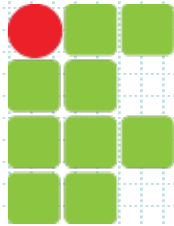


Instituto Federal de Educação, Ciência e Tecnologia de Santa Catarina

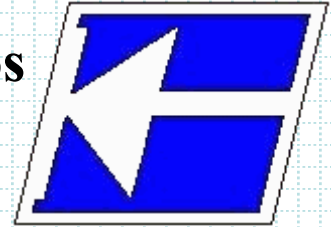
Departamento Acadêmico de Eletrônica

Pós-Graduação em Desen. de Produtos Eletrônicos

Processamento Eletrônico de Energia



**INSTITUTO FEDERAL
SANTA CATARINA**



Introdução à Eletrônica de Potência

**Prof. Clóvis Antônio Petry.
Prof. Mauro Tavares Peraça.**

Florianópolis, outubro de 2015.

Agenda para esta aula

Parte 1 (19h até 20h):

- Exposição inicial sobre introdução à eletrônica de potência.

Intervalo

Parte 2 (20h20min até 22h):

- Ferramentas de projeto em eletrônica de potência;
- Tecnologias de componentes eletrônicos.

Parte 3 (22h até 22h20min):

- Acesso ao moodle e trabalho individual.

Agenda para esta aula

Parte 1 (19h até 20h):

- Exposição inicial sobre introdução à eletrônica de potência.

Intervalo

Parte 2 (20h20min até 22h):

- Ferramentas de projeto em eletrônica de potência;
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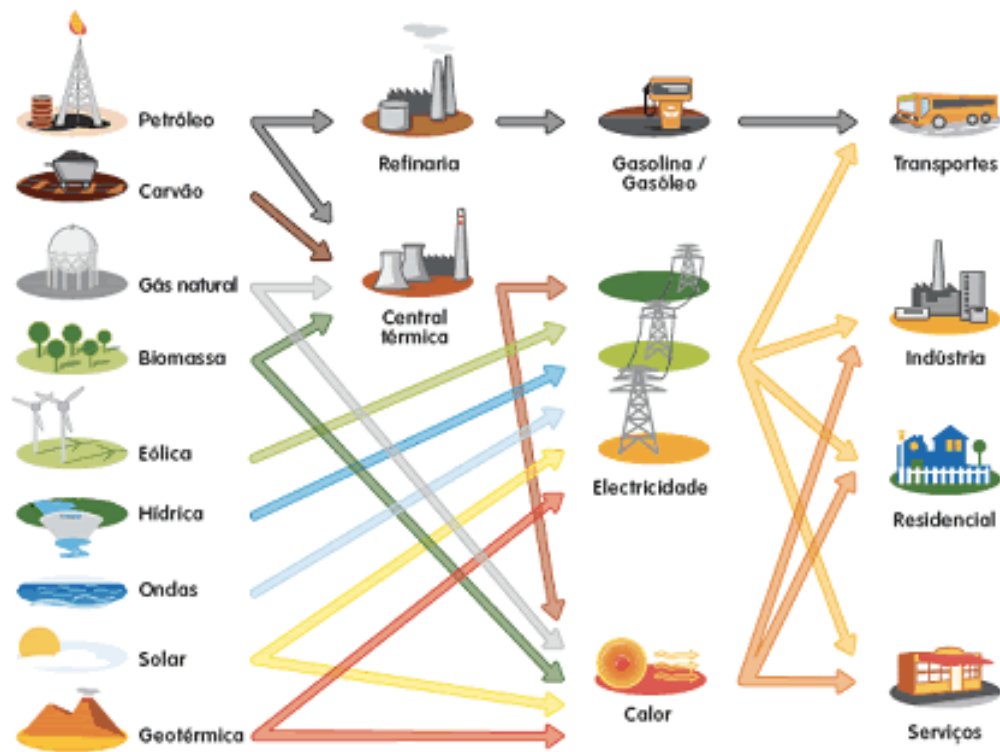
Parte 3 (22h até 22h20min):

- Acesso ao moodle e trabalho individual.

Conversão de energia

Finalidade da conversão de energia:

- Aplicações diferentes conforme a forma;
- Dificuldades de armazenamento;
- Dificuldades de transmissão;
- Alteração/adaptação de amplitudes, formas e quantidades;
- Reaproveitamento de energia.



Conversores estáticos



Definição:

- Conversor rotativo: aquele converte energia usando mecanismos móveis (gerador-motor-gerador);
- Conversor estático: dispositivo eletrônico que converte energia sem usar componentes móveis (giratórios).



Conversor rotativo
Motor + gerador



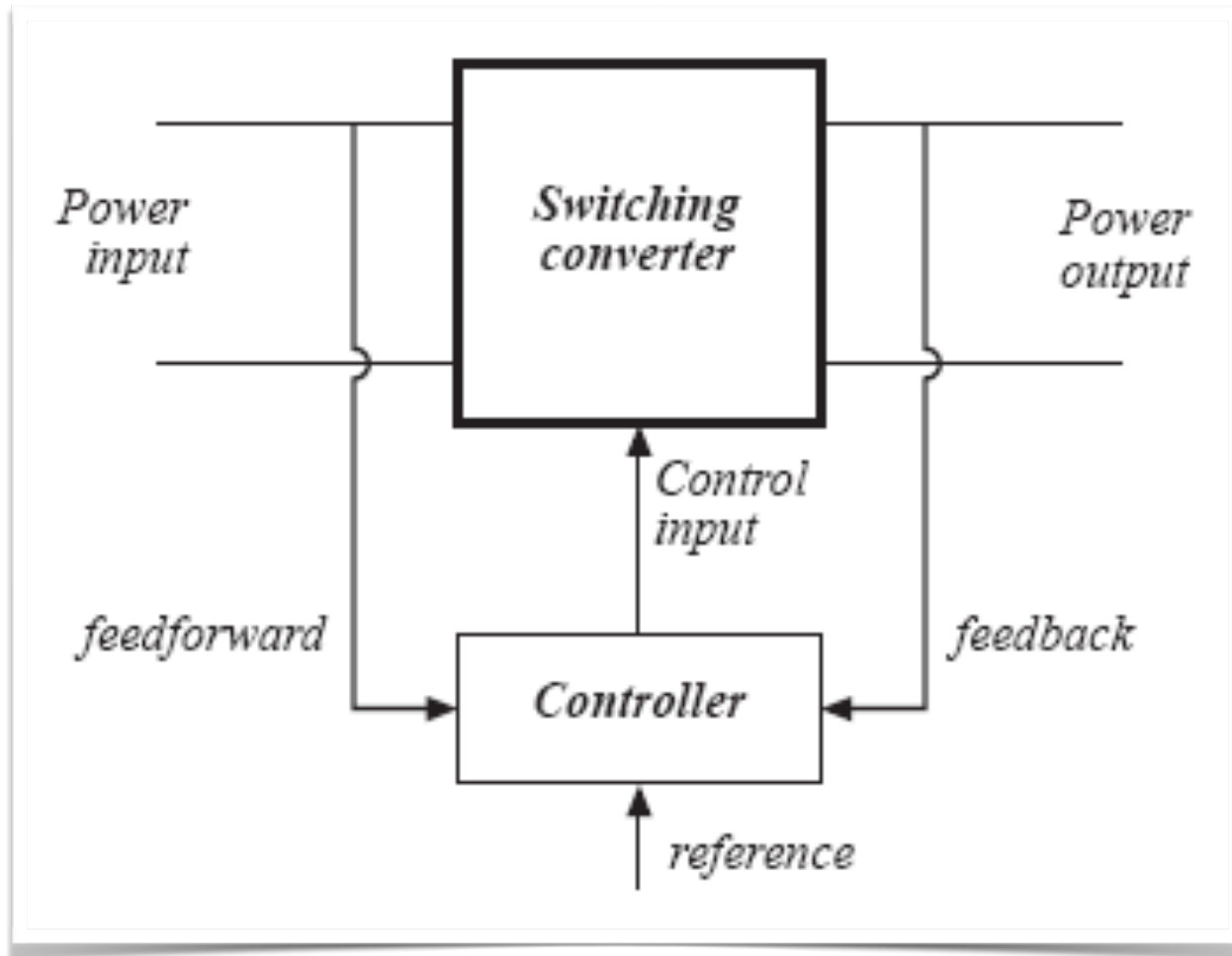
Conversor estático
Inversor de freqüência

Definições:

- Eletrônica de Potência é a tecnologia associada com conversão eficiente, controle e condicionamento de potência elétrica através de interruptores estáticos de uma fonte disponível na entrada numa saída desejada;
- Eletrônica de Potência pode ser definida como uma ciência aplicada dedicada ao estudo dos conversores estáticos de energia elétrica. Este último pode ser definido com um sistema, constituído por elementos passivos (resistores, capacitores e indutores) e elementos ativos (interruptores), tais como Diodos, Tiristores, Transistores, GTO's, Triacs, IGBT's e MOSFET's, associados segundo uma lei pré-estabelecida.
- **Entende-se que Eletrônica de Potência é uma área da Engenharia Elétrica que tem a finalidade de estudar e construir conversores de potência visando o controle de energia elétrica.**

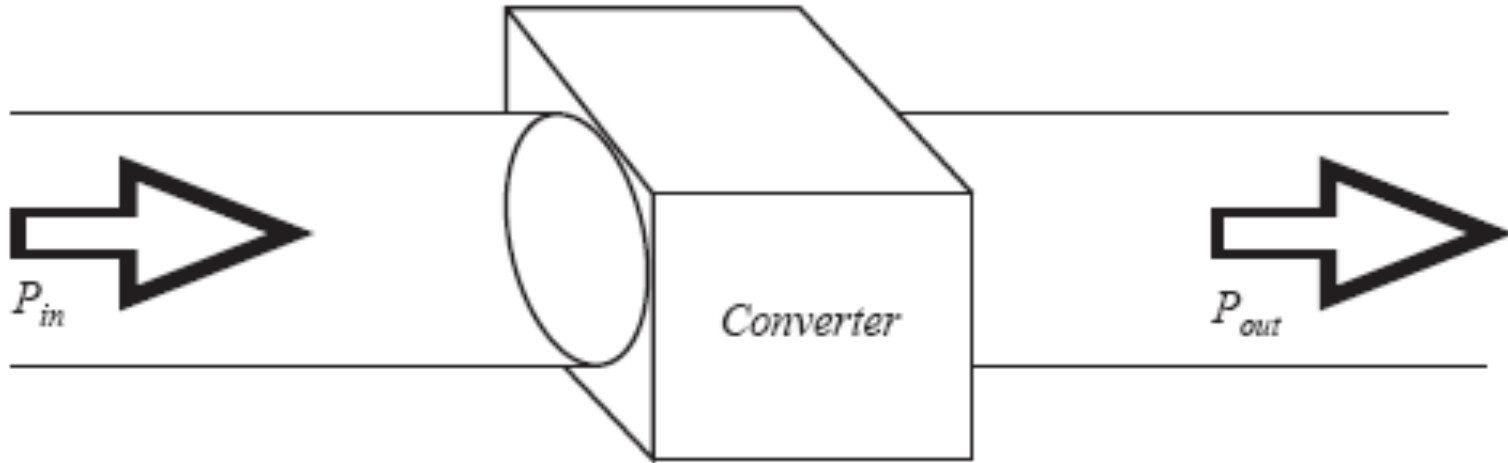
Princípio:

- Os circuitos em eletrônica de potência são denominados não-lineares, pois utilizam os semicondutores como chaves, ligadas ou desligadas.



Objetivo maior:

- Busca da máxima eficiência.



$$\eta = \frac{P_{out}}{P_{in}}$$

Eletrônica de potência



Primeiro computador Apple
(1976)

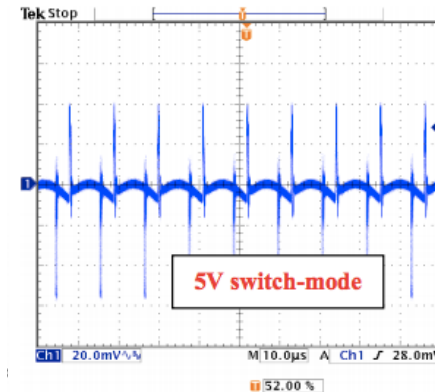
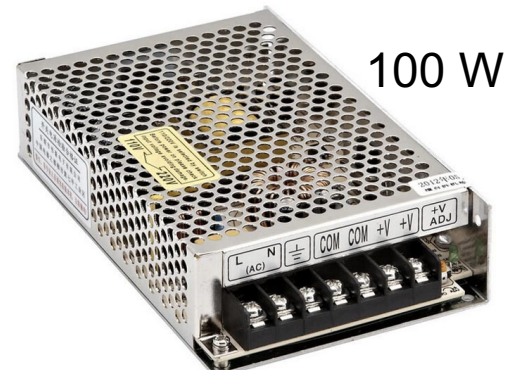
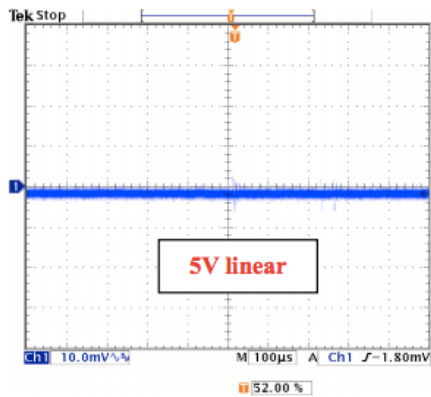


Notebook Apple atual
(2015)



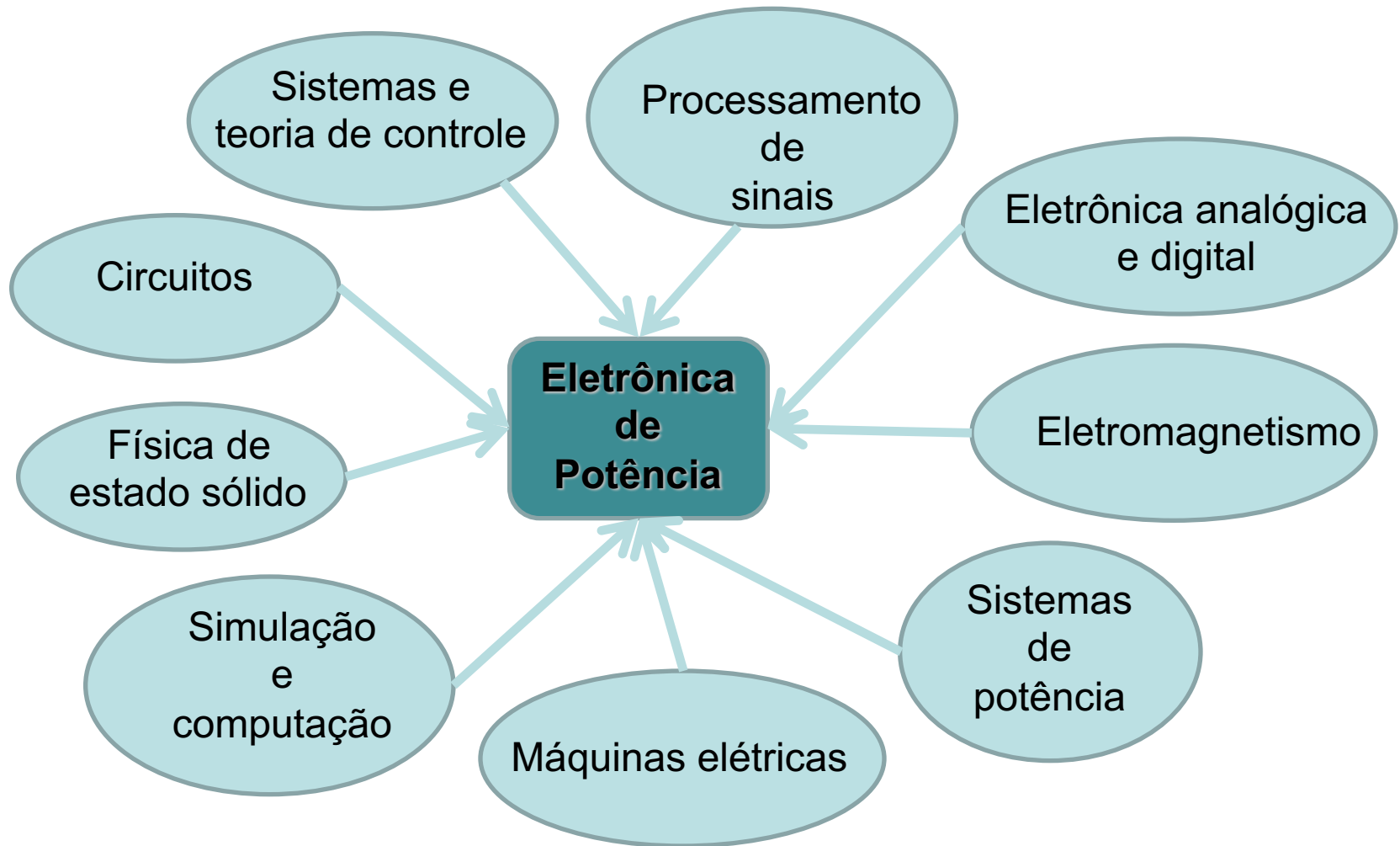
<http://www.righto.com/2014/05/a-look-inside-ipad-chargers-pricey.html>

Fonte linear versus comutada

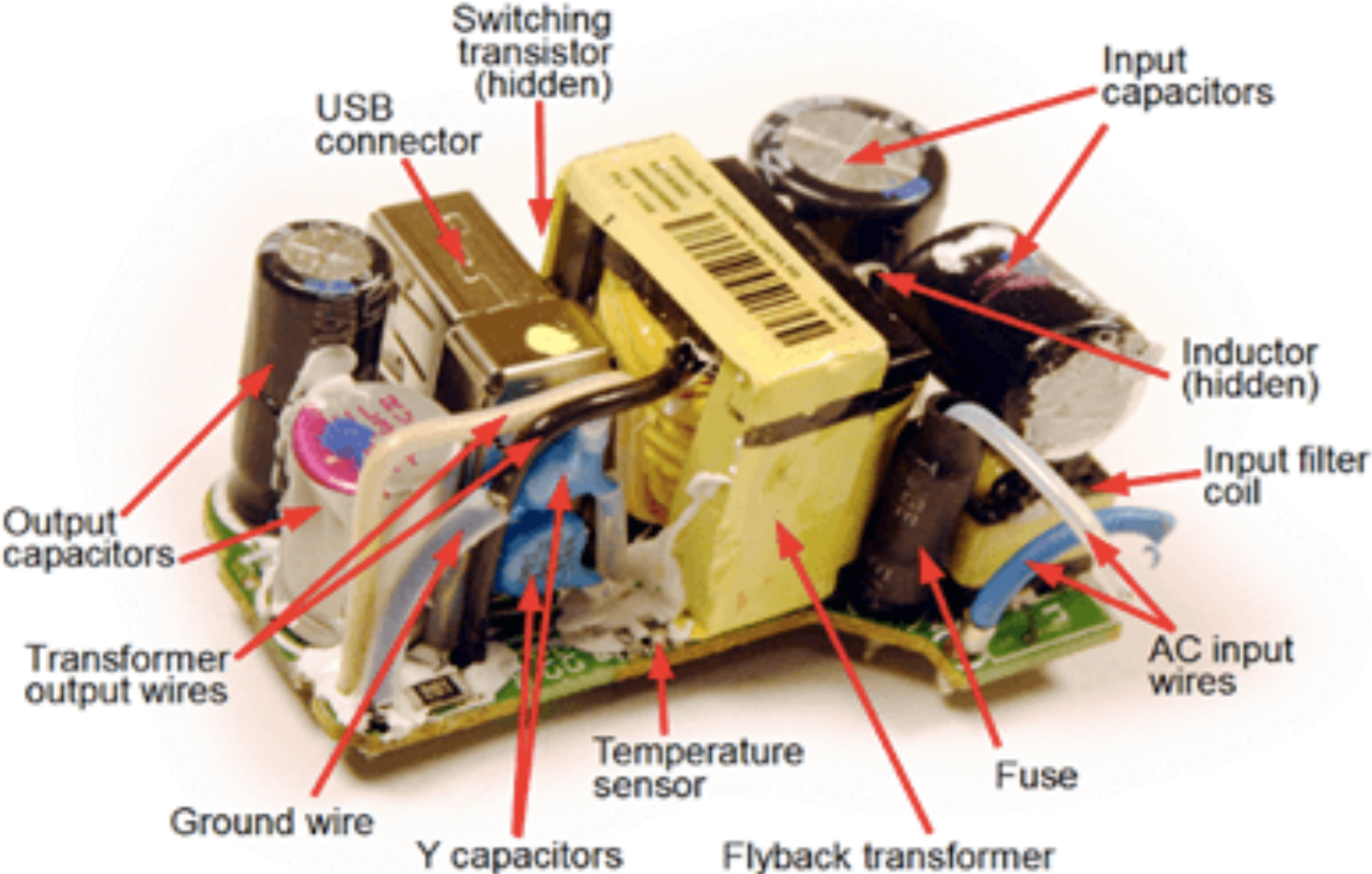


	Linear	Switch-mode	Comments
Size	✗	✓	Typically 80% smaller
Weight	✗	✓	Typically 80% lighter
Input Voltage Range	✗	✓	10% vs. up to 300% range
Efficiency	✗	✓	Calculate it long term!
Reliability	✓	✗/✓	Component count method, demonstrated probably equal
Ripple & Noise	✓	✗/✓	Up to 10,000 times - often possible to overcome though
Transient Response	✓	✗	Up to 100 times - necessary in specialized areas
Low leakage Current	✓	✗/✓	Often used in medical systems, switch-mode gaining share

Interdisciplinaridade da eletrônica de potência



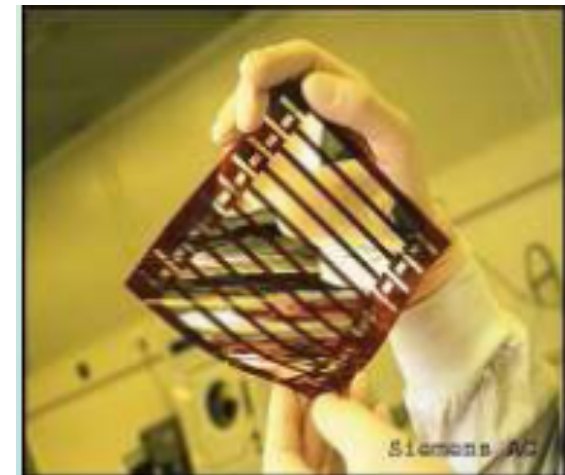
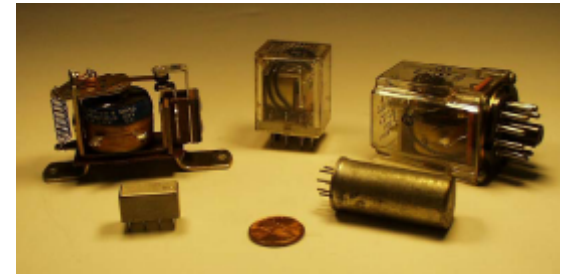
Interdisciplinaridade da eletrônica de potência



Iphone charger

Breve histórico da eletrônica de potência

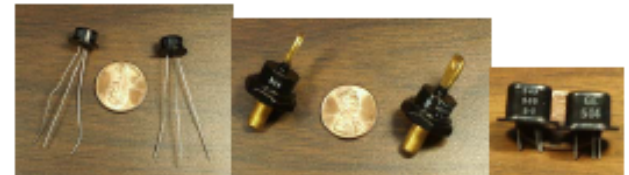
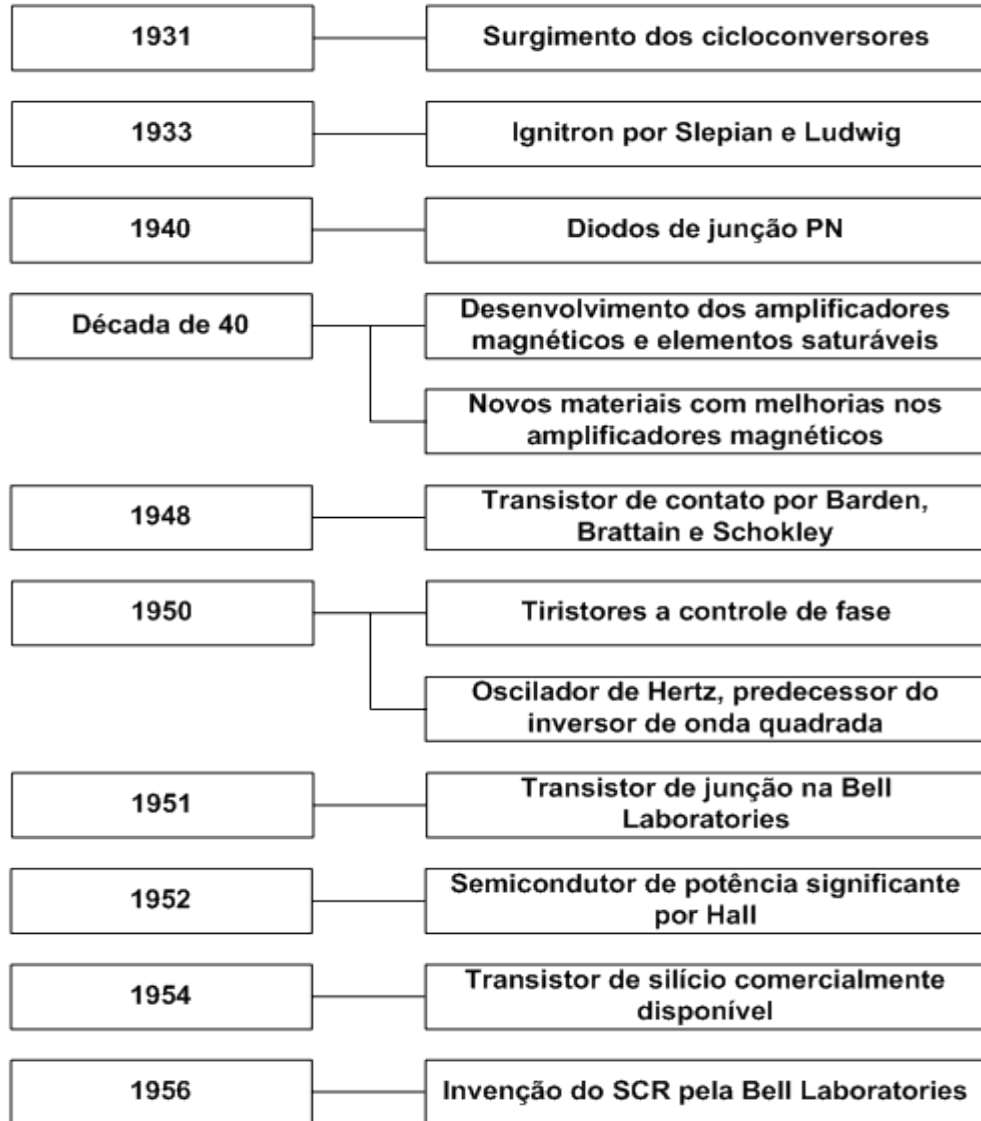
.... 1880	Estudo de métodos de retificação
1880	George Stanley implementou o transformador
1883	Diodo de selenium por C. T. Fritts
1883	Efeito termiônico
1888	Motor de indução por Tesla
1891	Geração hidrelétrica por Siemens
1900	Lâmpadas de vapor de mercúrio por P. Cooper-Hewitt
1901	Explicação do efeito termiônico por O. W. Richardson
1903	Diodo de tubo de vácuo
1903	Previsão de controlar o retificador de mercúrio por Cooper-Hewitt
1904	Retificação com o efeito termiônico por J. A. Fleming



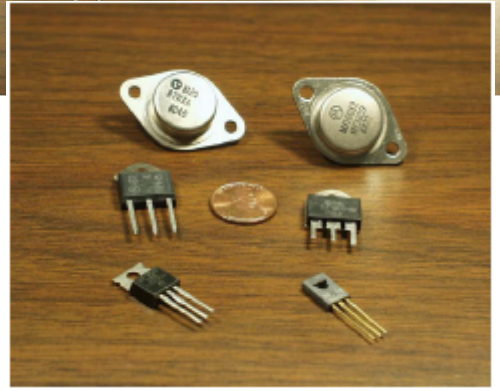
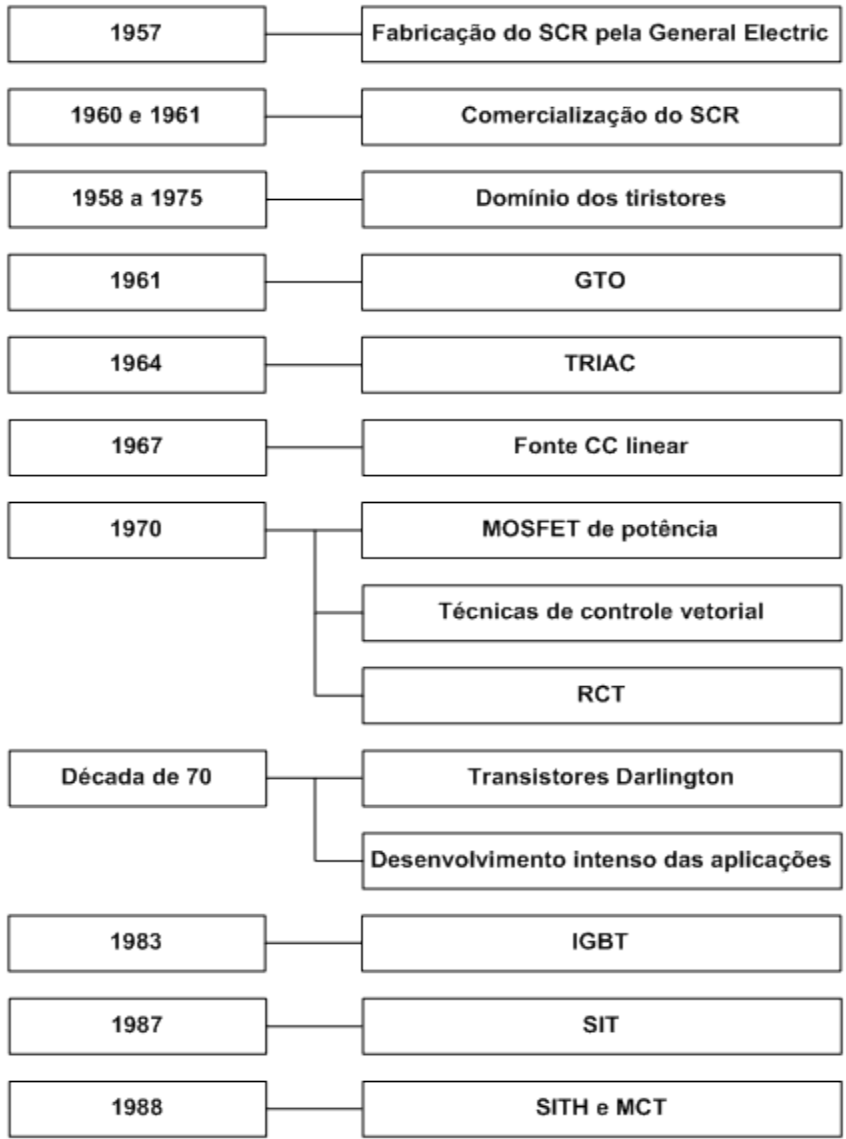
Breve histórico da eletrônica de potência



Breve histórico da eletrônica de potência



Breve histórico da eletrônica de potência



Artigo Prof. Ewaldo L. M. Mehl



Breve histórico da eletrônica de potência



history | barry brusso



The Past, Present, and Future of Power Electronics

I started my career as a power engineer in India in the mid 1950s. I was an engineer in a hydron power company in the early and then I started teaching generation, transmission, distribution, and electric machines undergraduate college. The power electronics field was called unknown in those days glass-bulb and steel-tank in arc and ignition rectifiers in tube electronics (thyratrons in tubes) were known long before and widely used in industry interesting to note that the first in New York installed grid-converter mercury rectifiers (3 MW motor traction in 1930, and C railroads introduced mercury cycloconverters for universal traction drives almost at the time (1931). The first thyristor converter-based variable-voltage-frequency synchronous drive (400 hp) was installed U.S. Logan power station in 1957. Induced draft (ID) fan drive. In days, power electronics was as industrial electronics because gas tubes were mainly used in industrial applications, whereas vacuum tubes were used in signal processing and communication.

