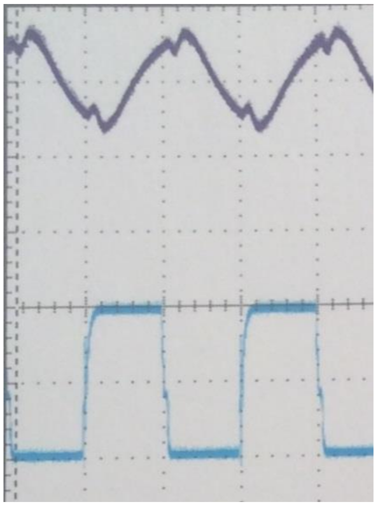


Figure 11 : Voltage (curve in light blue) and current (curve in dark blue) across the inductive load

We obtain a square and periodic, of period T=20 µs, output voltage signal across the inductive load. This voltage signal has an average value of <v>= 14.6V and an rms value equal to Vc=22.3V. We obtain the expected shape of the intensity curve of the inductive load.

We can thus notice that the results obtained correspond to the ones expected.

We also note that the transistors do not heat.

Chapter I: The Chopper

Chapter II: The IR2113

The chopper will be realized in this part of the project using an integrated circuit, the IR2113 (data sheet in annex). The IR2113 function is to issue two complementary square wave signals at its output, on the basis of an input signal emitted by the function generator. Thereby, we will be able to direct the two transistors of the chopper so that to obtain similar results on the output of the chopper with the electric assembly of the chopper with the IR2113 as we obtained with the electric assembly of the chopper without the IR2113 (as seen in Chapter I).

1. Operating principles of the IR2113

The IR2113 is an integrated circuit which serves to control at high frequency 2MOSFET or 2 IGBT, at voltages up to 600V, ensuring electrical isolation of each floor.

a. *Functional diagram*

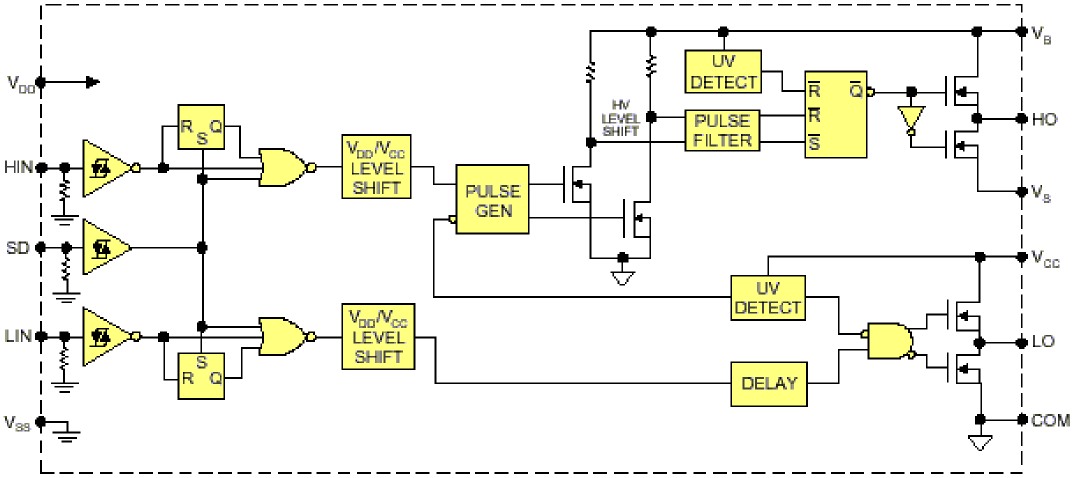


Figure 12 : Functional diagram of the IR2113

b. Functioning of logic inputs

The inputs HIN, HIL and SD are logic inputs, compatible with standard CMOS and TTL LS. The changeover levels are linked to the value of the supply voltage VDD. For example, for VDD = 15V, the high level is between 9.5V and 15V and the low level is between 0V and 6V.

The following study concerns HIN, but applies equally to HIL.

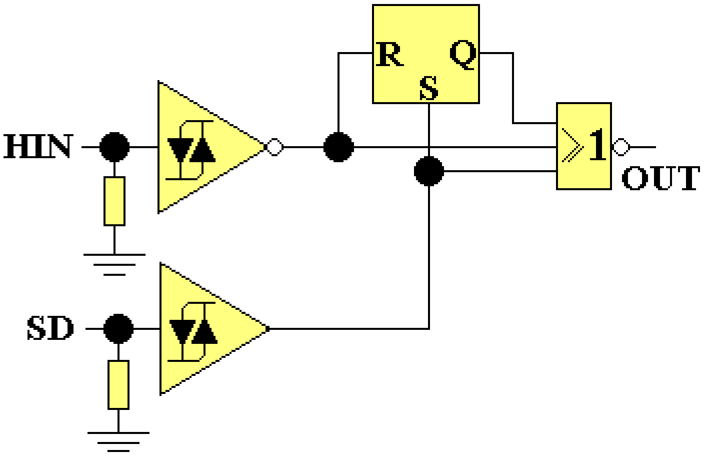


Figure 13 : Logic inputs HIN and SD

The SD logic input, when high, blocks the output OUT (OUT = 0). When SD is low, the impulses arriving on HIN are present on the output OUT. Thanks to the RS flip-flop, an impulse partially blocked by SD, remains blocked until its end. This property can be used to modulate the impulse widths from the SD input.

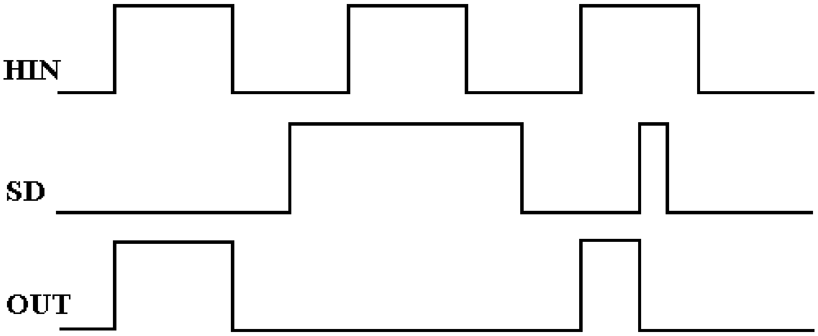


Figure 14 : Input/Output diagram for HIN and SD

c. Low output floor

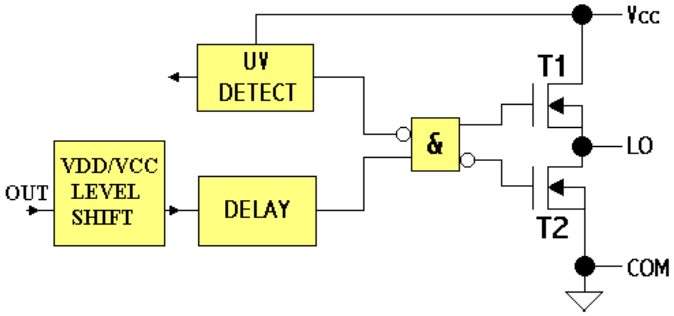


Figure 15 : Functional diagram of the low output floor

This floor has an LO output that can deliver a current of 2A through the push-pull T1-T2. These transistors have a complementary operation.

When the voltage Vcc is insufficient, T1 is blocked and T2 is saturated. Otherwise, it is DELAY which sets the state of T1 and T2.

d. High output floor

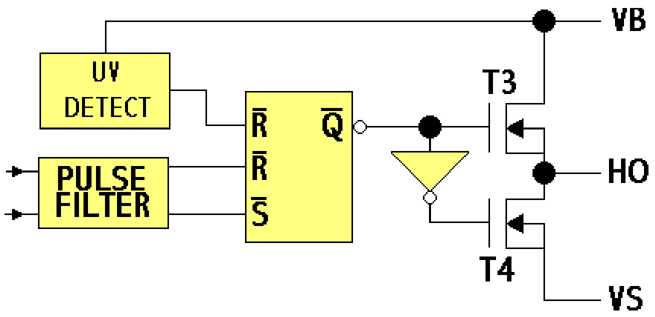


Figure 16 : Functional diagram of the high output floor

This floor has an HO output that can deliver a current of 2A through the push-pull T3-T4. These transistors have a complementary operation.

When the voltage V_B is insufficient, T3 is blocked and T4 is saturated. Otherwise, it is PULSE FILTER which sets the state of T1 and T2.

e. *Stage of high voltage level shifter*

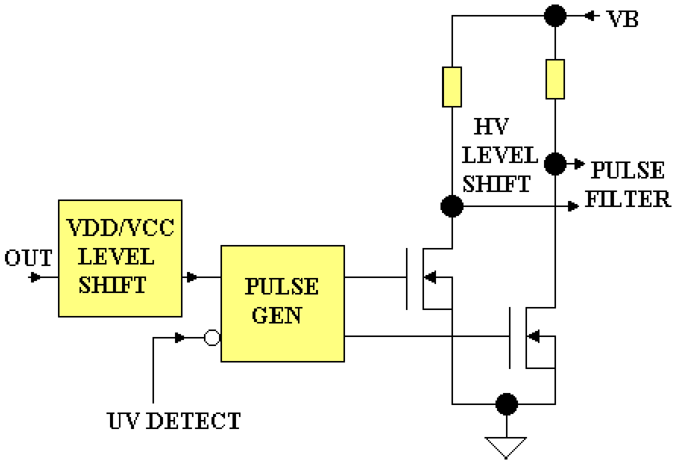


Figure 17 : Functional diagram of the stage of high voltage level shifter

f. *Assembly of application: Command of 2MOSFET*

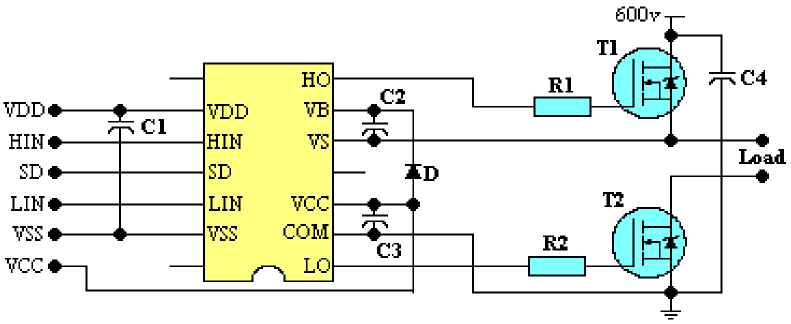


Figure 18 : Typical connection of an IR2113 for the command of 2 MOSFET

In this assembly, the capacitors C1, C2 and C3 provide the filtering of the power supplies V_{DD}, V_{CC} and V_B. The V_{CC} voltage must be between 10V and 20V, the V_{DD} voltage must be between 4.5V and 20V. The supply V_B is derived from V_{CC} by charging C2 through D and Load, when T2 is saturated.

2. Chopper implemented in this project using the IR2113

a. Electric assembly

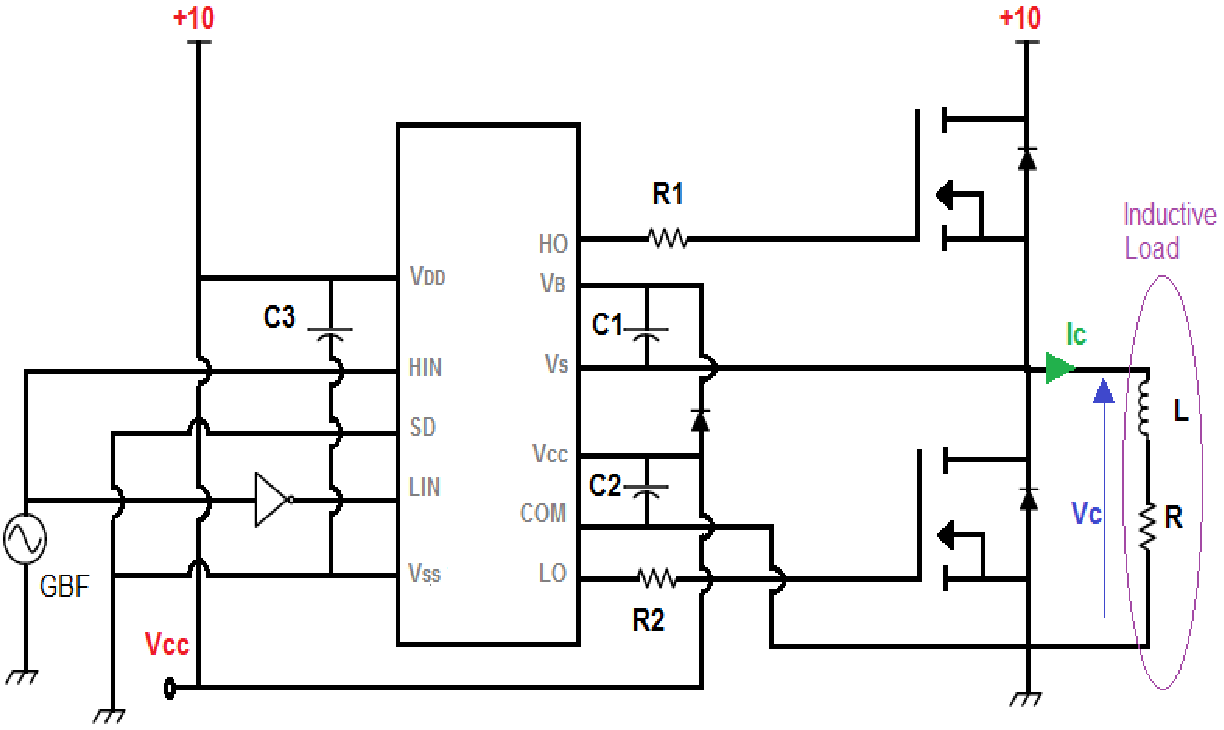


Figure 19 : Schematic of the chopper using the IR2113

b. Components used

To be able to realize this assembly, we needed:

- 1 breadboard;
- 2 transistors MOS SMP60N06-18 (Data sheet in annex);
- 1 function generator (GBF in figure 16): Frequency = 50 kHz and V = 15V;

- 1 DC source E;
- 1 inductive load;
- 1 IR2113 (Data sheet in annex);
- 1 NAND gate;
- 3 capacitors:
  C1 = 0.47 µF
  C2 = 2.2 µF
  C3 = 22 nF;
- 2 resistors:
  R1 = R2 = 22 Ω;
- 1 oscilloscope.

3. <u>Encountered difficulties</u>

a. First difficulty encountered

The IR2113 only works for resistances and capacitors with specific values set at its output and input (C1, C2, C3 and R1). I had a lot of trouble finding the exact values as the ones found on the internet are in general approximate values and the IR2113 works properly only with exact values.

b. Second difficulty encountered

After the IR2113 was successfully operating, we noticed that there was a lot of noise at the output of the chopper. Therefore, we reduced the noise by putting smoothing capacities at the terminals of the source.

4. Function generator and expected results

We apply to the circuit a DC voltage of 10V and we adjust the function generator to have a duty ratio equal to ½ and a frequency of 50 kHz.

