FTF | FREESCALE TECHNOLOGY FORUM
POWERING INNOVATION

Managing Photovoltaic Systems with Freescale Digital Signal Controllers

FTF-SEG-F0008

Gao Xiang
Freescale Application Engineer

August 2012

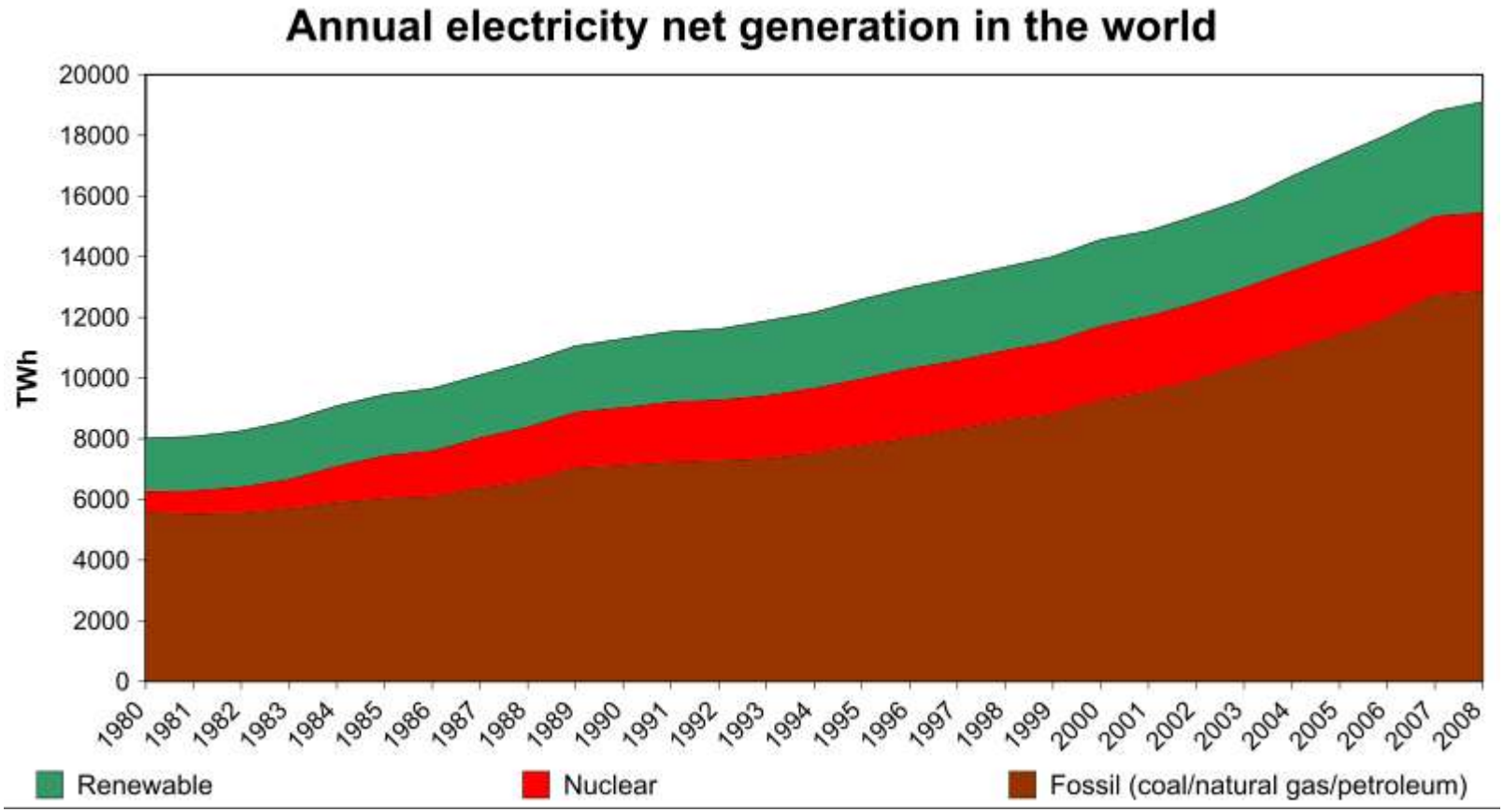
Agenda

This presentation will review the photovoltaic (PV) market and various inverter technologies, and explain how Freescale's Digital Signal Controllers (DSCs) can manage the system and increase efficiency — thereby improving ROI.

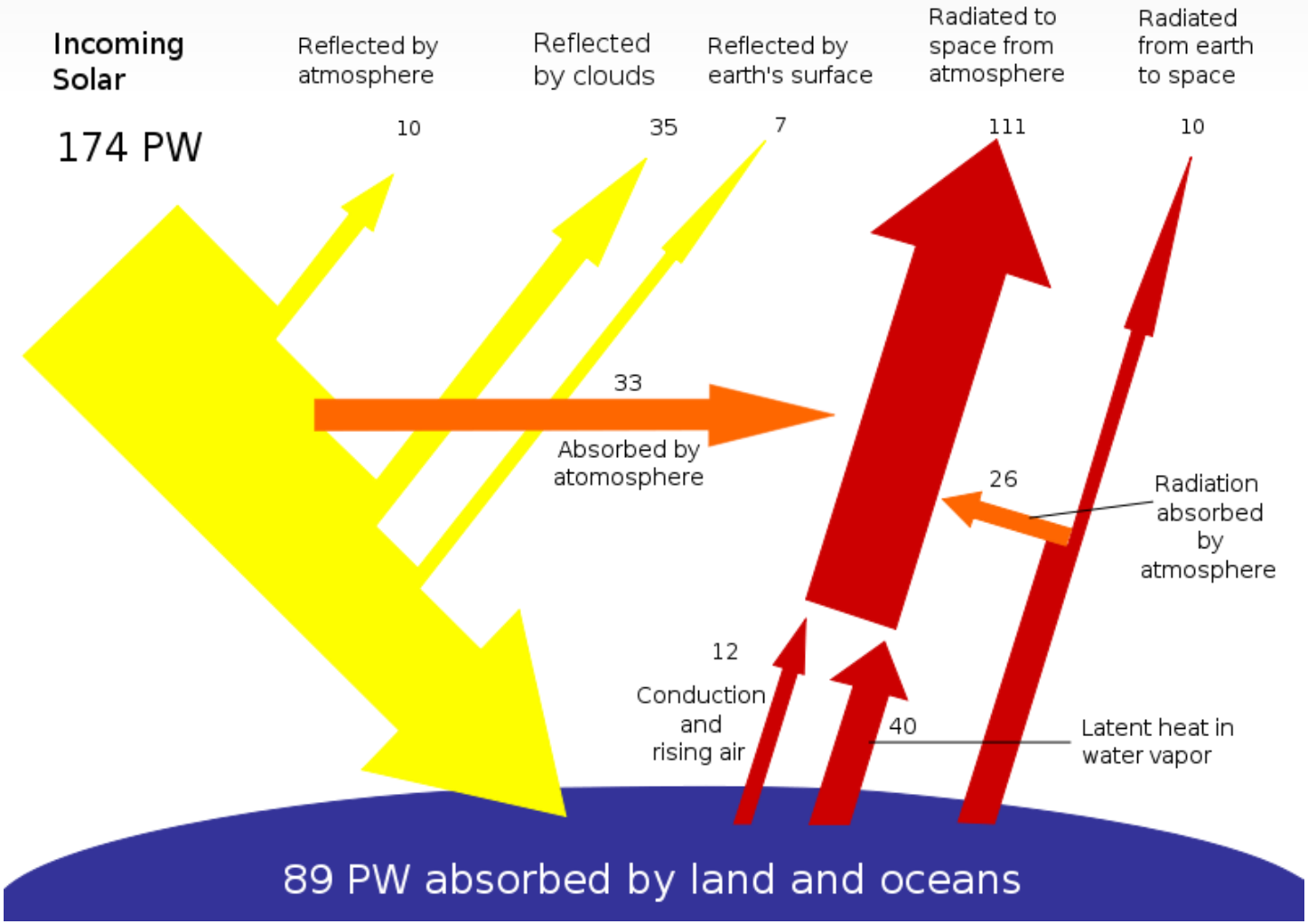
- Market overview
- Technology review with focus on micro-inverters
- Freescale benefits