Electronic Revolutions

After completing my studies at the University of Wisconsin (1960), I returned to India and introduced a number of electronic devices in industrial electronics for the first time at my college. In those 11

2858

IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 60, NO. 7, JULY 2012

Global Energy Scenario and Impact of Power Electronics in 21st Century

Bimal K. Bose, Life Fellow, IEEE

Abstract—Power electronics technology has gained significant maturity after several decades of dynamic evolution of power semiconductor devices, converters, pulse width modulation (PWM) techniques, electrical machines, motor drives, advanced control, and simulation techniques. According to the estimate of the Electric Power Research Institute, roughly 70% of electrical energy in the USA now flows through power electronics, which will eventually grow to 100%. In the 21st century, we expect to see the tremendous impact of power electronics not only in global industrialization and general energy systems, but also in energy saving, renewable energy systems, and electric/hybrid vehicles. The resulting impact in mitigating climate change problems is expected to be enormous. This paper, in the beginning, will discuss the global energy scenario, climate change problems, and the methods of their mitigation. Then, it will discuss the impact of power electronics in energy saving, renewable energy systems, bulk energy storage, and electric/hybrid vehicles. Finally, it will review several example applications before coming to conclusion and future prognosis.

Index Terms—Climate change, electric/hybrid vehicles, energy storage, future of power electronics, global warming, motor drives, power electronics, renewable energy systems.

I. INTRODUCTION

IT IS WELL known that power electronics is based on high efficiency and fast-switching silicon power semiconductor switches, such as diode, thyristor, triac, gate turn-off thyristor (GTO), power MOSFET, insulated gate bipolar transistor (IGBT), and integrated gate-commutated thyristor (IGCT), and their applications include dc and ac regulated power supplies, uninterruptible power supply (UPS) systems, electrochemical processes (such as electroplating, electrolysis, anodizing, and metal refining), heating and lighting control, electronic welding, power line static volt-ampere reactive (VAR) compensators [SVC, static var generator, or static synchronous compensator (STATCOM)] and flexible ac transmission systems (FACTS), active harmonic filters (AHFs), HVdc systems, photovoltaic (PV) and fuel cell (FC) converters, dc and ac circuit breakers, high-frequency heating, energy storage, and dc/ac motor drives. Motor drive area may include applications in computers and peripherals, solid-state motor starters, transportation

systems, home appliances, paper and textile mills, pumps and compressors, rolling and cement mills, machine tools and robotics, variable-speed constant-frequency systems, etc. The widespread applications of power electronics in global industrialization are bringing a kind of industrial revolution in the 21st century which has been somewhat unprecedented in history. We have already seen how computer, communication, and information technology advancements have turned geographically remote countries as close neighbors. In particular, the Internet communication has brought revolution in our society, bringing the whole world close together into a global village. Today, we now live in a global society, where the nations in the world are being increasingly interdependent. What happens today in India or Egypt, for example, affects the USA and vice versa. In the present trend, it is expected that future wars in the world will be fought in economic front rather than in military front. In the global marketplace, free from trade barriers, all the nations in the world will face fierce industrial competitiveness for survival and prosperity of living standard. In such an environment, power electronics with motion control will play a dominant role in the 21st century. Moreover, as the energy price increases and environmental regulations are tightened, power electronics applications will spread in every corner of industrial, commercial, residential, transportation, aerospace, military, and utility systems. The role of power electronics in this era will be as important as that of computers, communication, and information technologies, if not more.

It may be relevant to mention here that the author recently published two survey papers [1], [2] of which the first paper has no relevance to the content of this paper. This paper is comprehensive and mainly deals with the discussion of energy systems. The technology advancement and trends are briefly reviewed in the "Future Scenario" of Section VI which can be considered as supplementary to the second paper [2].

II. ENERGY SCENARIO

Let us discuss, in the beginning, with the global energy scenario [6]–[9]. We have come a long way in the history of our industrial civilization. Prior to industrial revolution, which started in 1785, we were essentially in the muscle age when our energy primarily came from human and animal muscles. In those days, world population was small, life was simple and unsophisticated, and the environment was relatively clean. The mechanical age, or the age of steam and heat engines, started with industrial revolution. Then, the electrical age started in the late nineteenth century by the commercial availability of electricity and, particularly, by the invention of commercial

Power Electronics—Historical Perspective and My Experience

Bimal Bose, Guest Author



Power electronics technology with its advanced power efficiency switching mode devices for applications as power supplies, electronic processes, heating and control, electronic welders, volt-ampere reactive (VAR) compensators, HVdc systems, flexible cell power conversion, (HF) heating, and motion control define the 21st century golden age of power electronics after the technology stabilized in the latter century with major innovations or generate new knowledge that helps to solve our problems and contribute to the advancement of our civilization in a broad perspective. The sincerity, purity, and tranquility of our mind, possibly blended with some spirituality, help us concentrate our mind for doing research. Research accomplishment gives supreme satisfaction of mind. Note that doing research and learning always go together. Learning is essentially a lifelong process. Albert Einstein said that we cease to learn only when we die.

How does our brain function for doing research? The human brain, the thinking machine with a biological neural network that gives us natural intelligence, is the most complex machine on earth. Neurobiologists have attempted to understand the structure of the brain and its functioning over a prolonged period of time, but these remain extremely inadequate even today. The neural network [1] in our brain consists of the interconnection of billions of neurons or nerve cells, where the synaptic junction of each input dendrite is filled with neurotransmitter fluid. The impedance of this junction contributes to the intelligence or associative-memory

Digital Object Identifier 10.1109/TIE.2012.2201371

Date of publication: 10 February 2012

Digital Object Identifier 10.1109/TIE.2012.2201371

Date of publication: 19 March 2012

6 IEEE INDUSTRIAL ELECTRONICS MAGAZINE | MARCH 2012

Doing Research in Power Electronics

Do you do research in power electronics? Are you a professor or graduate student in a university or an engineer in an industrial research laboratory? Power electronics research is not different from any other area of engineering or scientific research. For doing research, we discipline and dedicate our mind to make inventions or generate new knowledge that helps to solve our problems and contribute to the advancement of our civilization in a broad perspective. The sincerity, purity, and tranquility of our mind, possibly blended with some spirituality, help us concentrate our mind for doing research. Research accomplishment gives supreme satisfaction of mind. Note that doing research and learning always go together. Learning is essentially a lifelong process. Albert Einstein said that we cease to learn only when we die.

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property of each cell. The intelligence of the brain is thus distributed in the cells of the whole neural network. The supervised learning from our education conditions the junction impedances to acquire knowledge in a specific domain, such as power electronics. It is interesting to note that our brain does not have a computer-like central memory. The neural network has the ability to interpolate or extrapolate this knowledge to create new knowledge. The brain has the additional cognitive capability to invent, which we do not really understand.

The creative capability of the human brain is tremendous. We use hardly more than 5% of our creative capability for doing research, and the remaining is mostly "wasted" in the triviality of our daily thoughts. The research can be defined as fundamental or basic type and applied or application oriented. Thomas Edison, the wizard of applied experimental research in electrical engineering, defined genius as 1% inspiration and 99% perspiration. Edison had 1,093 U.S. patents even though he did not complete his high school education. However, according to Charles Steinmetz, the wizard of basic research, genius is defined as 99% inspiration and 1% perspiration. These are, of course, extreme examples in the early days of engineering research. A modern research project typically requires idea formulation—system analysis—design—simulation study—and validation by experiment. Finally, suffice it to say that a good researcher should also be a good communicator in both writing and speaking.

Now, let me fall back to power electronics. What is special about research

in power electronics? It is a complex and interdisciplinary technology that basically deals with the conversion and control of electrical power using switching-mode power semiconductor devices. The applications of power electronics include regulated dc and ac power supplies, electrochemical processes, heating and lighting control, electronic welding, power line volt-ampere reactive (VAR) and harmonic compensation, high-voltage dc (HVDC), flexible ac transmission systems (FACTS), photovoltaic (PV) systems, fuel cell power conversions, high-frequency (HF) heating, and motor drives. After several decades of technology evolution, power electronics applications have recently become extremely important for energy saving, electric/hybrid vehicles, the smart grid, renewable energy systems, and bulk energy storage, besides the usual applications in industrial automation and high-efficiency energy systems.

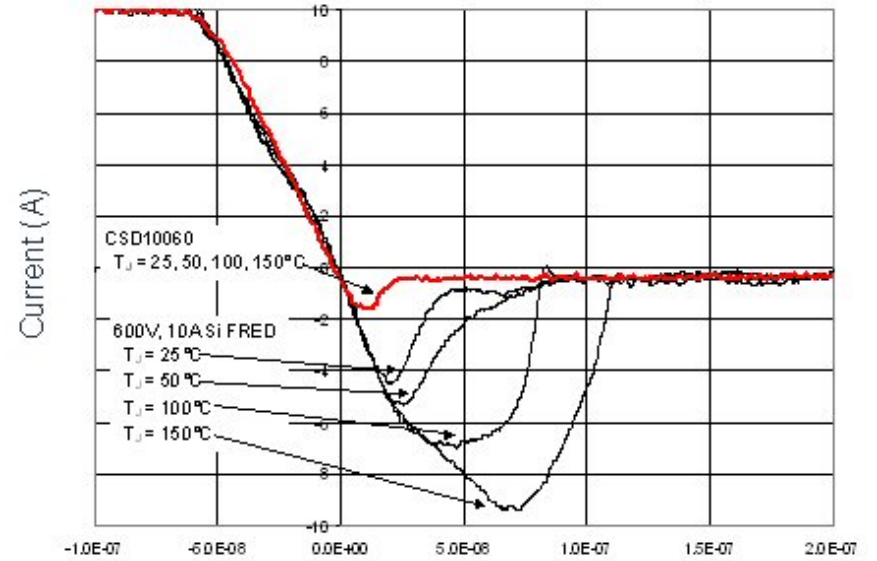
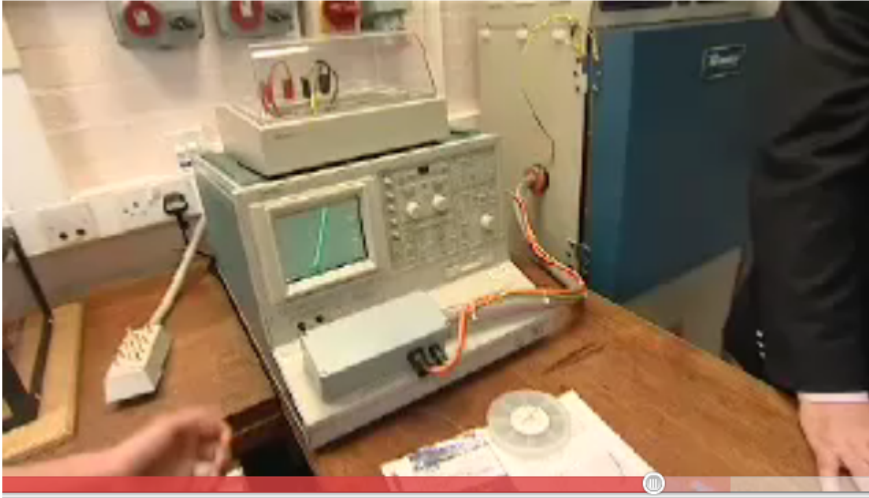
In general, doing research in power electronics requires expertise in power semiconductor and peripheral devices, converter circuits, control theories, electrical machines, digital signal processors (DSPs), field programmable gate arrays, power systems, and computer-aided design and simulation techniques. Recently, artificial intelligence (AI) techniques, such as fuzzy logic and artificial neural networks (ANNs), are advancing the frontier of power electronics. Each of these component disciplines is advancing rapidly, thus presenting greater challenges to power electronics researchers. A thorough knowledge of the application environment is essential for doing research in a power electronics project.



Silicon Carbide - SiC

How silicon carbide could help in the development of electri

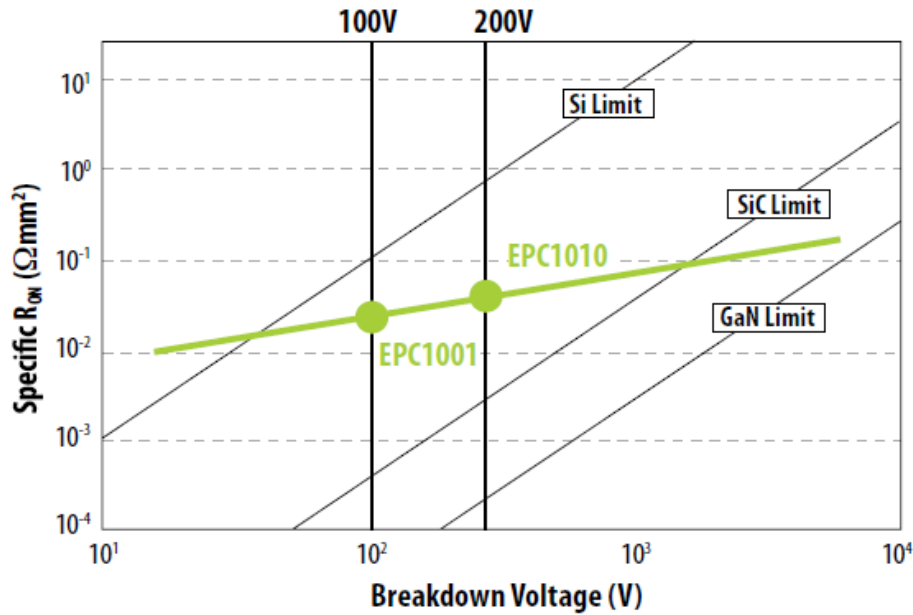
WarwickCAST 130 videos Inscrever-se



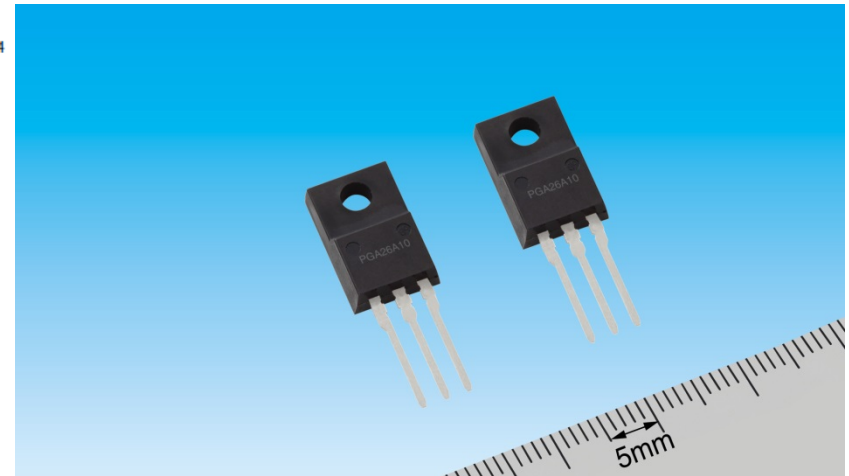
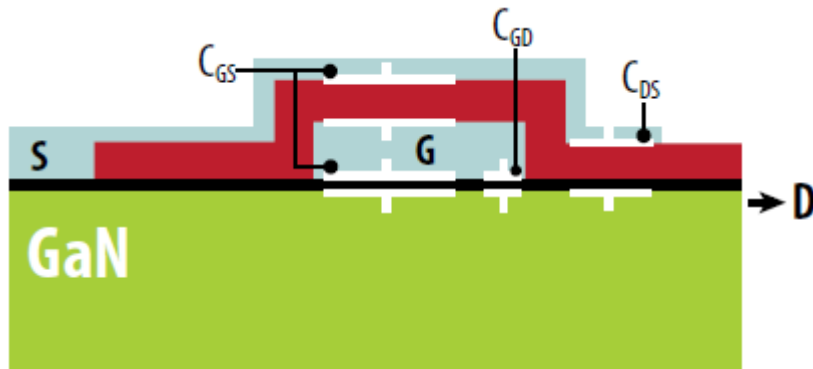
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Nitreto de Gálio - GaN



http://panasonic.net/id/news/20130319_1.html

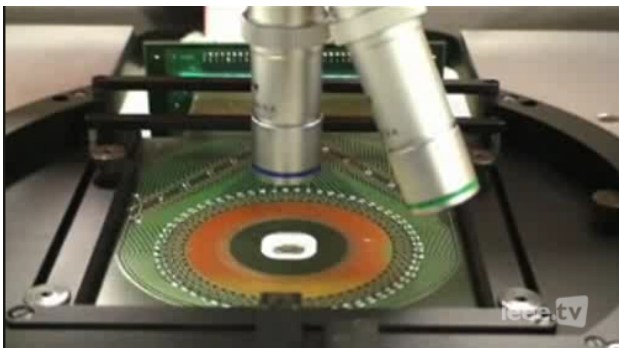


<https://www.youtube.com/watch?v=4tIRFutPFPO>

Memristor



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<http://www.ieee.org>

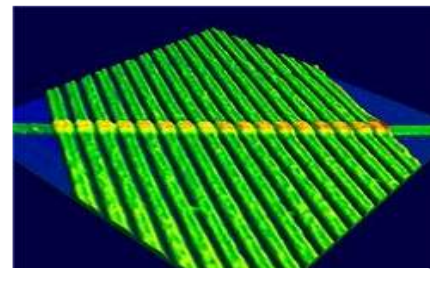
Eletrônica

Memristor: cientistas comprovam existência do quarto componente eletrônico fundamental

Redação do Site Inovação Tecnológica - 02/05/2008

Cientistas da HP anunciaram que um novo componente eletrônico, construído por eles em 2005, é na verdade um memristor, o quarto componente eletrônico básico, teorizado pelo cientista Leon Chua, em 1971.

Até agora os cientistas da HP chamavam seu componente de *crossbar latch* - veja a descrição completa de sua estrutura e funcionamento em [Cientistas criam novo componente que poderá substituir o transistor](#). Eles deram outro passo importante em sua pesquisa em 2007 (veja [Descoberta avança três gerações na construção de chips](#)).



Im
17

[Fonte Chaveada Tecnotrafo](#)

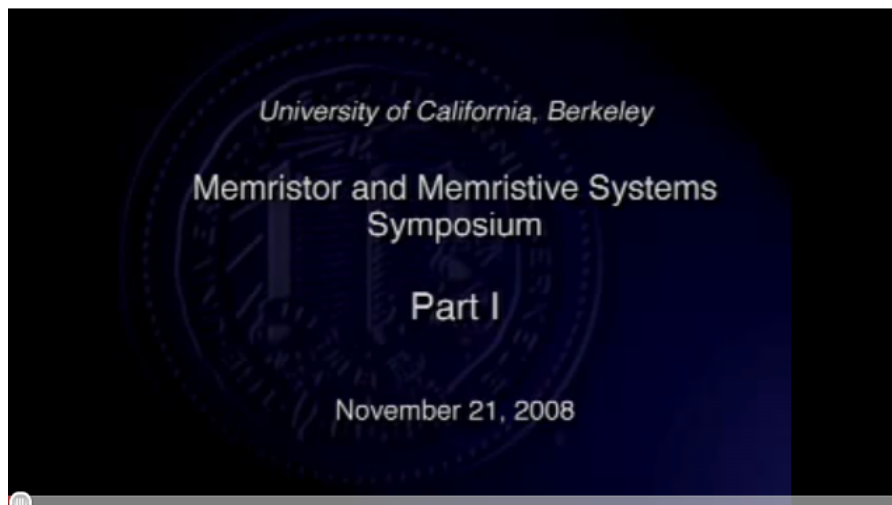
Fábrica, Projeto: Fontes, Carregadores
Conversores. Inversores (11) 5563-4303

<http://www.inovacaotecnologica.com.br>



<http://www.youtube.com>

Ver
Parte 1, 2, 3 e 4



<http://www.youtube.com/watch?v=QFdDPzcZwbs>

Current-Voltage Characteristics of a Memristor

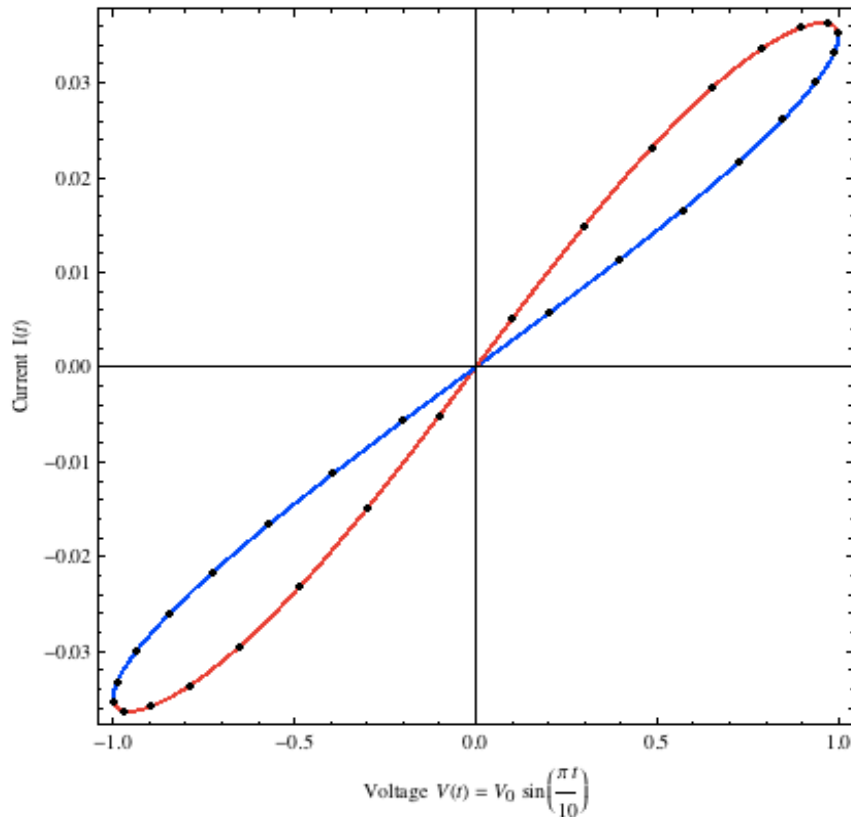
Wolfram CDF Player

period T of the AC voltage applied across the memristor

initial fraction w_0 of low-resistivity region in the memristor

0.5

Current-voltage characteristics of a Memristor: *period - dependent hysteresis*



Transistores de grafeno

Materiais Avançados

Nobel de Física vai para estudos com o grafeno

Redação do Site Inovação Tecnológica - 05/10/2010

Andre Geim e Konstantin Novoselov, ambos da Universidade de Manchester, no Reino Unido, vão dividir o Prêmio Nobel de Física de 2010 pelos seus trabalhos com o grafeno.


A premiação, de certa forma inesperada - o grafeno foi descoberto por eles em 2004 - mostra o reconhecimento do potencial desse novo material, que possui uma infinidade de usos possíveis, da eletrônica ao sequenciamento de DNA.




Konstantin Novoselov tem 3...
tem 51. Ambos nasceram n...
Unido. [Imagem: Univ.Manch...