As we mentioned at the beginning of this chapter, we should have similar outputs to the ones obtained with the electric assembly of the chopper without the IR2113 (as done in the previous chapter) across the inductive load (similar and not the same as we are applying different DC voltage value to the circuit and we are using a different resistance value for the inductive load) since the IR2113 is controlling the two transistors. Therefore, following the same reasoning as in point 5 of the previous chapter, the expected results should be the following:

- A square and periodic (of period $T = \frac{1}{50}$ = 20 μs) output voltage signal from the chopper (signal across the inductive load) that varies between 0V and 10V;
- An average voltage across the inductive load of value: <v> = α.E = $\frac{10}{2}$ = 5V and an rms voltage across the inductive load of value: Vc = 10 (√½) = 7.07V;
- The shape of the intensity curve of the inductive load must be close to the shape of the intensity curve of the inductive load of the assembly of the chopper without the IR2113 (Figure 8).

5. Results obtained

a. First result

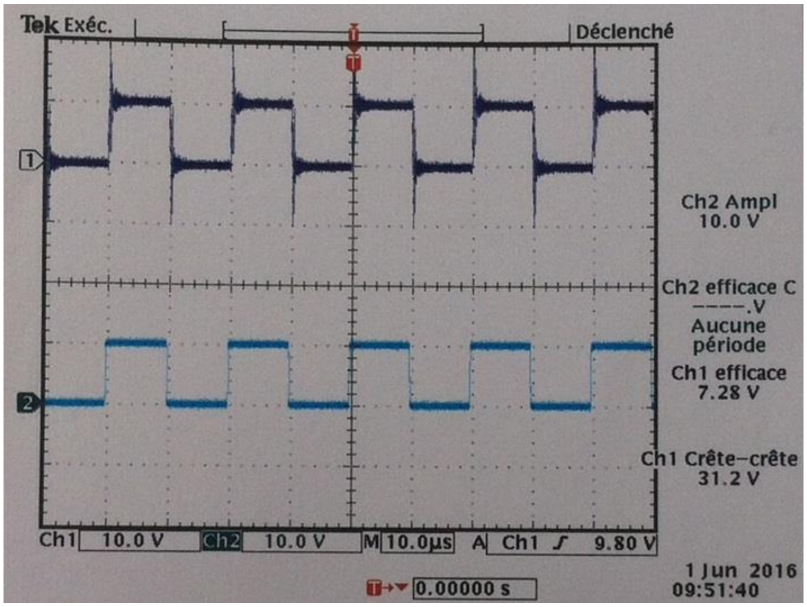


Figure 20 : Voltage across the inductive load (curve in dark blue)

Channel 1 of the oscilloscope: Voltage across the inductive load Vc

Channel 2 of the oscilloscope: Input function generator (HIN)

We obtain a square and periodic, of period T=20 µs, output voltage signal across the inductive load. This voltage signal has approximately an average value of <v>= 5V and an rms value equal to Vc=7.28V. We can thus notice that the results obtained correspond to the ones expected.

By zooming on the voltage signal across the inductive load, we can notice some oscillations. These oscillations are due to the variation of the current in the inductive load.

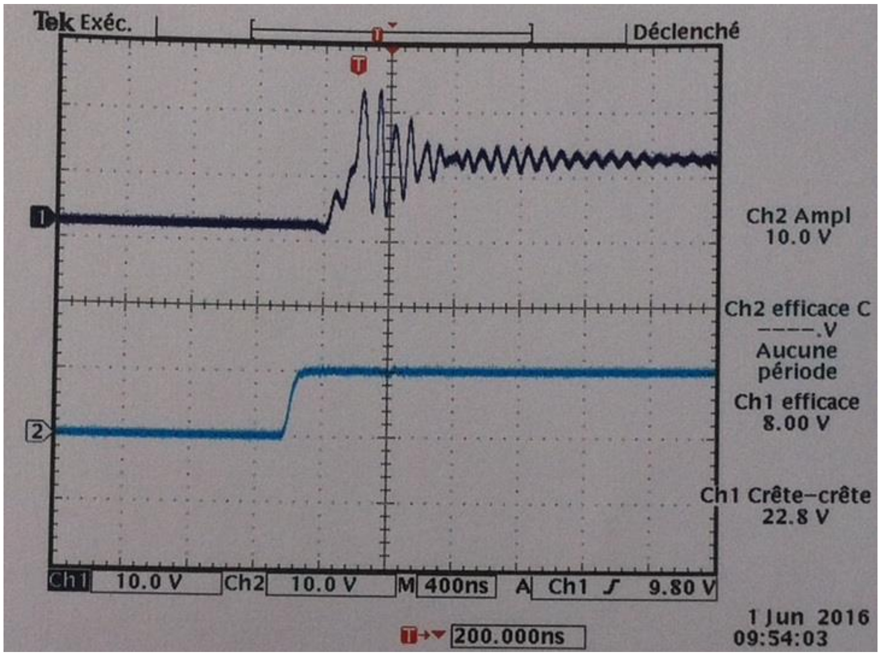


Figure 21 : Some oscillations of the voltage signal across the inductive load (curve in dark blue)

Channel 1 of the oscilloscope: Voltage across the inductive load Vc

Channel 2 of the oscilloscope: Input function generator (HIN)

b. Second result

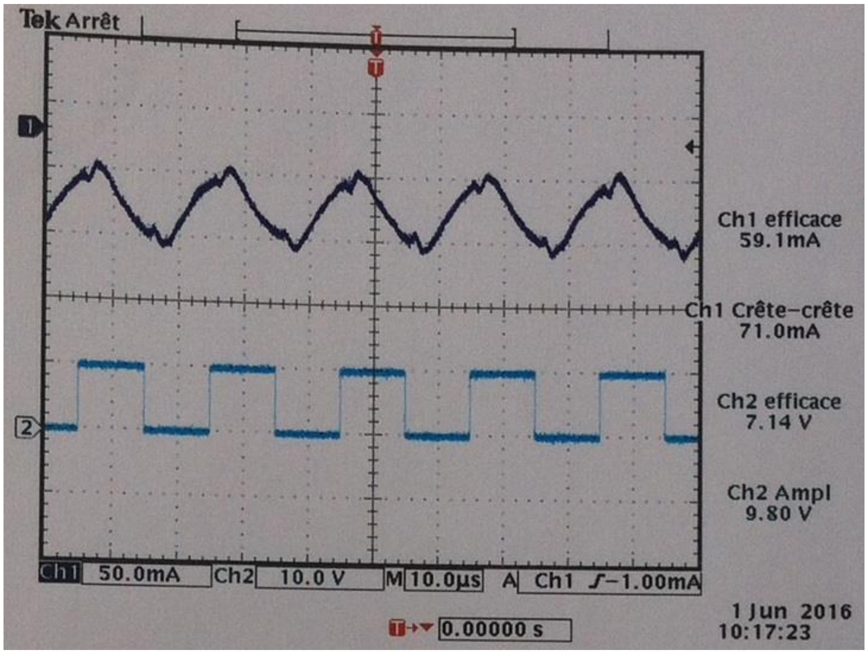


Figure 22 : Intensity of the inductive load (curve in dark blue)

Channel 1 of the oscilloscope: Intensity of the inductive load Ic

Channel 2 of the oscilloscope: Input function generator (HIN)

We obtain the expected shape of the intensity curve of the inductive load.

Chapter III: Final Assembly: The Inverter

In this part of the project, we are going to realize the last assembly of the project: the autonomous inverter that will allow us to supply power to the wireless power transmission system.

For the realization of this inverter, we are going to add an arm to the electric assembly of the chopper realized in the previous chapter. This arm, parallel to the arm formed by the two MOS, will consist of two capacitors. The inductive load will be connected to both arms.

1. Definition of an inverter

An inverter is an electronic device capable of converting electrical energy in continuous form into energy in an alternative form of any frequency.

The inverter is a DC/AC static converter.

Energy sources can be batteries, solar panels, or the EDF (Electricity of France) single or three-phase straightened AC network.

The inverter realized in this stage of the project is an autonomous inverter, an inverter capable of supplying alternative energy for all types of load:

- Capacitive load: the continuous source is of current type (current inverter);
- Inductive load: the continuous source is of voltage type (voltage inverter).

In this part of the project, we are going to realize an autonomous voltage inverter.

2. Single-phase autonomous voltage inverter

a. Structure

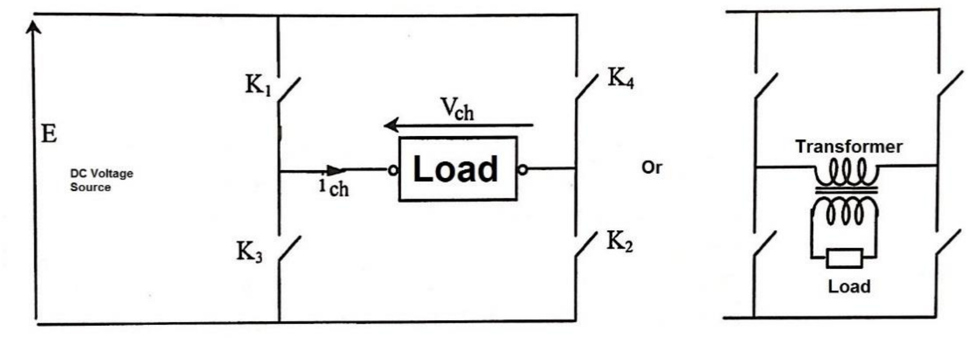


Figure 23 : Structure of a single-phase autonomous voltage inverter

The alternative load can be connected directly at the output of the inverter or, for isolation reasons and (or) for a question of adaptation of electrical quantities, through a transformer.

Within the framework of this project, we are going to work with an inductive load.

The operating rules to follow are:

- Not to short-circuit the power source E, it is prohibited to simultaneously close the two switches of the same arm;
- Not to cause a sudden cancellation of the current in the inductive load, it is essential not to open the switches of the same arm simultaneously. This will have consequences on the realization and the command of switches.

b. Control of the switches

Let T be the period of switching of the switches. In the framework of this project, we are going to use a symmetric control for the switches, that is to say that during half of the period T K_1 and K_2 are closed and during the other half of the period T K_3 and K_4 are closed. This means:

K_1 is closed between 0 and $\frac{T}{2}$, and K_3 is closed between $\frac{T}{2}$ and T;

K_2 is closed between 0 and $\frac{T}{2}$, and K_4 is closed between $\frac{T}{2}$ and T.

- The switches of the same column are controlled in a complementary way.
- The switches of same diagonal are controlled simultaneously.

We thus find the following signals of voltage and current on the inductive load:

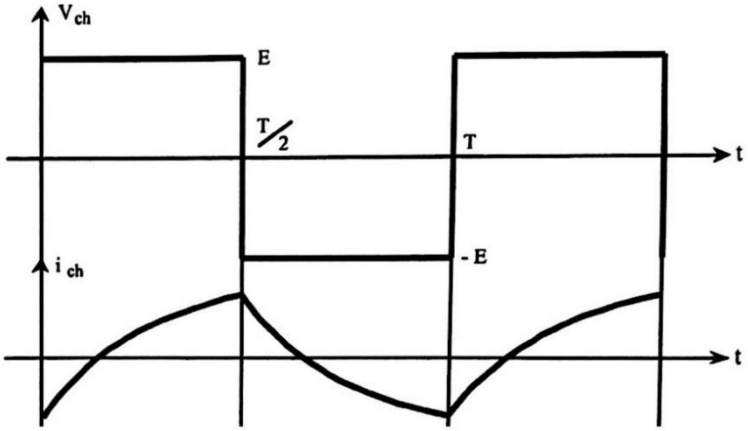


Figure 24 : Voltage and current across the inductive load of a single-phase autonomous voltage inverter with a symmetric control of the switches

The current in the load is calculated using the following equations:

$$E = R.i_{ch} + L.\frac{dich}{dt} \quad \text{for} \quad 0<t<\frac{T}{2},$$

And $$-E=R.i_{ch} + L.\frac{dich}{dt} \quad \text{for} \quad \frac{T}{2}<t<T$$

The autonomous inverter realized in this project is an autonomous capacitor half-bridge voltage inverter.

3. Autonomous capacitor half-bridge voltage inverter

a. Structure

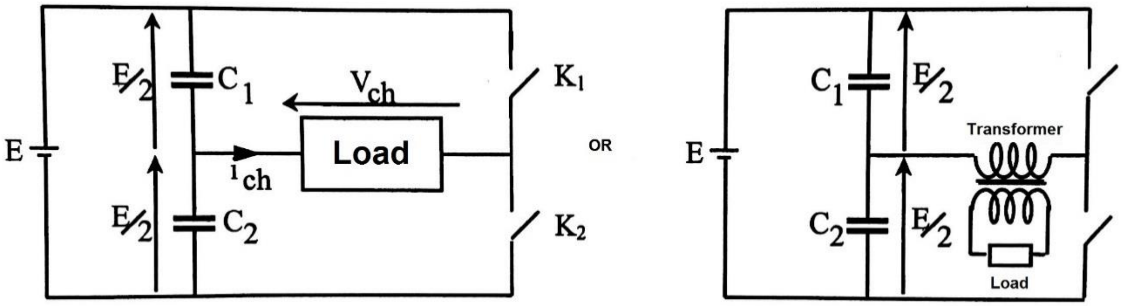


Figure 25 : Structure of an autonomous capacitor half-bridge voltage inverter

In this project, we are going to use, for the switches K_1 and K_2, two transistors.

b. Functioning

Firstly, we will describe the operation of this inverter with a resistive load.

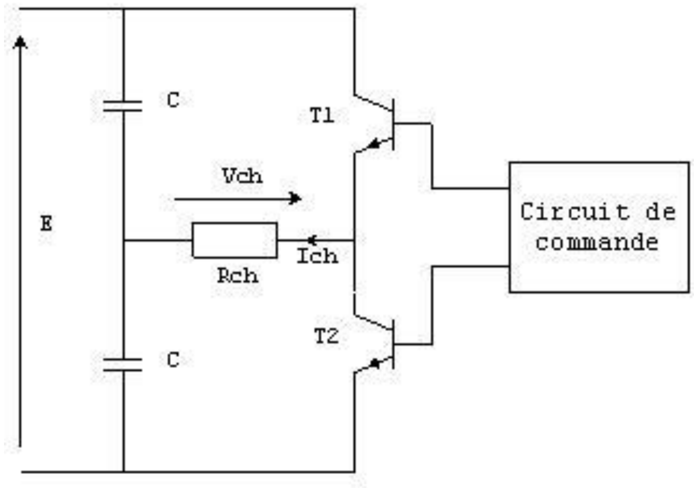


Figure 26 : Structure of an autonomous capacitor half-bridge voltage inverter with a resistive load

The two capacitors form a voltage divider. If their capacity is rather high, the voltage at the terminals of each capacitor is constant and equal to E/2.

The load is a pure resistance.

When the transistor T1 is conducting, the load sees a voltage Vch = E/2.

When the transistor T2 is conducting, the load sees a voltage Vch = -E/2.

Since the control that we are going to use in this project is a symmetric one, the transistors will conduct during the same time interval.

The voltage signal across the load will thus be a rectangular one:

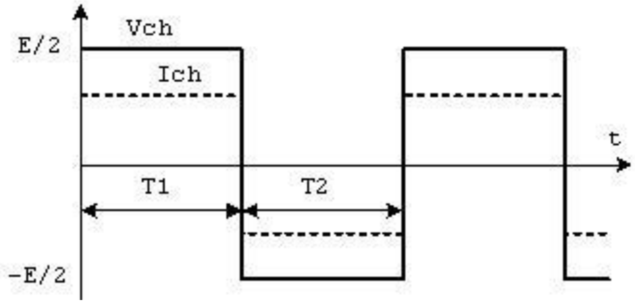


Figure 27 : Voltage across a resistive load of an autonomous capacitor half-bridge voltage inverter

The current Ich has the same shape.