Global Share of Energy Market

- Biomass generation dominates in renewable space
- Solar steadily increasing share of renewable market

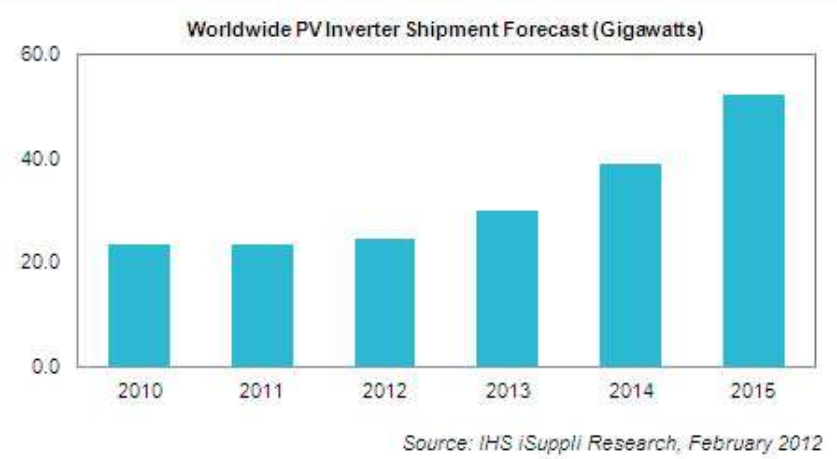


Solar irradiance



source: wikipedia

Global PV Market

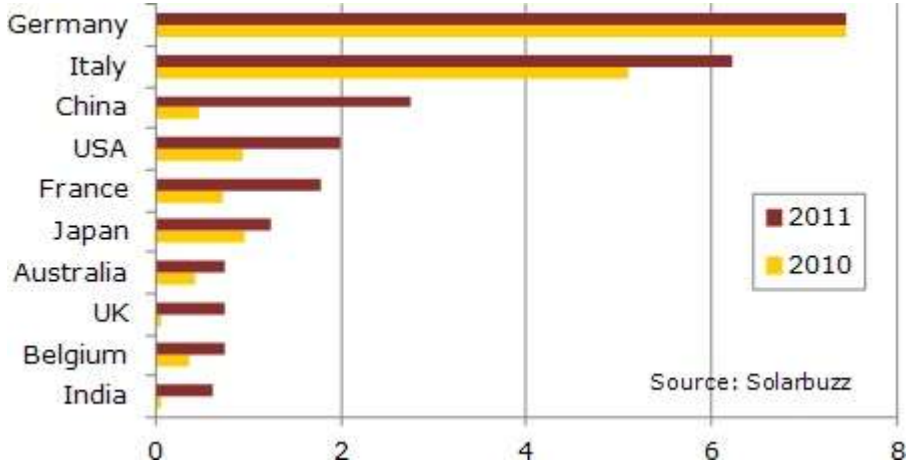


Source: IHS iSuppli Research, February 2012

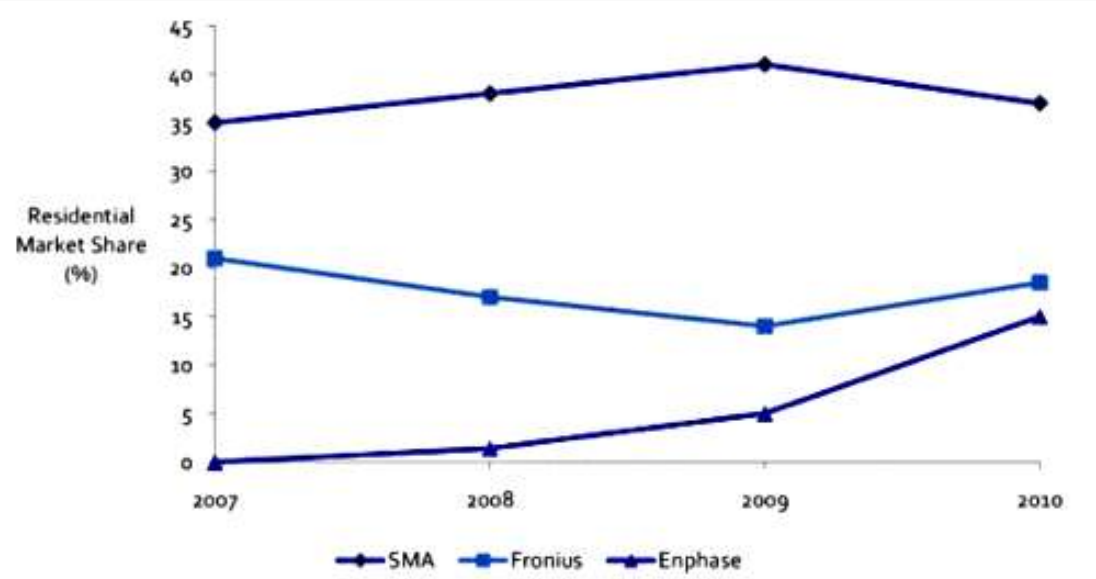
- Germany's SMA clearly in the lead (31% share)
- California's Power-One is #2 (12% market share)
- U.S. and China gaining larger global share

- Germany still largest market
- Market remains primarily determined by supply-side subsidies

Installations



Residential Trends



- Traditional architectures losing share to newer micro-architectures (SMA pushing into micro-inverter market)
- Larger manufacturers investing in micro-inverters
- Trends depend heavily on geography