<http://www.inovacaotecnologica.com.br>

Understanding Graphene and Graphene Nanostructures
keiouniversity 405 vídeos



Keio University
Spintronics Research Network

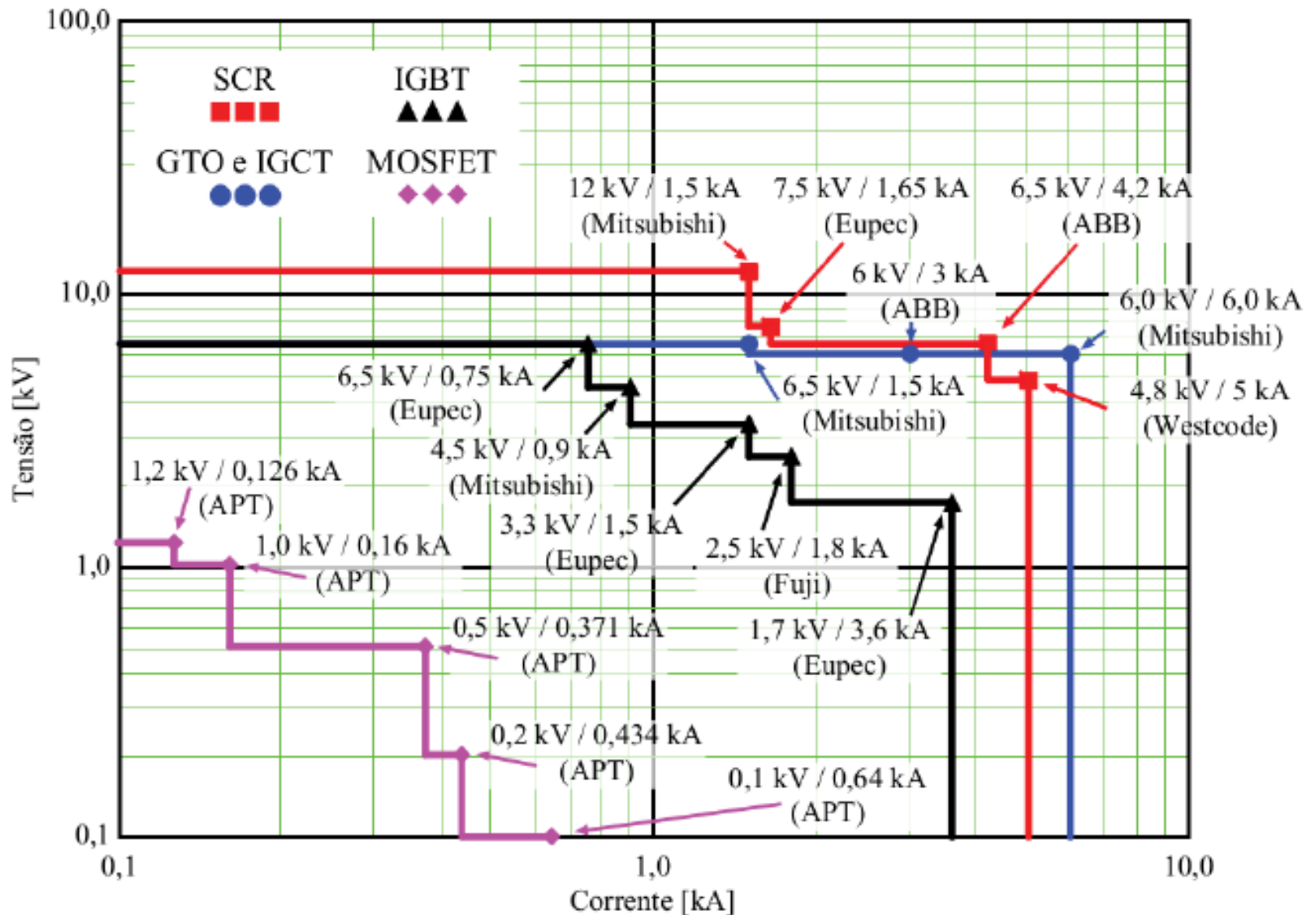


Osaka University
G-COE Program

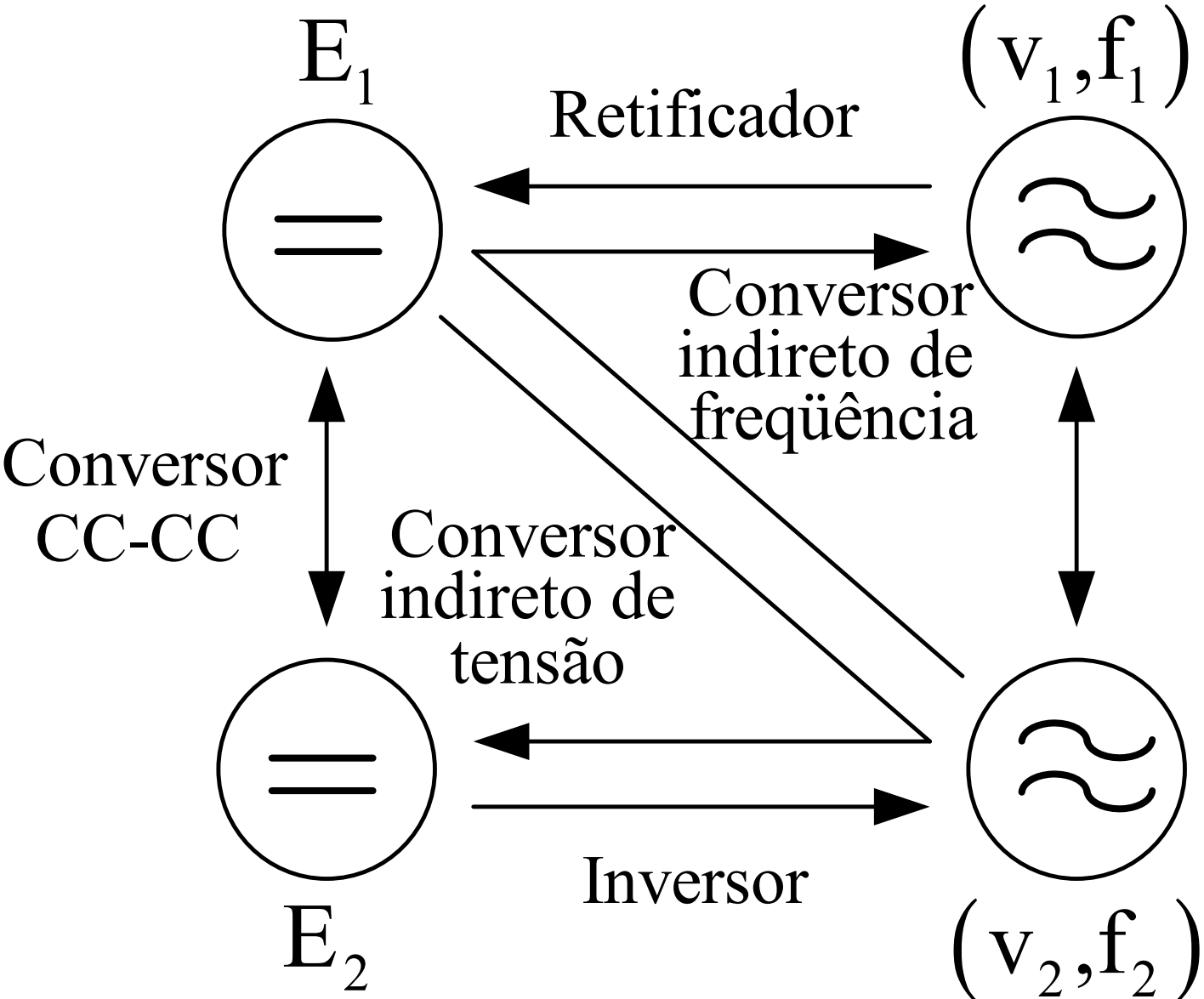
00:00 / 36:46 360p

<http://www.youtube.com/watch?v=8KgrEIRhMCg&feature=related>

Capacidade dos Transistores atualmente



Divisão da eletrônica de potência



Divisão da eletrônica de potência

Conversores CA-CC:

- Denominados de retificadores: convertem a tensão alternada da rede de energia elétrica em uma tensão contínua;

Conversores CC-CC:

- Denominados de choppers: convertem tensão contínua em tensão contínua;

Conversores CC-CA:

- Denominados de inversores: convertem tensão contínua em alternada, muito usados em acionamento;

Conversores CA-CA:

- Denominados de choppers CA: convertem a tensão alternada da rede de energia elétrica em tensão alternada estabilizada, por exemplo.

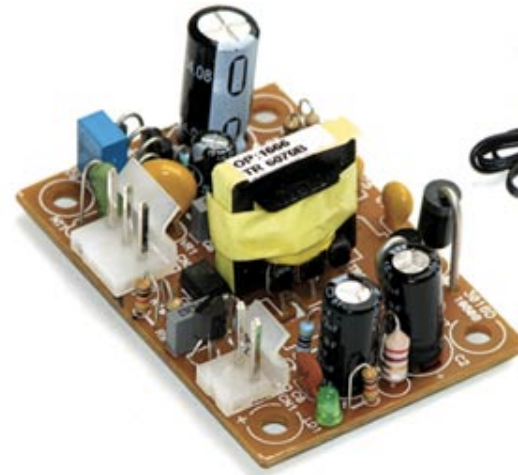
Aplicações:

- Fontes chaveadas;
- Controle de motores de corrente contínua e alternada;
- Conversores para soldagem;
- Alimentação de emergência;
- Carregadores de bateria;
- Retificadores para eletroquímica;
- Transmissão em corrente contínua;
- Reatores eletrônicos;
- Filtros ativos;
- Compensadores estáticos;
- Processamento de energias alternativas;
- Amplificadores de potência;
- Controles de temperatura;
- Entre outras.

Aplicações da eletrônica de potência

Aplicações:

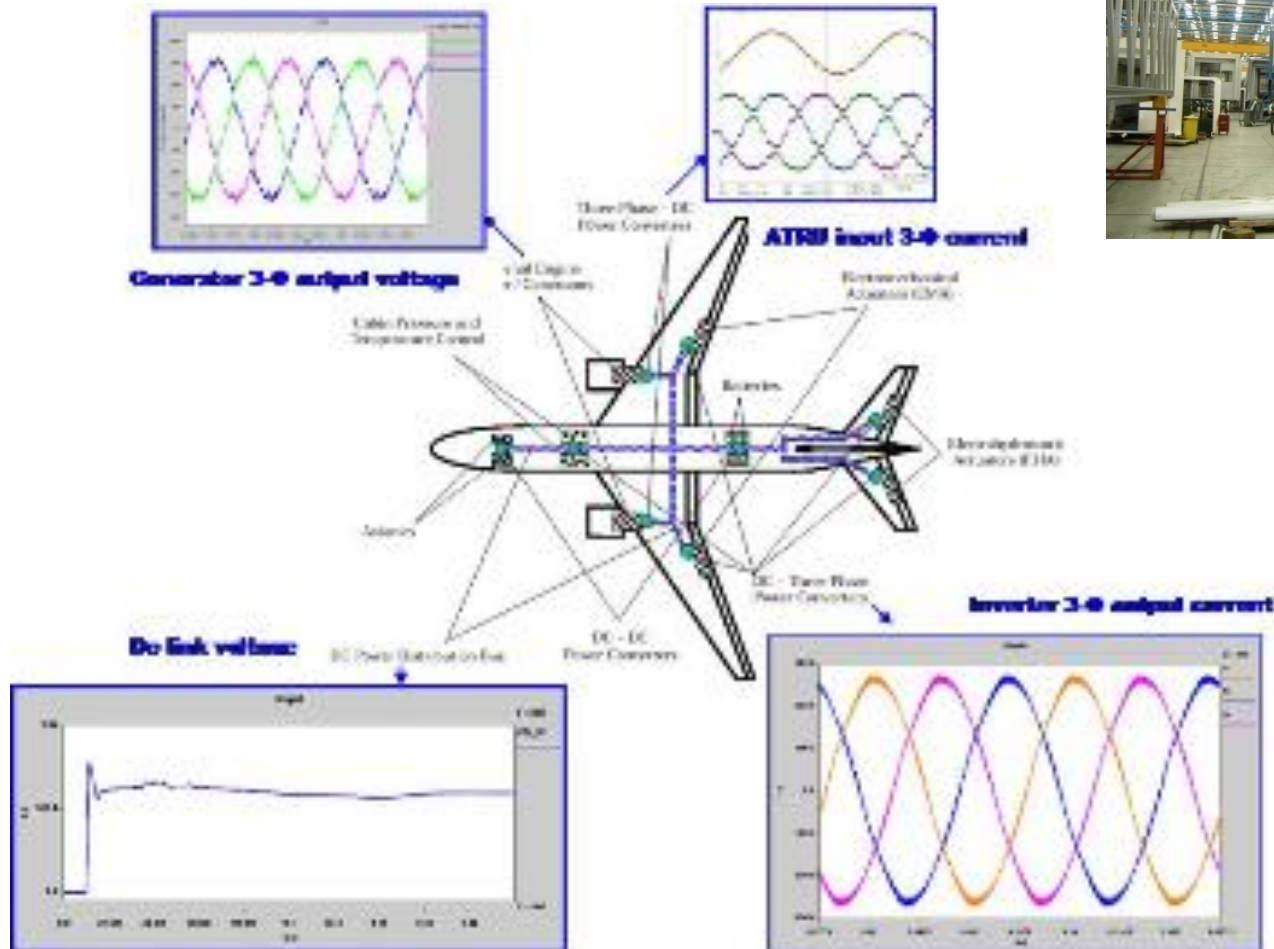
- Fontes chaveadas;



Aplicações da eletrônica de potência

Aplicações:

- Sistema de alimentação de aviões;

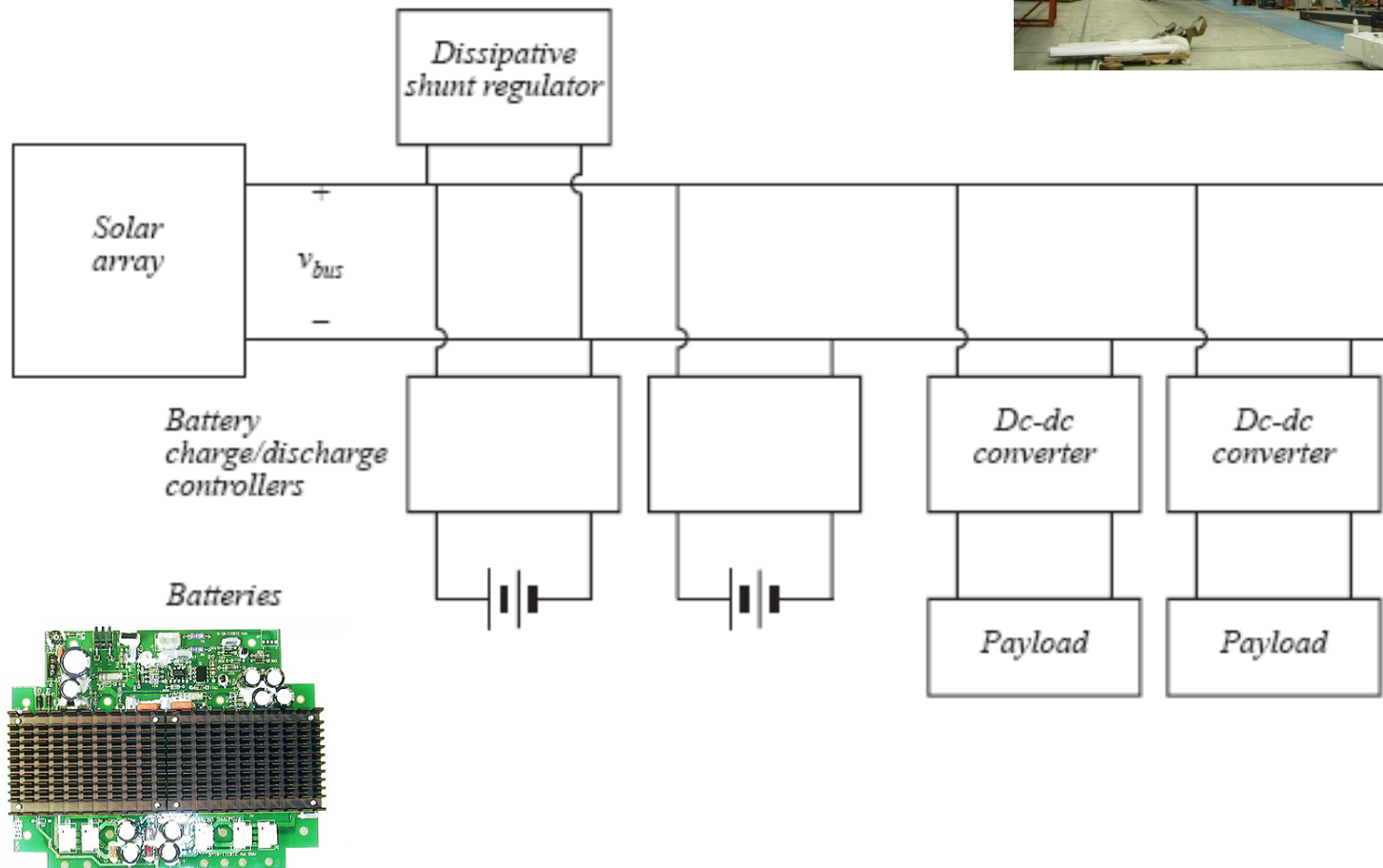


Aplicações da eletrônica de potência



Aplicações:

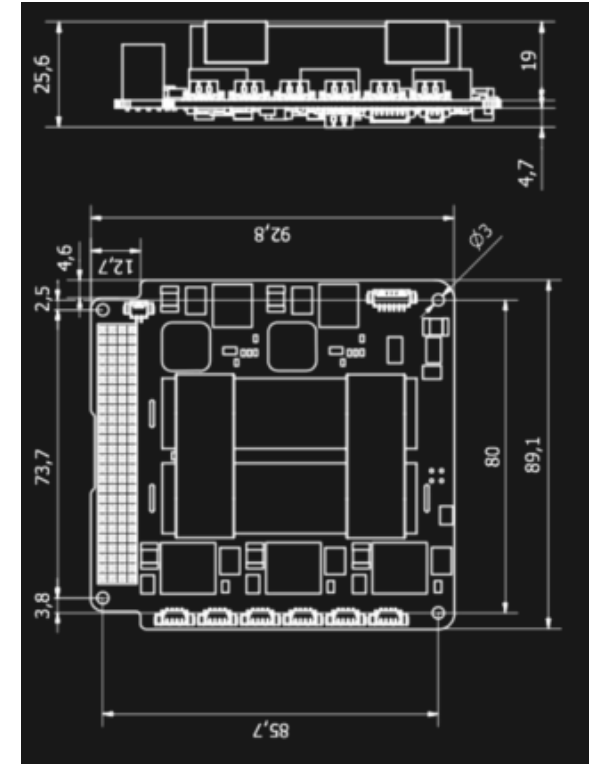
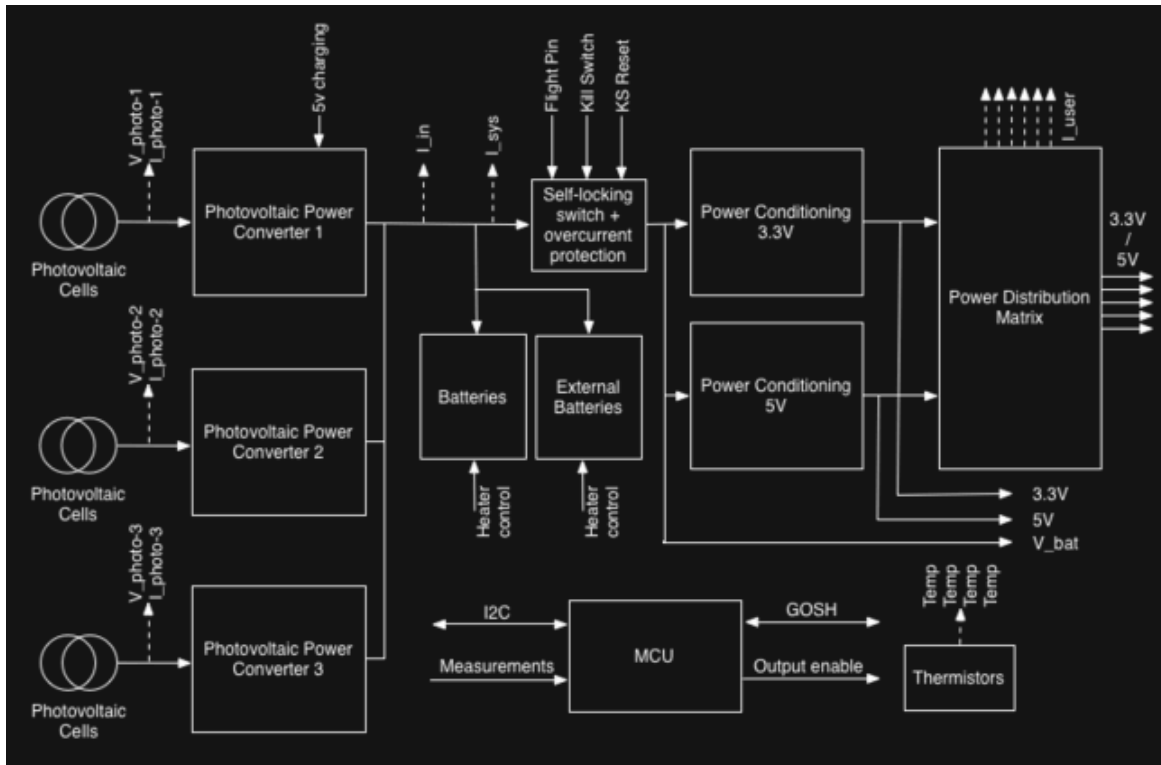
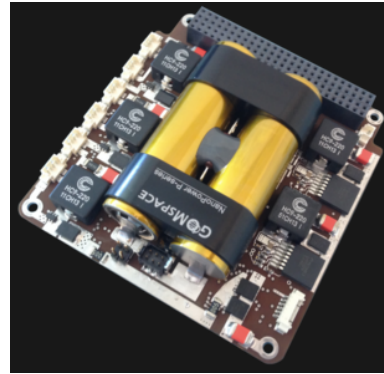
- Sistema Elétrico de Satélite;



Aplicações da eletrônica de potência

Aplicações:

- Nano Satélites;

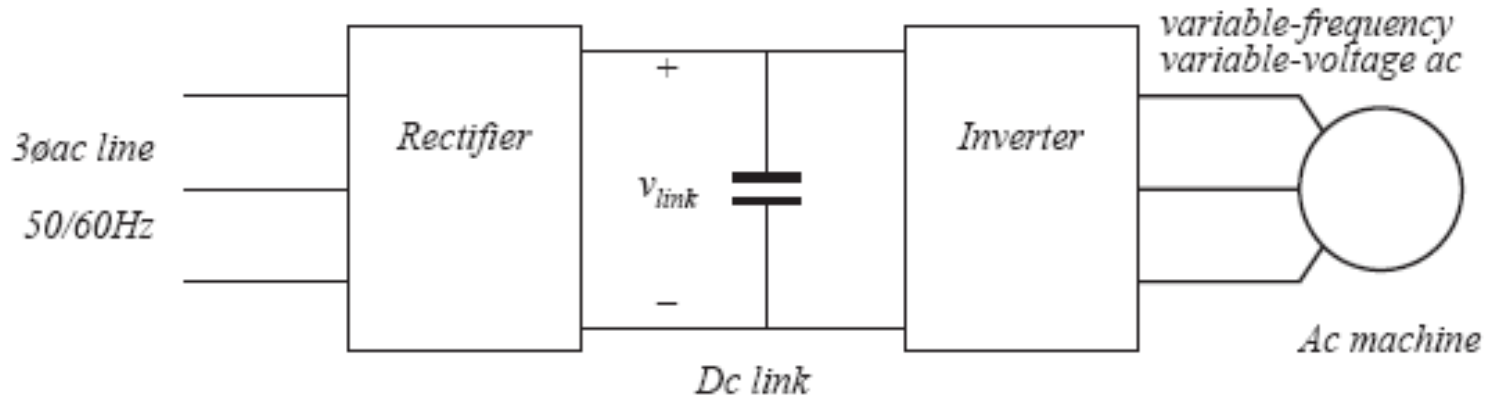


<http://gomspace.com>

Aplicações da eletrônica de potência

Aplicações:

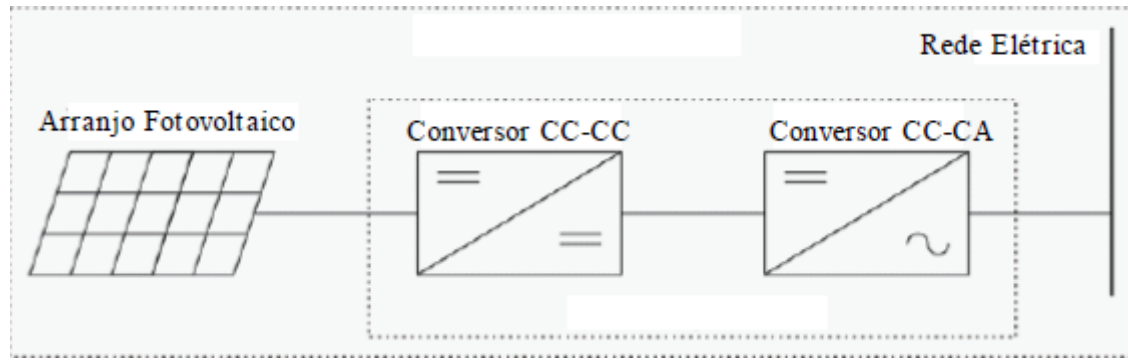
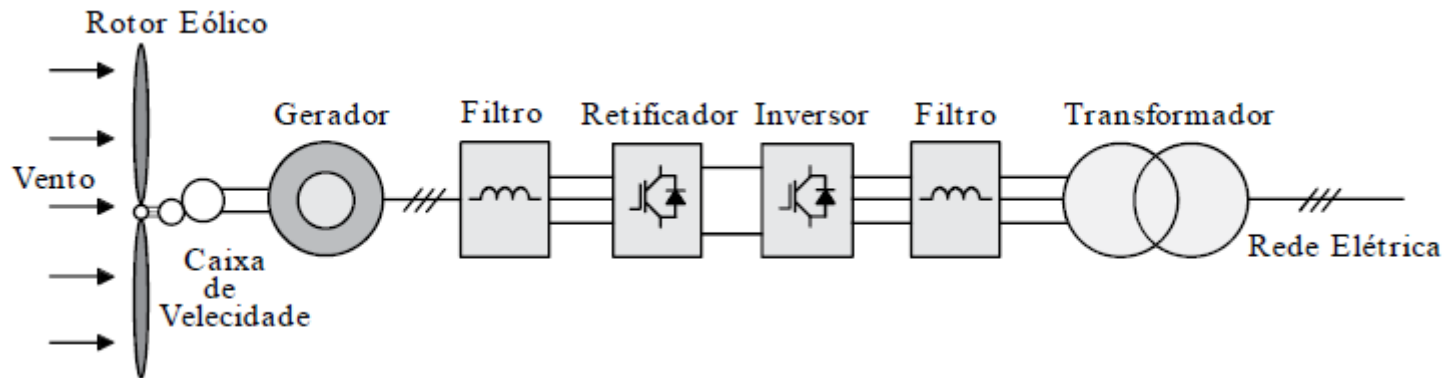
- Acionamento de motores CA;



Aplicações da eletrônica de potência

Aplicações:

- Microgerações – Interface com a rede elétrica;



<http://www.sma.com>

Agenda para esta aula

Parte 1 (19h até 20h):

- Exposição inicial sobre introdução à eletrônica de potência.

Intervalo

Parte 2 (20h20min até 22h):

- Ferramentas de projeto em eletrônica de potência;
- Tecnologias de componentes eletrônicos.

Parte 3 (22h até 22h20min):

- Acesso ao moodle e trabalho individual.

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Parte 1 (19h até 20h):

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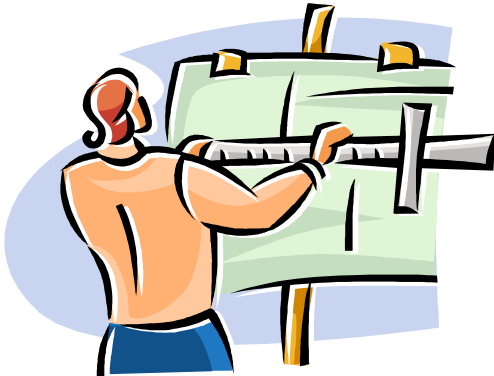
- Ferramentas de projeto em eletrônica de potência;
- Tecnologias de componentes eletrônicos.

Parte 3 (22h até 22h20min):

- Acesso ao moodle e trabalho individual.

Razões para usar softwares específicos:

- a) Complexidade dos circuitos eletrônicos;
- b) Dificuldade de representar o mundo real;
- c) Possibilidade de uso inúmeras vezes;
- d) Diminuição do custo de projeto;
- e) Aprendizagem via software;
- f) Outras...