Now we will describe the operation of this inverter with an inductive load.

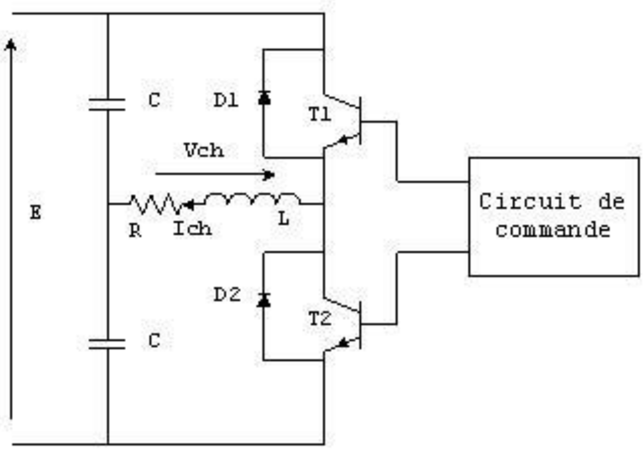


Figure 28 : Structure of an autonomous capacitor half-bridge voltage inverter with an inductive load

Diodes are placed in parallel with the transistors. Their role is to ensure the continuity of the current. Indeed, an inductive load does not support the sudden interruption of current. Thus, after the blocking of T1, the current Ich continues to flow through the diode D2 which conducts spontaneously.

When the transistor T1 is conducting, the load sees a voltage Vch = E/2.

The current Ich grows exponentially according to a time constant.

When the transistor T1 is blocked, the diode D2 begins to conduct to ensure the continuity of the current. The load then sees a voltage Vch = -E/2. The current Ich then decreases. When the current passes through 0, we send a control signal to the base of T2. The diode D2 is blocked and the current Ich continues to grow in the opposite direction.

At the blocking of T2, the diode D1 takes over and the load sees again a voltage Vch = E/2. When the current passes through 0, we conduct T1 and the cycle resumes.

We thus find the following signals of voltage and current on the inductive load:

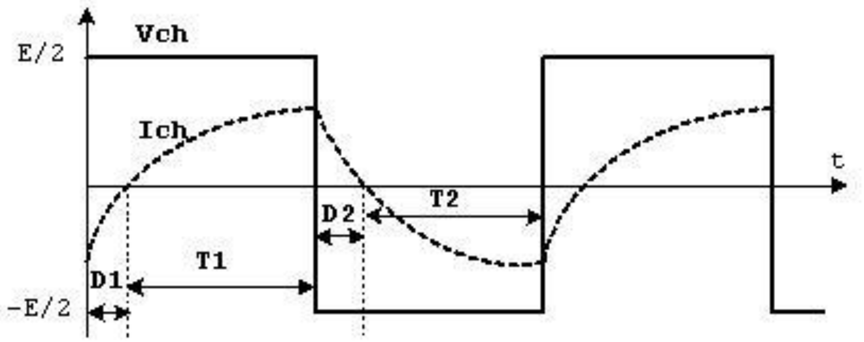


Figure 29 : Voltage and current across an inductive load of an autonomous capacitor half-bridge voltage inverter

In this project, the two transistors used are two MOS SMP60N06-18 (data sheet in the annex) and the command circuit used is the same one that we used in the previous chapter. That is to say, the command circuit formed by the IR2113 (with the resistances and capacitors that permit its good functioning) and the function generator.

4. Inverter realized in this project

a. Electric assembly

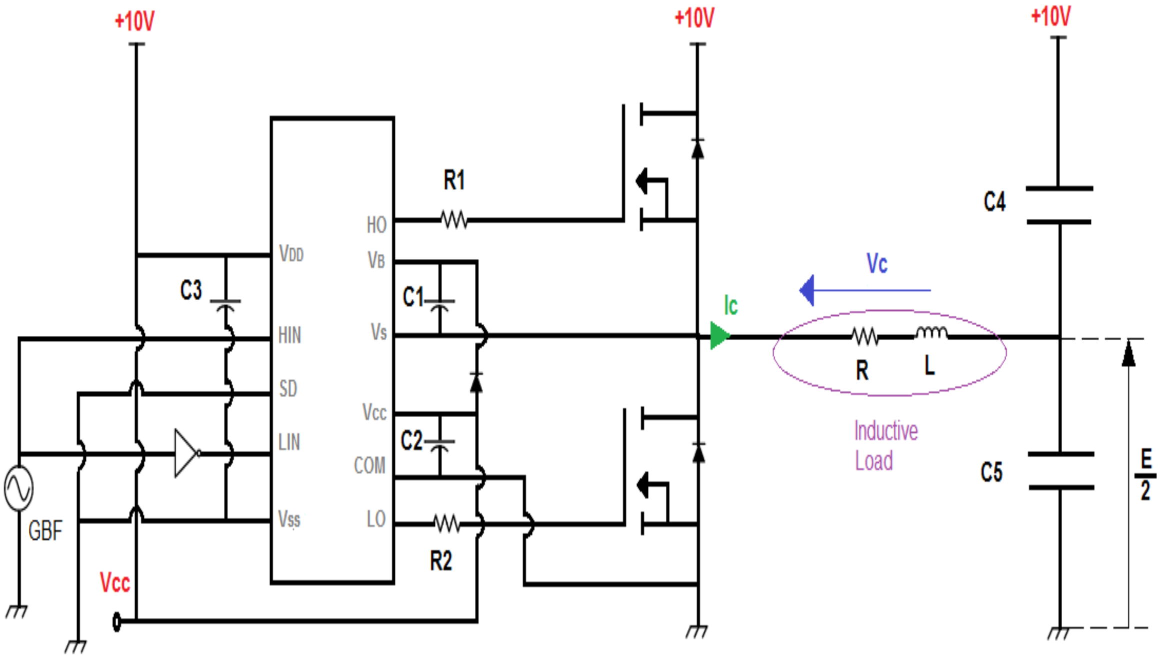


Figure 27 : Schematic of the inverter realized in this project

b. Components used

To be able to realize this assembly, we needed:

- 1 breadboard;
- 2 transistors MOS SMP60N06-18 (Data sheet in annex);
- 1 function generator (GBF in figure 27) : Frequency = 50 kHz and V = 15V;
- 1 DC source E;
- 1 inductive load;
- 1 IR2113 (Data sheet in annex);
- 1 NAND gate;
- 5 capacitors:

  C1 = 0.47 µF

C2 = 2.2 µF
C3 = 22 nF
C4 = 2.2 µF
C5 = 2.2 µF;

- 2 resistors:
  R1 = R2 = 22 Ω;
- 1 oscilloscope.

5. Expected results

We apply to the circuit a DC voltage of 10V and we adjust the function generator to have a duty ratio equal to ½ and a frequency of 50 kHz.

The function generator emits the input signal of the IR2113 which will in turn emit two complementary signals at its output to control the two transistors of the inverter (the operating principles of the IR2113 are described in point 1 of the previous chapter).

By adjusting the function generator to have a duty ratio equal to ½, the signal that the function generator will emit to the IR2113 will be half of its period active and the other half inactive. This leads to a symmetric control of the transistors.

Following the reasoning done in the previous point (point 4) of this chapter and the one done for the functioning of the function generator in point 5 of Chapter I, the expected results should be the following:

- A square, periodic (of period T = $\frac{1}{50}$ = 20 µs) and alternating output voltage signal from the inverter (signal across the inductive load).
  This alternating voltage signal should vary from –5V to +5V. Being a square periodic and alternating voltage signal with a maximum voltage equal to +5V, its rms value should be equal to +5V;
- The shape of the intensity curve of the inductive load must be close to the shape of the intensity curve of the inductive load that is theoretically drawn in the previous point (point 4) of this chapter (Figure 26).

6. Results obtained

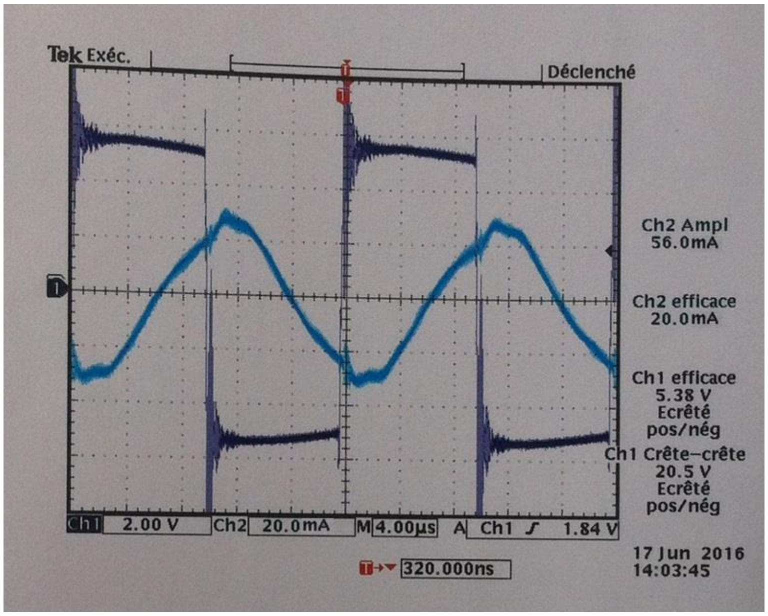


Figure 30 : Voltage (curve in dark blue) and intensity (curve in light blue) across the inductive load

Channel 1 of the oscilloscope: The voltage of the inductive load Vc

Channel 2 of the oscilloscope: The intensity of the inductive load Ic

The voltage across the inductive load is a square, periodic (of period $T = \frac{1}{50} = 20$ µs) and alternating voltage that varies between approximately -5 V and + 5 V (the rms value being equal to +5.38V) which corresponds to what we expected.

We obtain the expected shape of the intensity curve of the inductive load.

Conclusion

We realized in this project an inverter which enables the supply of alternating voltages from a DC voltage source of different voltage and different frequency.

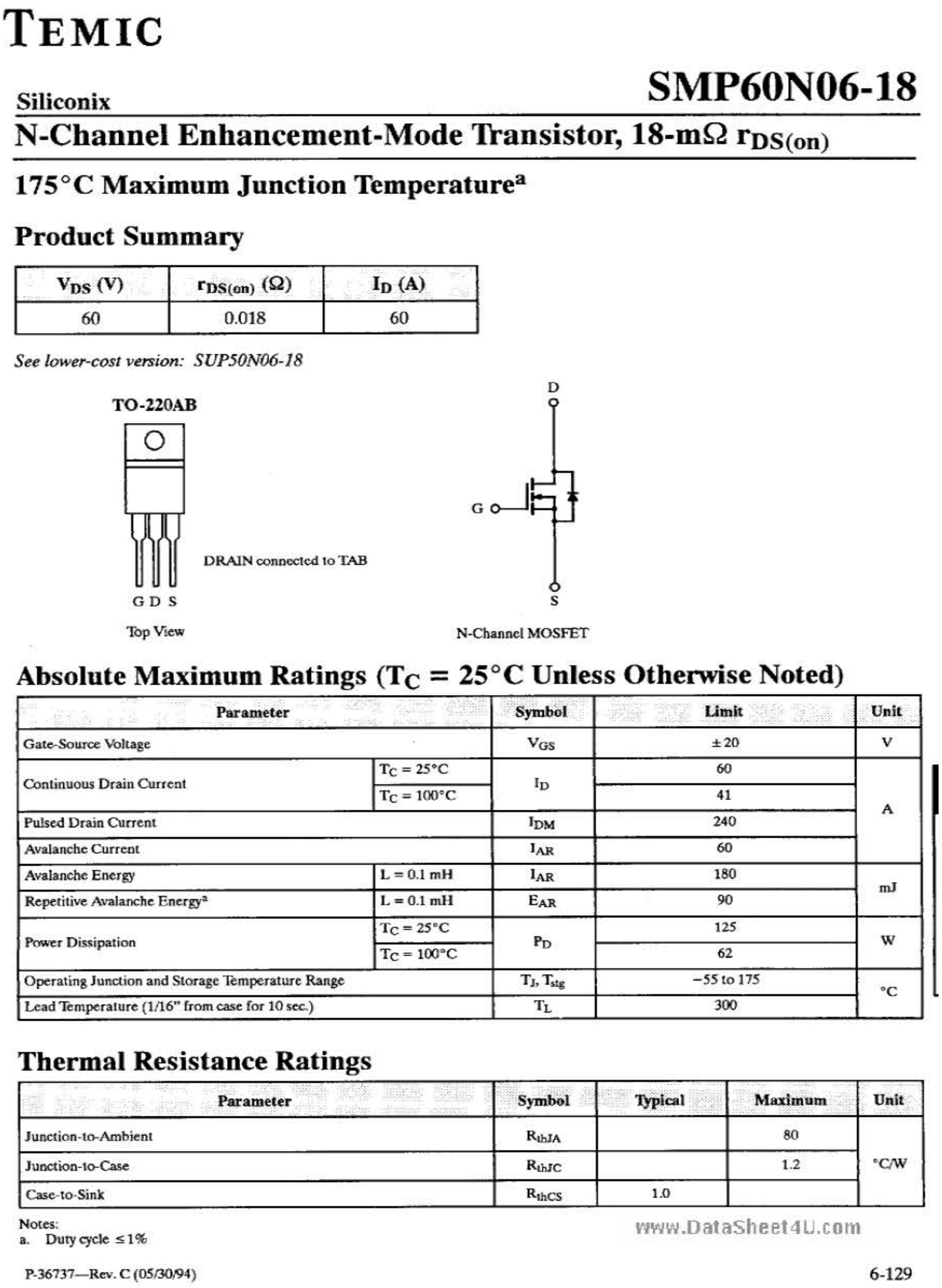
The coupling coefficient, a measure of efficiency of the transmission of energy by magnetic fields using inductive coupling between coils of wire, is lower the more the coils are separated from one another. By using an inverter to generate alternating voltages, from a DC voltage source of different voltage and different frequency, to the transmitter coil of the wireless power transmission system, we can thereby work in the vicinity of the resonance and transfer a significant energy with proper efficiency.

We were able to create a system capable of providing an alternating square voltage signal of desired amplitude and desired frequency from a DC source. To be able to achieve this, we used a symmetric control for both transistors of the power inverter.

By applying the principle of pulse width modulation PWM to the inverter, we will have an alternating sinusoid voltage signal at its output instead of having an alternating square voltage signal at its output; which might be more interesting in some other cases.