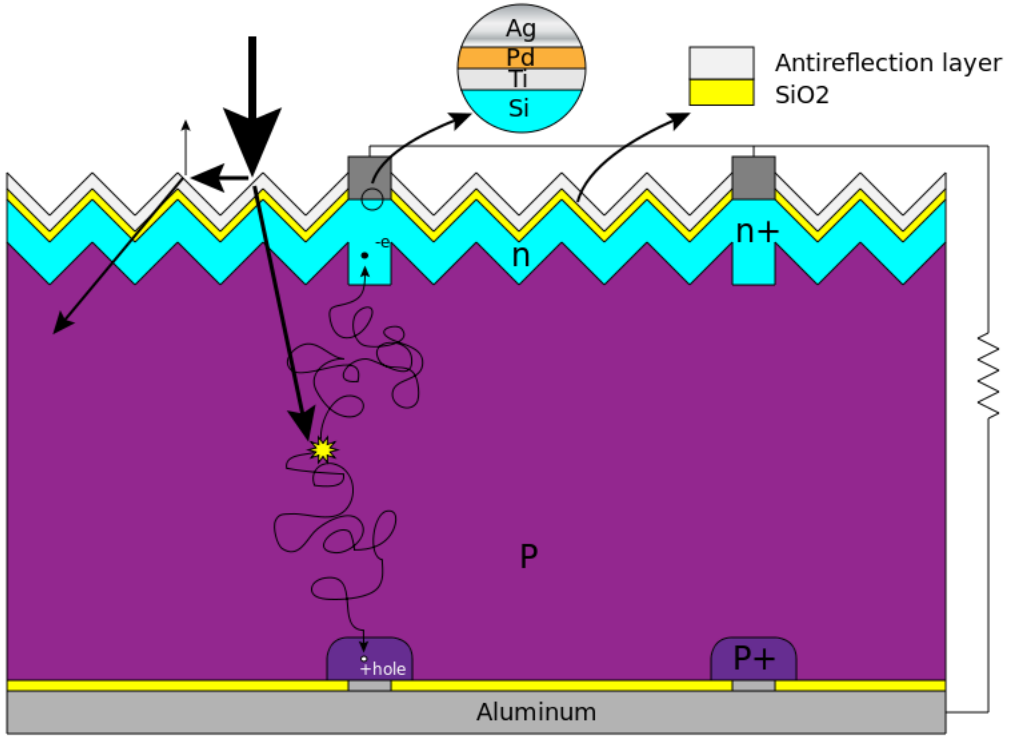
freescale™

FTF | FREESCALE TECHNOLOGY FORUM
POWERING INNOVATION

Technology Review

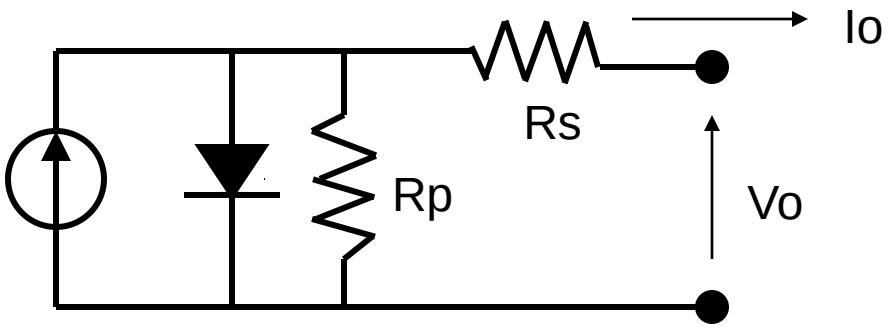
Solar cell simple description

- Photons in sunlight hit the solar panel and are absorbed by semiconductor material – silicon.
- Electrons (negatively charged) are knocked loose from their atoms, allowing them to flow through the material to produce electricity. Due to special composition of solar cell, the electrons are only allowed to move in a single direction.
- An array of the solar cells converts solar energy into a usable amount of direct current (DC) electricity.



Solar Cell Characteristics

A solar cell is a current source, not a voltage source!



Vo ~ 0.5 Volts

Io ~ 1 to 3 Amps

Simplified circuit model of a solar cell

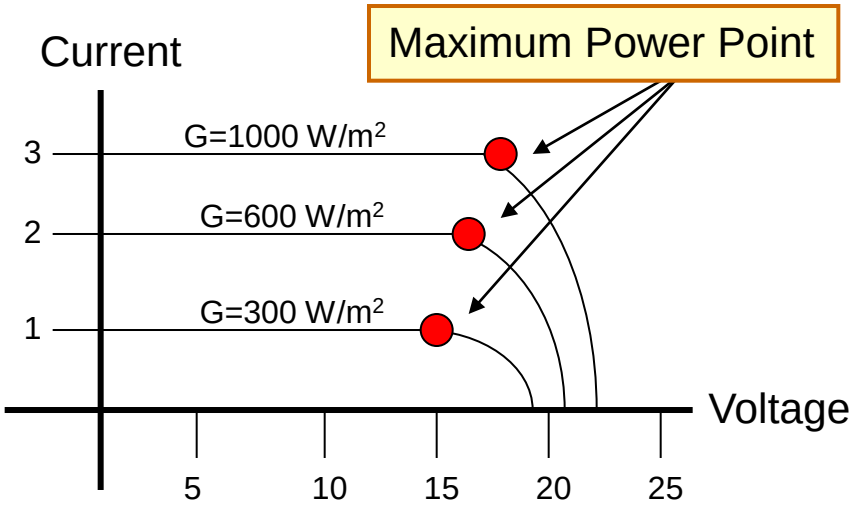
Current is dependent on illumination, voltage more dependent on temperature.

Effective use of series connected solar cells depends on identical currents being generated by each cell.

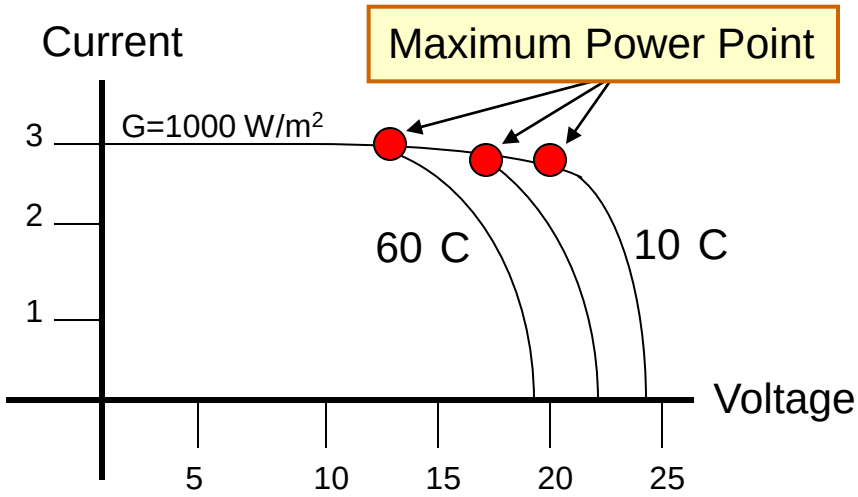
!!! It is <u>not</u> like stacking battery cells together !!!

Solar Cell – Characteristics

Solar cells output continually varies with LIGHT and TEMP



I-V versus Illumination (36 cell string)