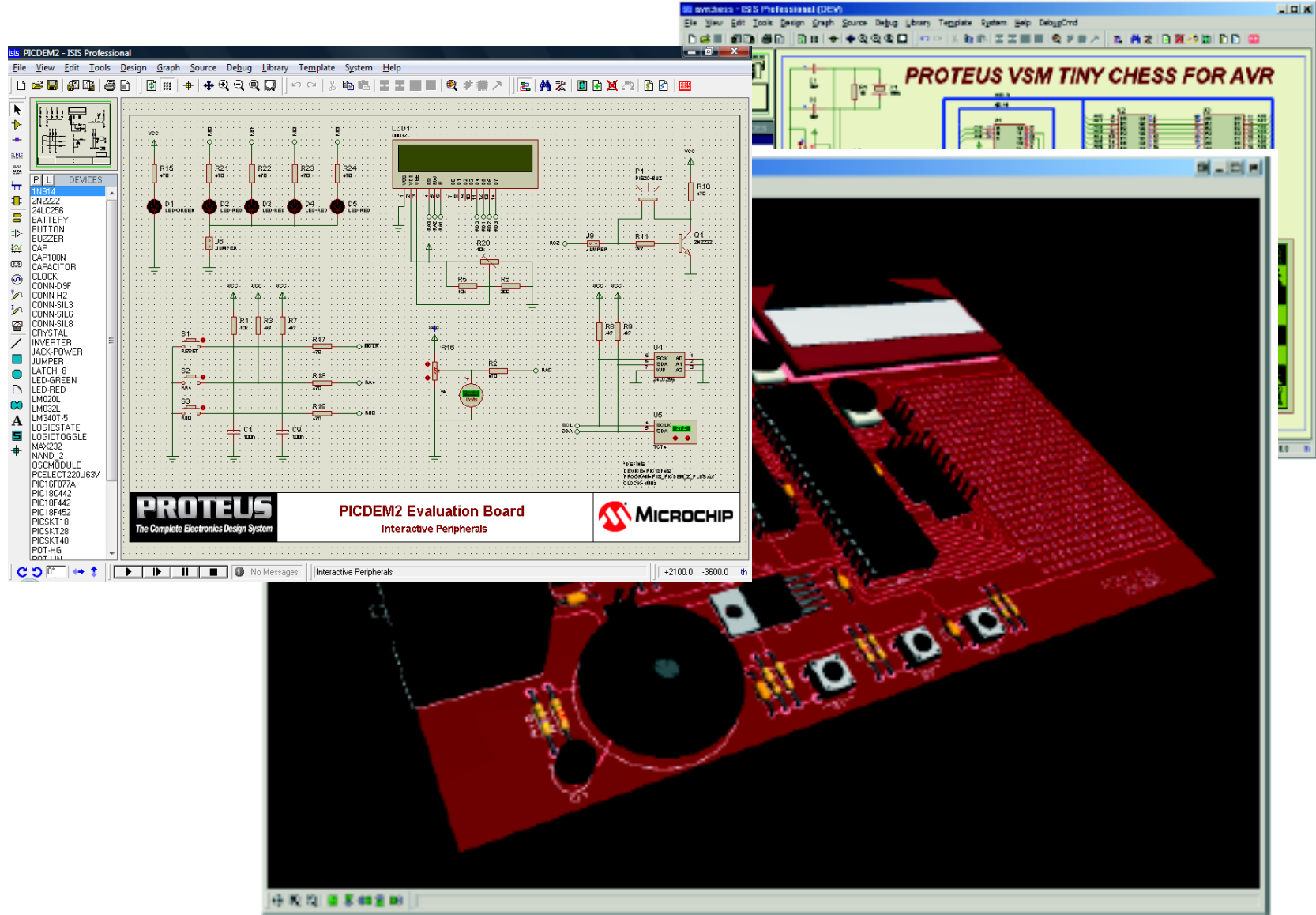


Qual a necessidade de se realizar uma simulação computacional:

- Averiguação do funcionamento do circuito projetado
 - Comprovação com a teoria
 - Evitar gastos desnecessários
 - Tempo
 - Compra de componentes
- Segurança
 - Ex: Aviação, Aeroespacial

Como funcionam os simuladores de circuitos:

- Os componentes elétricos/eletrônicos são modelados matematicamente
 - Ideal
 - Considerando os parâmetros do componente



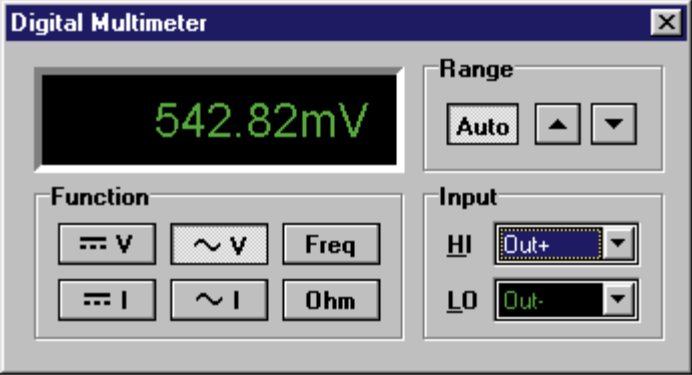
Invert Gain OPA350 Test Circuit Design - Schematic Editor

File Edit Insert View Analysis Interactive I&M Tools Help

Basic Switches Meters Sources Semiconductors Optoelectronic Spice Macros Gates Flip-flops Logic ICs-MC

Sample Circuit Using the O

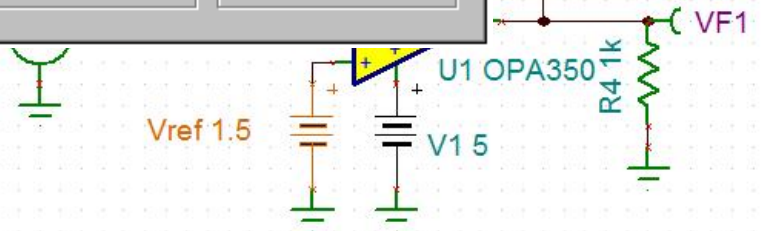
Structure



Range: Auto

Function: V, ~V, Freq, I, ~I, Ohm

Input: HI (Out+), LO (Out-)



Vref 1.5

V1 5

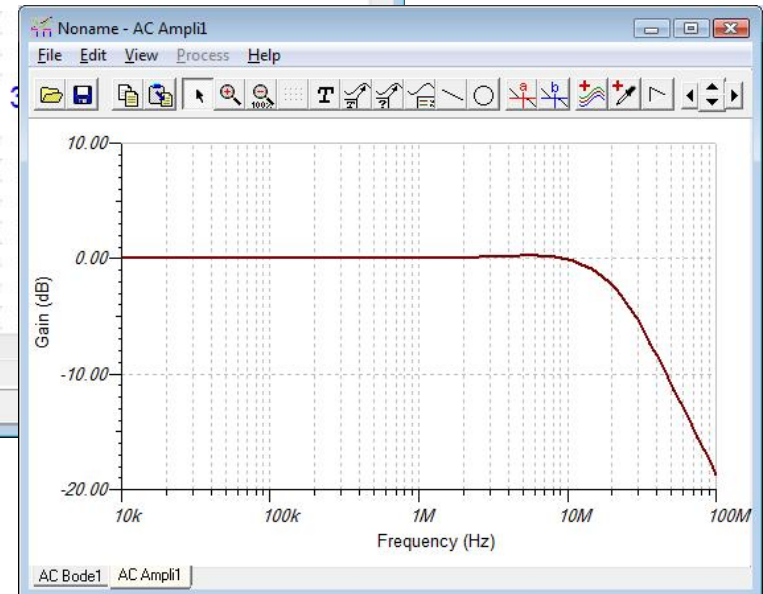
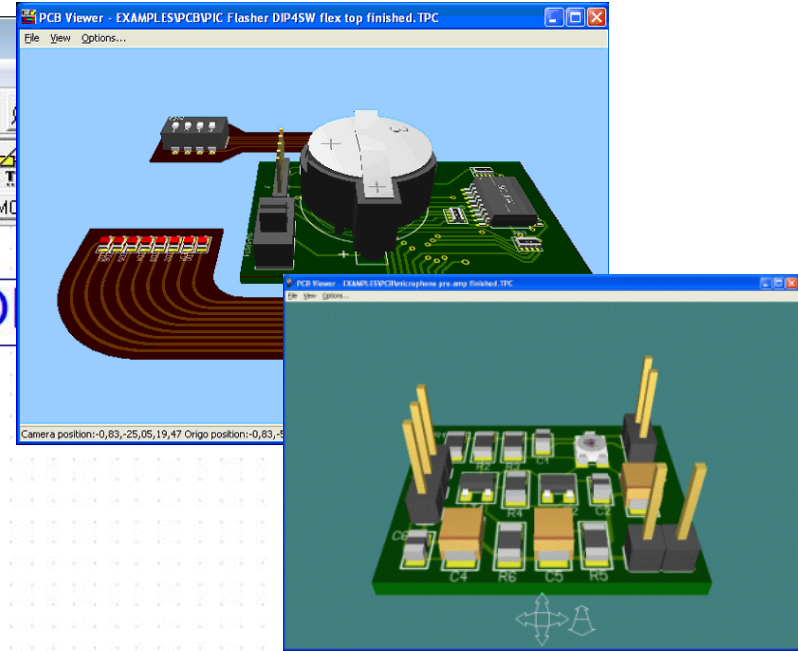
U1 OPA350

R4 1k

VF1

Invert Gain OPA350 Test Circuit Design

Exit



The image displays a comprehensive view of the Multisim simulation environment. At the top left, the main project window shows a schematic diagram with components U28A (74HC139DW_4V) and U27. A 'Select a Component' dialog is open, listing various 74HC series logic components. To the right, a 3D perspective view of the PCB is shown with components placed on a green board. Below the schematic, a 'Spreadsheet View' window displays a table of component properties.

RefDes	Sheet	Section	Section Name	Fam...	Value	Footprint	Manufacturer	Description
VDD1	CO...			PD...	5V			
VDD1	CO...			PD...	5V			
U28	CO...	A	A	74H...	74H...	DW016		Number=2;Package=DW016;
U28	CO...	B	B	74H...	74H...	DW016		Number=2;Package=DW016;
U27	CO...			74H...	74H...	DO16		Number=1;Package=DO16;
U26	CO...			LIN...	MA...	DIP-18	Maxim	Number=4;Package=DIP-18;
U25	CO...			LIN...	DS...	SON-8(...)		

At the bottom, a virtual oscilloscope (XSC1) is shown with two waveforms: a yellow sine wave on CH1 and a cyan sine wave on CH2. The oscilloscope controls include menu buttons, trigger settings, and vertical/horizontal scale adjustments.



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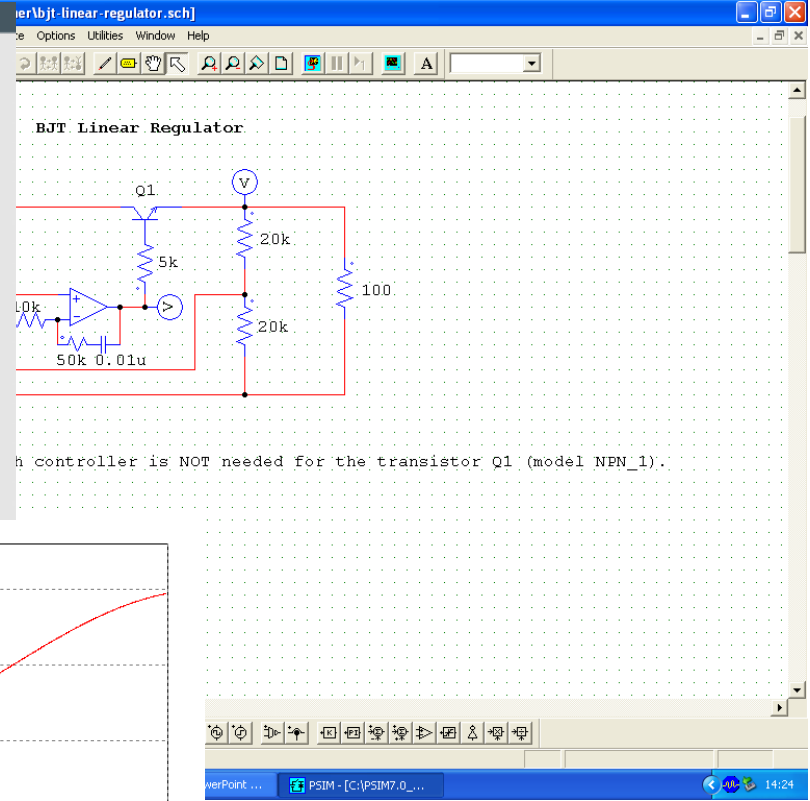
Simulation Made Simple

Version **10**

With fast simulation & a friendly user interface, PSIM provides a powerful simulation environment to address your power electronics simulation needs.

Learn more about PSIM
SIM Version 10!

Get Started | News & Events



verbjt-linear-regulator.sch

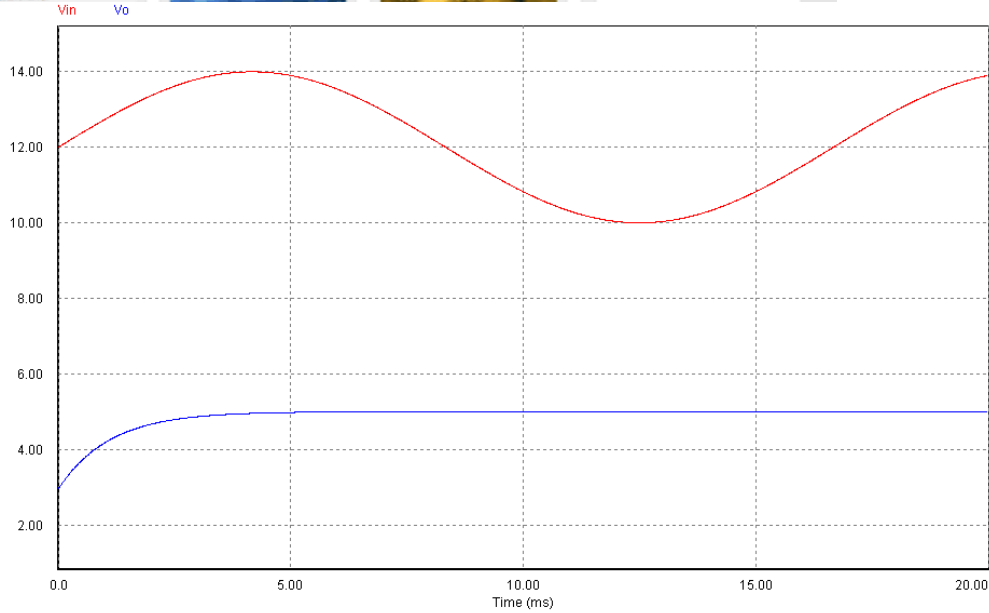
File Options Utilities Window Help

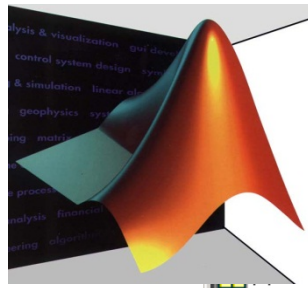
BJT Linear Regulator

Circuit diagram showing a BJT linear regulator with a transistor Q1, resistors (5k, 20k, 100, 20k), a diode (50k 0.01u), and a voltage source (10k).

h controller is NOT needed for the transistor Q1 (model NPN_1).

VerPoint ... PSIM - [C:\PSIM7_0_... 14:24





The screenshot displays the MATLAB environment with several open windows:

- Editor:** Contains MATLAB code for a sine wave:

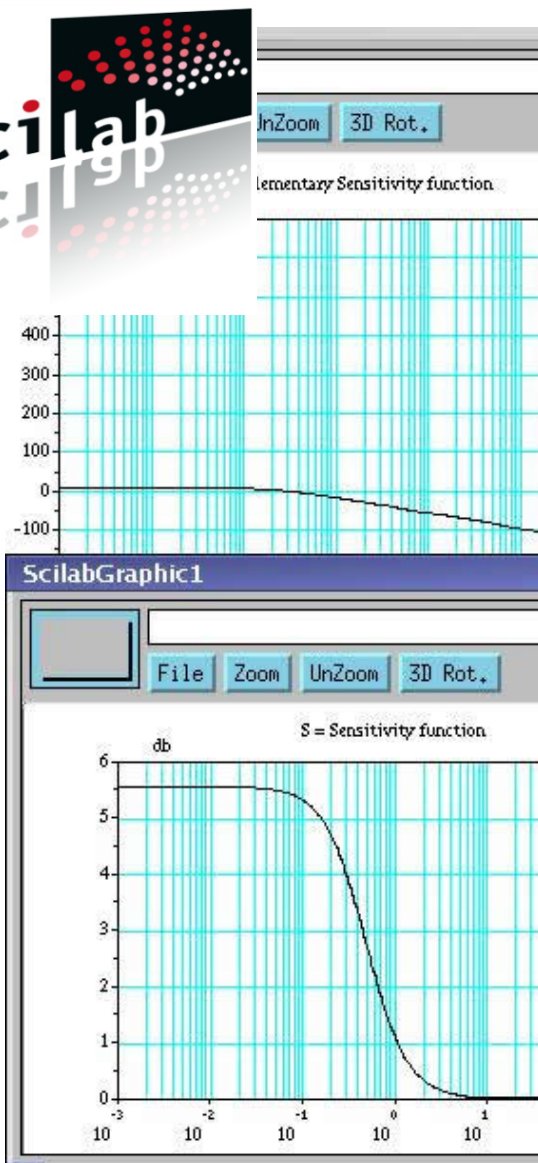

```

            %% Low frequency
            % First define a sample rate
            y=sin(2*pi*f1*t);
            plot(t, y);
            
```
- Figures - Figure 1:** A 3D surface plot titled "Electrode Charge (pC)".
- Array Editor - L:** A table with two columns and eight rows of numerical data:

	1	2
1	-0.16776	-0.17522
2	-0.099968	-0.092546
3	-0.031874	-0.011195
4	0.029369	0.060619
5	0.07763	0.11591
6	0.10844	0.14963
7	0.11947	0.15923
8	0.11075	0.14492
- Command Window:** Shows MATLAB commands:


```

            >> plot (Channel3,
            >> figure
            >> surf (surfacemap)
            >> f=@(t) sin(2*pi*f
            f =
            @ (t) sin(2*pi*f
            >> |
            
```
- Emission Tests:** A 2D line plot showing CO₂ concentration versus Airfuel Ratio. It includes two data series (Test 1 and Test 2) and a quadratic fit curve. The fit equation is $y = -0.29x^2 + 9x - 55$. A data point is highlighted at X: 17.4 and Y: 16.01.



scilab-2.7

```

1 1.8132668 0.5193587 1.1210
1 0.0066408 - 0.4235322 0.5904
-->lin(rand(9,9))
ans =
2.7617992 0.8036397 - 3.0656
- 1.3766708 0.7318738 - 2.4869
- 3.1347005 - 0.2880930 - 4.3802
5.2358496 - 2.9417706 - 14.667
- 2.3095349 - 2.3060676 6.6899
- 5.6858408 - 3.0964923 13.495
10.600871 3.3874405 - 28.030
- 9.6004909 - 3.5149264 27.604
0.0411598 0.6686495 - 2.6398
-->tp(1+2*s*s^2)/(2-s*s^3)
p =
1 + 2s - s^2
2 - s + s^3
-->res(p*p^2;p*p^2)
ans =
1 + 2s - s^2 1 + 4s + 2s^2 - 4
2 - s + s^3 4 - 4s + s^2 + 4s^3
- 1 - 2s + s^2 1 + 4s + 2s^2 - 4
2 - s + s^3 4 - 4s + s^2 + 4s^3 - 2s + s^4
-->function re=(a,b)
-->resin(a)+cos(b)
-->endfunction
-->f(pi/12,-pi/12)
ans =
1.2247449
-->sin(rand(3,3))
ans =
0.3964403 0.5975281 0.0002195
0.4173087 0.4054269 0.4869002
0.0370632 0.7444363 0.4577828

```

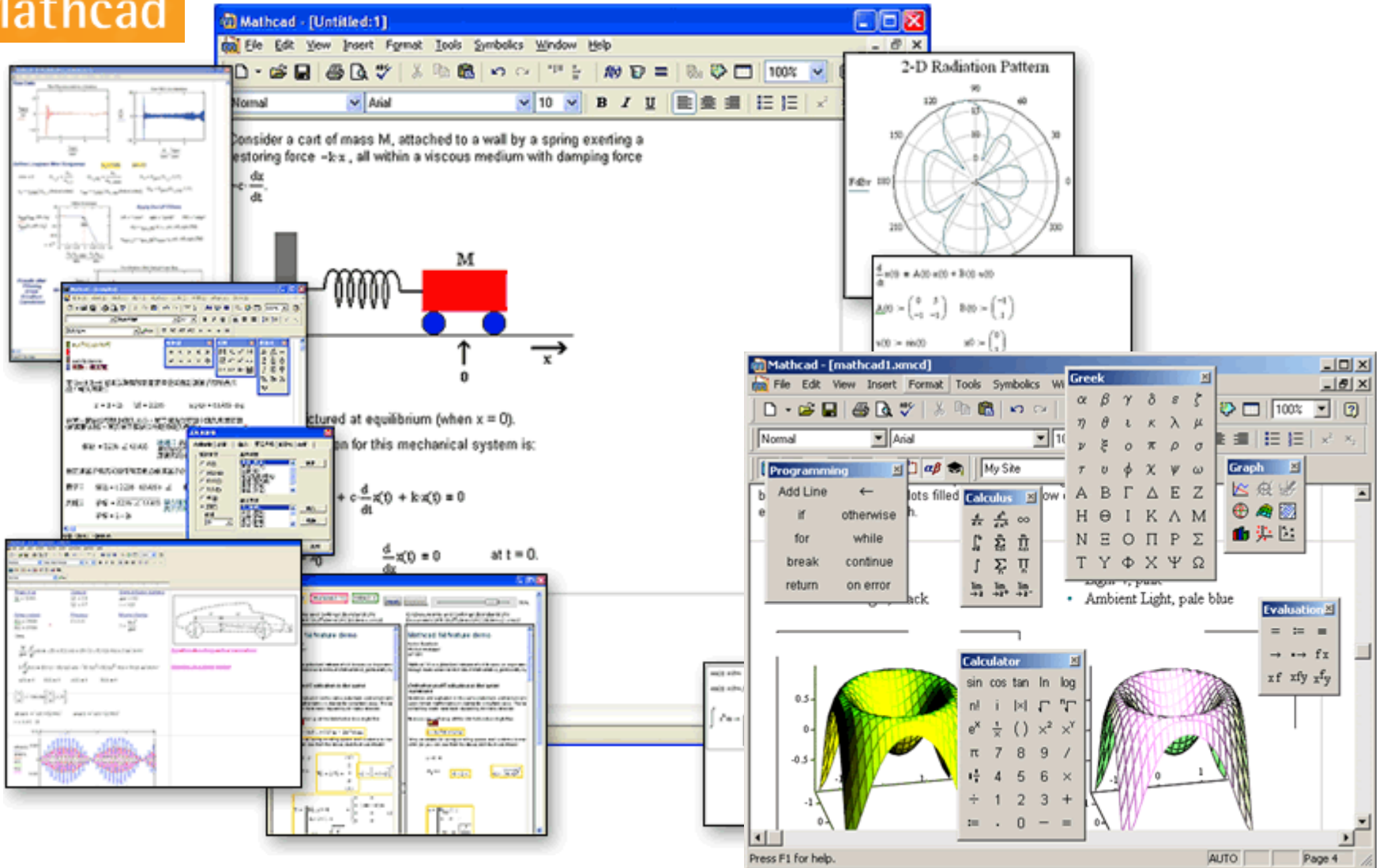
X-# demo1

X-# ScilabGraphic0

File Zoom UnZoom 3D Rot.

Mathcad

Mathcad



Mathcad - [Untitled:1]

File Edit View Insert Format Tools Symbolics Window Help

Normal Arial 10 B I U

Consider a cart of mass M , attached to a wall by a spring exerting a restoring force $-kx$, all within a viscous medium with damping force

$$c \frac{dx}{dt} + kx = 0$$

at equilibrium (when $x = 0$).

Equation for this mechanical system is:

$$c \frac{dx}{dt} + kx = 0$$

$\frac{dx}{dt} = 0$ at $t = 0$.

2-D Radiation Pattern

$\frac{d}{dt} = A \frac{d}{dt} + B \frac{d}{dt} + C \frac{d}{dt}$

$\Delta U = \begin{pmatrix} 0 & 3 \\ -1 & -1 \end{pmatrix}$ $B U = \begin{pmatrix} -1 \\ 1 \end{pmatrix}$

$U(0) = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$ $U(1) = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$

Mathcad - [mathcad1.mcd]

File Edit View Insert Format Tools Symbolics Window Help

Normal Arial 10

Programming

- Add Line
- if otherwise
- for while
- break continue
- return on error

Calculus

Integration, Differentiation, Limits, Derivatives, etc.

Greek

$\alpha \beta \gamma \delta \epsilon \zeta$
 $\eta \theta \iota \kappa \lambda \mu$
 $\nu \xi \omicron \pi \rho \sigma$
 $\tau \upsilon \phi \chi \psi \omega$
 $\Delta \Gamma \Lambda \Sigma$
 $\Theta \Pi \Phi \Psi \Omega$
 $\Upsilon \Phi \chi \Psi \Omega$

Graph

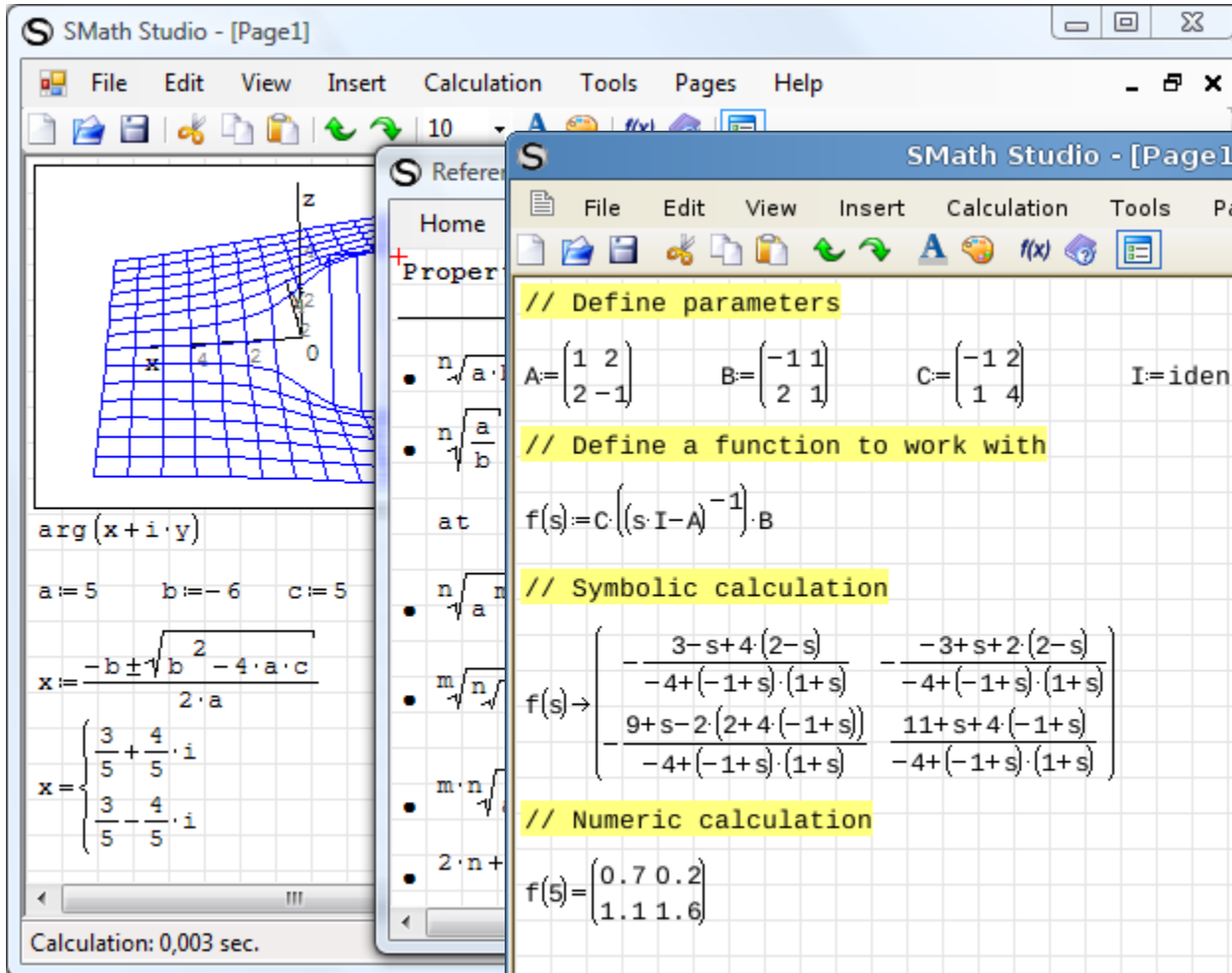
Evaluation

Calculator

sin cos tan ln log
n! i |x| Γ \sqrt{x}
 $e^x \frac{1}{x} ()^2 \times^y$
 π 7 8 9 /
 \sqrt{x} 4 5 6 \times
 \div 1 2 3 +
= . 0 - =

3D Surface Plots

Press F1 for help. AUTO Page 4



SMath Studio - [Page1]

File Edit View Insert Calculation Tools Pages Help

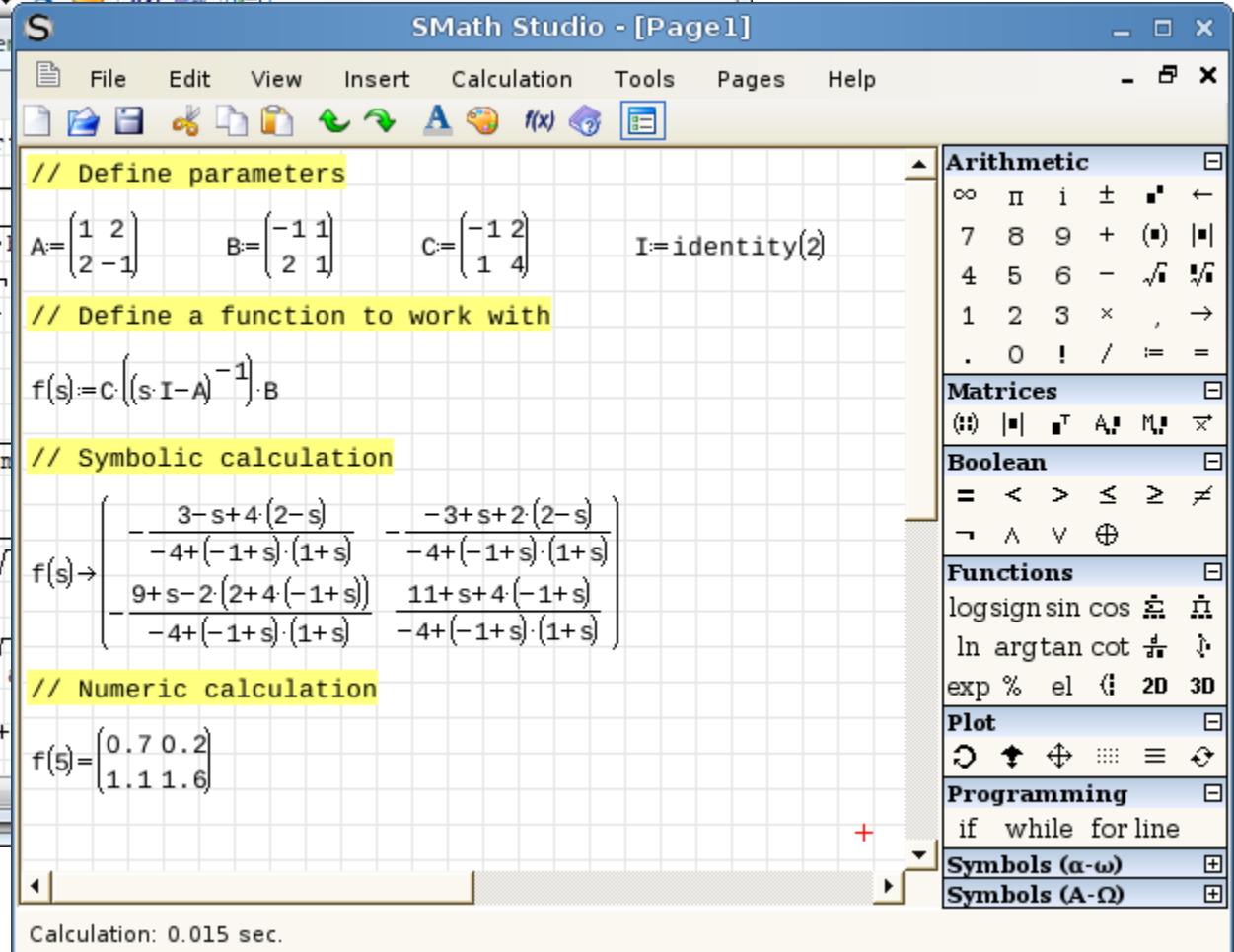
arg(x+i·y)

a:=5 b:=-6 c:=5

$$x := \frac{-b \pm \sqrt{b^2 - 4 \cdot a \cdot c}}{2 \cdot a}$$

$$x = \begin{cases} \frac{3}{5} + \frac{4}{5} \cdot i \\ \frac{3}{5} - \frac{4}{5} \cdot i \end{cases}$$

Calculation: 0,003 sec.