ANNEX

ANNEX A : SMP60N06-18



TEMIC

Siliconix

SMP60N06-18

N-Channel Enhancement-Mode Transistor, 18-mΩ $r_{DS(on)}$

175°C Maximum Junction Temperature[a]

Product Summary

V_{DS} (V)	$r_{DS(on)}$ (Ω)	I_D (A)
60	0.018	60

See lower-cost version: SUP50N06-18

Absolute Maximum Ratings (T_C = 25°C Unless Otherwise Noted)

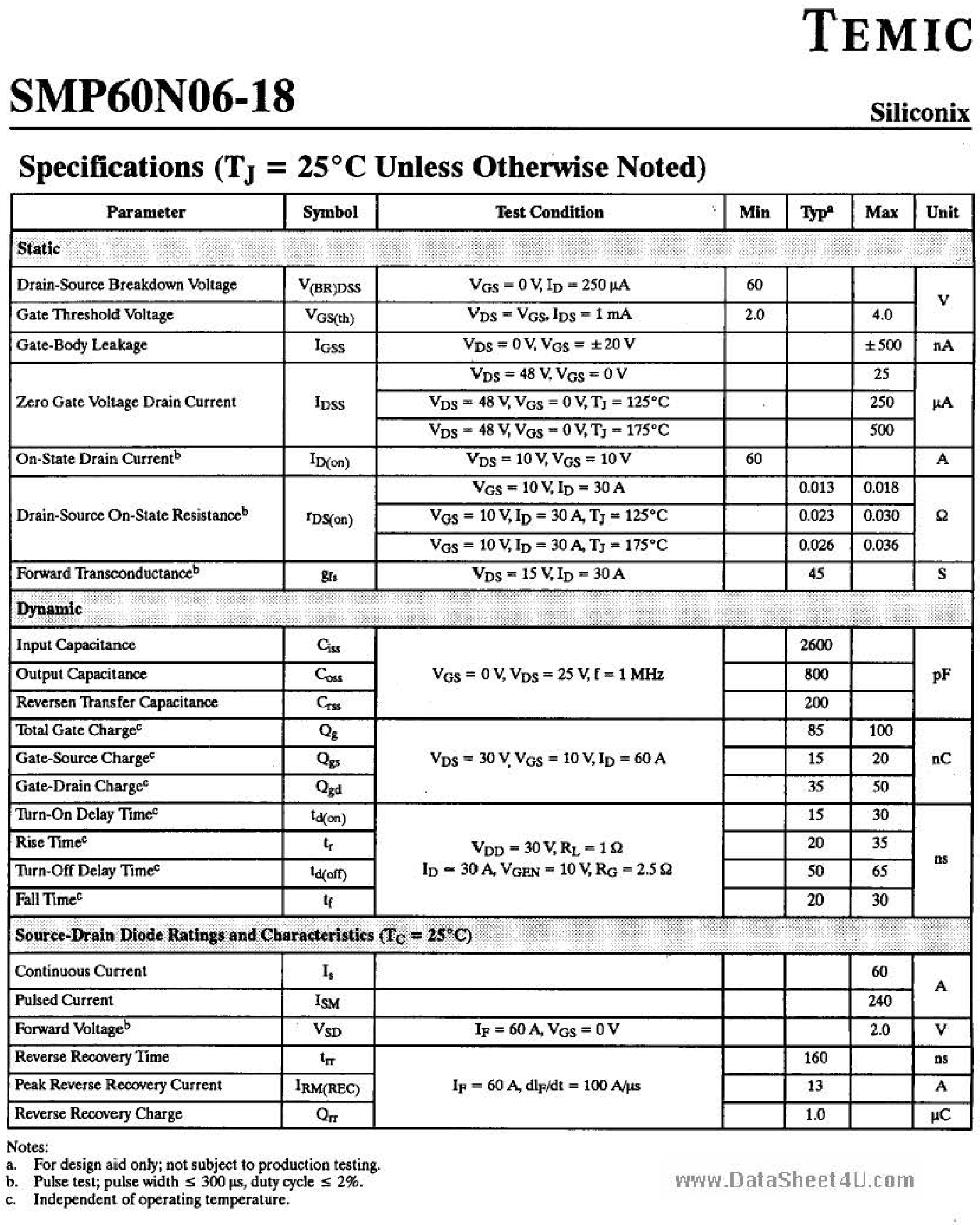
Parameter		Symbol	Limit	Unit
Gate-Source Voltage		V_{GS}	± 20	V
Continuous Drain Current	T_C = 25°C	I_D	60	A
	T_C = 100°C		41	
Pulsed Drain Current		I_{DM}	240	
Avalanche Current		I_{AR}	60	
Avalanche Energy	L = 0.1 mH	I_{AR}	180	mJ
Repetitive Avalanche Energy[a]	L = 0.1 mH	E_{AR}	90	
Power Dissipation	T_C = 25°C	P_D	125	W
	T_C = 100°C		62	
Operating Junction and Storage Temperature Range		T_J, T_{stg}	−55 to 175	°C
Lead Temperature (1/16" from case for 10 sec.)		T_L	300	

Thermal Resistance Ratings

Parameter	Symbol	Typical	Maximum	Unit
Junction-to-Ambient	R_{thJA}		80	°C/W
Junction-to-Case	R_{thJC}		1.2	
Case-to-Sink	R_{thCS}	1.0		

Notes:

a. Duty cycle ≤ 1%



TEMIC

SMP60N06-18

Siliconix

Specifications (T_J = 25°C Unless Otherwise Noted)

Parameter	Symbol	Test Condition	Min	Typ[a]	Max	Unit
Static						
Drain-Source Breakdown Voltage	$V_{(BR)DSS}$	$V_{GS} = 0$ V, $I_D = 250$ µA	60			V
Gate Threshold Voltage	$V_{GS(th)}$	$V_{DS} = V_{GS}$, $I_{DS} = 1$ mA	2.0		4.0	
Gate-Body Leakage	I_{GSS}	$V_{DS} = 0$ V, $V_{GS} = \pm 20$ V			±500	nA
Zero Gate Voltage Drain Current	I_{DSS}	$V_{DS} = 48$ V, $V_{GS} = 0$ V			25	µA
		$V_{DS} = 48$ V, $V_{GS} = 0$ V, $T_J = 125$°C			250	
		$V_{DS} = 48$ V, $V_{GS} = 0$ V, $T_J = 175$°C			500	
On-State Drain Current[b]	$I_{D(on)}$	$V_{DS} = 10$ V, $V_{GS} = 10$ V	60			A
Drain-Source On-State Resistance[b]	$r_{DS(on)}$	$V_{GS} = 10$ V, $I_D = 30$ A		0.013	0.018	Ω
		$V_{GS} = 10$ V, $I_D = 30$ A, $T_J = 125$°C		0.023	0.030	
		$V_{GS} = 10$ V, $I_D = 30$ A, $T_J = 175$°C		0.026	0.036	
Forward Transconductance[b]	g_{fs}	$V_{DS} = 15$ V, $I_D = 30$ A		45		S
Dynamic						
Input Capacitance	C_{iss}	$V_{GS} = 0$ V, $V_{DS} = 25$ V, f = 1 MHz		2600		pF
Output Capacitance	C_{oss}			800		
Reversen Transfer Capacitance	C_{rss}			200		
Total Gate Charge[c]	Q_g	$V_{DS} = 30$ V, $V_{GS} = 10$ V, $I_D = 60$ A		85	100	nC
Gate-Source Charge[c]	Q_{gs}			15	20	
Gate-Drain Charge[c]	Q_{gd}			35	50	
Turn-On Delay Time[c]	$t_{d(on)}$	$V_{DD} = 30$ V, $R_L = 1$ Ω $I_D = 30$ A, $V_{GEN} = 10$ V, $R_G = 2.5$ Ω		15	30	ns
Rise Time[c]	t_r			20	35	
Turn-Off Delay Time[c]	$t_{d(off)}$			50	65	
Fall Time[c]	t_f			20	30	
Source-Drain Diode Ratings and Characteristics (T_C = 25°C)						
Continuous Current	I_s				60	A
Pulsed Current	I_{SM}				240	
Forward Voltage[b]	V_{SD}	$I_F = 60$ A, $V_{GS} = 0$ V			2.0	V
Reverse Recovery Time	t_{rr}	$I_F = 60$ A, $dI_F/dt = 100$ A/µs		160		ns
Peak Reverse Recovery Current	$I_{RM(REC)}$			13		A
Reverse Recovery Charge	Q_{rr}			1.0		µC

Notes:

a. For design aid only; not subject to production testing.

b. Pulse test; pulse width ≤ 300 µs, duty cycle ≤ 2%.

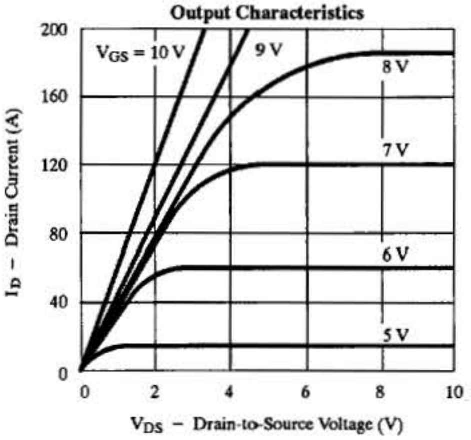
c. Independent of operating temperature.

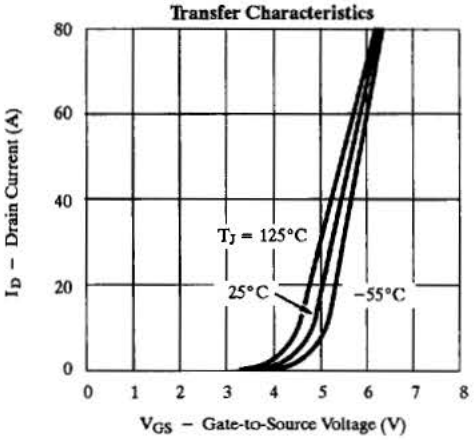
TEMIC

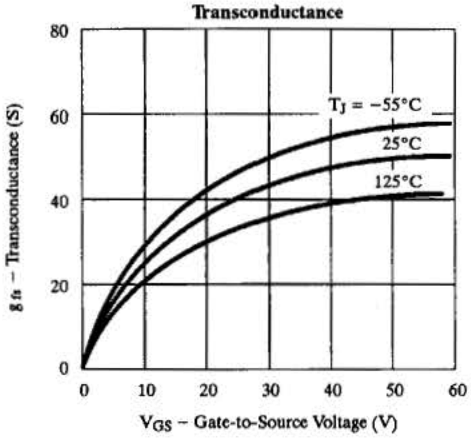
Siliconix

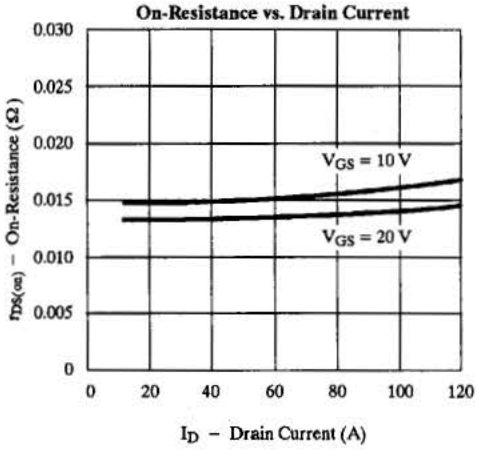
SMP60N06-18

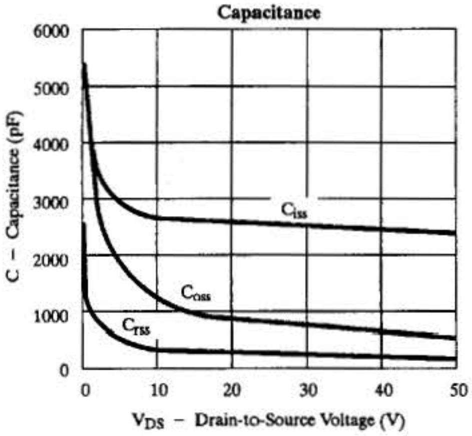
Typical Characteristics (25°C Unless Otherwise Noted)

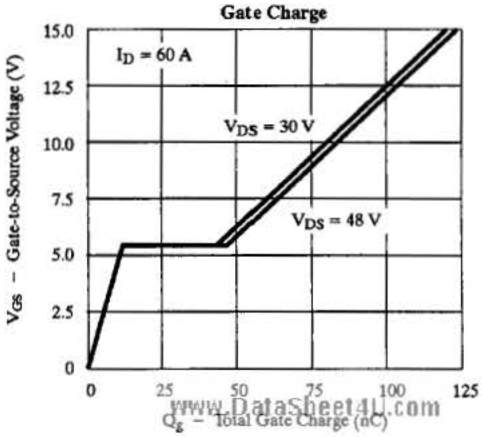

Output Characteristics


Transfer Characteristics


Transconductance

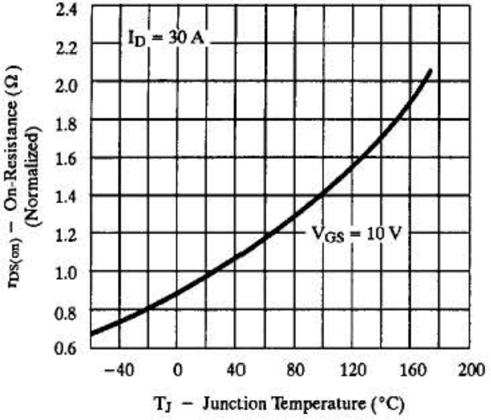

On-Resistance vs. Drain Current


Capacitance

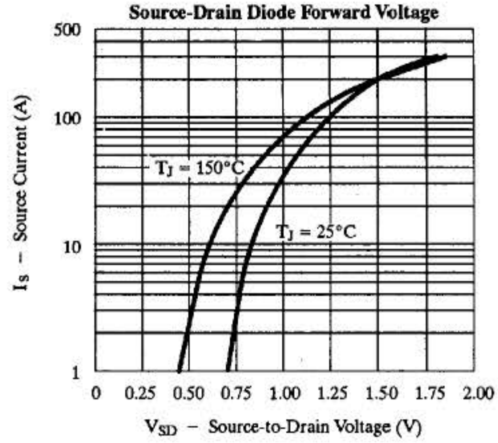

Gate Charge

Typical Characteristics (25°C Unless Otherwise Noted)

On-Resistance vs. Junction Temperature

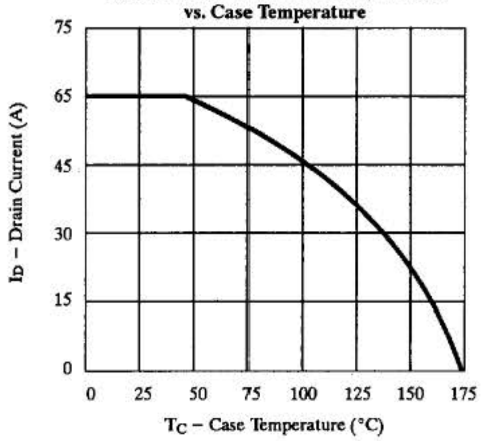


Source-Drain Diode Forward Voltage

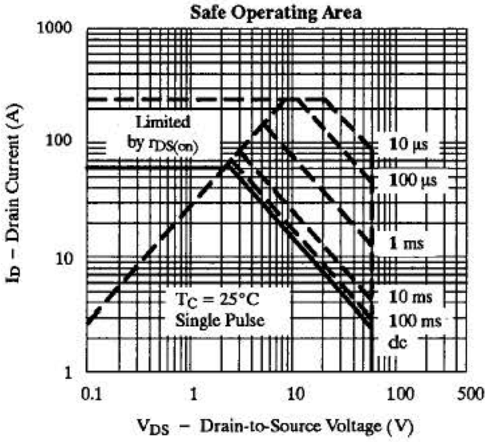


Thermal Ratings

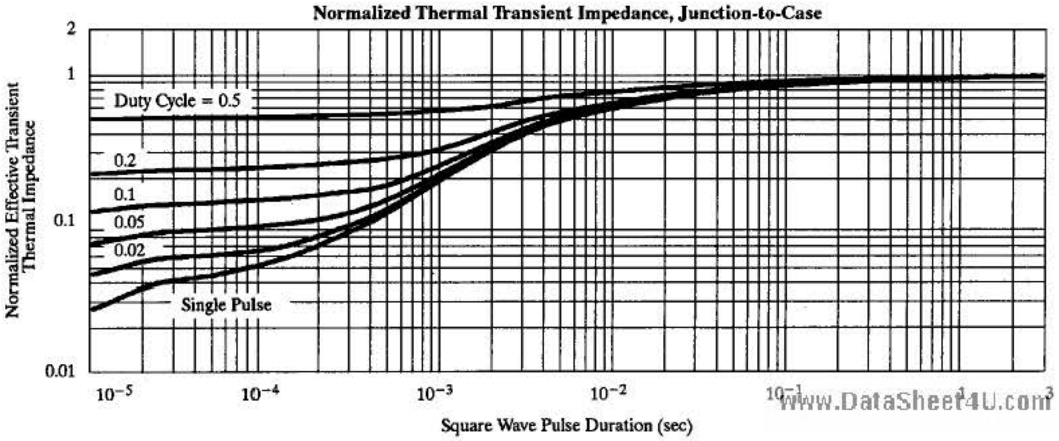
Maximum Avalanche and Drain Current vs. Case Temperature