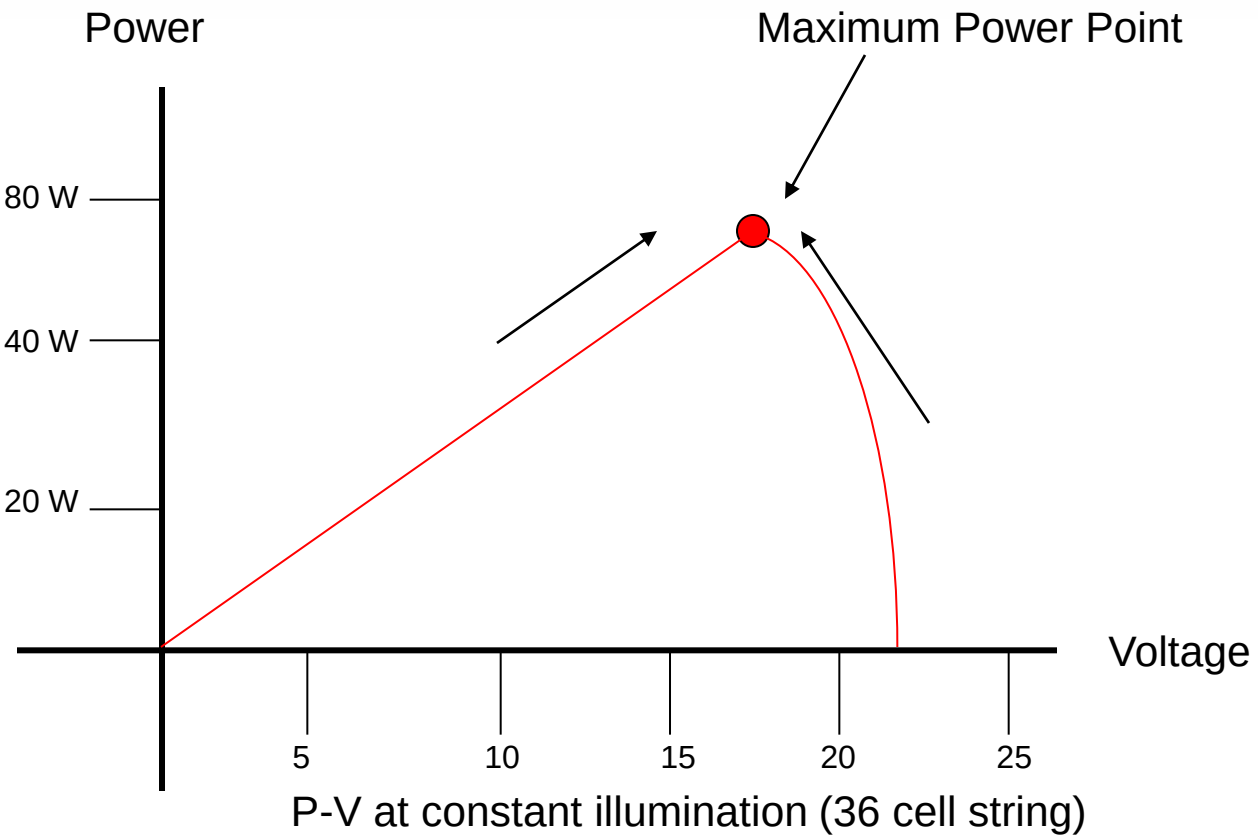


I-V versus Temp (36 cell string)

Maximum Power Point Tracking Algorithm (MPPT)

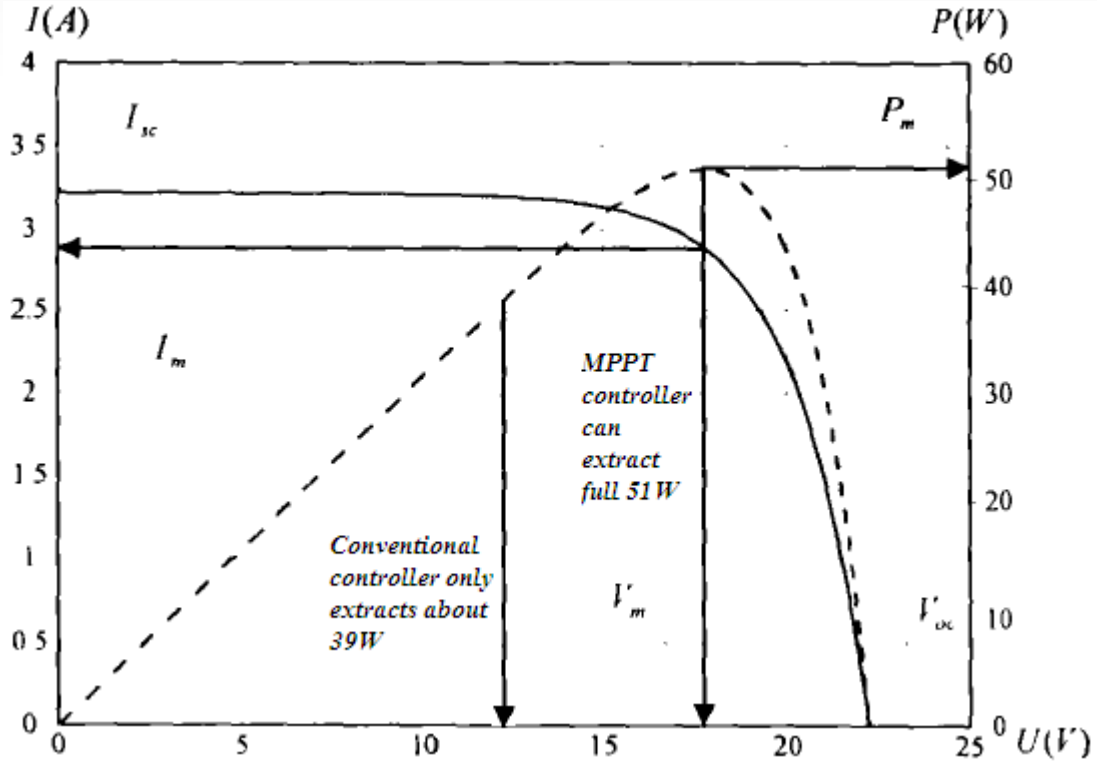
- **Closed loop algorithm continually adjusts input V / I to operate at the point of maximum power output**
- **Requires 20-30 MIPS – typically DSCs/MCUs are used**

Solar Cell –Maximum Power Point Tracker (MPPT)



The MPPT algorithm constantly searches for optimum peak power point at which to extract power from solar panel.

MPPT Principle and Techniques



When irradiance or/and temperature vary, MPPT real-time detects the output power of PV modules, predicts possible maximum output power of PV modules through special algorithm under current conditions and varies the electrical operating point of the PV modules so that the modules are able to deliver maximum available power.

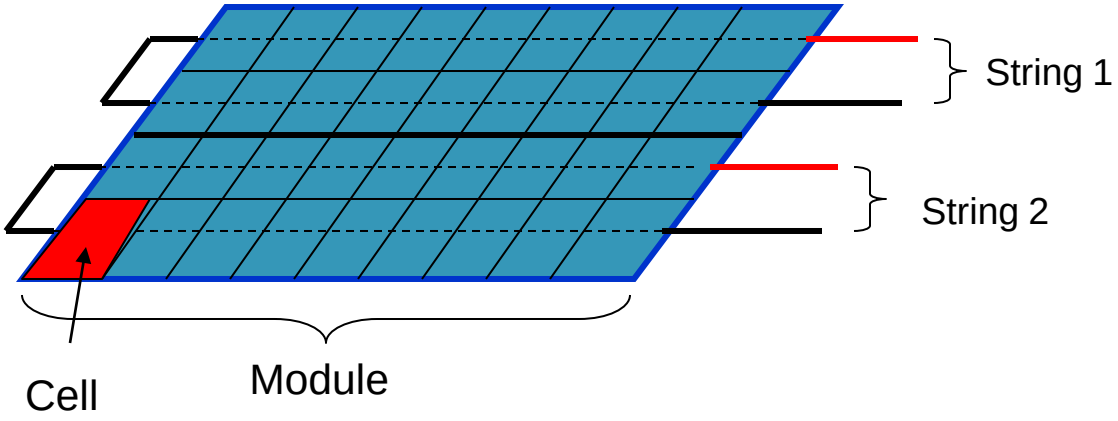
MPPT techniques:

- Perturb & Observe
- Incremental Conductance
- Open-Circuit Voltage
- Short-Circuit Current
- Intermittent Sweep
- Optimal Gradient
- Sliding Mode
- State Space Model
- Fuzzy Logic Control
- Neural Network Control

Perturb and Observe (P&O)