SMath Studio - [Page1]

File Edit View Insert Calculation Tools Pages Help

```
// Define parameters
A=⎡ 1 2 ⎤    B=⎡ -1 1 ⎤    C=⎡ -1 2 ⎤    I:=identity(2)
  ⎣ 2 -1 ⎦    ⎣ 2 1 ⎦    ⎣ 1 4 ⎦

// Define a function to work with
f(s):=C·(s·I-A)-1·B

// Symbolic calculation
f(s)→ ⎡ -3-s+4(2-s)    -3+s+2(2-s) ⎤
      ⎣ -4+(-1+s)·(1+s)    -4+(-1+s)·(1+s) ⎦
      ⎡ 9+s-2(2+4(-1+s))    11+s+4(-1+s) ⎤
      ⎣ -4+(-1+s)·(1+s)    -4+(-1+s)·(1+s) ⎦

// Numeric calculation
f(5)=⎡ 0.7 0.2 ⎤
     ⎣ 1.1 1.6 ⎦
```

Calculation: 0.015 sec.

Arithmetic

∞ π i ± √ ←

7 8 9 + (•) |

4 5 6 - √ √

1 2 3 × , →

. 0 ! / := =

Matrices

(•) | ∙^T A ∙ M ∙

Boolean

= < > ≤ ≥ ≠

¬ ∧ ∨ ⊕

Functions

logsign sin cos ∫ ∫

ln argtan cot ∫ ∫

exp % el (i) 2D 3D

Plot

↺ ↻ ↷ ⋮ ≡ ↻

Programming

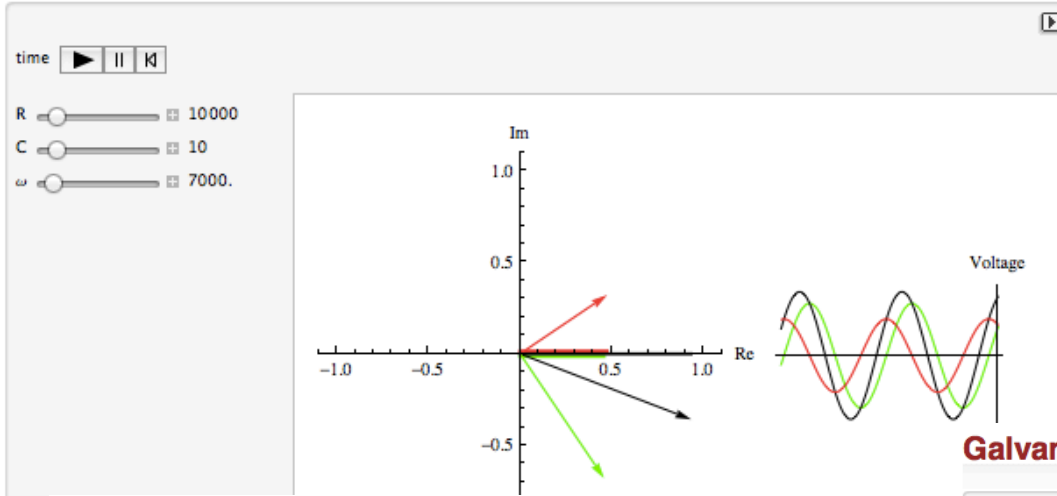
if while for line

Symbols (α-ω)

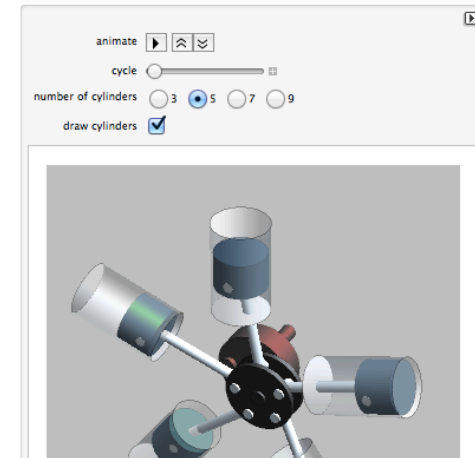
Symbols (A-Ω)



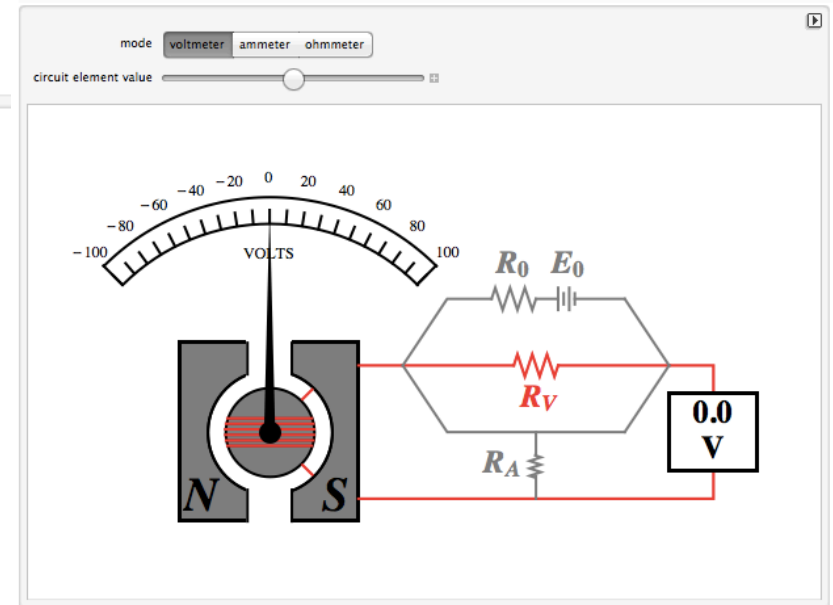
Phasor Model for RC Filter Electronic Circuit



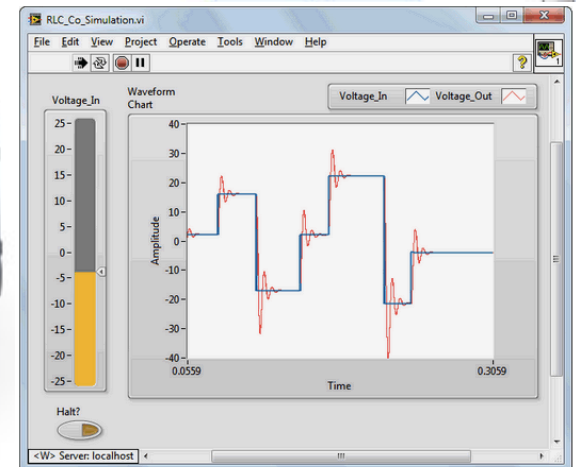
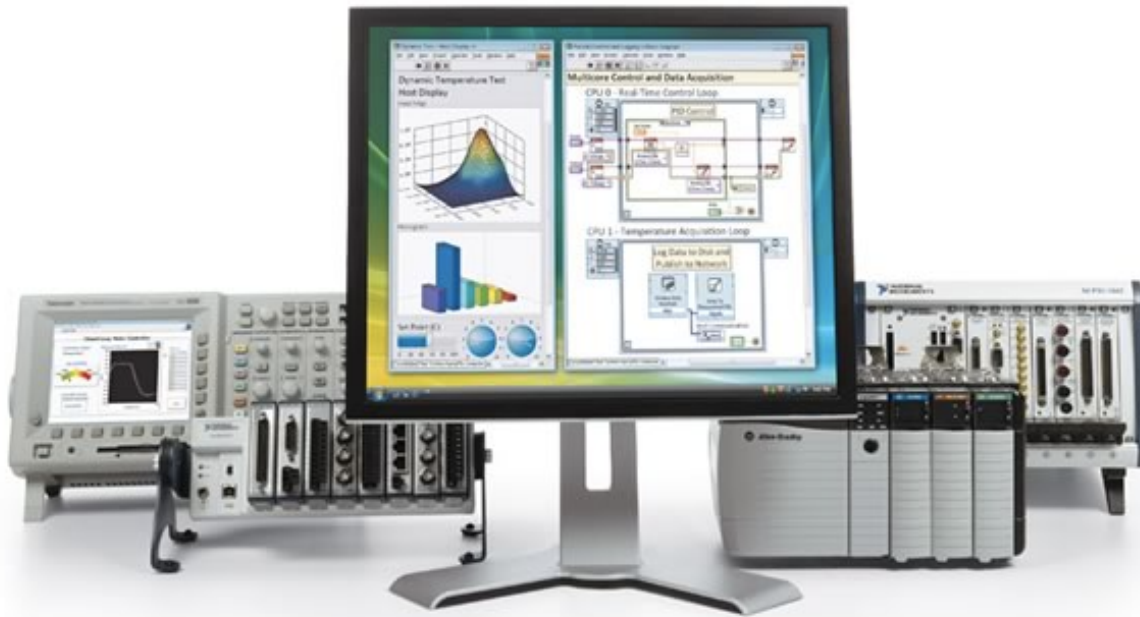
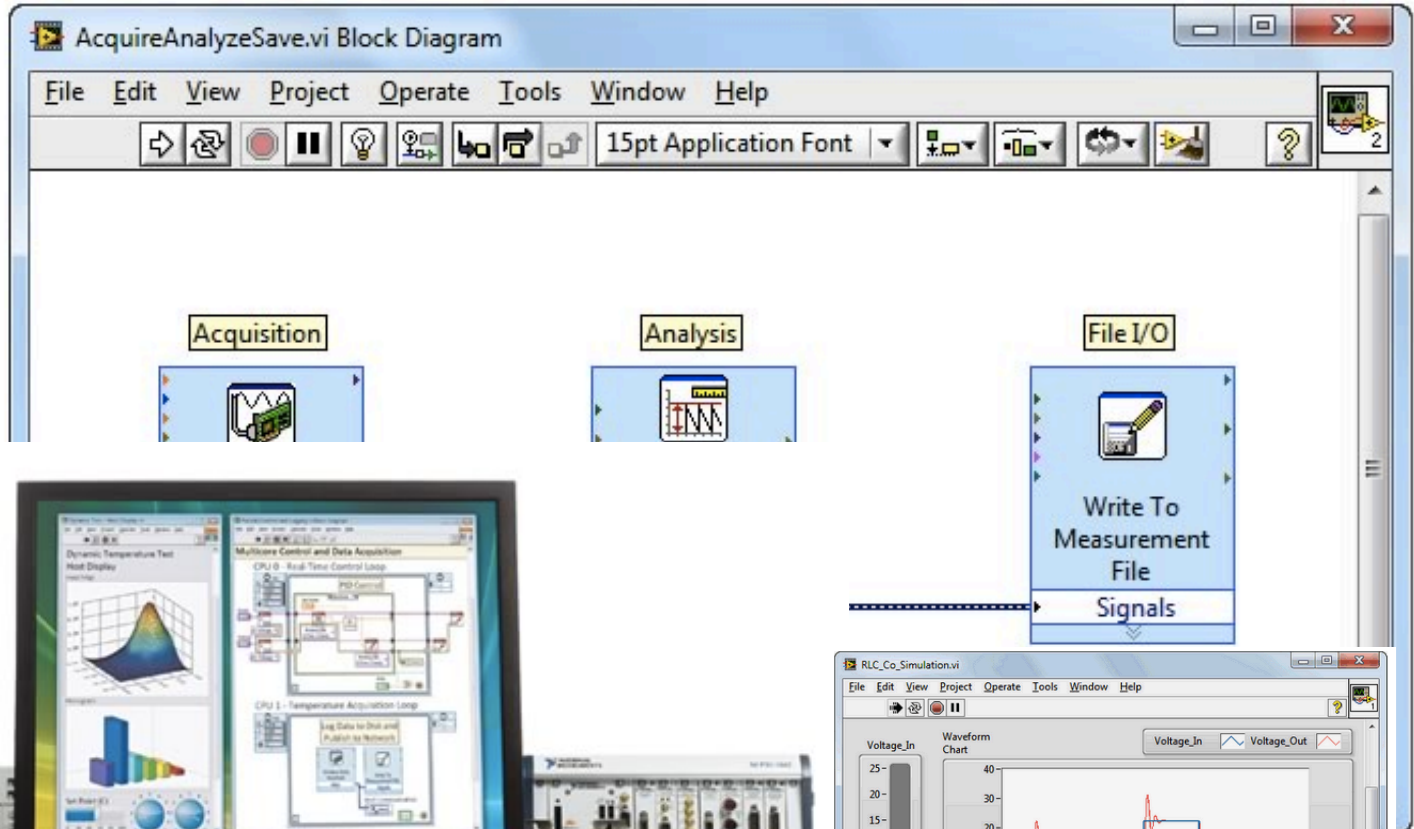
```
Manipulate[
  Grid[{
    {
      Show[
        Graphics[
          {
            {Thickness[0.0075], RGBColor[0, 1, 0],
              Line[{0, -0.015}, {
 $\frac{1}{\sqrt{(\omega R C c * 10^{-9})^2 + 1}}$ 
              Cos[ωt - π/2], -0.015}}]},
            {Thickness[0.0075], RGBColor[1, 0, 0],
              Line[{0, 0.015}, {
 $\frac{\omega R C c * 10^{-9}}{\sqrt{(\omega R C c * 10^{-9})^2 + 1}}$ 
              Cos[ωt], 0.015}}]},
            {Thickness[0.0075], Line[{0, 0}, {
              Cos[ωt - ArcTan[
 $\frac{1}{\omega R C c * 10^{-9}}$ 
              ], 0]}]},
            {RGBColor[1, 0, 0],
              Arrow[{0, 0}, {
 $\frac{\omega R C c * 10^{-9}}{\sqrt{(\omega R C c * 10^{-9})^2 + 1}}$ 
              Cos[ωt],
 $\frac{\omega R C c * 10^{-9}}{\sqrt{(\omega R C c * 10^{-9})^2 + 1}}$ 
              Sin[ωt]}]}]}]}]}]}]
```



Galvanometer as a DC Multimeter



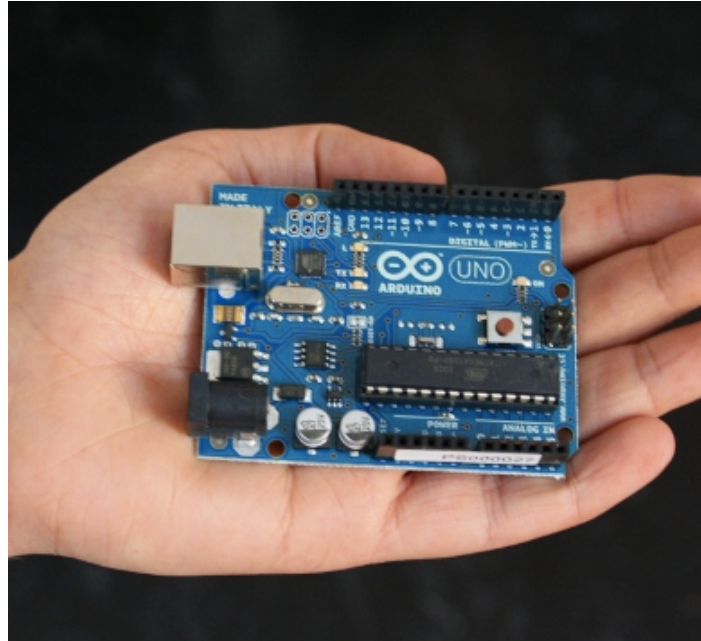
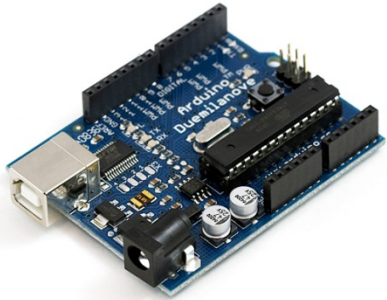
LabVIEW



Arduino



INSTITUTO FEDERAL
SANTA CATARINA

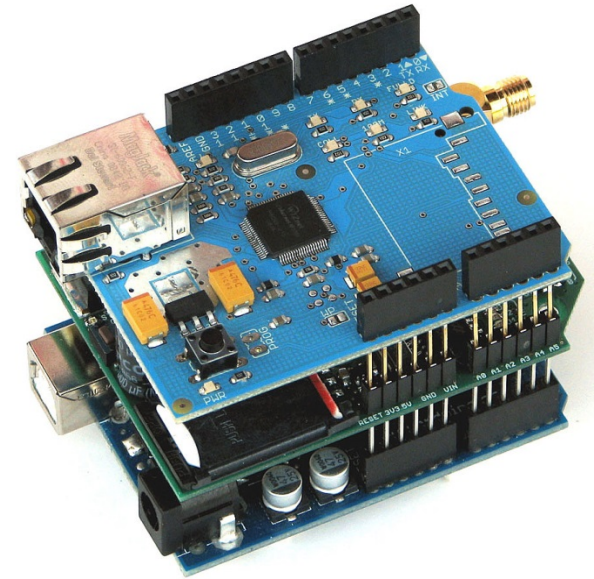
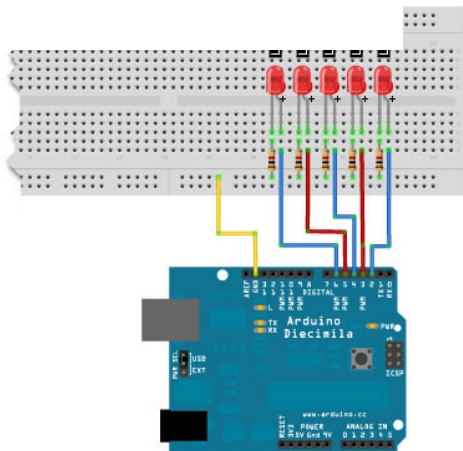


```
Arduino - 0011 Alpha
File Edit Sketch Tools Help
Blink
/*
 * Blink
 *
 * The basic Arduino example. Turns on an LED on for one second,
 * then off for one second, and so on... We use pin 13 because,
 * depending on your Arduino board, it has either a built-in LED
 * or a built-in resistor so that you need only an LED.
 *
 * http://www.arduino.cc/en/Tutorial/Blink
 */

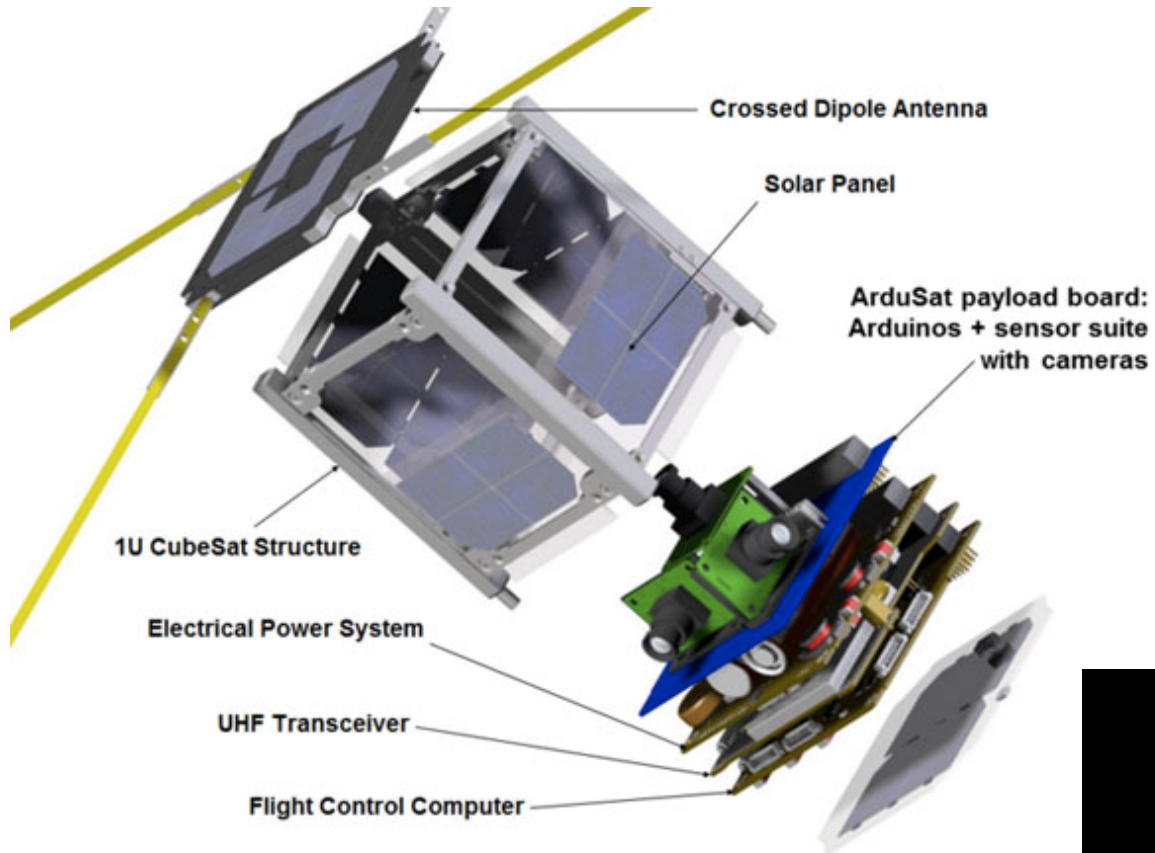
int ledPin = 13;           // LED connected to digital pin 13

void setup()              // run once, when the sketch starts
{
  pinMode(ledPin, OUTPUT); // sets the digital pin as output
}

void loop()               // run over and over again
{
  digitalWrite(ledPin, HIGH); // sets the LED on
  delay(1000);                // waits for a second
  digitalWrite(ledPin, LOW);  // sets the LED off
  delay(1000);                // waits for a second
}
```



<http://www.arduino.cc>



Agenda para esta aula

Parte 1 (19h até 20h):

- Exposição inicial sobre introdução à eletrônica de potência.

Intervalo

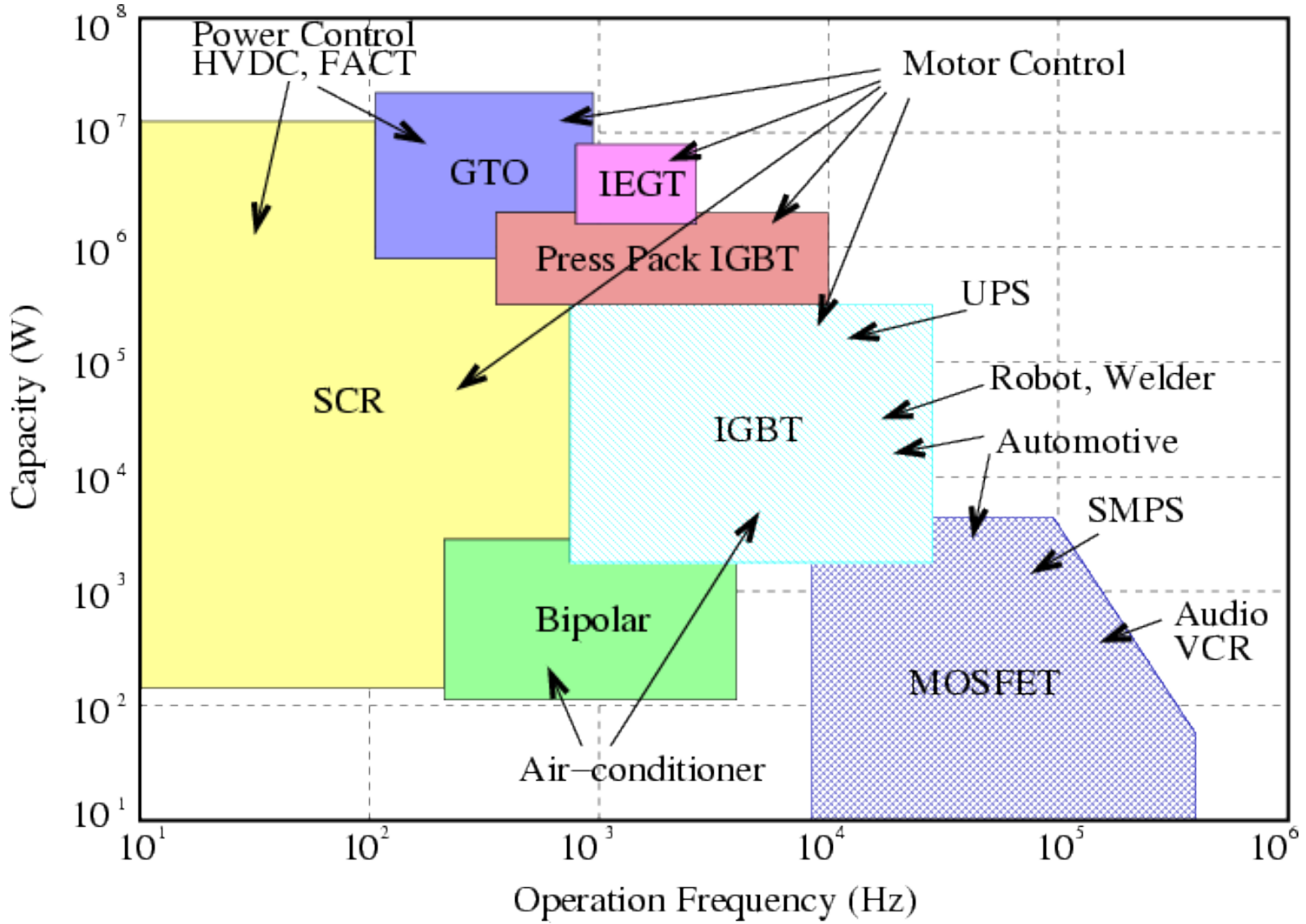
Parte 2 (20h20min até 22h):

- Ferramentas de projeto em eletrônica de potência;
- Tecnologias de componentes eletrônicos.

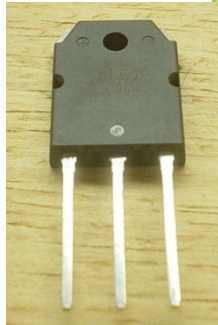
Parte 3 (22h até 22h20min):

- Acesso ao moodle e trabalho individual.

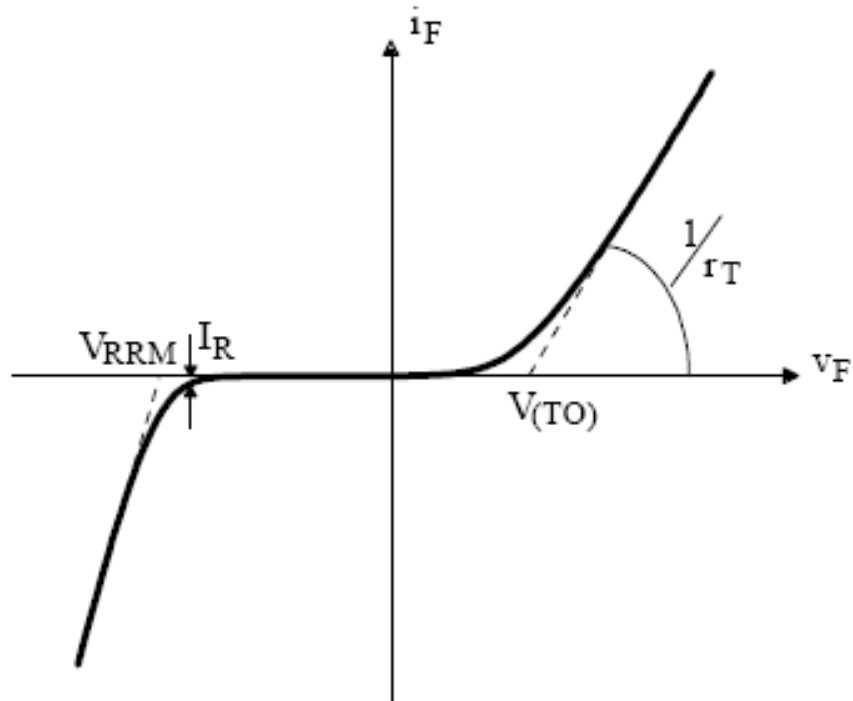
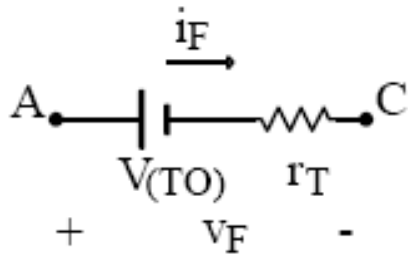
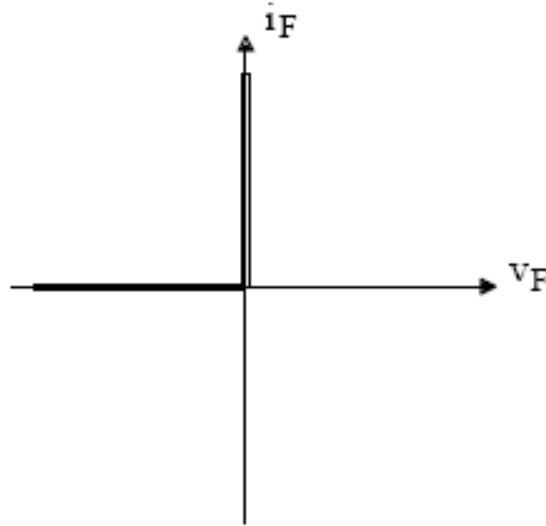
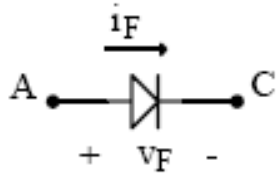
Semicondutores de potência



Semicondutores de potência



Diodo ideal e real



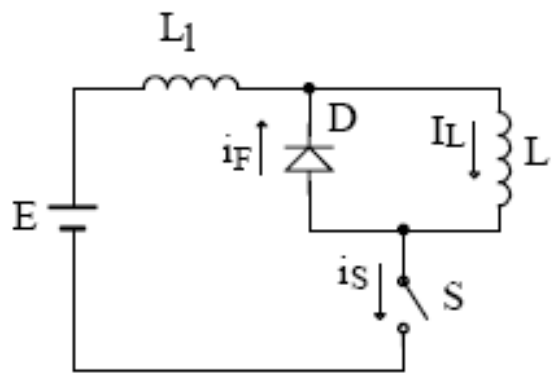
Exemplo: Diodo SKN20/08

- $V_{RRM} = 800 \text{ V}$;
- $V_{(TO)} = 0,85 \text{ V}$;
- $r_T = 11 \text{ m}\Omega$;
- $I_{Dmed} = 20 \text{ A}$;
- $I_R = 0,15 \text{ mA}$.