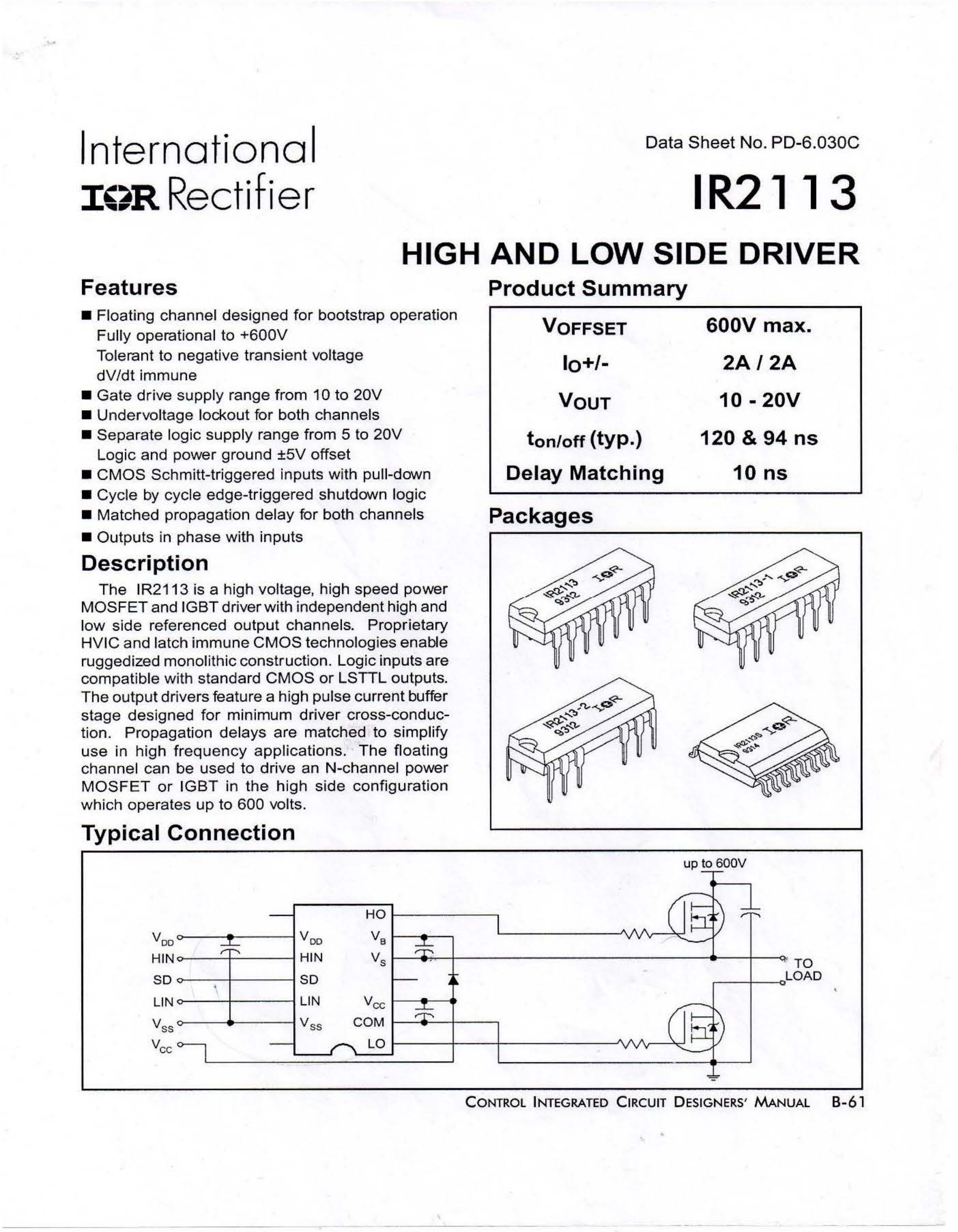
Safe Operating Area



Normalized Thermal Transient Impedance, Junction-to-Case



ANNEX B : IR2113



International
IOR Rectifier

Data Sheet No. PD-6.030C

IR2113

HIGH AND LOW SIDE DRIVER

Features

- Floating channel designed for bootstrap operation
  Fully operational to +600V
  Tolerant to negative transient voltage
  dV/dt immune
- Gate drive supply range from 10 to 20V
- Undervoltage lockout for both channels
- Separate logic supply range from 5 to 20V
  Logic and power ground ±5V offset
- CMOS Schmitt-triggered inputs with pull-down
- Cycle by cycle edge-triggered shutdown logic
- Matched propagation delay for both channels
- Outputs in phase with inputs

Description

The IR2113 is a high voltage, high speed power MOSFET and IGBT driver with independent high and low side referenced output channels. Proprietary HVIC and latch immune CMOS technologies enable ruggedized monolithic construction. Logic inputs are compatible with standard CMOS or LSTTL outputs. The output drivers feature a high pulse current buffer stage designed for minimum driver cross-conduction. Propagation delays are matched to simplify use in high frequency applications. The floating channel can be used to drive an N-channel power MOSFET or IGBT in the high side configuration which operates up to 600 volts.

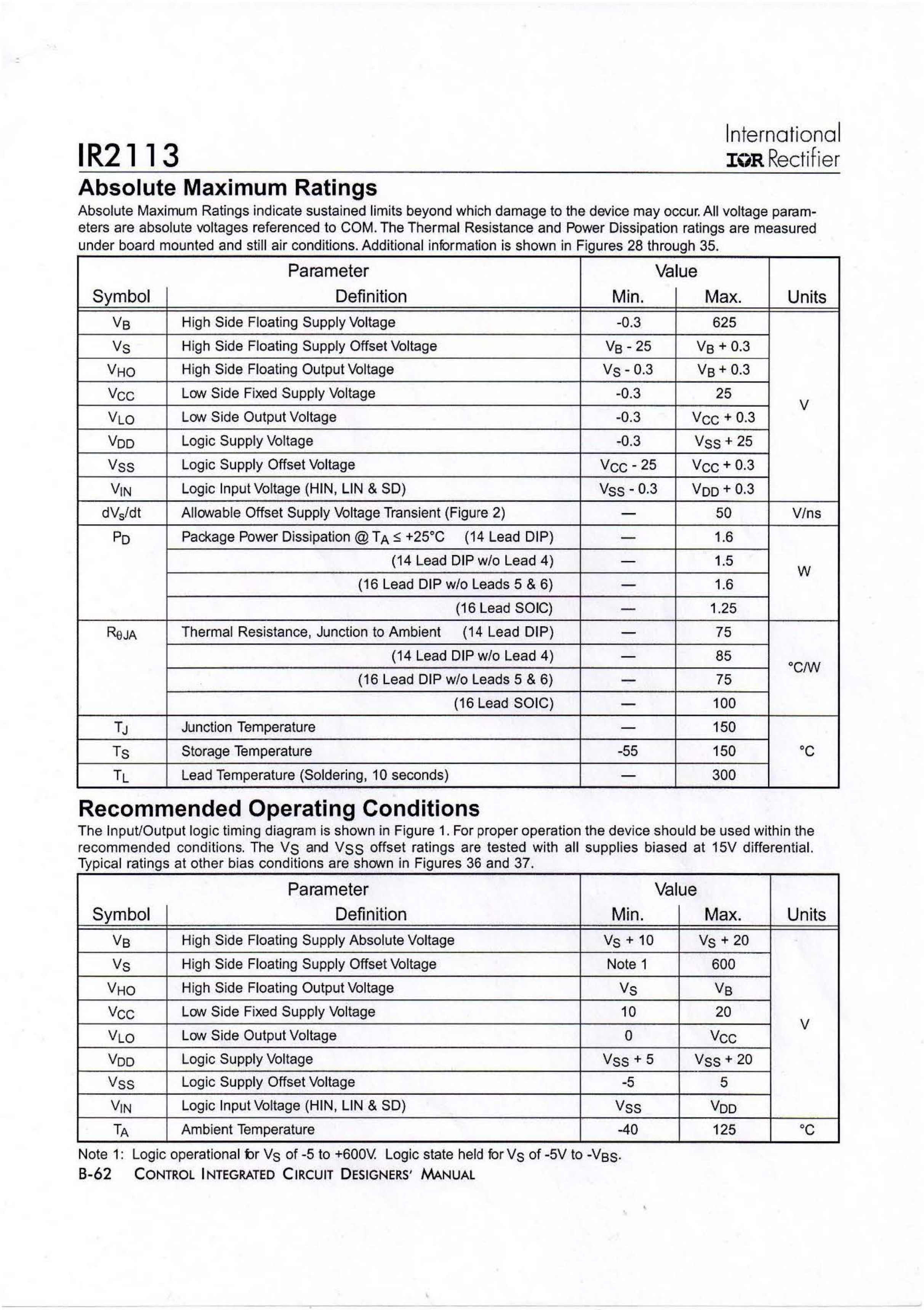
Product Summary

V_{OFFSET}	600V max.
I_O+/-	2A / 2A
V_{OUT}	10 - 20V
$t_{on/off}$ (typ.)	120 & 94 ns
Delay Matching	10 ns

Packages

Typical Connection

CONTROL INTEGRATED CIRCUIT DESIGNERS' MANUAL B-61



IR2113

International
IOR Rectifier

Absolute Maximum Ratings

Absolute Maximum Ratings indicate sustained limits beyond which damage to the device may occur. All voltage parameters are absolute voltages referenced to COM. The Thermal Resistance and Power Dissipation ratings are measured under board mounted and still air conditions. Additional information is shown in Figures 28 through 35.

Symbol	Parameter Definition	Value Min.	Value Max.	Units
V_B	High Side Floating Supply Voltage	-0.3	625	V
V_S	High Side Floating Supply Offset Voltage	V_B - 25	V_B + 0.3	
V_{HO}	High Side Floating Output Voltage	V_S - 0.3	V_B + 0.3	
V_{CC}	Low Side Fixed Supply Voltage	-0.3	25	
V_{LO}	Low Side Output Voltage	-0.3	V_{CC} + 0.3	
V_{DD}	Logic Supply Voltage	-0.3	V_{SS} + 25	
V_{SS}	Logic Supply Offset Voltage	V_{CC} - 25	V_{CC} + 0.3	
V_{IN}	Logic Input Voltage (HIN, LIN & SD)	V_{SS} - 0.3	V_{DD} + 0.3	
dV_s/dt	Allowable Offset Supply Voltage Transient (Figure 2)	—	50	V/ns
P_D	Package Power Dissipation @ $T_A \leq +25°C$ (14 Lead DIP)	—	1.6	W
	(14 Lead DIP w/o Lead 4)	—	1.5	
	(16 Lead DIP w/o Leads 5 & 6)	—	1.6	
	(16 Lead SOIC)	—	1.25	
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient (14 Lead DIP)	—	75	°C/W
	(14 Lead DIP w/o Lead 4)	—	85	
	(16 Lead DIP w/o Leads 5 & 6)	—	75	
	(16 Lead SOIC)	—	100	
T_J	Junction Temperature	—	150	°C
T_S	Storage Temperature	-55	150	
T_L	Lead Temperature (Soldering, 10 seconds)	—	300	

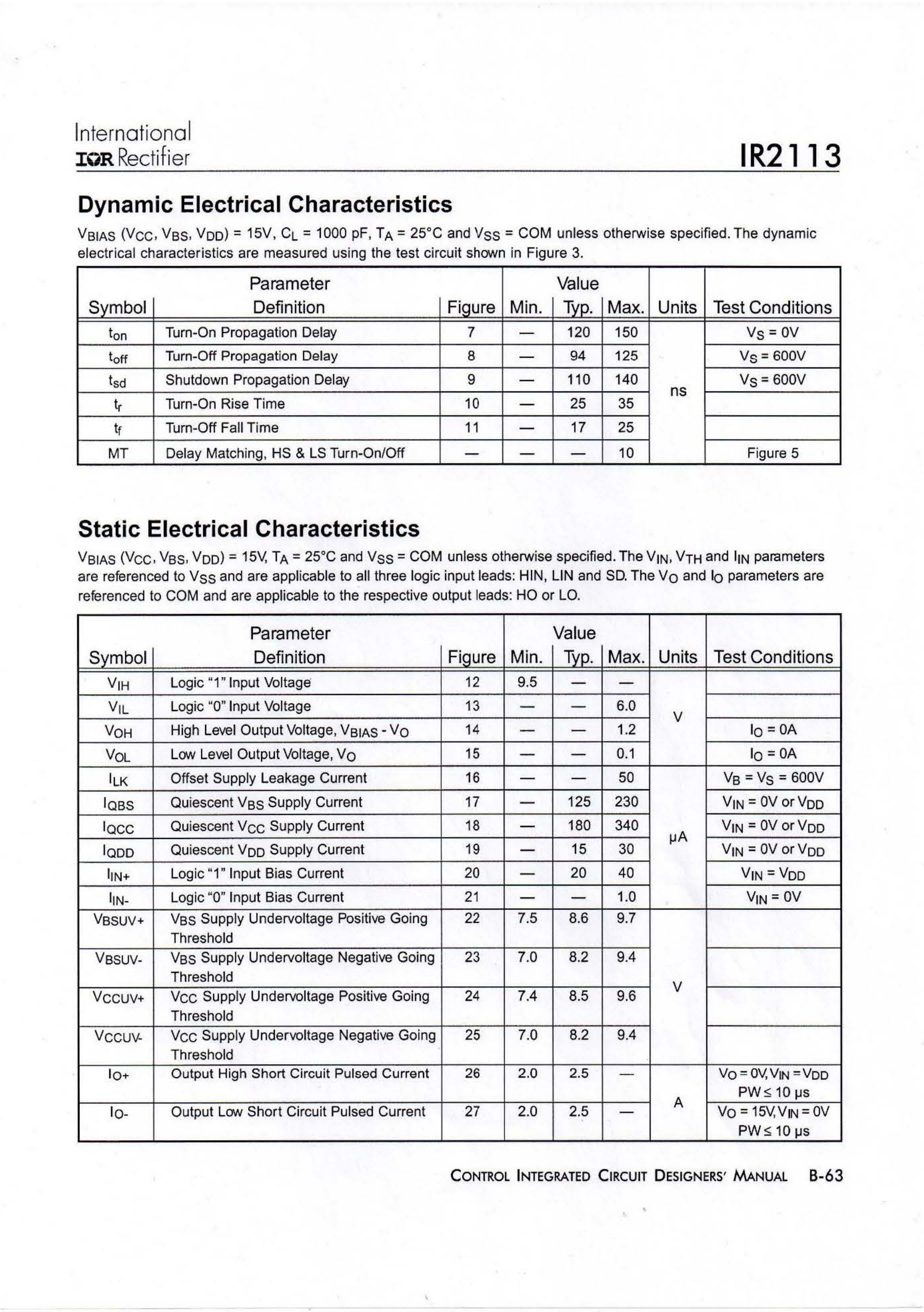
Recommended Operating Conditions

The Input/Output logic timing diagram is shown in Figure 1. For proper operation the device should be used within the recommended conditions. The V_S and V_{SS} offset ratings are tested with all supplies biased at 15V differential. Typical ratings at other bias conditions are shown in Figures 36 and 37.