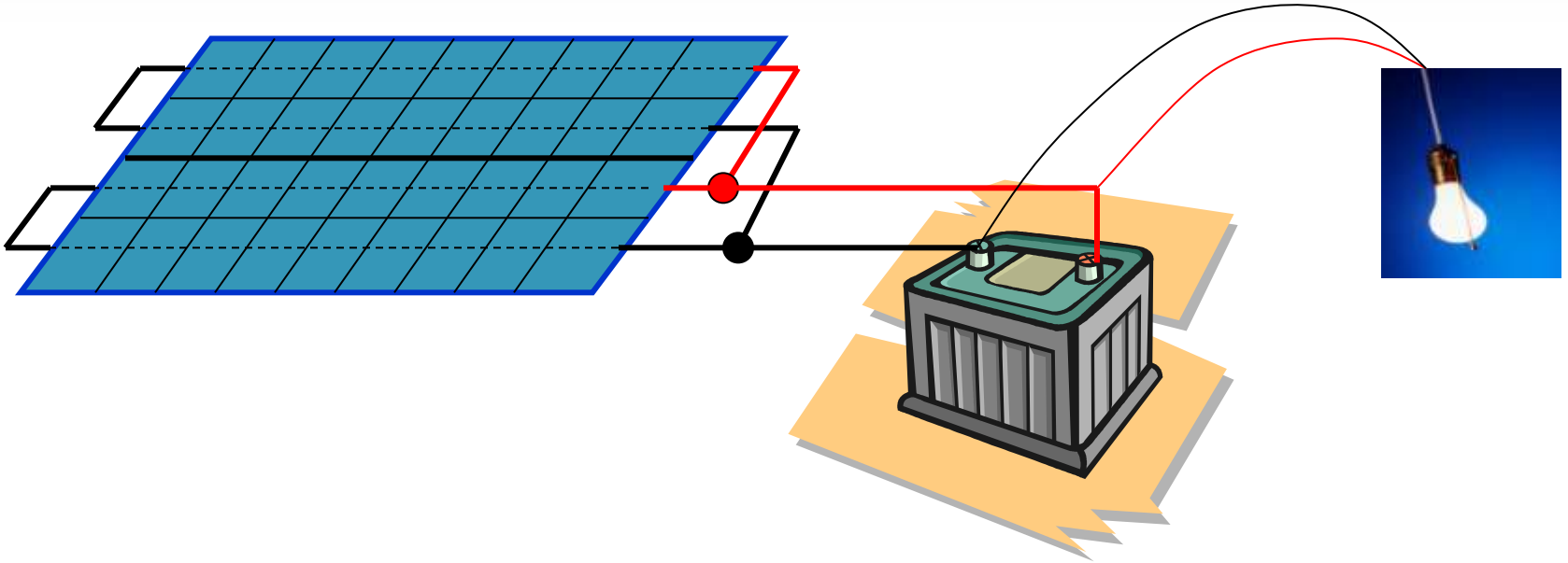
- Simple to Implement
- Oscillate around Maximum Power Point
  - Result in loss of power in case of rapid change in weather
- It might track in wrong direction in rapid changing weather condition

Basic Solar Panel Construction



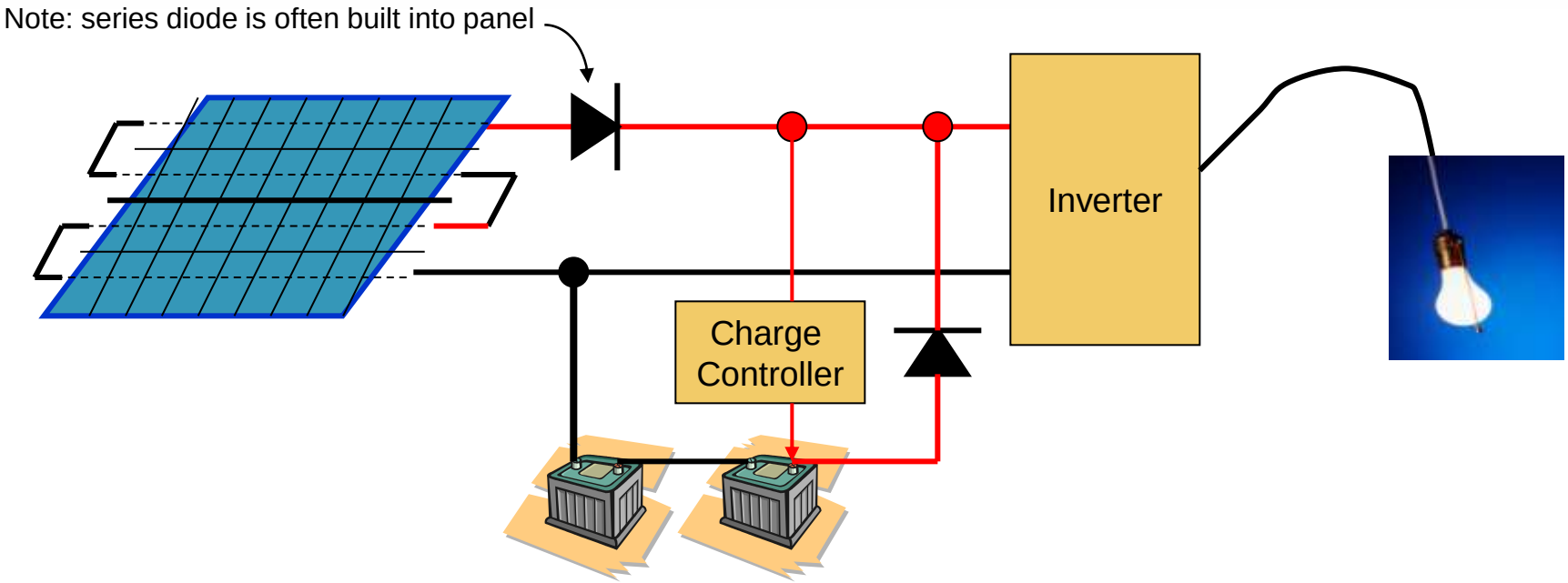
- **Strings** - Multiple Cells are connected together in series to raise the output voltage.
- **Modules** – Multiple Strings connected in parallel to raise the output current.
- **Arrays** – Multiple Modules connected in series and/or parallel to raise output power