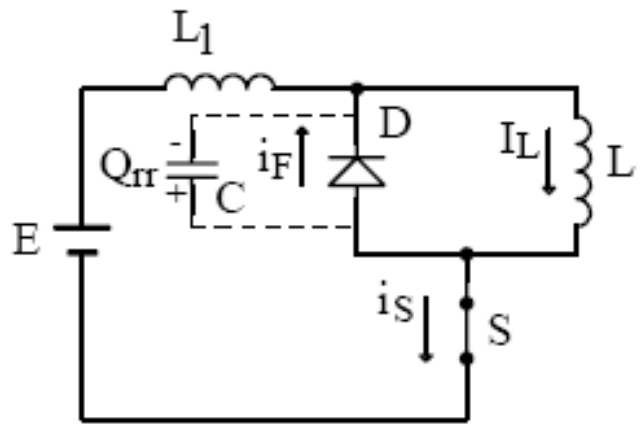
Característica estática

Diodo real - comutação

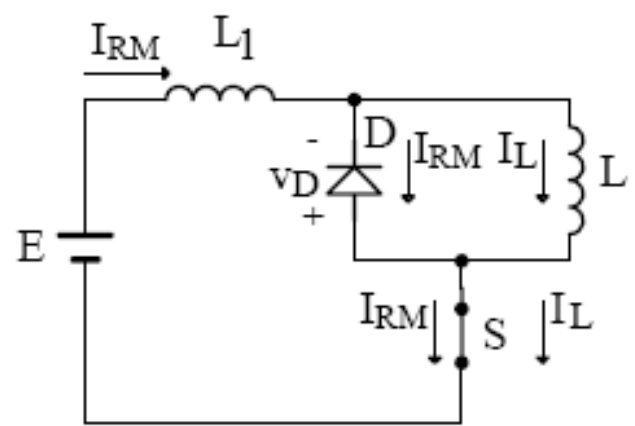
Bloqueio



Circuito para estudo da comutação



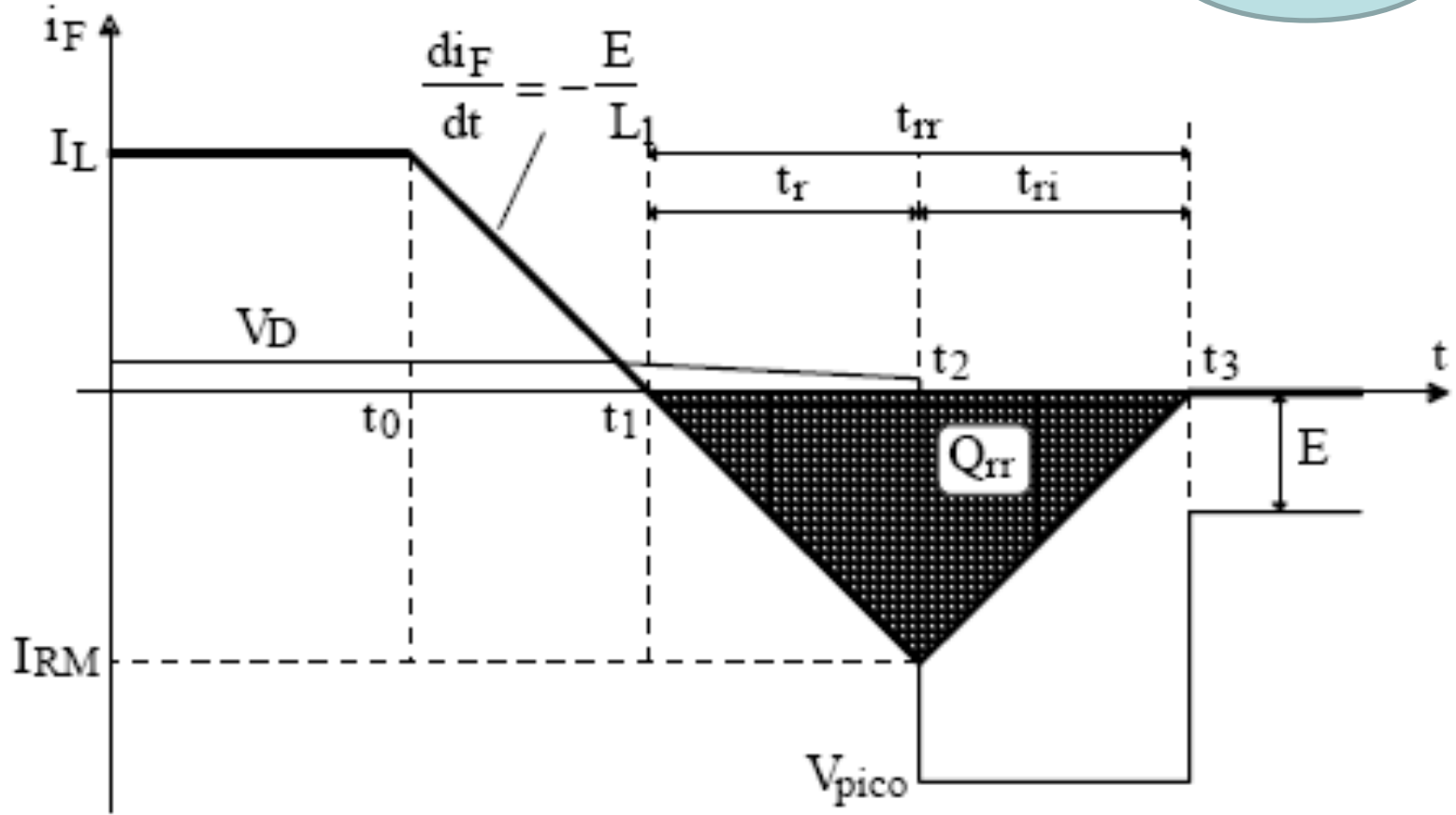
Primeira etapa de comutação



Segunda etapa de comutação

Diodo real - comutação

Bloqueio



Bloqueio

No bloqueio do diodo (comutação crítica):

$$\frac{di_F}{dt} = -\frac{E}{L_1}$$

Derivada da corrente depende da indutância

$$t_{rr} \cong \sqrt{\left(\frac{3Q_{rr}}{di_F/dt} \right)}$$

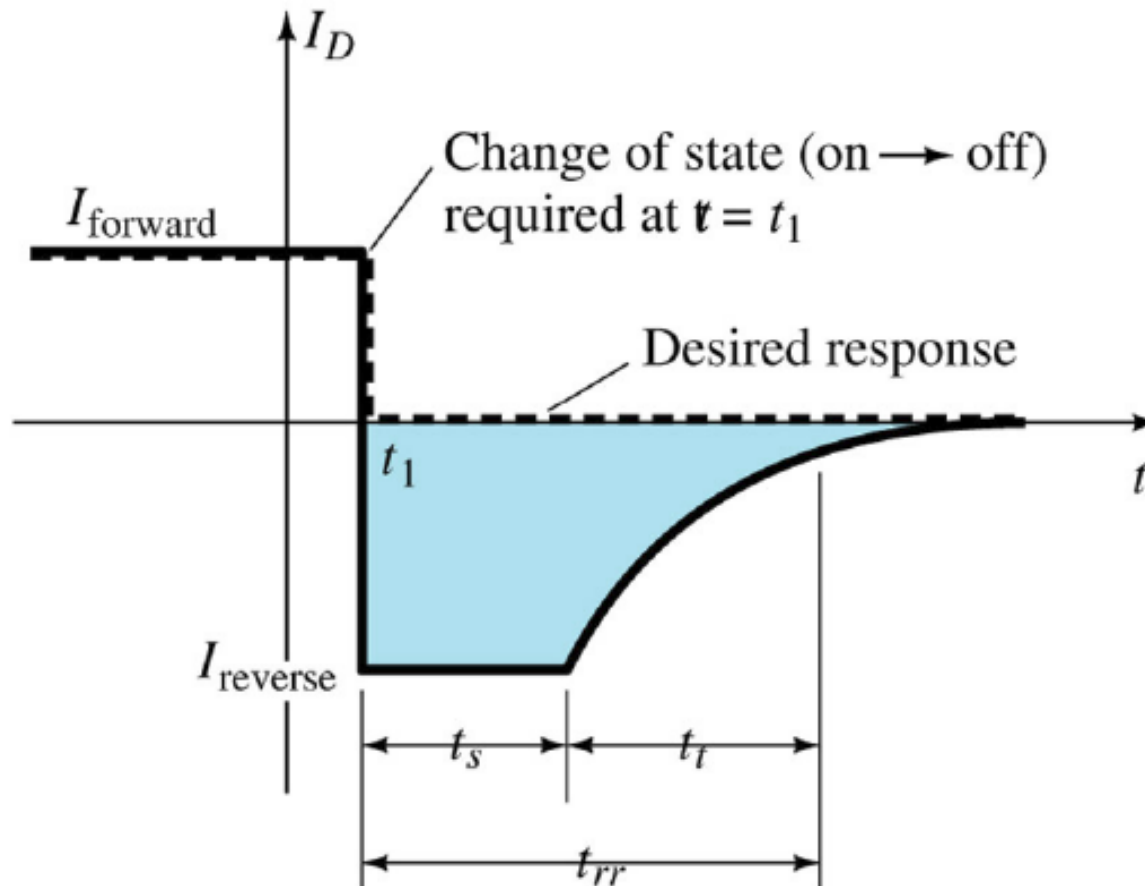
Tempo de recuperação reversa

$$I_{RM} \cong \sqrt{\left(\frac{4}{3} Q_{rr} \frac{di_F}{dt} \right)}$$

Corrente máxima devido a recuperação reversa

Diodos de carbeto de silício (silicon carbide):

Diminuem acentuadamente o fenômeno da recuperação reversa.



<http://www.infineon.com>

<http://www.cree.com>

Diodo real - comutação

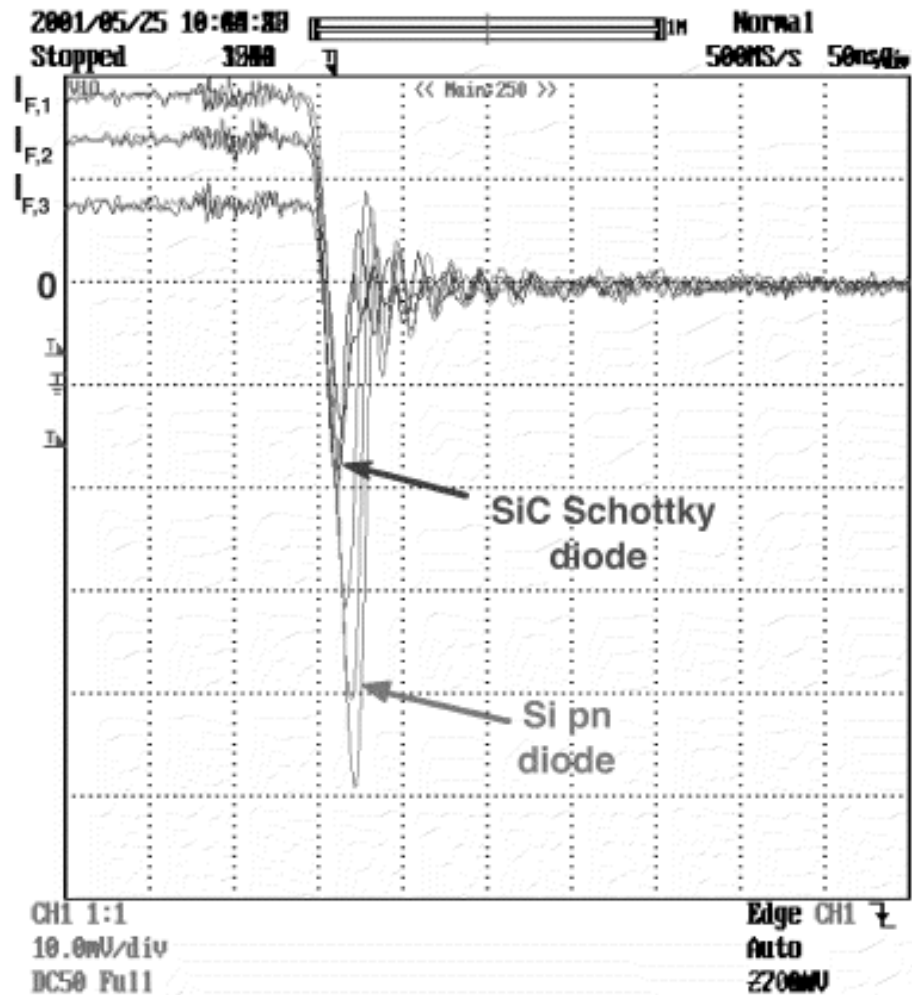


Fig. 5. Typical reverse recovery waveforms of the Si pn and SiC Schottky diode for three different forward currents (2 A/div.).

Diodo real - comutação

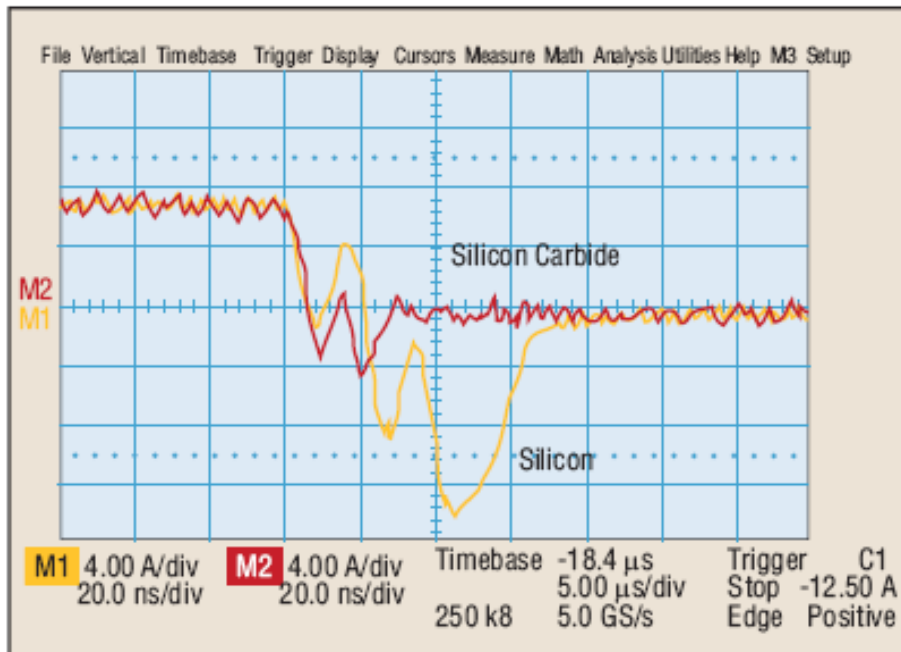


Fig. 4. Low-line diode recovery currents in PFC front-end converter.

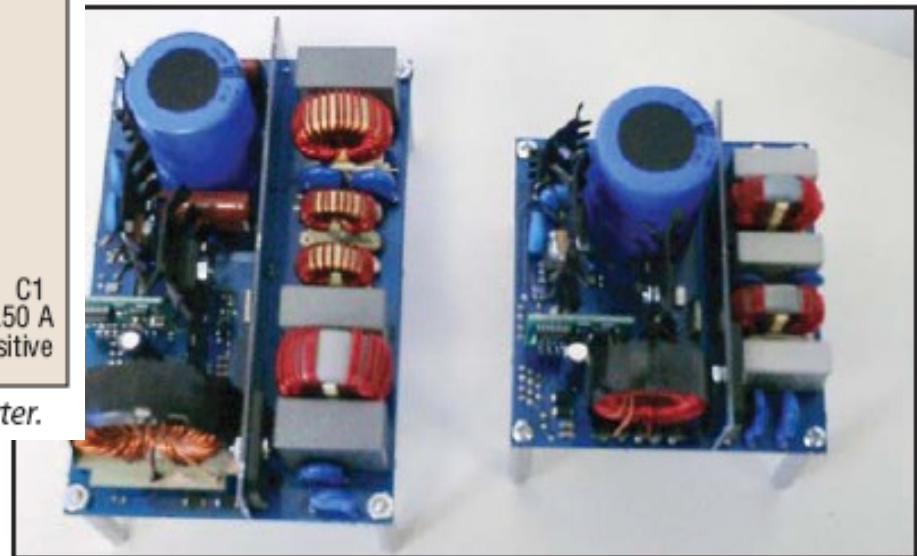


Fig. 8. A size comparison of an 80-kHz PFC front-end built with Si rectifiers (left) and a 200-kHz PFC front-end with SiC rectifiers.

Classificação das perdas:

1. Condução;

$$P = V_{(TO)} \cdot I_{Dmed} + r_T \cdot I_{Def}^2$$

2. Comutação:

- Entrada em condução;

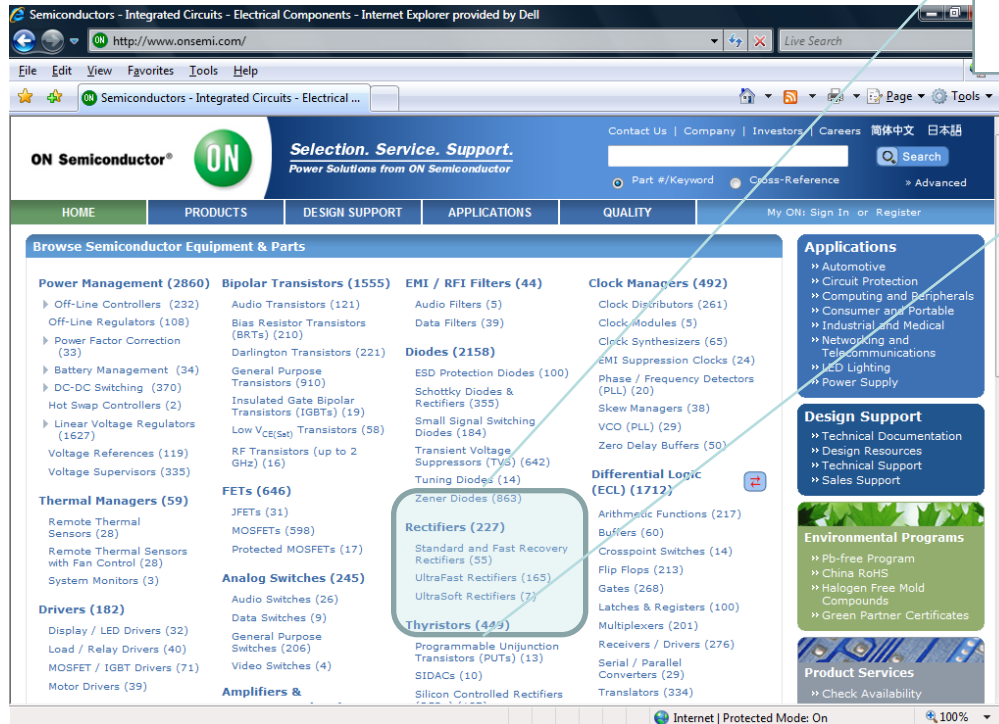
$$P_1 = 0,5(V_{FP} - V_F)I_o \cdot t_{rf} \cdot f$$

- Bloqueio.

$$P_2 = Q_{rr} \cdot E \cdot f$$

Tipos de diodos de potência:

1. Standard and fast recovery;
2. Ultrafast rectifiers;
3. Ultrasoft rectifiers;
4. Silicon carbide (zero recovery).



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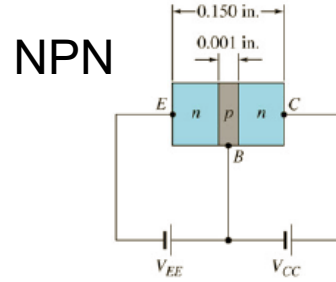
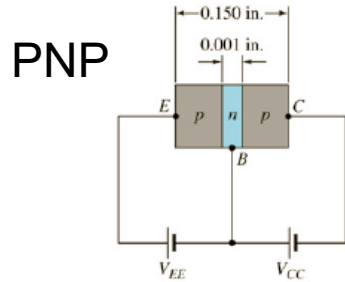
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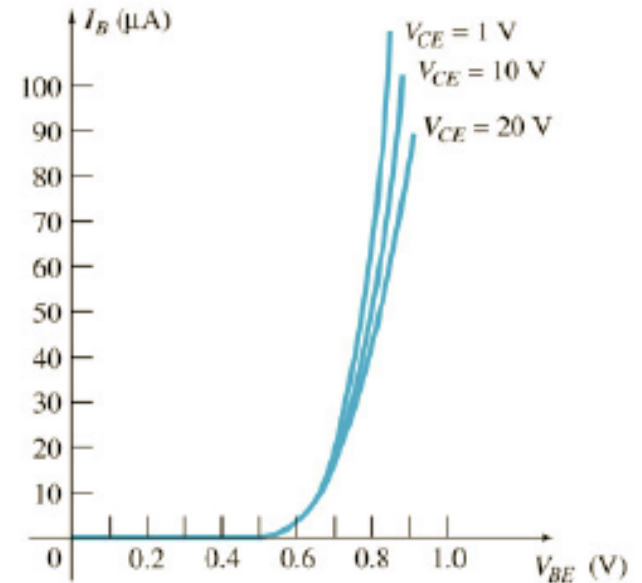
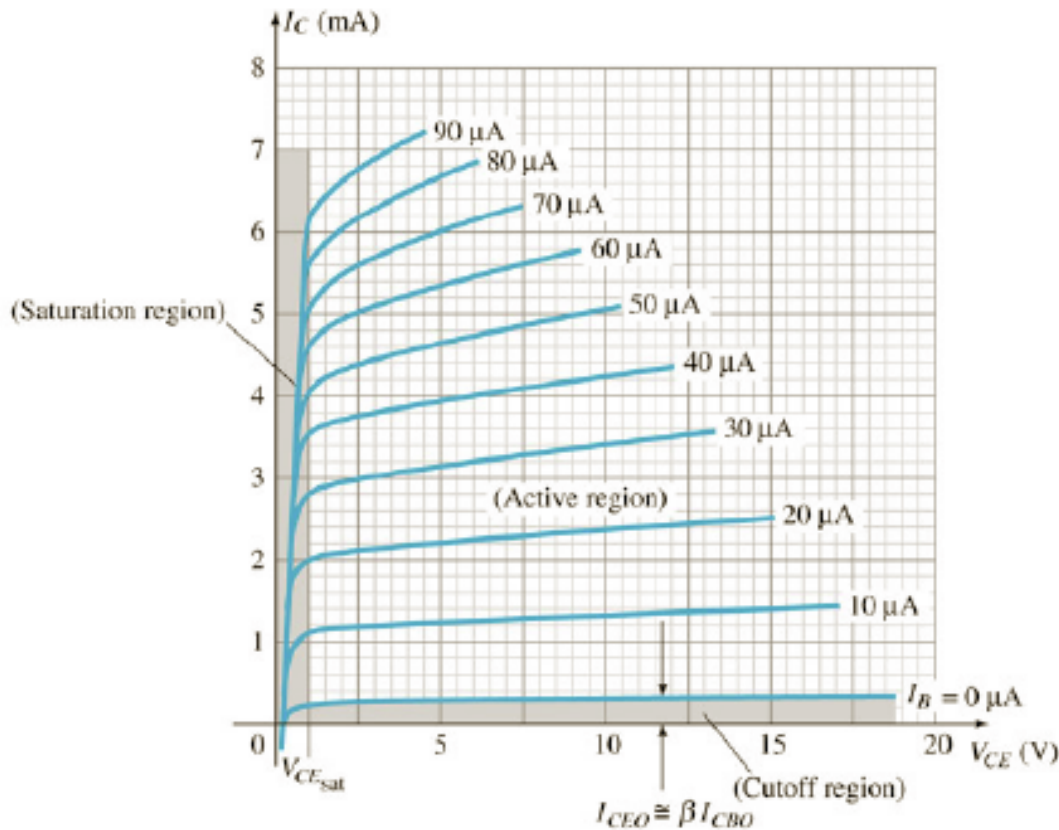
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BJT – Transistor bipolar de junção



The SiC BJT: Most Efficient 1200 V Power Conversion Switch Ever Made

A growing assortment of power switch technologies are on the market and in development today, including several that leverage the features of silicon carbide. Most promising among these choices are SiC bipolar junction transistors (BJTs). They offer very fast switching speed; the industry's lowest conduction losses; easy high temperature operation; very good robustness; and ease of manufacturing. Working in conjunction with a properly designed gate driver, SiC BJTs also offer safe operation with high ruggedness and reliability.