Symbol	Parameter Definition	Value Min.	Value Max.	Units
V_B	High Side Floating Supply Absolute Voltage	V_S + 10	V_S + 20	V
V_S	High Side Floating Supply Offset Voltage	Note 1	600	
V_{HO}	High Side Floating Output Voltage	V_S	V_B	
V_{CC}	Low Side Fixed Supply Voltage	10	20	
V_{LO}	Low Side Output Voltage	0	V_{CC}	
V_{DD}	Logic Supply Voltage	V_{SS} + 5	V_{SS} + 20	
V_{SS}	Logic Supply Offset Voltage	-5	5	
V_{IN}	Logic Input Voltage (HIN, LIN & SD)	V_{SS}	V_{DD}	
T_A	Ambient Temperature	-40	125	°C

Note 1: Logic operational for V_S of -5 to +600V. Logic state held for V_S of -5V to $-V_{BS}$.

B-62 CONTROL INTEGRATED CIRCUIT DESIGNERS' MANUAL



International
IOR Rectifier

IR2113

Dynamic Electrical Characteristics

V_{BIAS} (V_{CC}, V_{BS}, V_{DD}) = 15V, C_L = 1000 pF, T_A = 25°C and V_{SS} = COM unless otherwise specified. The dynamic electrical characteristics are measured using the test circuit shown in Figure 3.

Symbol	Parameter Definition	Figure	Min.	Typ.	Max.	Units	Test Conditions
t_{on}	Turn-On Propagation Delay	7	—	120	150	ns	V_S = 0V
t_{off}	Turn-Off Propagation Delay	8	—	94	125		V_S = 600V
t_{sd}	Shutdown Propagation Delay	9	—	110	140		V_S = 600V
t_r	Turn-On Rise Time	10	—	25	35		
t_f	Turn-Off Fall Time	11	—	17	25		
MT	Delay Matching, HS & LS Turn-On/Off	—	—	—	10		Figure 5

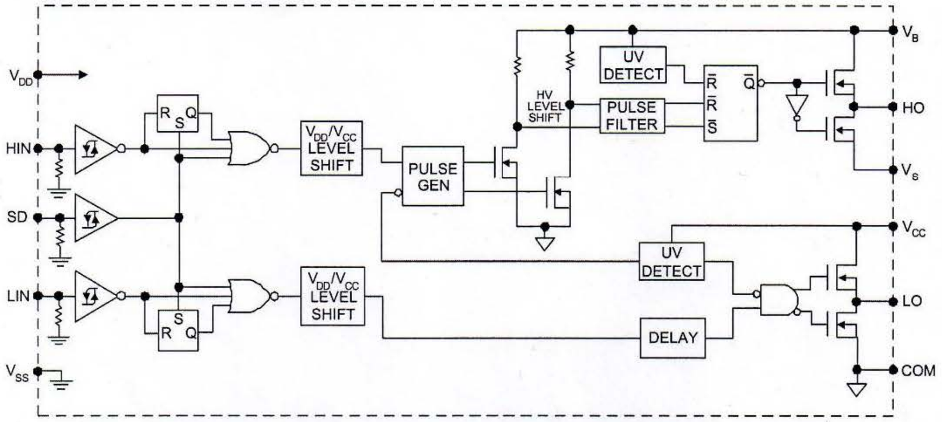
Static Electrical Characteristics

V_{BIAS} (V_{CC}, V_{BS}, V_{DD}) = 15V, T_A = 25°C and V_{SS} = COM unless otherwise specified. The V_{IN}, V_{TH} and I_{IN} parameters are referenced to V_{SS} and are applicable to all three logic input leads: HIN, LIN and SD. The V_O and I_O parameters are referenced to COM and are applicable to the respective output leads: HO or LO.

Symbol	Parameter Definition	Figure	Min.	Typ.	Max.	Units	Test Conditions
V_{IH}	Logic "1" Input Voltage	12	9.5	—	—	V	
V_{IL}	Logic "0" Input Voltage	13	—	—	6.0		
V_{OH}	High Level Output Voltage, V_{BIAS} - V_O	14	—	—	1.2		I_O = 0A
V_{OL}	Low Level Output Voltage, V_O	15	—	—	0.1		I_O = 0A
I_{LK}	Offset Supply Leakage Current	16	—	—	50	µA	V_B = V_S = 600V
I_{QBS}	Quiescent V_{BS} Supply Current	17	—	125	230		V_{IN} = 0V or V_{DD}
I_{QCC}	Quiescent V_{CC} Supply Current	18	—	180	340		V_{IN} = 0V or V_{DD}
I_{QDD}	Quiescent V_{DD} Supply Current	19	—	15	30		V_{IN} = 0V or V_{DD}
I_{IN+}	Logic "1" Input Bias Current	20	—	20	40		V_{IN} = V_{DD}
I_{IN-}	Logic "0" Input Bias Current	21	—	—	1.0		V_{IN} = 0V
V_{BSUV+}	V_{BS} Supply Undervoltage Positive Going Threshold	22	7.5	8.6	9.7	V	
V_{BSUV-}	V_{BS} Supply Undervoltage Negative Going Threshold	23	7.0	8.2	9.4		
V_{CCUV+}	V_{CC} Supply Undervoltage Positive Going Threshold	24	7.4	8.5	9.6		
V_{CCUV-}	V_{CC} Supply Undervoltage Negative Going Threshold	25	7.0	8.2	9.4		
I_{O+}	Output High Short Circuit Pulsed Current	26	2.0	2.5	—	A	V_O = 0V, V_{IN} = V_{DD} PW ≤ 10 µs
I_{O-}	Output Low Short Circuit Pulsed Current	27	2.0	2.5	—		V_O = 15V, V_{IN} = 0V PW ≤ 10 µs

CONTROL INTEGRATED CIRCUIT DESIGNERS' MANUAL B-63

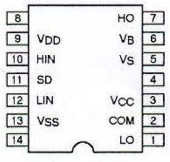
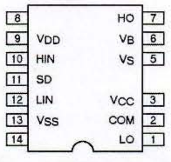
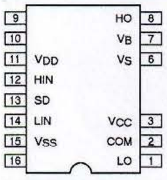
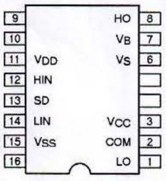
Functional Block Diagram

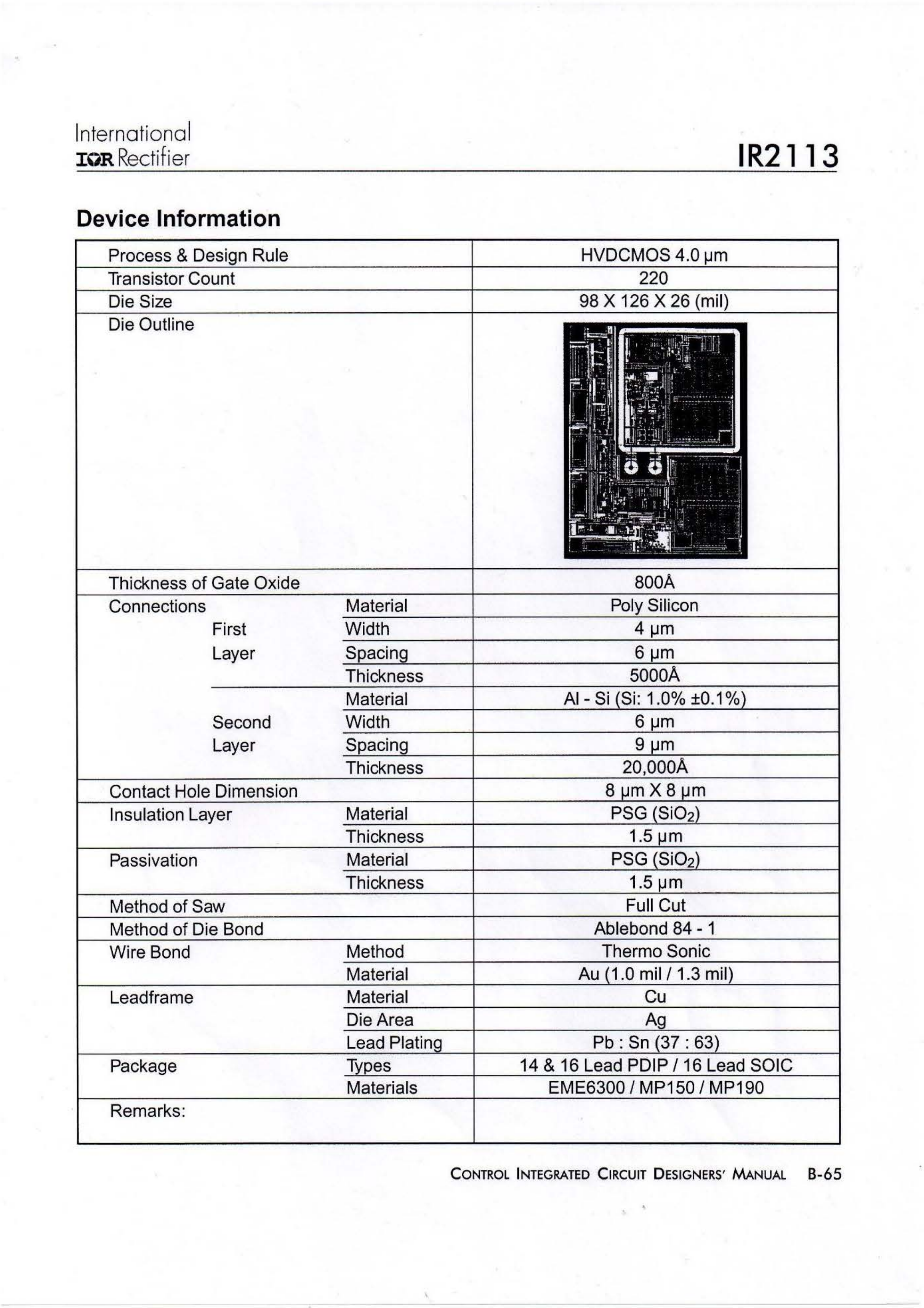


Lead Definitions

Lead Symbol	Description
V_{DD}	Logic supply
HIN	Logic input for high side gate driver output (HO), in phase
SD	Logic input for shutdown
LIN	Logic input for low side gate driver output (LO), in phase
V_{SS}	Logic ground
V_B	High side floating supply
HO	High side gate drive output
V_S	High side floating supply return
V_{CC}	Low side supply
LO	Low side gate drive output
COM	Low side return

Lead Assignments

			
14 Lead DIP	14 Lead DIP w/o Lead 4	16 Lead DIP w/o Leads 4 & 5	16 Lead SOIC (Wide Body)
IR2113	**IR2113-1**	**IR2113-2**	**IR2113S**
Part Number			



Device Information

Process & Design Rule			HVDCMOS 4.0 µm
Transistor Count			220
Die Size			98 X 126 X 26 (mil)
Die Outline			
Thickness of Gate Oxide			800Å
Connections	First Layer	Material	Poly Silicon
		Width	4 µm
		Spacing	6 µm
		Thickness	5000Å
	Second Layer	Material	Al - Si (Si: 1.0% ±0.1%)
		Width	6 µm
		Spacing	9 µm
		Thickness	20,000Å
Contact Hole Dimension			8 µm X 8 µm
Insulation Layer		Material	PSG (SiO_2)
		Thickness	1.5 µm
Passivation		Material	PSG (SiO_2)
		Thickness	1.5 µm
Method of Saw			Full Cut
Method of Die Bond			Ablebond 84 - 1
Wire Bond		Method	Thermo Sonic
		Material	Au (1.0 mil / 1.3 mil)
Leadframe		Material	Cu
		Die Area	Ag
		Lead Plating	Pb : Sn (37 : 63)
Package		Types	14 & 16 Lead PDIP / 16 Lead SOIC
		Materials	EME6300 / MP150 / MP190
Remarks:			