Solar Power Evolution: The beginning



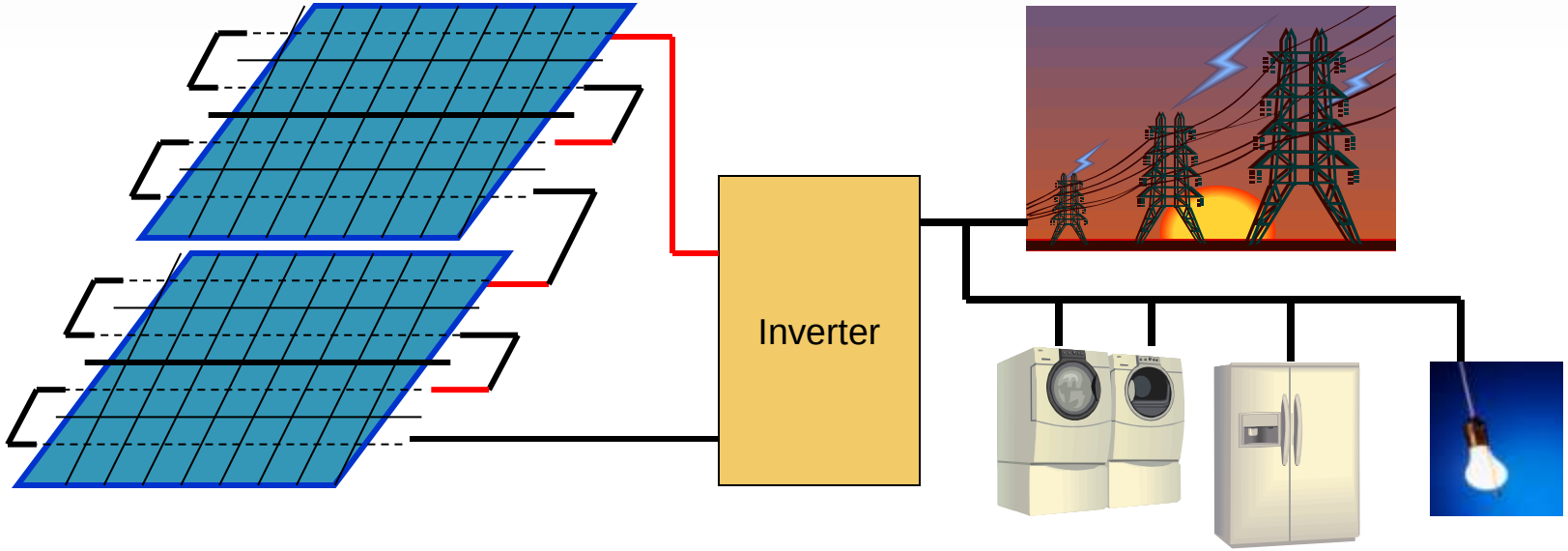
- **Log Cabin System** – Simple 12 volt DC system providing lighting for isolated cabins. Low wattage (<100 W) solar panels connected directly to battery. Battery connected to lamps and other 12 volt DC appliances.
- Battery life compromised by unregulated charging. Limited appliances available for 12 volt DC power. Wire resistance limits power to few hundred watts.
- This system is not connected to the AC power lines (Off-Grid).

Solar Power Evolution:
Simple Inverters with battery charger



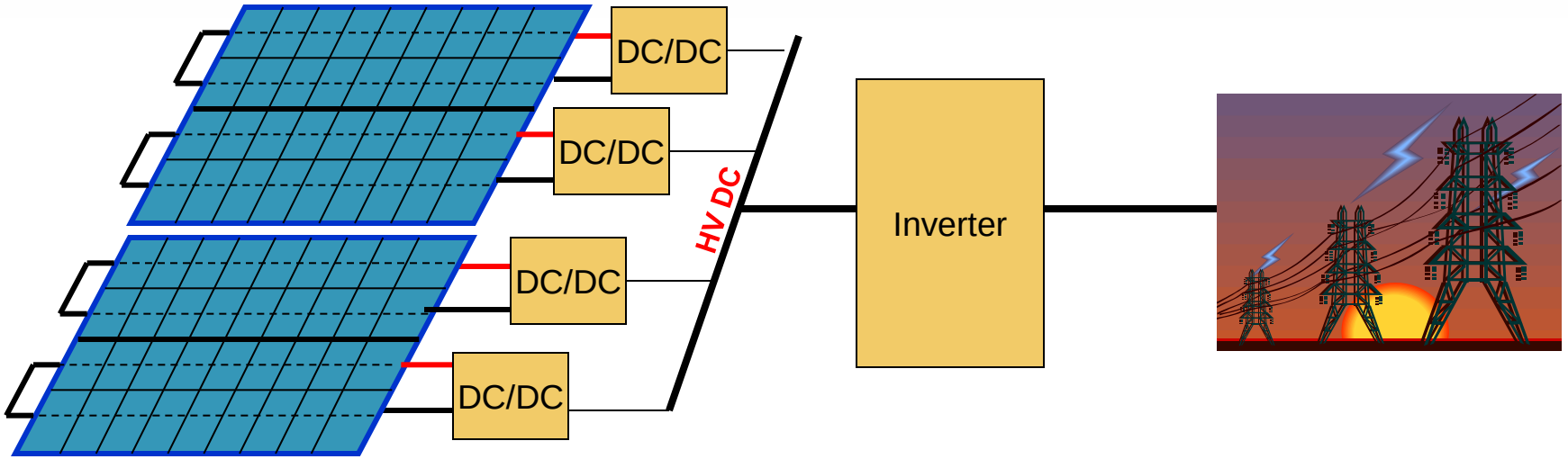
- **Country Home System** – Larger panels providing 24 – 96 volts are connected to an inverter to yield 120/240 VAC to operate standard lighting and appliances. Battery life improved with regulated charging module. The higher DC voltages support moderate power levels.
- This system is not connected to the AC power lines (Off-Grid).

Solar Power Evolution: Grid Connected Inverter



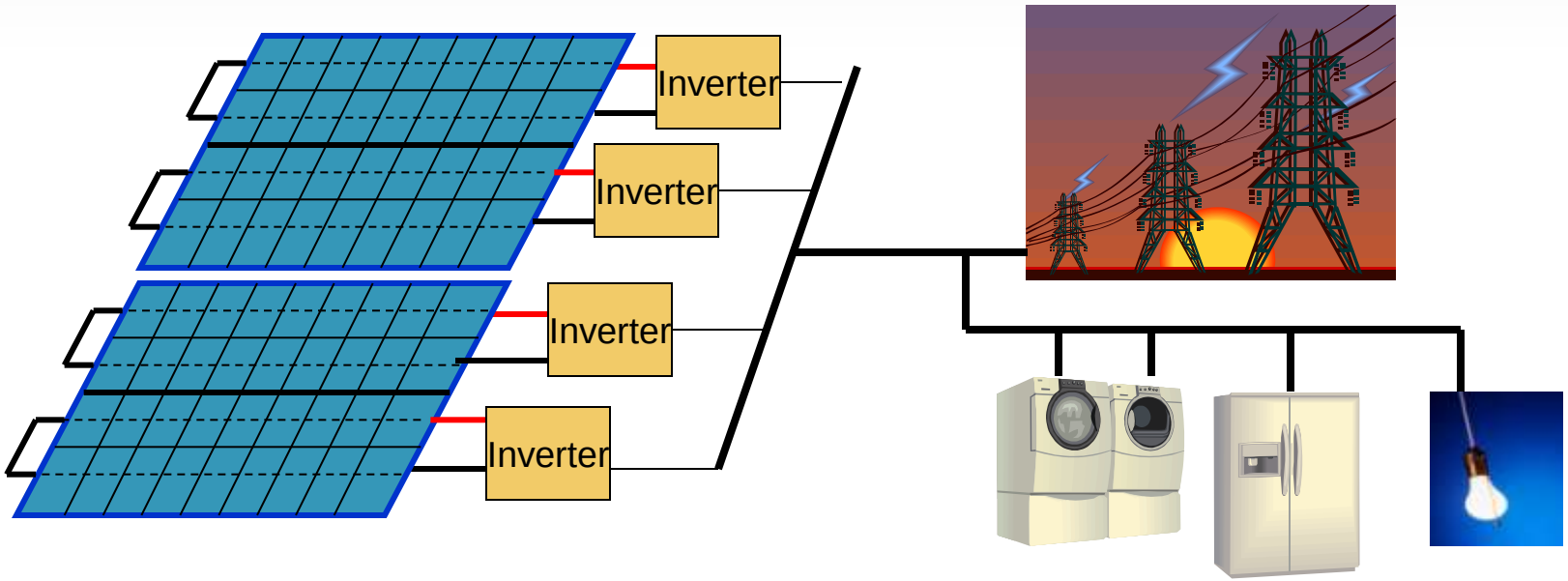
- **Urban Home System** – Larger panels providing 200 - 400 volts are connected to an inverter to yield 120/240 VAC at medium power levels (2 -10KW)
- This system is connected to the AC power lines (Grid-Tied). The customer sells power to the power company during the day, buys power from the power company during the night. Grid-Tied approach eliminates expensive and short lived batteries.
- Issues: Inverter has potential as a single point failure. Non optimal power harvest from solar panel especially in partial shading conditions.