SiC BJT vs Si IGBT

	V	I	V _{CE}	E _{ON}	E _{OFF}
Si IGBT	1200	40	3	2500	1800
SiC BJT	1200	40	1.6	1000	600
Improvement (lowered by)			47%	60%	67%

SiC BJT Features

Lowest Losses on the Market

- Lowest conduction losses ($R_{ON} < 2.2 \text{ m}\Omega\text{cm}^2 @ \text{RT}$)
- Very low switching losses
- Lowest total losses; including driver losses
- High gain; SiC BJT DC current gain >70

Fast Switching

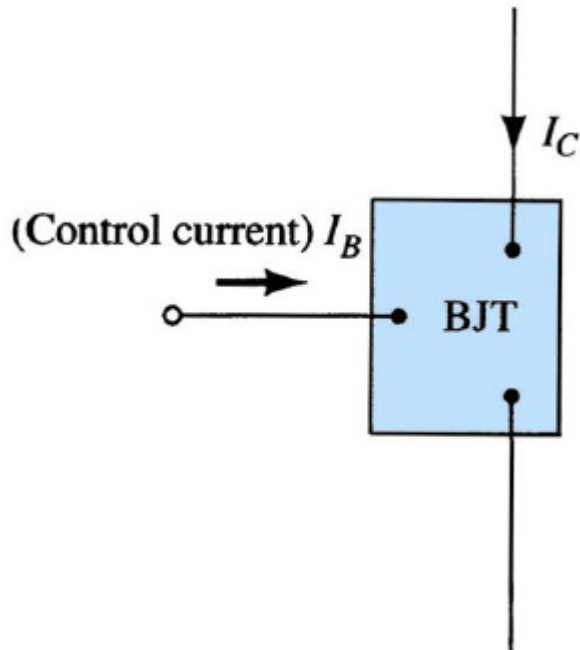
- Approximately 20 ns for turn-on and turn-off
- Switching behavior is not temperature dependent
- No current tailing for SiC BJT

Robust and Reliable

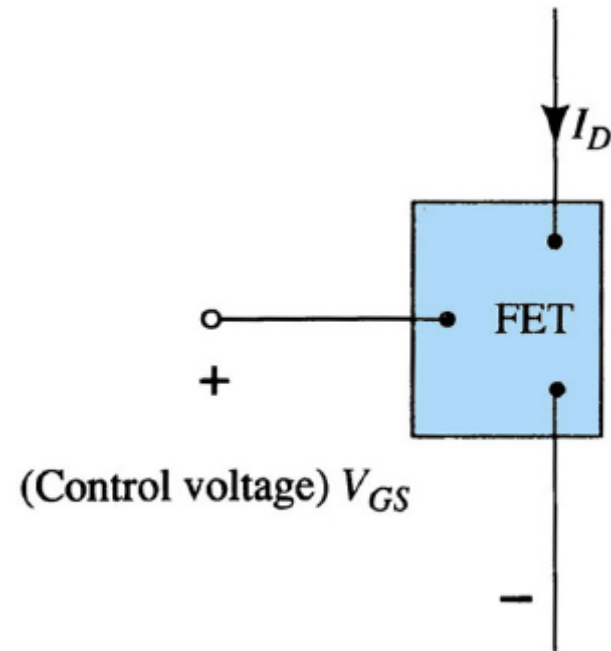
- Normally OFF device
- Highest rated operating temperature; $T_j = 175^\circ\text{C}$
- Positive temperature coefficient (R_{ON}); Easy paralleling
- No secondary breakdown for SiC BJT
- No SiO_2 gate oxide reliability issue
- Short circuit resistant
- Low leakage current

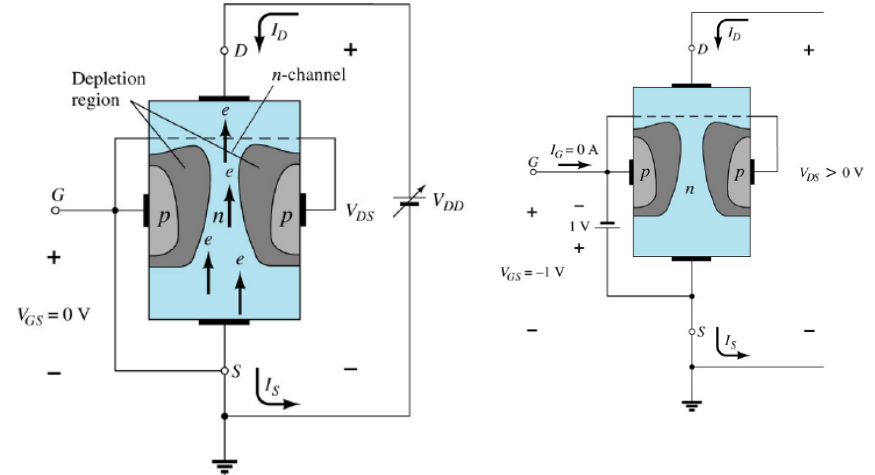
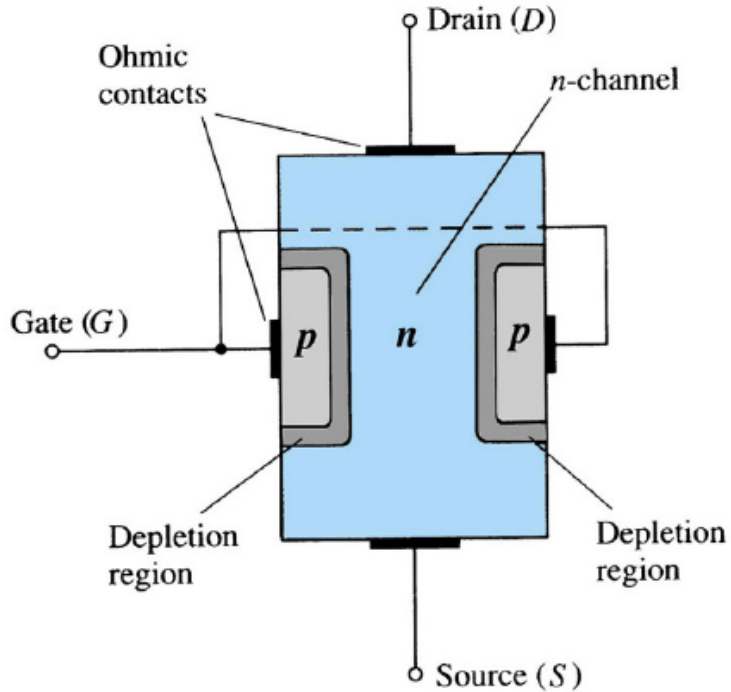
BJT x FET

BJT – Transistor bipolar de junção

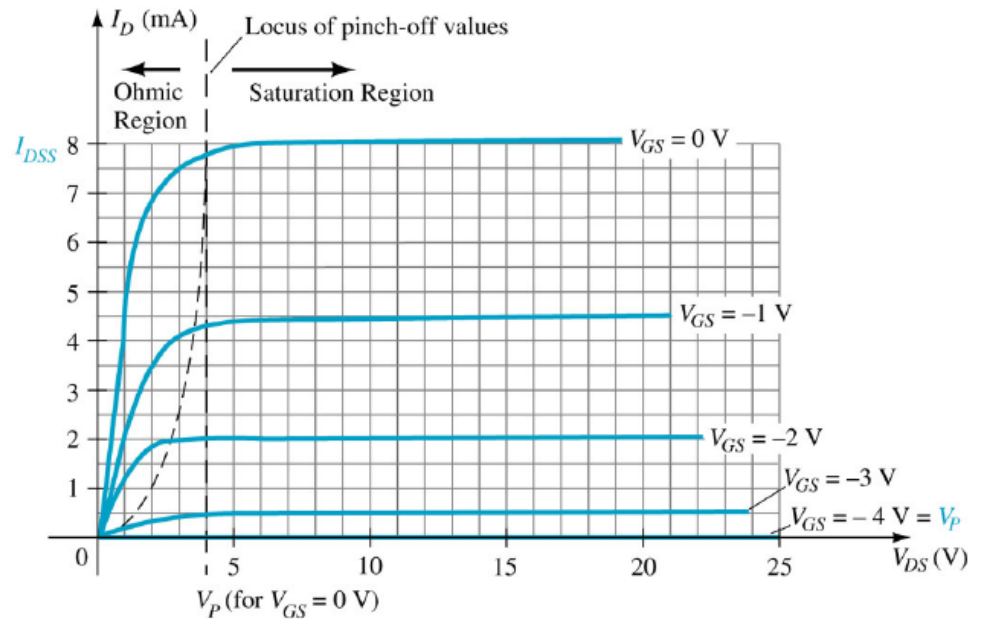


FET – Transistor de efeito de campo

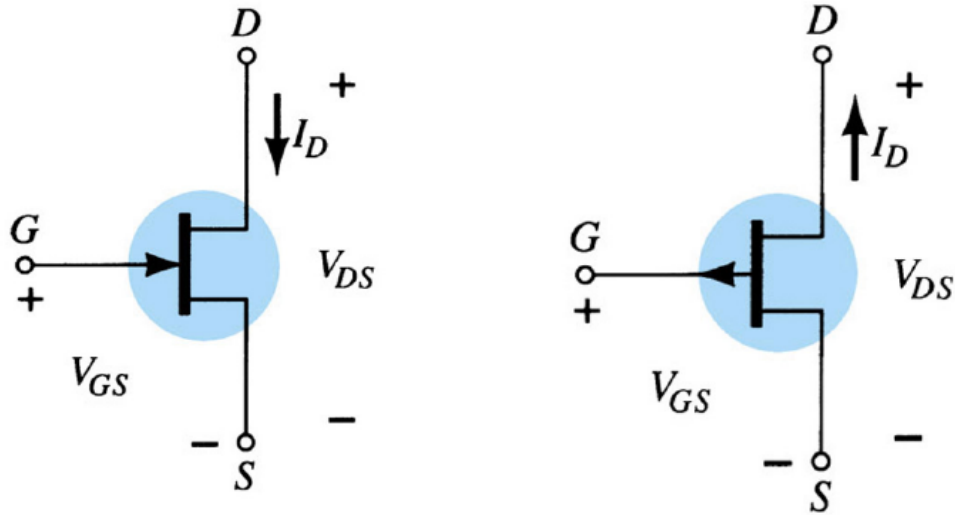




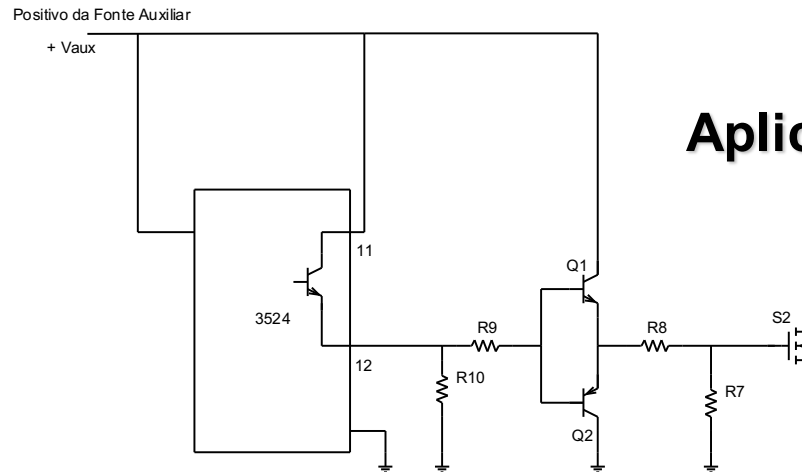
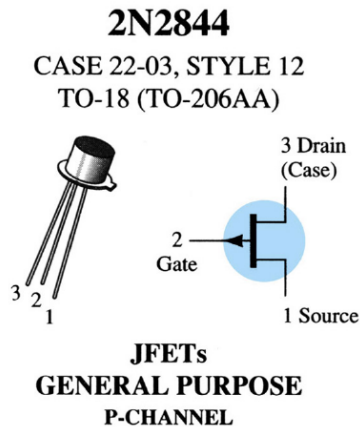
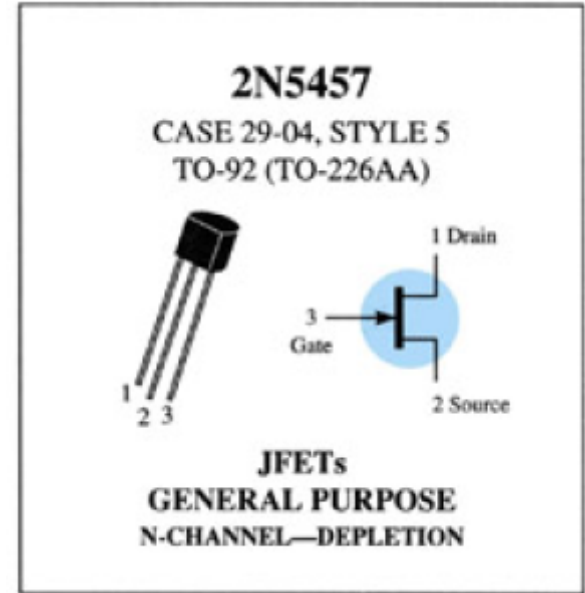
JFET: Operação básica.



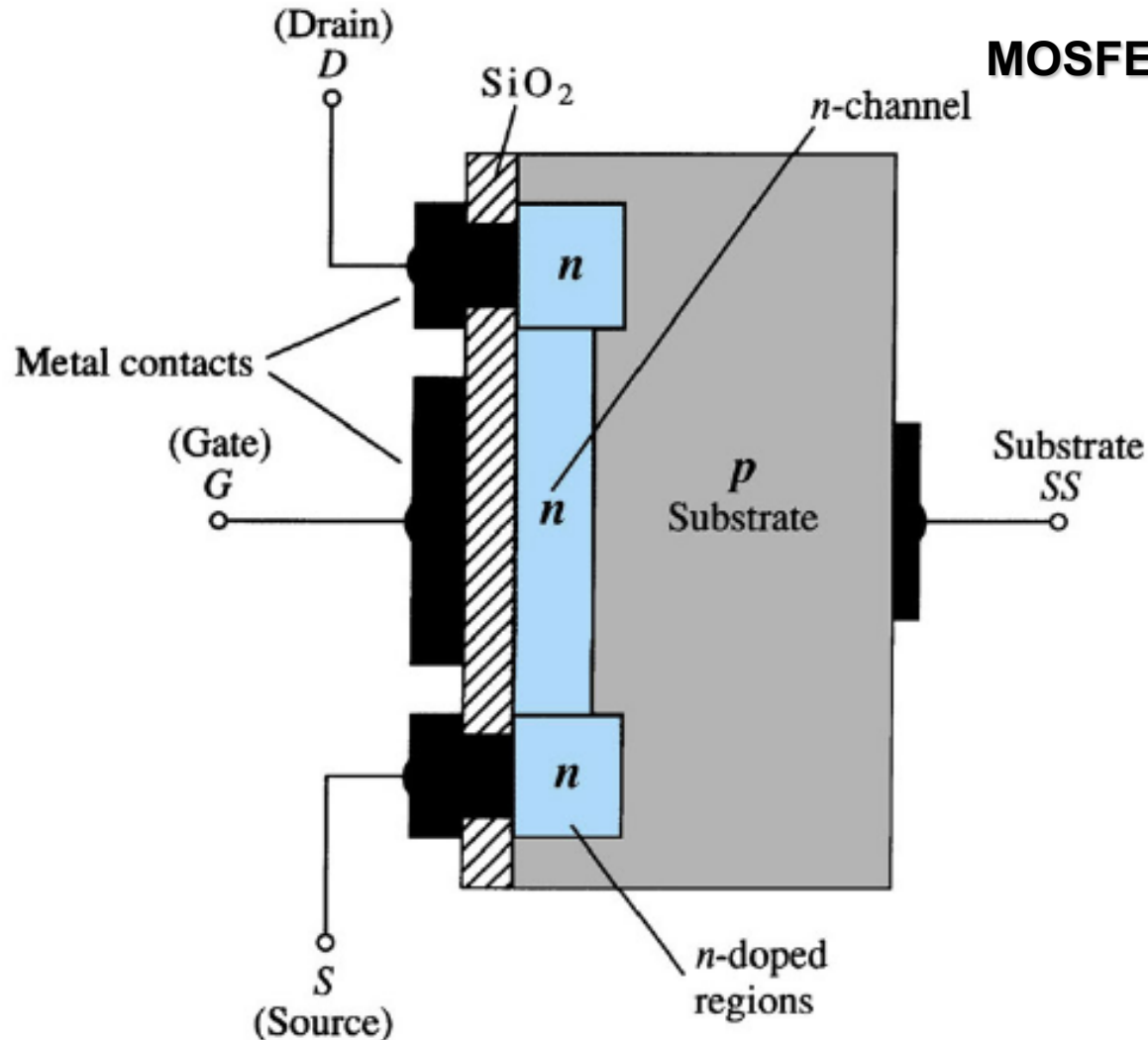
FET



JFET canal n e canal p

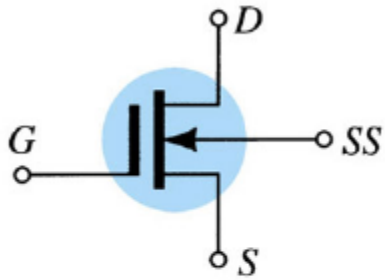


Aplicação do JFET

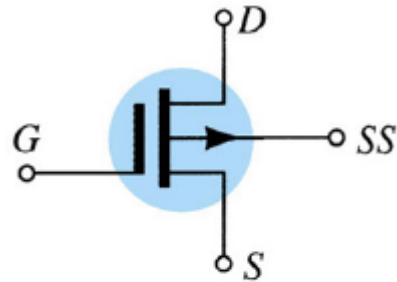


MOSFET

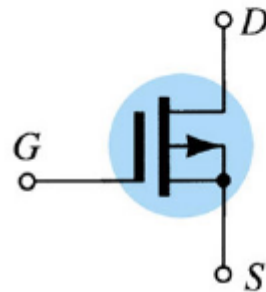
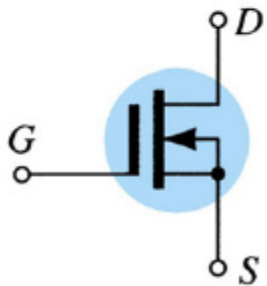
n-channel

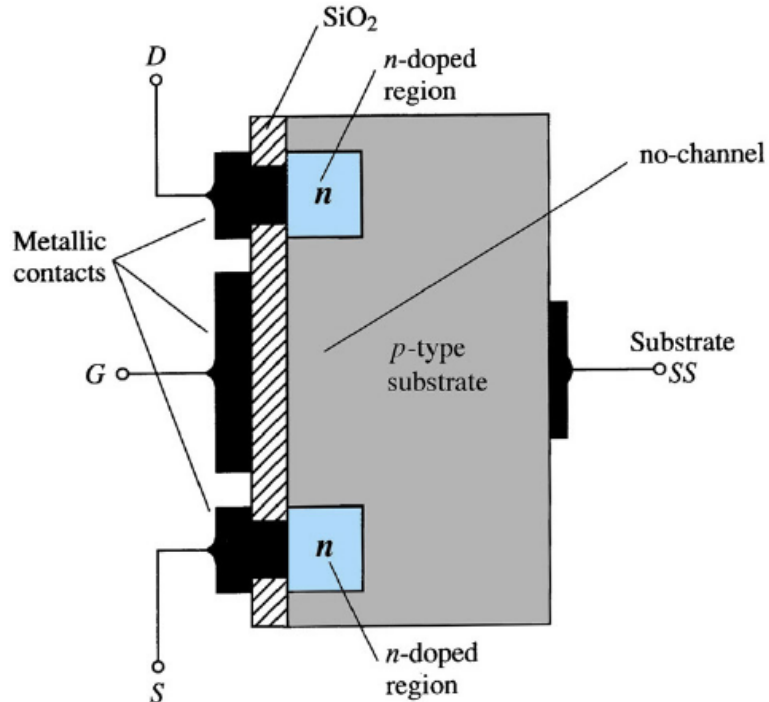


p-channel



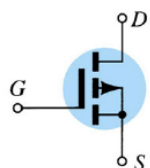
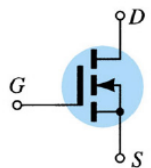
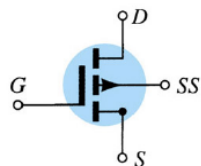
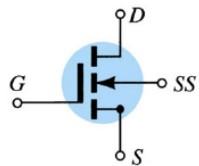
MOSFET tipo Depleção



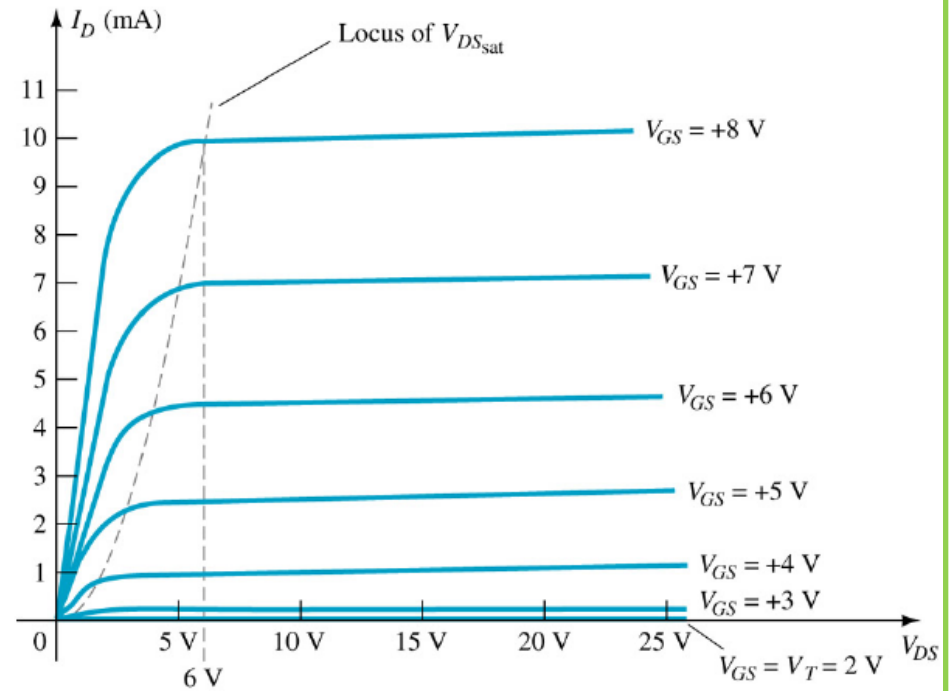


n-channel

p-channel

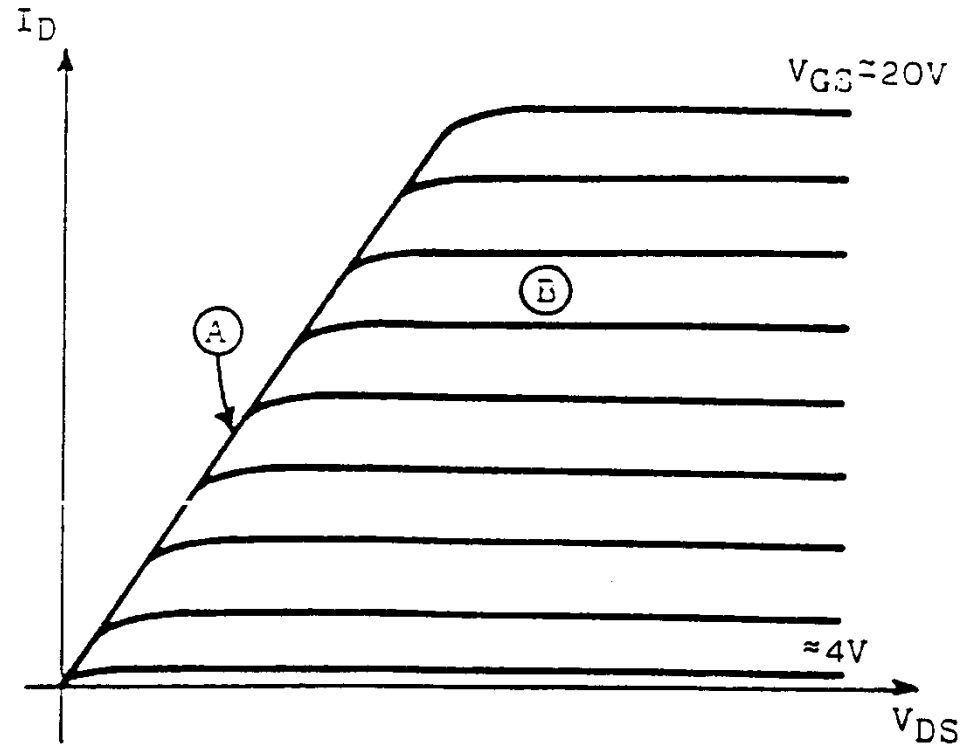
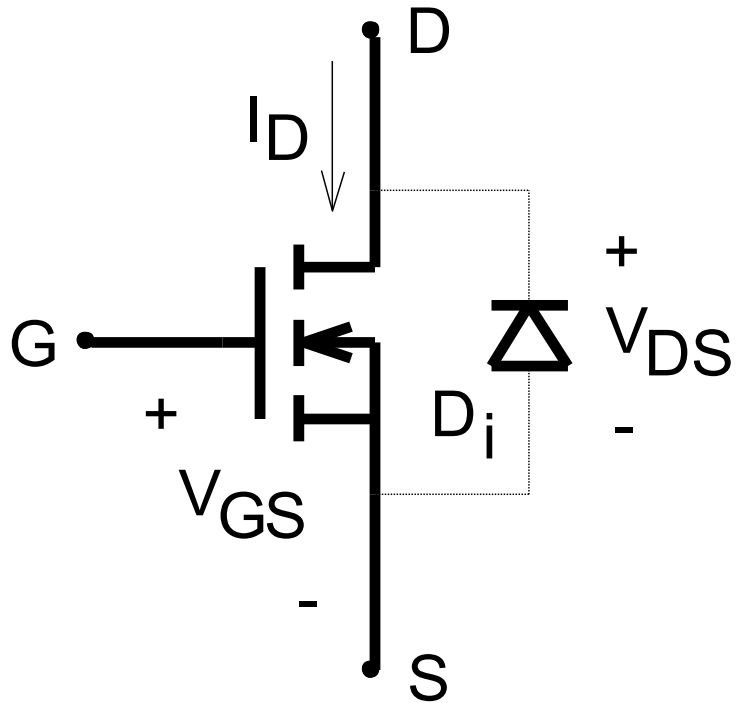


MOSFET tipo Intensificação



Canal n

MOSFET de potência



Classificação das perdas:

1. Condução;

$$P_{cond} = \frac{t_{on}}{T} \cdot r_{ds(on)} \cdot i_{d(on)}^2$$

2. Comutação:

- Entrada em condução e bloqueio;

$$P_{com} = \frac{f}{2} (t_r + t_f) \cdot i_{d(on)} \cdot v_{ds(off)}$$

- Onde:

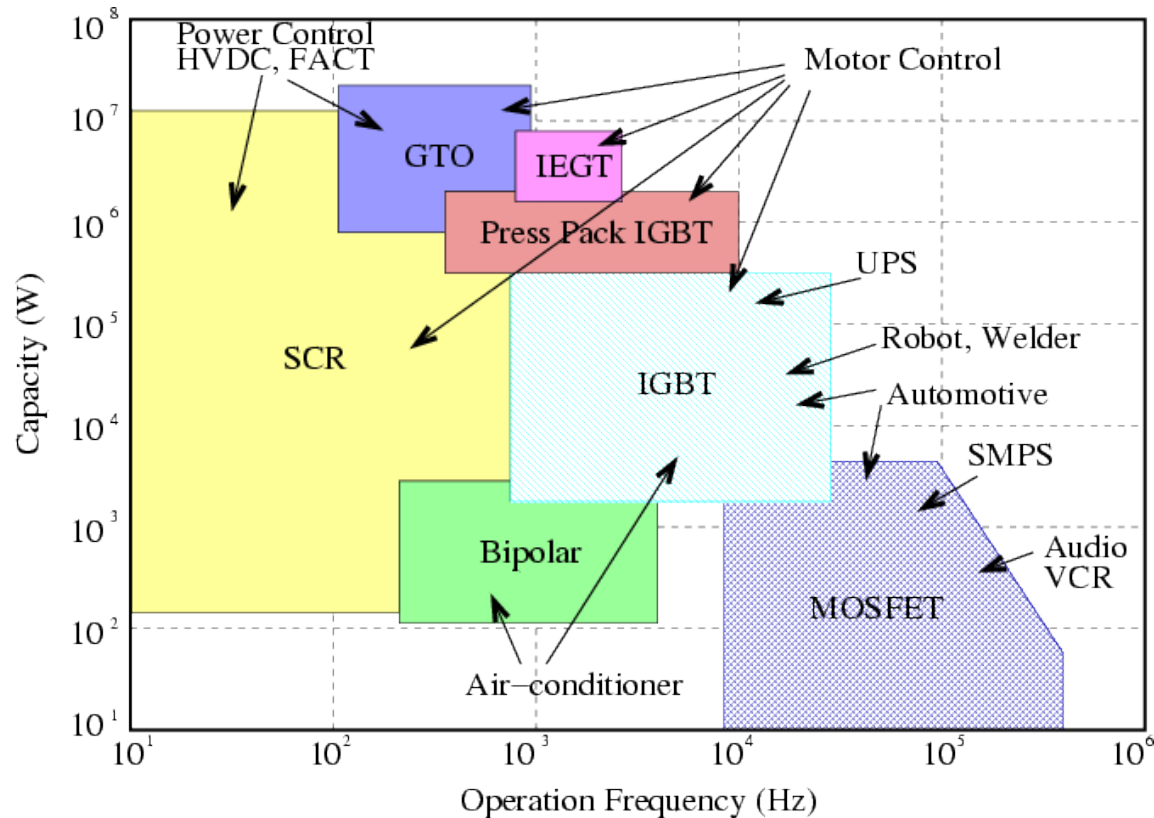
$$t_f \cong t_{on}$$

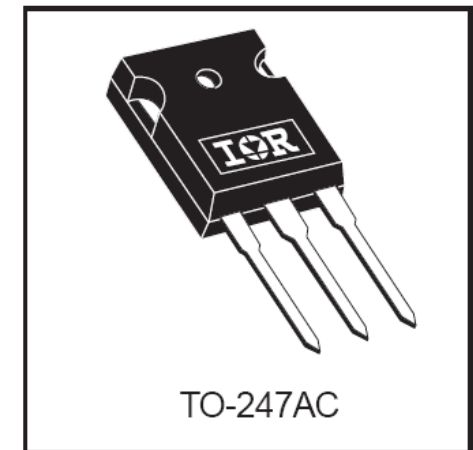
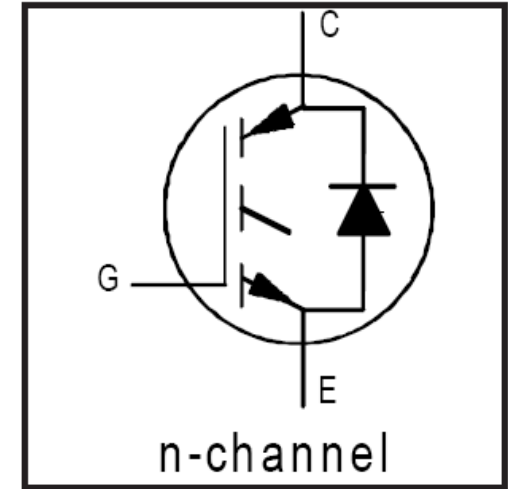
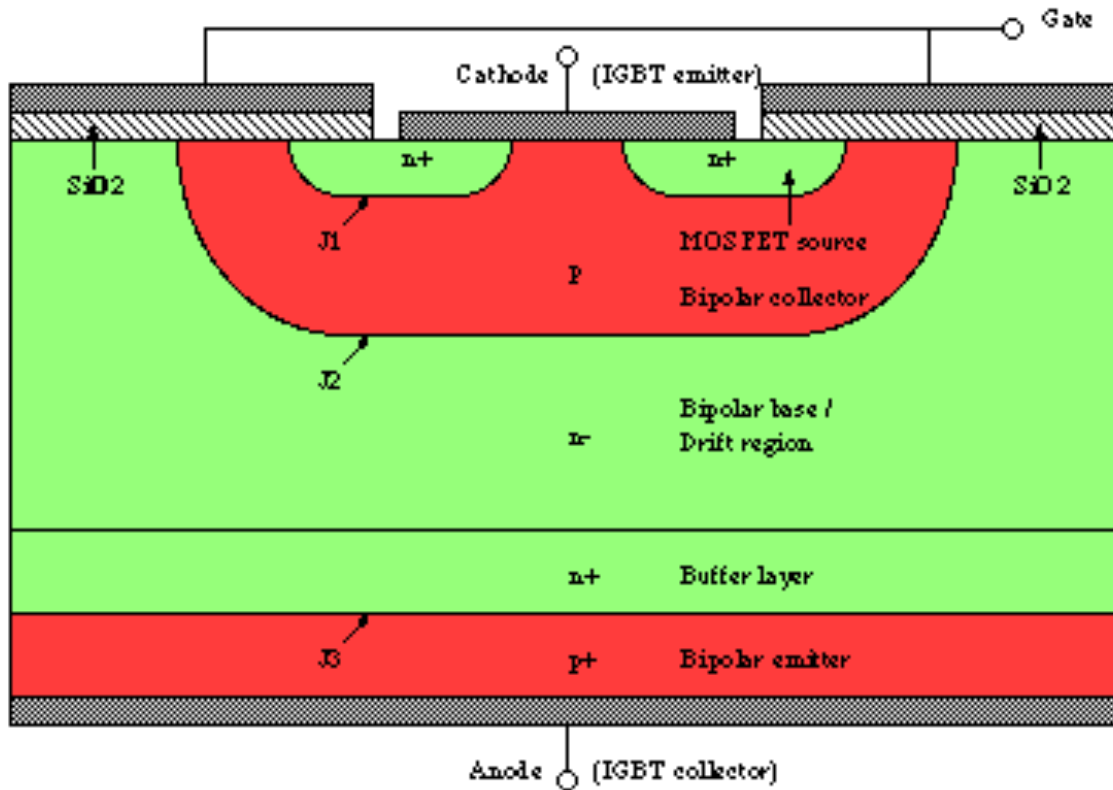
$$t_r \cong t_{off}$$