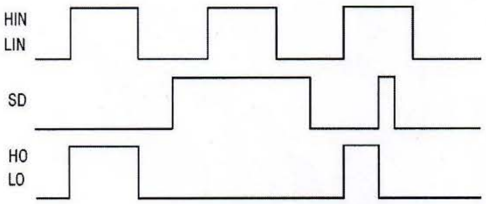


Figure 1. Input/Output Timing Diagram

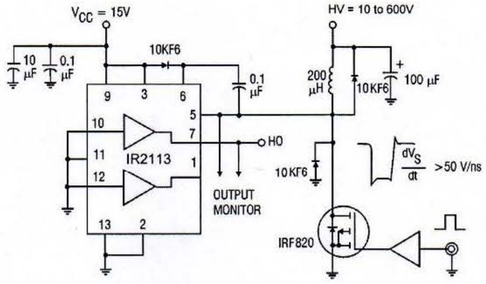


Figure 2. Floating Supply Voltage Transient Test Circuit

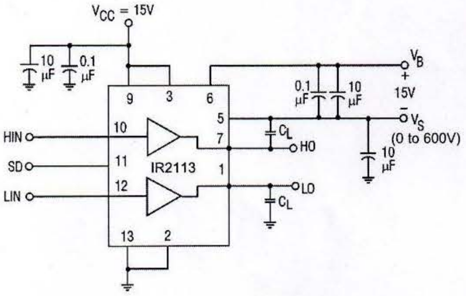


Figure 3. Switching Time Test Circuit

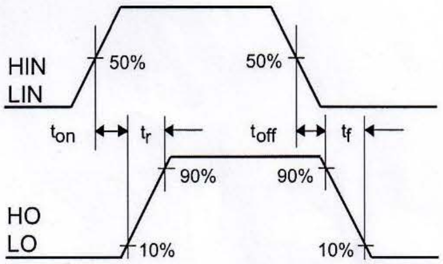


Figure 4. Switching Time Waveform Definition

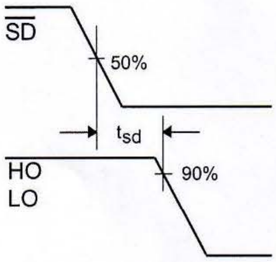


Figure 3. Shutdown Waveform Definitions

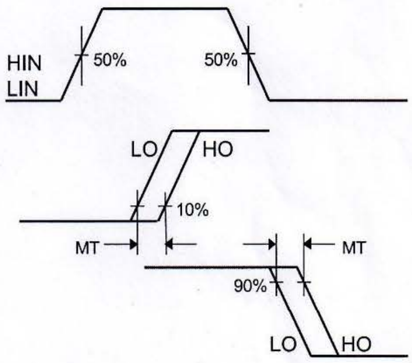


Figure 6. Delay Matching Waveform Definitions

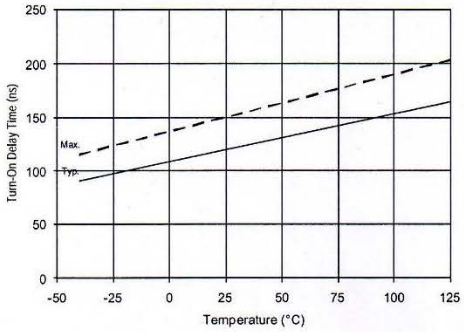


Figure 7A. Turn-On Time vs. Temperature

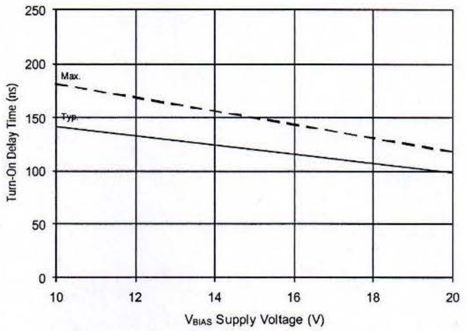


Figure 7B. Turn-On Time vs. Voltage

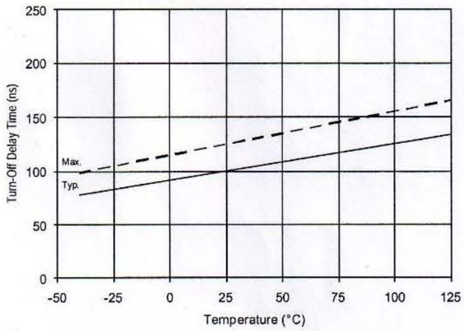


Figure 8A. Turn-Off Time vs. Temperature

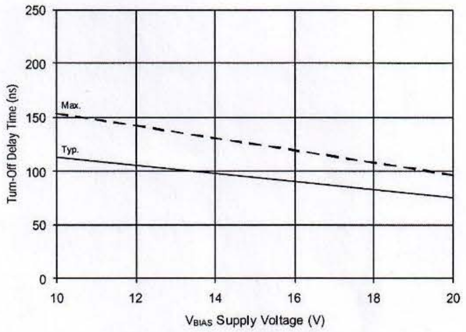


Figure 8B. Turn-Off Time vs. Voltage

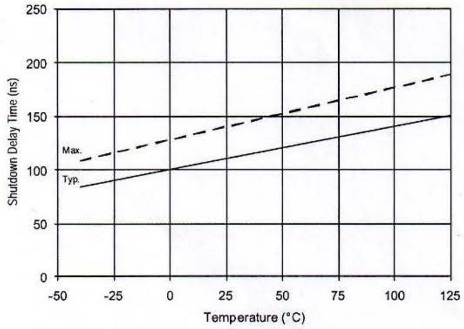


Figure 9A. Shutdown Time vs. Temperature

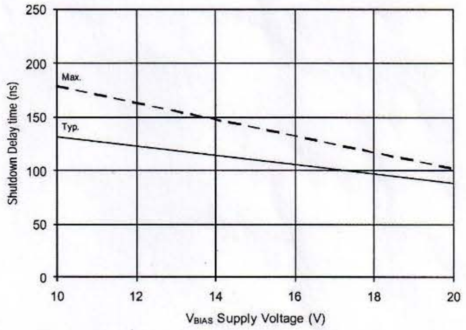


Figure 9B. Shutdown Time vs. Voltage

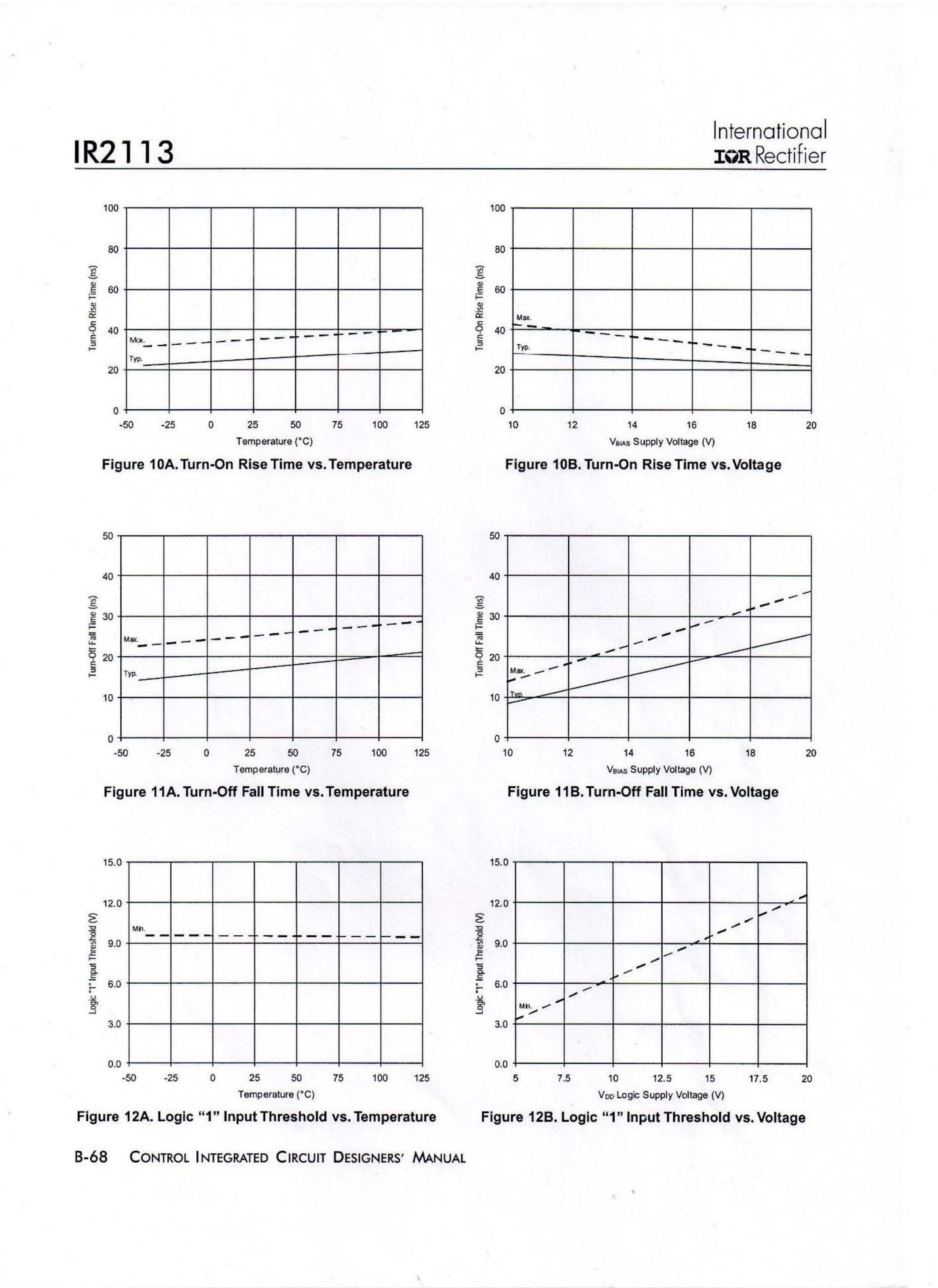


Figure 10A. Turn-On Rise Time vs. Temperature

Figure 10B. Turn-On Rise Time vs. Voltage

Figure 11A. Turn-Off Fall Time vs. Temperature

Figure 11B. Turn-Off Fall Time vs. Voltage

Figure 12A. Logic "1" Input Threshold vs. Temperature

Figure 12B. Logic "1" Input Threshold vs. Voltage

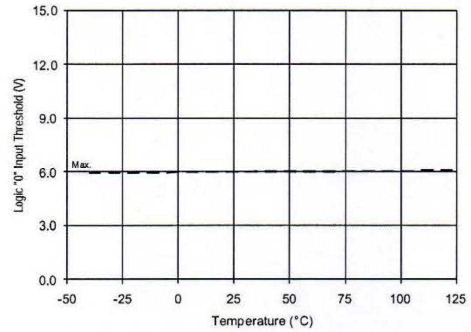


Figure 13A. Logic "0" Input Threshold vs. Temperature

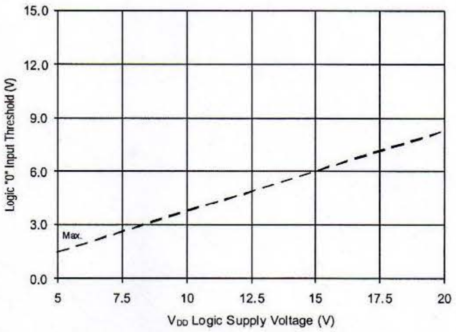


Figure 13B. Logic "0" Input Threshold vs. Voltage

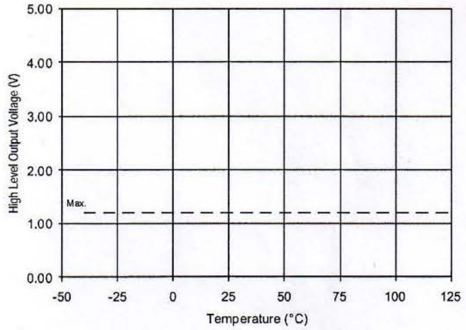


Figure 14A. High Level Output vs. Temperature

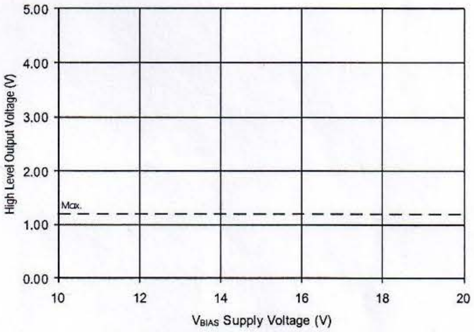


Figure 14B. High Level Output vs. Voltage

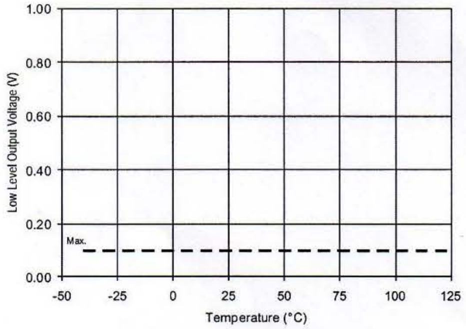


Figure 15A. Low Level Output vs. Temperature

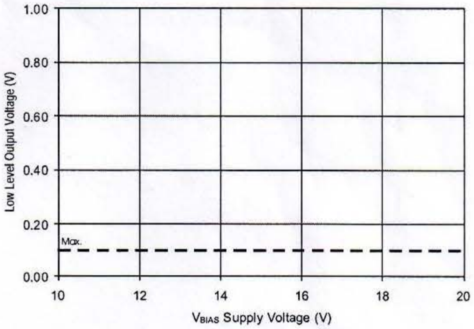


Figure 15B. Low Level Output vs. Voltage

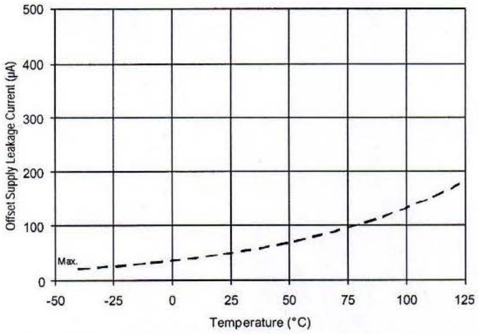


Figure 16A. Offset Supply Current vs. Temperature

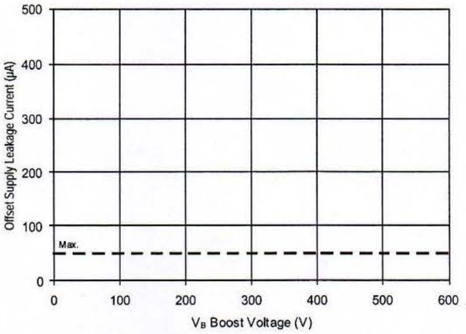


Figure 16B. Offset Supply Current vs. Voltage

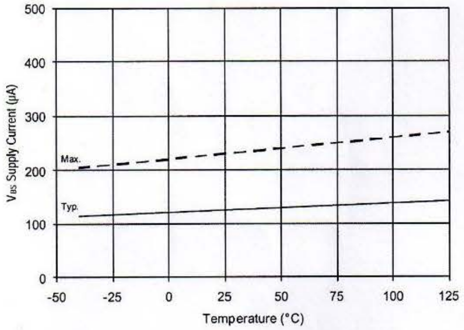


Figure 17A. V_{BS} Supply Current vs. Temperature

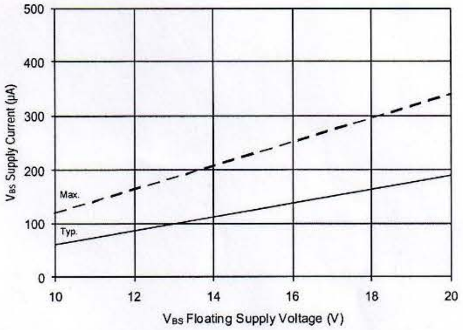


Figure 17B. V_{BS} Supply Current vs. Voltage

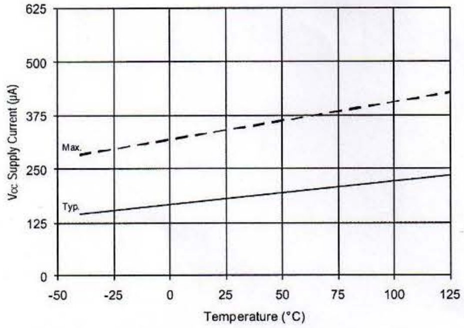