Solar Power Evolution: Individual DC/DC converters



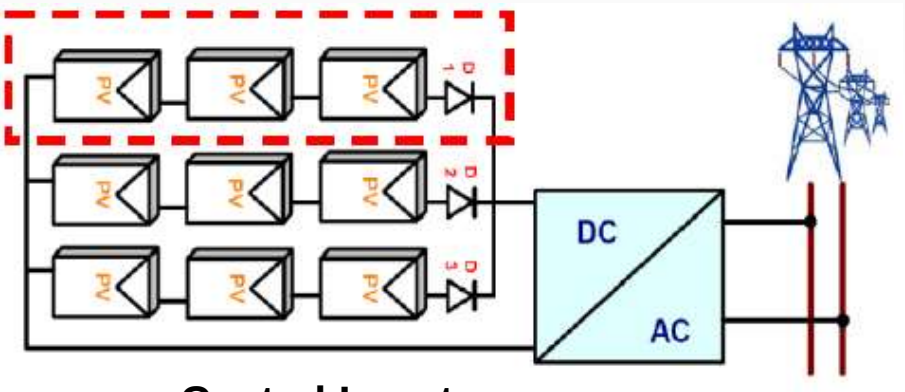
- **Single Inverter with multiple DC/DC Converters** – The use of DC/DC converters per string provide enhanced power harvest from solar panels. The DC/DC converters may be separate modules or reside within the Inverter module.
- This method is still susceptible to single point failure of inverter, and it involves the distribution of high voltage DC power – A dangerous situation because direct current power fusing is difficult to achieve.

Solar Power Evolution:
Grid Connected String Inverters

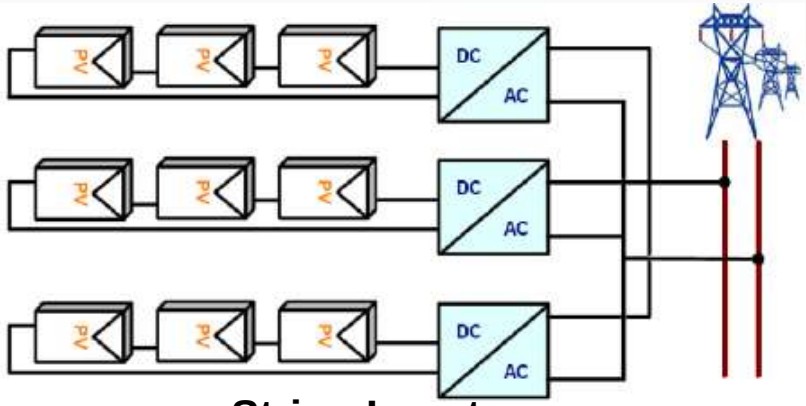


- **Urban Home System with String Inverters** - Panels providing 200 - 400 volts are connected to multiple inverters to yield 120/240 VAC at medium power levels (2 -10KW). The inverters are connected to the Grid.
- The use of multiple inverters provides enhanced power harvest from solar panels and provide enhanced system reliability.

Solar Inverter System Architectures



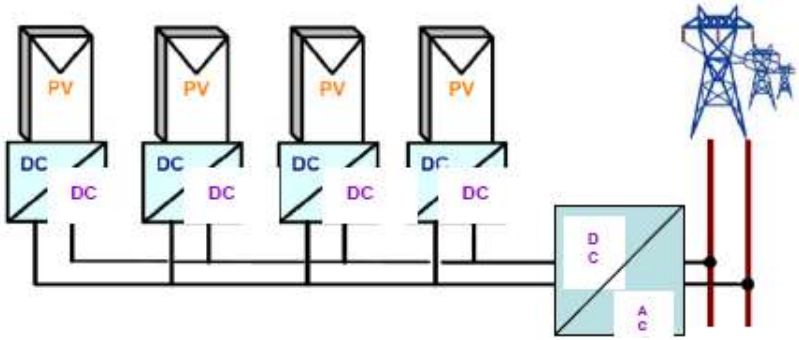
Central Inverter
DC/AC = DC/DC + DC/AC
10-250 kW



String Inverter
DC/AC = DC/DC + DC/AC
1.5-10 kW

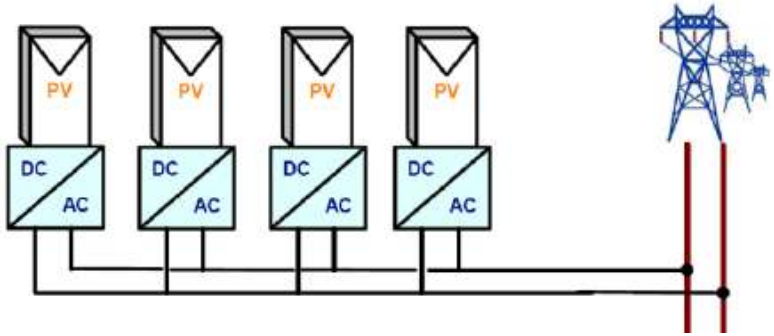
Traditional Architectures

New Architectures



Micro DC/DC Converter + Central Inverter

50-500 W per unit



Micro Inverter

freescale™

Pros and Cons

	Traditional	Micro (Optimizers)
Efficiency	95 – 97%	91 – 95%
Harvesting	up to 93%	up to 99%
Flexibility	Careful consideration of environment and system architecture	More flexible, allowing installation in dense urban areas and places with potential shading issues
Safety	Careful consideration for safety due to ~ 600V DC bus topology	Distributed AC architecture; AC handling known and familiar by installers
Reliability	Highly reliable; inverter removed from harsh environmental conditions	System warranties primary concern for industry; harsh environmental conditions; electrolytic capacitor issues
Price		More expensive than traditional architecture
Deployment	Strong growth in EU	Strong in U.S. and Asia

Types of Inverters

The choice of waveform depends on loads and applications.

- Stand-alone system
  - Square wave or modified sine wave
    - Cheaper and efficient
    - Noisy
    - Good enough for appliances and lights
  - True sine wave
    - More expensive, less efficient
    - High quality
    - Specifically needed for high-quality sound systems
- Grid-tied system
  - True sine wave mode required
  - Electrical isolation required (fundamental- or high-frequency transformer)
  - Synchronization operation
    - Synchronize its output with the grid supply, so that power can be fed back into the grid supply
    - Also include comprehensive safety features to protect anybody working on the electricity cables
    - Must be approved by the electricity company for connection to their network