MOSFET de potência

Quando usar MOSFET:

1. Frequências altas (acima de 50 kHz);
2. Tensões muito baixas (< 500 V);
3. Potências baixas (< 1 kW).



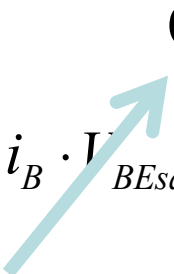


Características de BJT e MOSFET

IGBT – Insulated Gate Bipolar Transistor

Classificação das perdas:

1. Condução;

$$P_{cond} = (i_C \cdot V_{CEsat} + i_B \cdot V_{BEsat}) \cdot t_{on} \cdot f$$


2. Comutação:

- Entrada em condução e bloqueio;

$$P_{com} = \frac{1}{2} (t_r + t_f) \cdot I \cdot E \cdot f$$

Detalhamento do cálculo de perdas

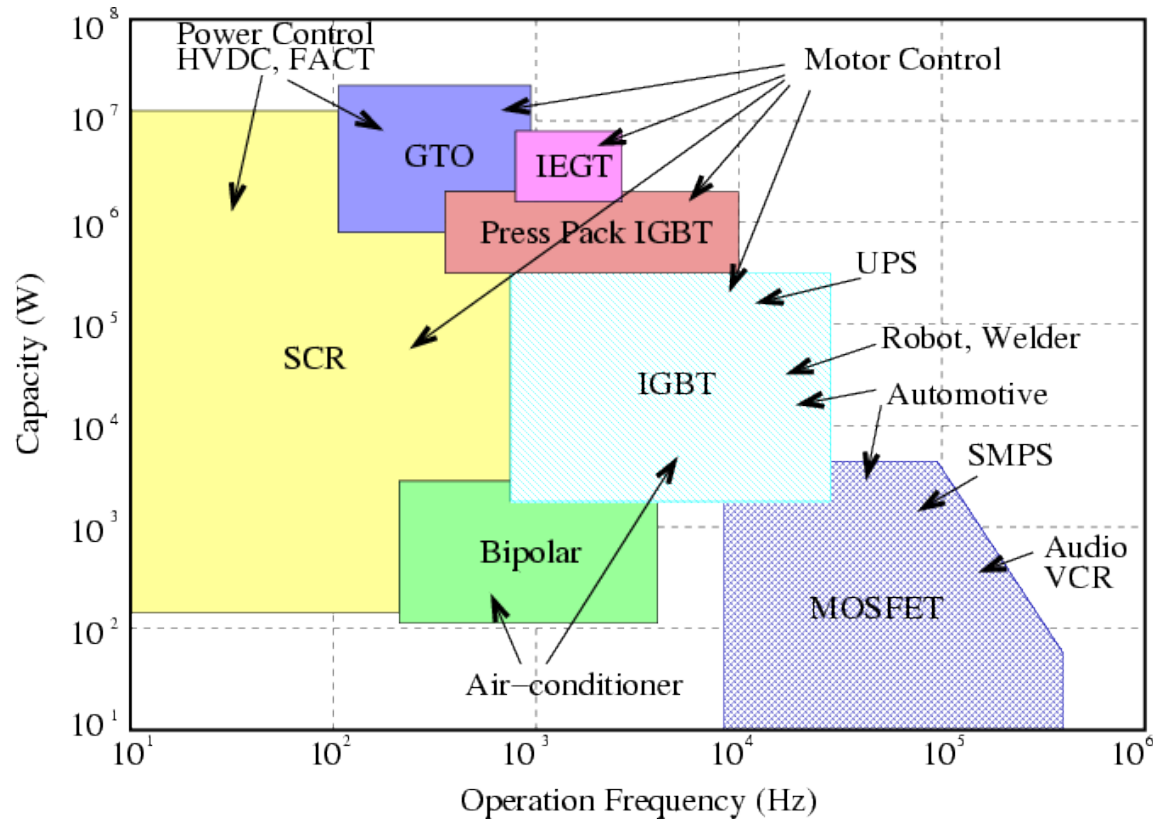


Quando usar IGBT:

1. Frequências baixas (menor que 50 kHz);
2. Tensões altas (> 500 V);
3. Potências altas (> 1 kW).

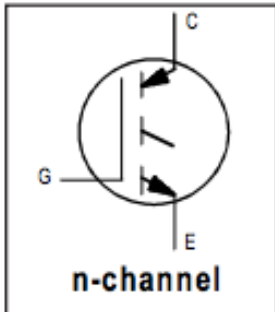
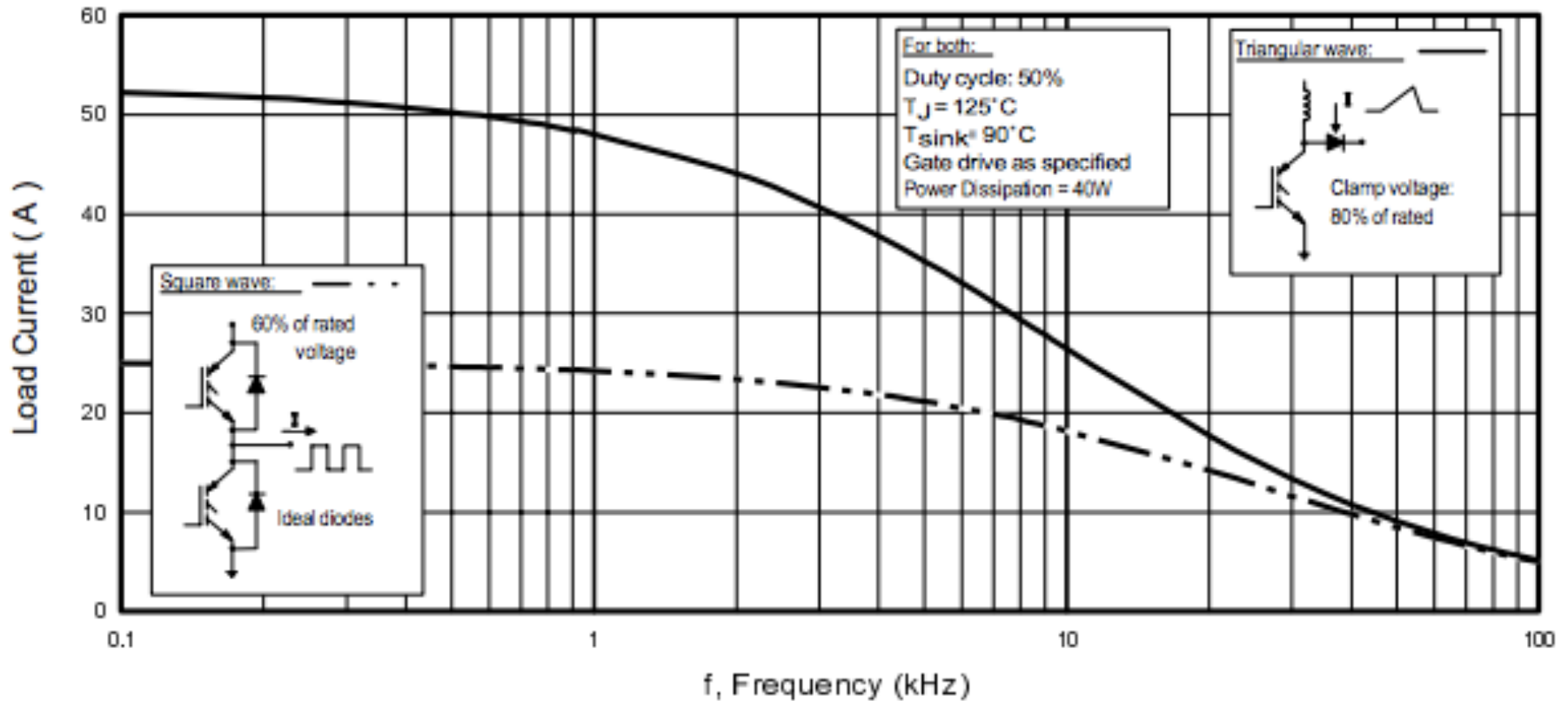


Part	Family	Package	Circuit	Switching Speed
IRG4PH30K	IGBT Discretes	TO-247AC	Discrete	ULTRAFAST 4-20 kHz
IRG4PC20U	IGBT Discretes	TO-247AC	Discrete	ULTRAFAST 8-60 kHz
IRG4PC30S	IGBT Discretes	TO-247AC	Discrete	DC-1 kHz (STANDARD)
IRG4PC60U	IGBT Discretes	TO-247AC	Discrete	ULTRAFAST 8-60 kHz
IRG4BC30W	IGBT Discretes	TO-220AB	Discrete	WARP 60-150 kHz
IRGB30B60K	IGBT Discretes	TO-220AB	Discrete	ULTRAFAST 10-30 kHz
IRGB8B60K	IGBT Discretes	TO-220AB	Discrete	ULTRAFAST 10-30 kHz
IRGS6B60K	IGBT Discretes	D2-Pak	Discrete	ULTRAFAST 10-30 kHz
IRGS14C40L	IGBT Discretes	D2-Pak	Discrete	Low-Vceon
IRGP40S0	IGBT Discretes	TO-247AC	Discrete	Low-Vceon

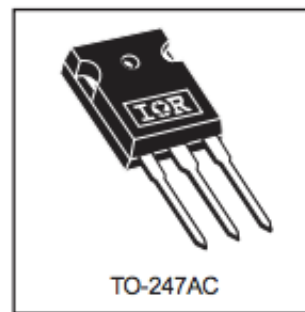


Package/Switching	Frequency	Voltage
<u>IGBT SINGLE / Soft</u>	<u>Ultrafast <30kHz</u>	<u>300V</u>
		<u>600V</u>
		<u>1200V</u>
<u>IGBT SINGLE / Hard</u>	<u>Standard <1kHz</u>	<u>600V</u>
		<u>1200V</u>
	<u>Fast 1-8kHz</u>	<u>600V</u>
		<u>Ultra Fast 8-30kHz</u>
	<u>600V</u>	
	<u>1200V</u>	
	<u>Warp 30-150kHz</u>	<u>600V</u>
<u>900V</u>		
<u>IGBT Co-Pack / Soft</u>	<u>Ultrafast <30kHz</u>	<u>1200V</u>
<u>IGBT Co-Pack / Hard</u>	<u>Standard <1kHz</u>	<u>600V</u>
		<u>600V</u>
	<u>Fast 1-8kHz</u>	<u>600V</u>
		<u>Ultra Fast 8-30kHz</u>
	<u>600V</u>	
	<u>1200V</u>	
	<u>Warp 30-150kHz</u>	<u>600V</u>
<u>900V</u>		

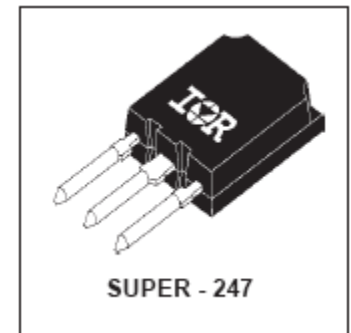
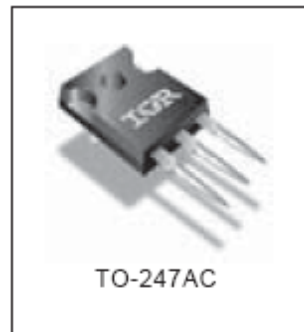
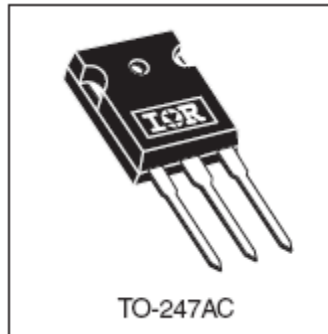
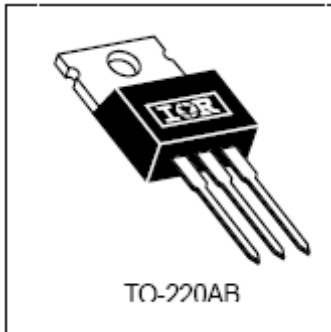
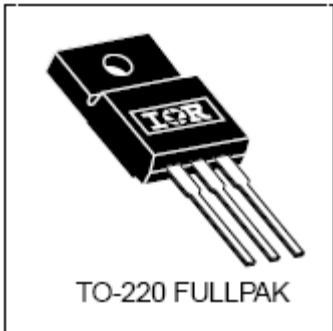
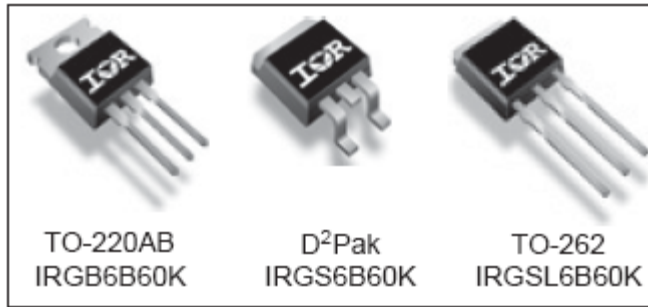
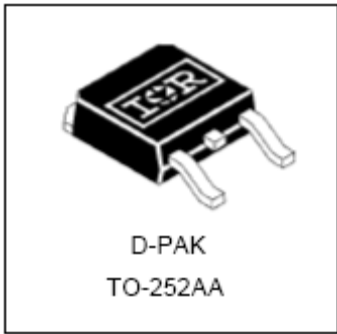
IRG4PF50W



$V_{\text{CES}} = 900\text{V}$
 $V_{\text{CE(ON) typ.}} = 2.25\text{V}$
 @ $V_{\text{GE}} = 15\text{V}$, $I_c = 28\text{A}$



Encapsulamentos:



www.irf.com



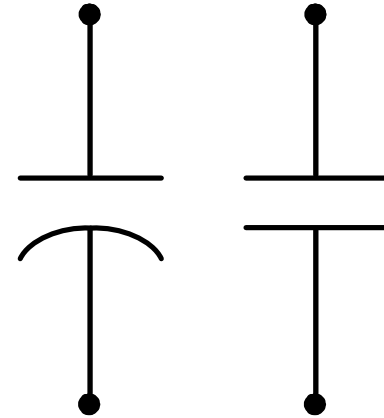
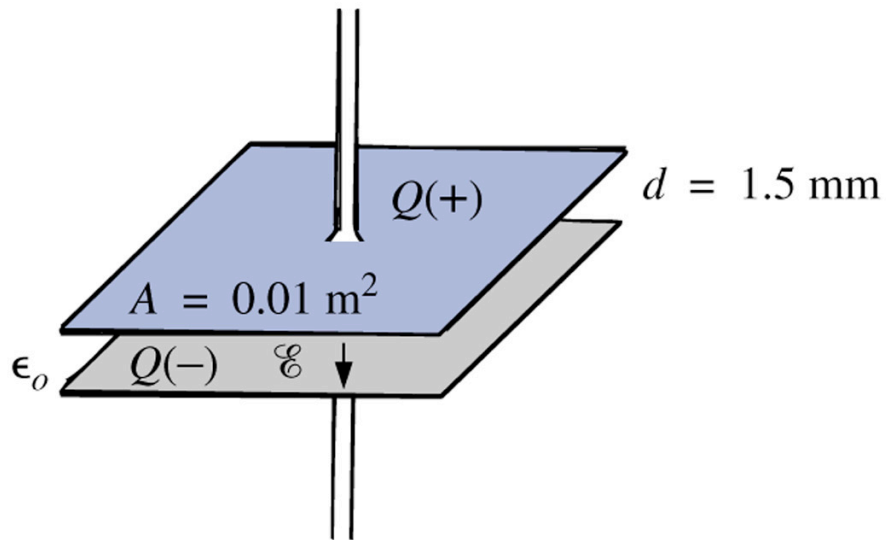
BJT x MOSFET x IGBT



	MOSFET	IGBT	BJT
Tipo de comando	Tensão	Tensão	Corrente
Potência do comando	Mínima	Mínima	Grande
Complexidade do comando	Simples	Simples	Média
Densidade de corrente	Elevada em baixas tensões e Baixa em altas tensões	Muito elevada	Média
Perdas de comutação	Muito baixa	Baixa para Média	Média para Alta

Capacitância depende de:

- Dielétrico (permissividade);
- Área das placas;
- Distância entre as placas.





Modelo equivalente do capacitor

Onde:

- C = Capacitância;
- RSE = Resistência série equivalente;
- LSE = Indutância série equivalente.

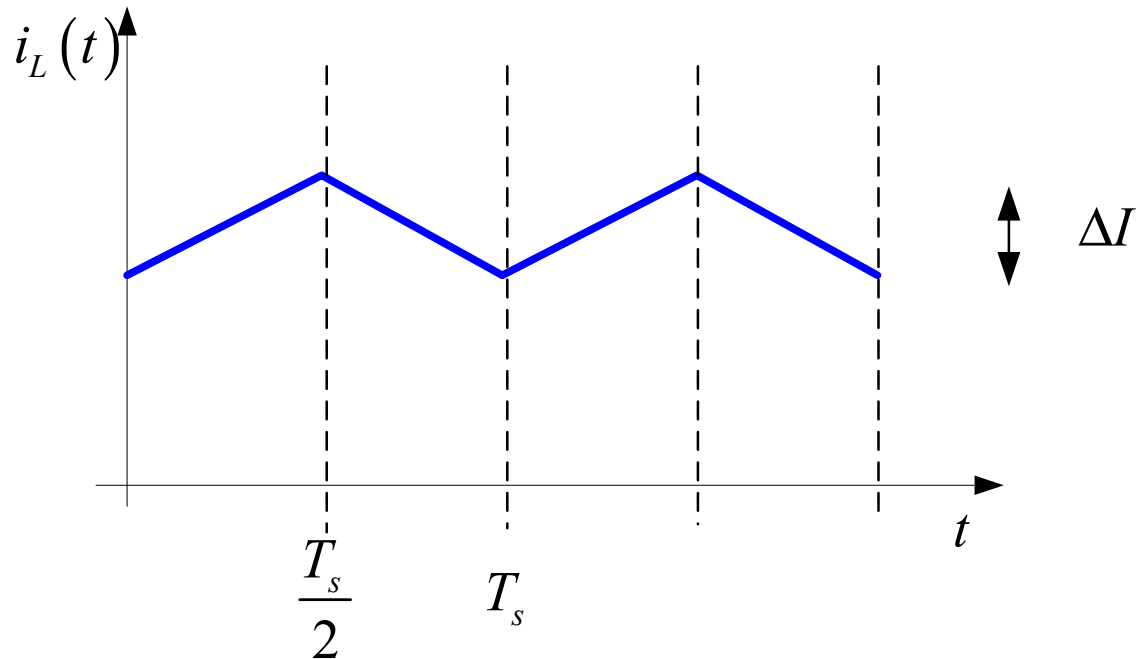
Perdas devido à RSE:

$$P = RSE \cdot I_{ef}^2$$



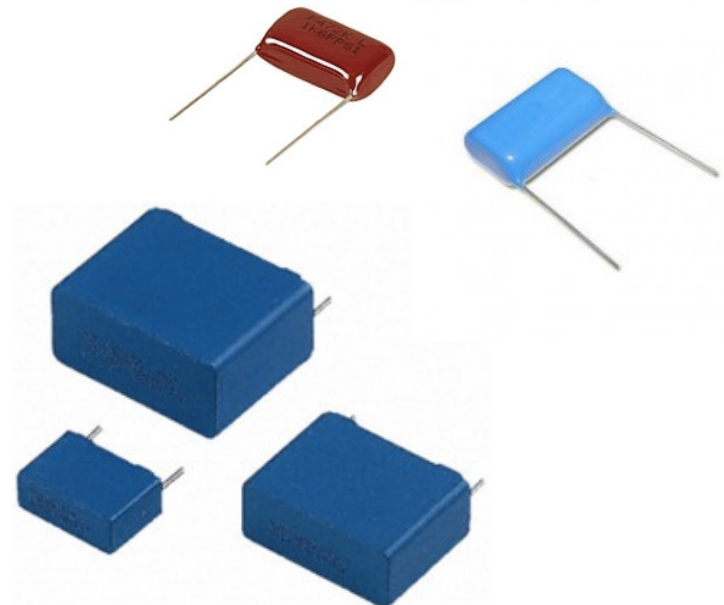
Ondulação da tensão:

$$\Delta V = RSE \cdot \Delta I$$



Tecnologias de capacitores:

- Filtro do retificador de entrada – São empregados capacitores eletrolíticos de alta tensão e grandes capacitâncias;
- Filtro de saída dos conversores – Empregam-se capacitores eletrolíticos alumínio com baixa RSE;
- Circuitos de grampeamento (snubber) – São utilizados capacitores com dielétricos de polipropileno para regime intermitente de funcionamento.



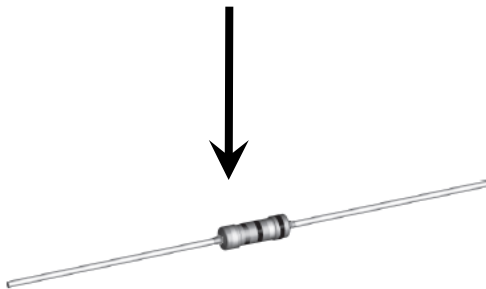
Fusíveis de ação lenta:

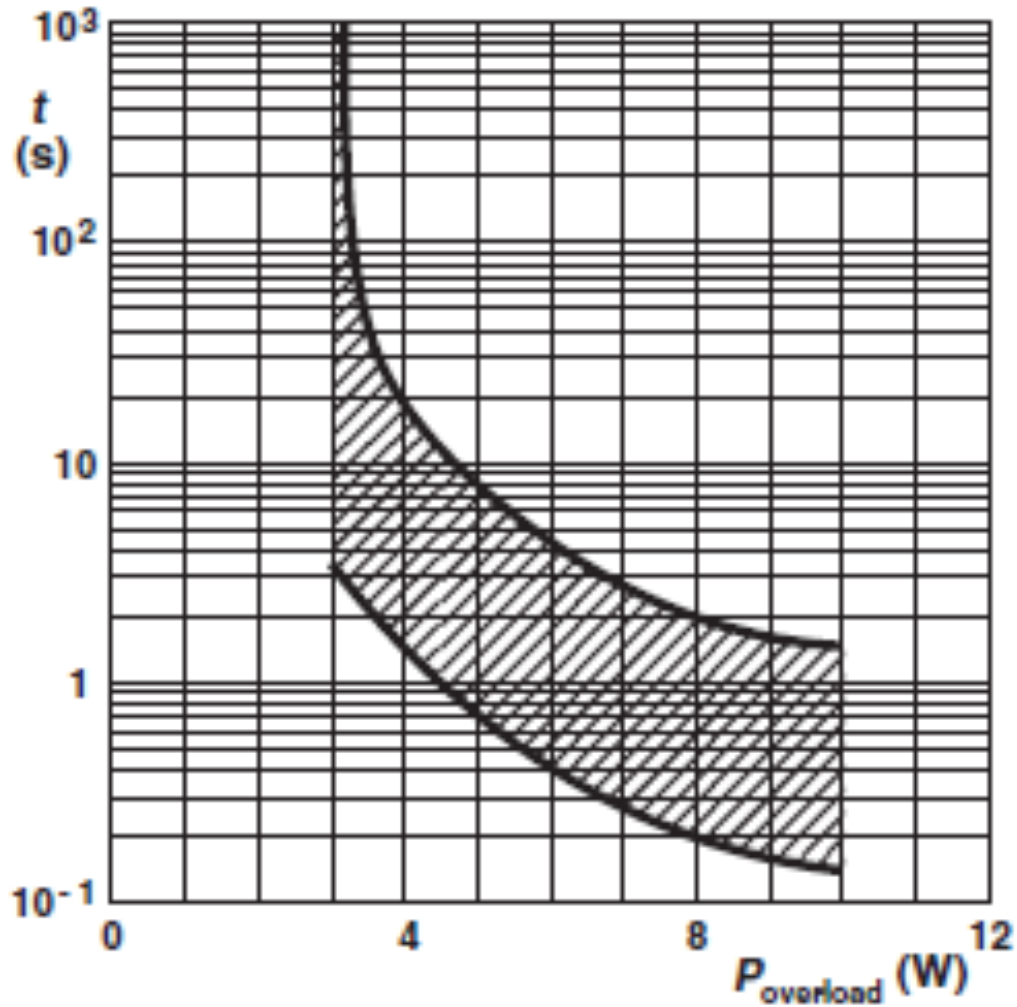
- Vidro;
- Areia;
- Cerâmica.

Fusíveis de ação rápida:

- Vidro;
- Areia;
- Cerâmica.

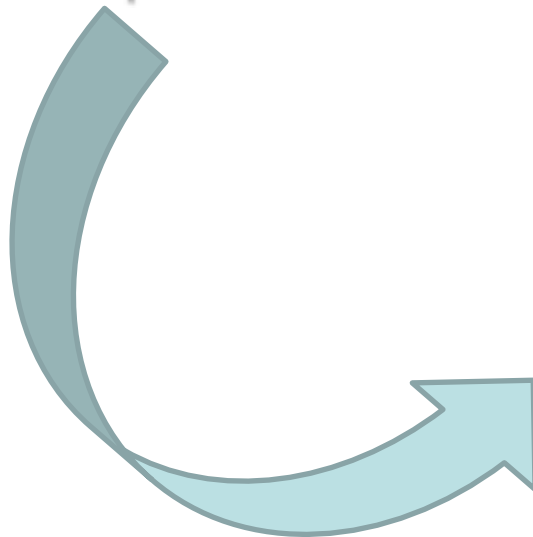
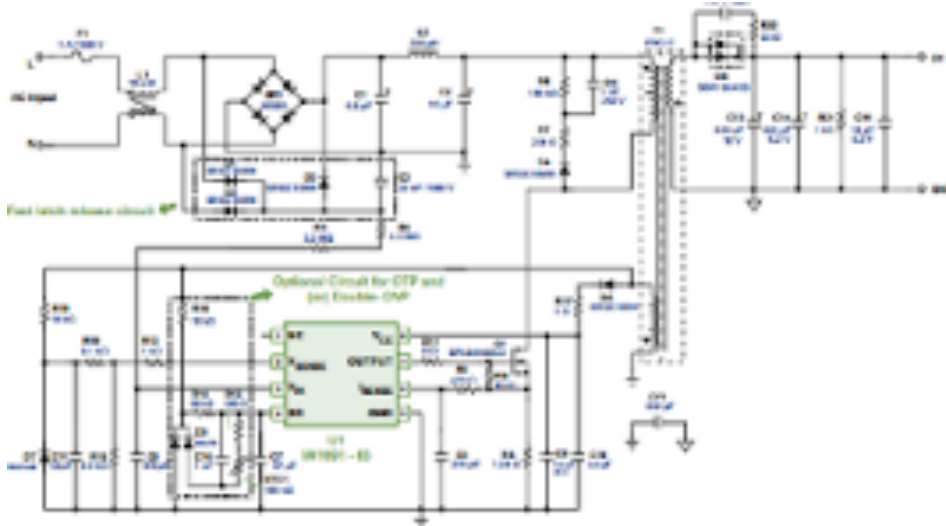
Resistores fusíveis (fusistor).



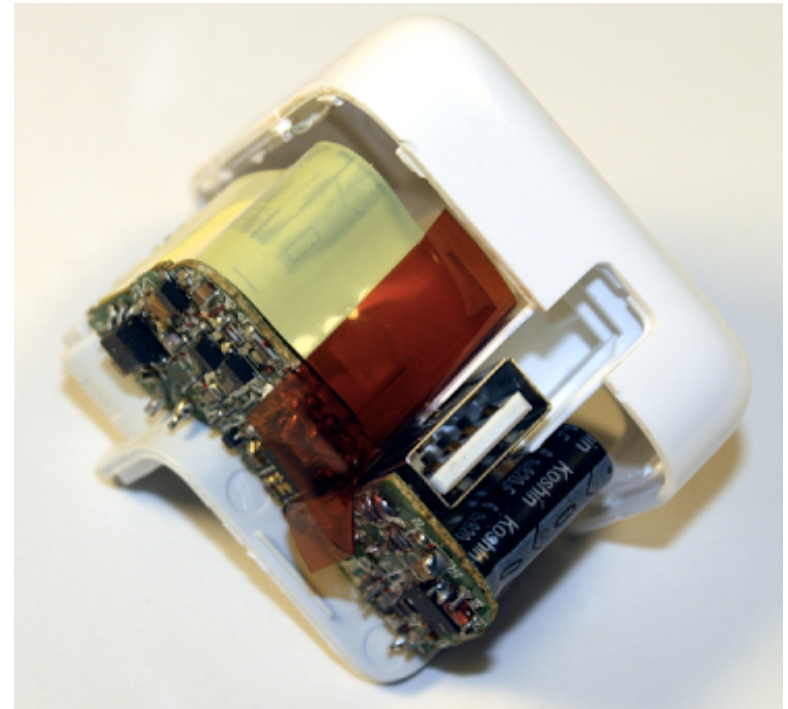


NR25 – $1 \Omega < R < 15 \Omega$

Considerações Finais



Como sair daqui e chegar ali?



Conversores ca-cc:

1. Principais topologias e tecnologias envolvidas;
2. Estudo de caso.