Figure 18A. V_{CC} Supply Current vs. Temperature

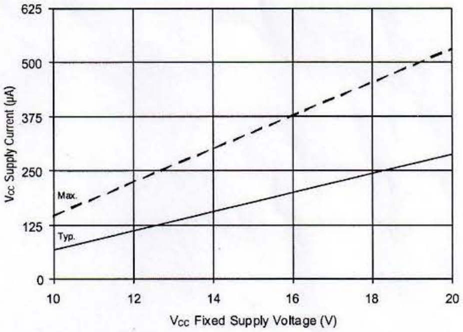


Figure 18B. V_{CC} Supply Current vs. Voltage

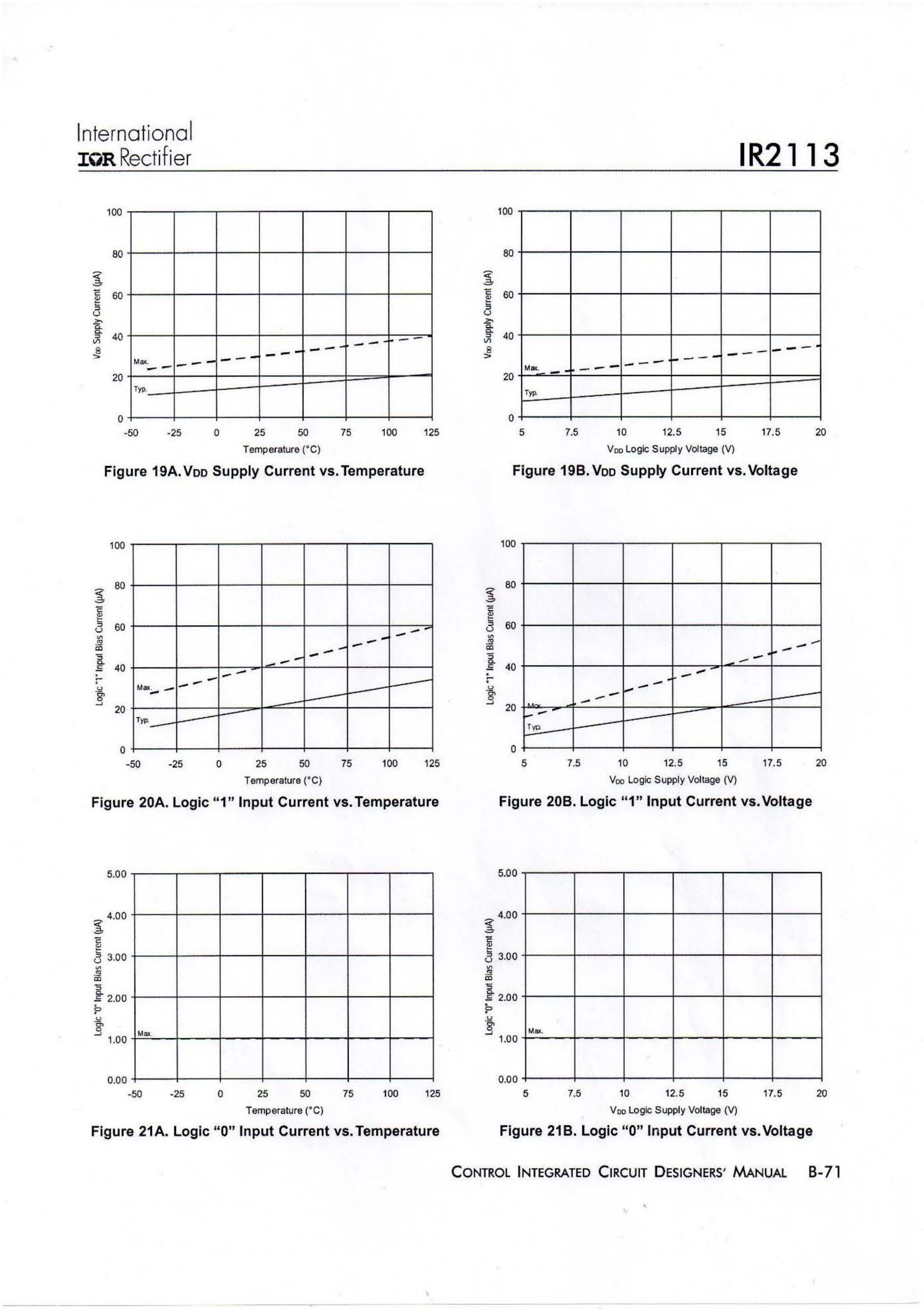


Figure 19A. VDD Supply Current vs. Temperature

Figure 19B. VDD Supply Current vs. Voltage

Figure 20A. Logic "1" Input Current vs. Temperature

Figure 20B. Logic "1" Input Current vs. Voltage

Figure 21A. Logic "0" Input Current vs. Temperature

Figure 21B. Logic "0" Input Current vs. Voltage

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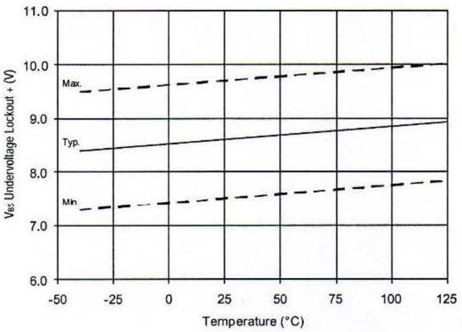

Figure 22. V_{BS} Undervoltage (+) vs. Temperature

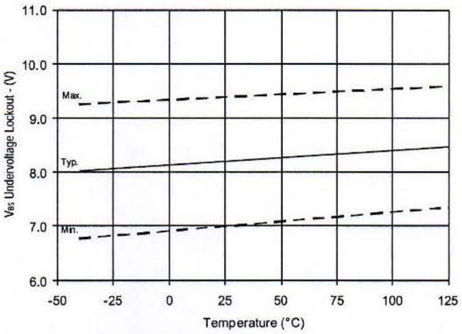

Figure 23. V_{BS} Undervoltage (-) vs. Temperature

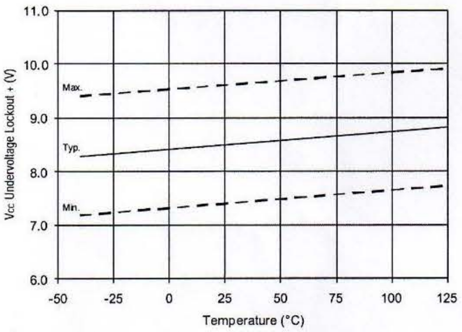

Figure 24. V_{CC} Undervoltage (+) vs. Temperature

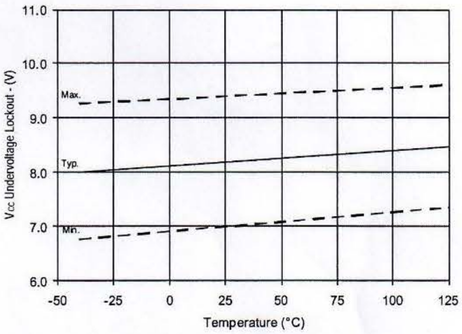

Figure 25. V_{CC} Undervoltage (-) vs. Temperature

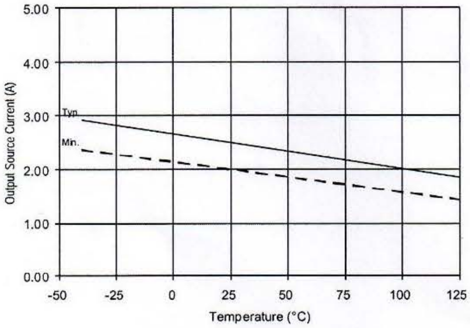

Figure 26A. Output Source Current vs. Temperature

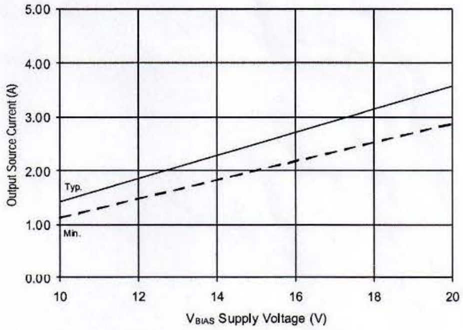

Figure 26B. Output Source Current vs. Voltage

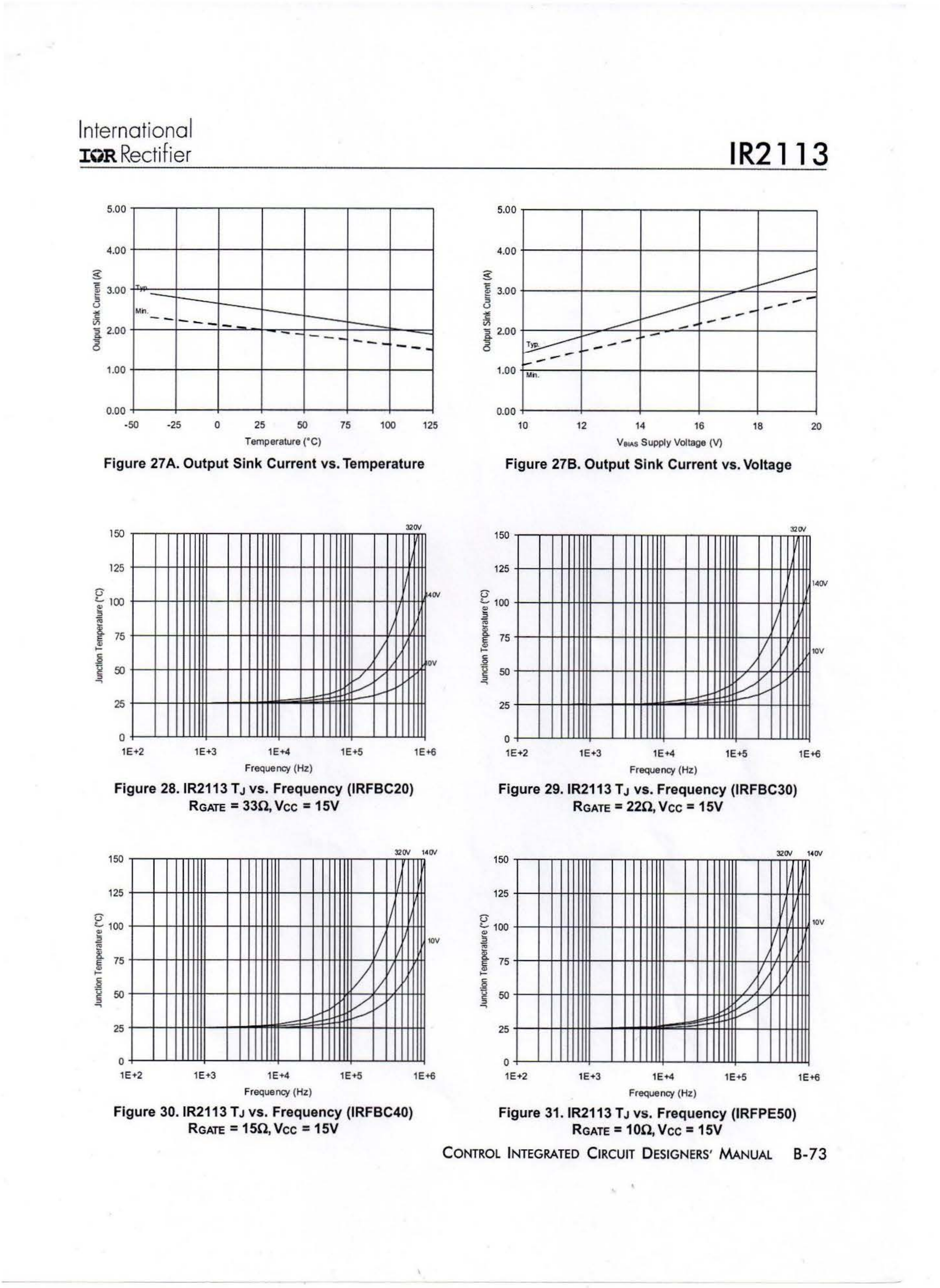

Figure 27A. Output Sink Current vs. Temperature

Figure 27B. Output Sink Current vs. Voltage

Figure 28. IR2113 T_J vs. Frequency (IRFBC20)
R_{GATE} = 33Ω, V_{CC} = 15V

Figure 29. IR2113 T_J vs. Frequency (IRFBC30)
R_{GATE} = 22Ω, V_{CC} = 15V

Figure 30. IR2113 T_J vs. Frequency (IRFBC40)
R_{GATE} = 15Ω, V_{CC} = 15V

Figure 31. IR2113 T_J vs. Frequency (IRFPE50)
R_{GATE} = 10Ω, V_{CC} = 15V

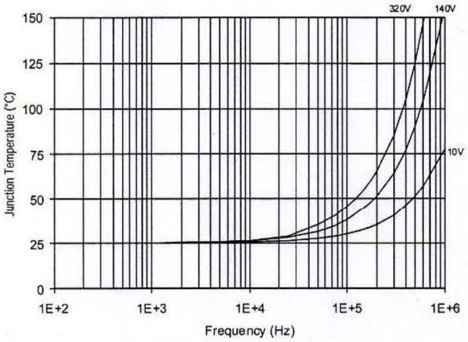

**Figure 32. IR2113S T_J vs. Frequency (IRFBC20)
R_{GATE} = 33Ω, V_{CC} = 15V**

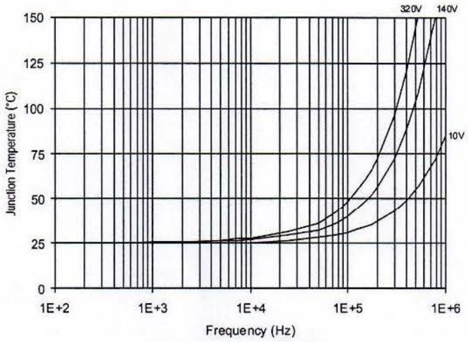

**Figure 33. IR2113S T_J vs. Frequency (IRFBC30)
R_{GATE} = 22Ω, V_{CC} = 15V**

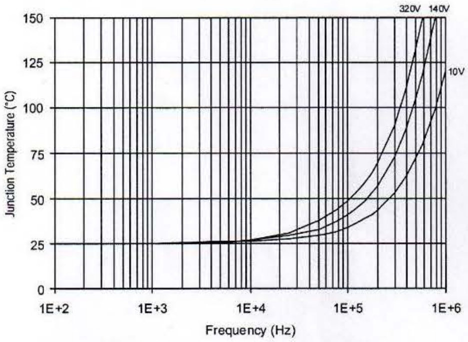

**Figure 34. IR2113S T_J vs. Frequency (IRFBC40)
R_{GATE} = 15Ω, V_{CC} = 15V**

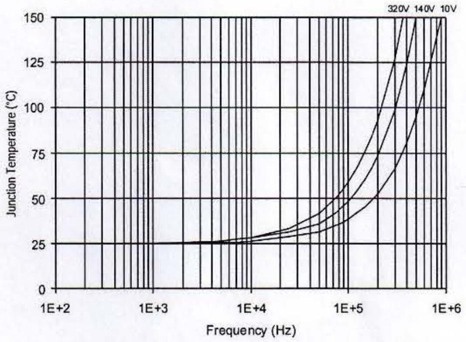

**Figure 35. IR2113S T_J vs. Frequency (IRFPE50)
R_{GATE} = 10Ω, V_{CC} = 15V**

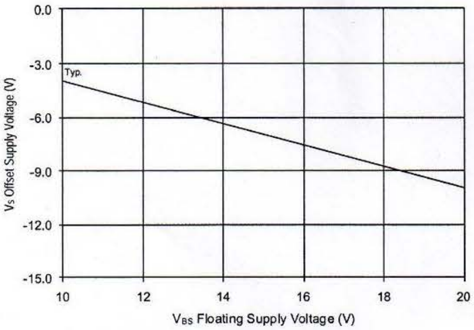

**Figure 36. Maximum V_S Negative Offset vs.
V_{BS} Supply Voltage**

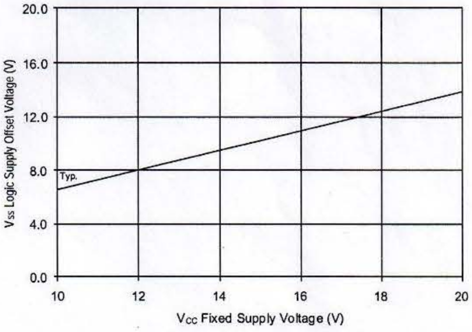

**Figure 37. Maximum V_{SS} Positive Offset vs.
V_{CC} Supply Voltage**

Annex

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