Concept of Island and International Standard

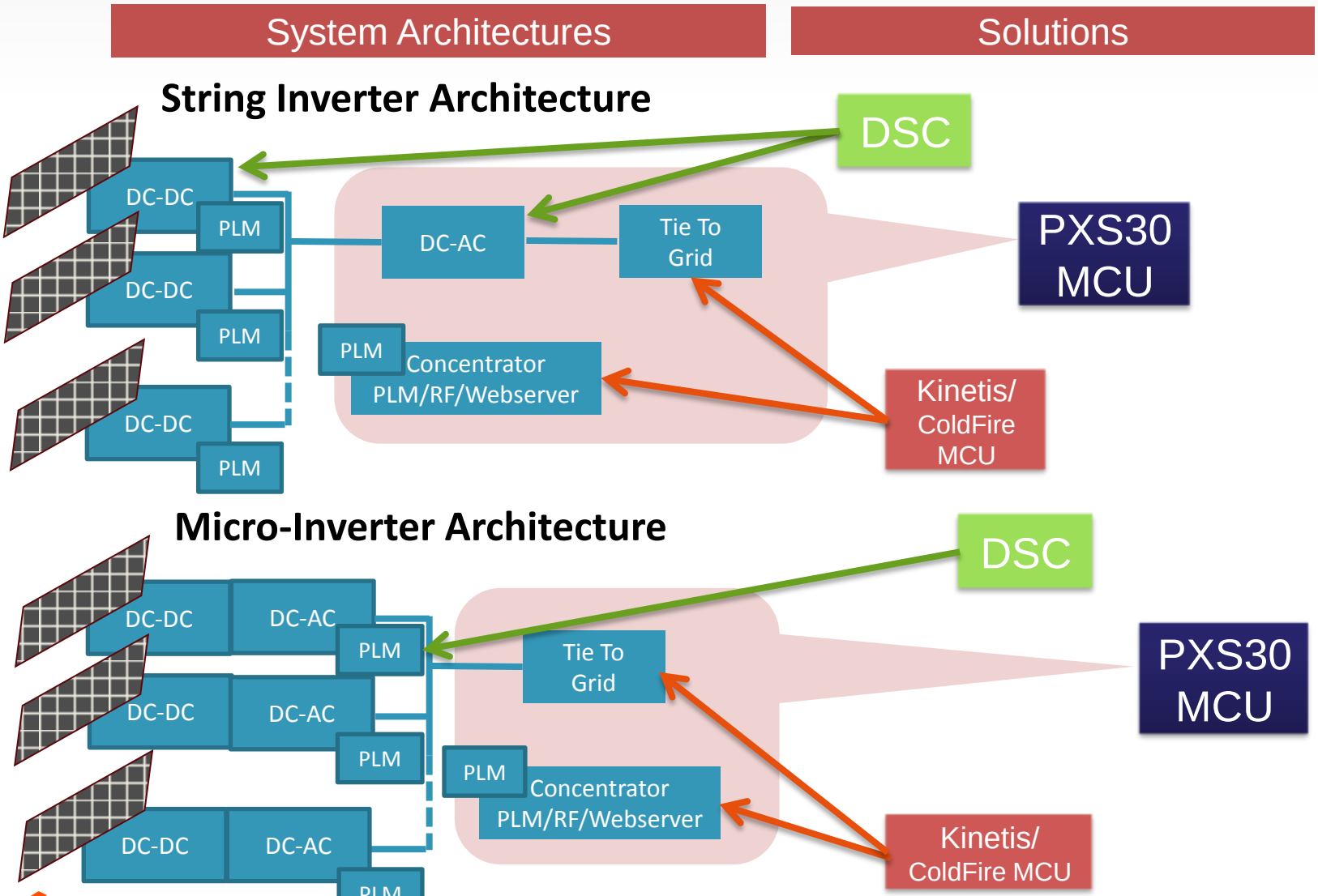
- According to IEEE std 929-2000, island is a part of grid supply including loads and distributed power supplies, which can keep running when it disconnects with other parts of grid supply.

- Effect of island
  - Lead to unstable voltage amplitude and frequency
  - Impact action program of breaker in distribution system
  - Asymmetrical phase supply for three-phase loads if single-phase power is generated
  - Lead to rushing current of inverter because of asynchronism between grid supply and inverter output when grid supply recovers
  - Have possibility of electric shock to maintenance worker when considering power supply disconnected
- International standards
  - IEEE Std 929-2000-Institute of Electrical and Electronics Engineers, Recommended Practices for Utility Interface of Photovoltaic (PV) Systems
  - UL Standard for Safety-Static Inverters and Charge Controllers for Use in Photovoltaic Power Systems
  - National Electrical Code 2002, NEC-2002 (U.S.)

Overall Requirements for Inverters

- Function requirements
  - Synchronization function
    - Amplitude and phase synchronization with grid supply
  - Protection function
    - Out of output voltage and frequency range
    - Output current limitation
    - Under- and over-voltage of input DC bus
    - Overload and short-circuit of load
    - Power component failure
  - Management and connectivity function
    - Inverter behavior management
    - Human-machine interface
    - Remote monitor and diagnosis
- Performance requirements
  - High efficiency/low cost
  - High stable precision (amplitude and frequency)
  - Good dynamic performance
  - Good THDi performance
  - Good load adaptability (advanced control algorithms such as PI, current hysteresis, deadbeat control and repetitive control, etc.)
  - Suitable overload capability
  - Good reliability and maintainability
  - Long lifecycle (good system architecture and platform)

Freescale Solution



freescale™

FTF | FREESCALE TECHNOLOGY FORUM
POWERING INNOVATION

Freescale DSC Solutions

Winning with Freescale DSCs in PV

- Ease of use of a microcontroller (MCU) and the processing power of a digital signal processor (DSP)
- Reduced complexity and latency with simplified memory structure, shadowed register set, interrupt prioritization and cache
- 32-bit core improves precision without compromising performance

- Very high speed ADCs capture events real-time
- Accurate PWMs improve switching efficiency and control
- Flexibility with the crossbar to simplify pin out and peripheral communication
- DMA to reduce CPU overhead

- Portfolio scales to exactly fit the applications' needs
- Flexible cores scale from 32 MHz to 100 MHz
- Flash extends from 32 kb to 256 kb with additional flex memory
- Packages range from 28 pins to 100 pins

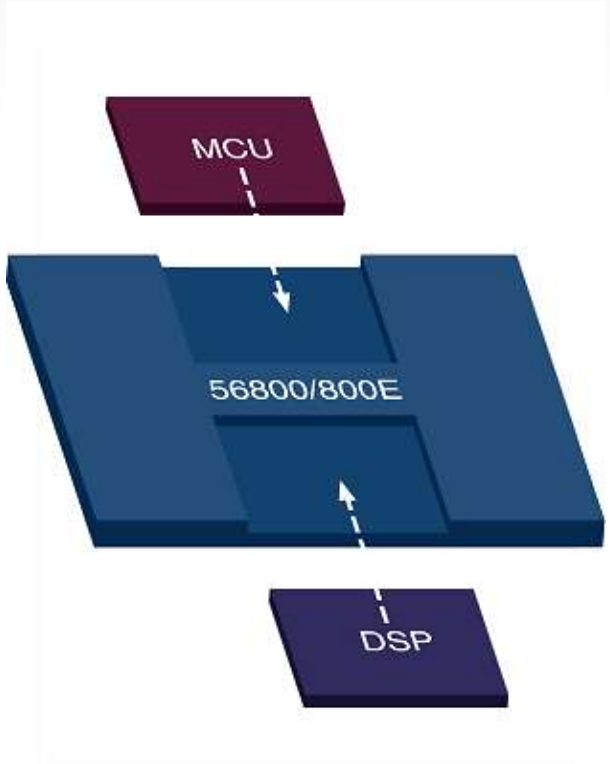
- Enhanced customer experience via integrated tools and reference designs
- Code reusable across the complete portfolio
- Extensive software libraries provide quick project ramp up

freescale™

Freescale Digital Signal Controller (DSC)

Traditional Microcontroller

- Design for Controller Code
- Compact Code Size
- Easy to Program
- Inefficient Signal Processing

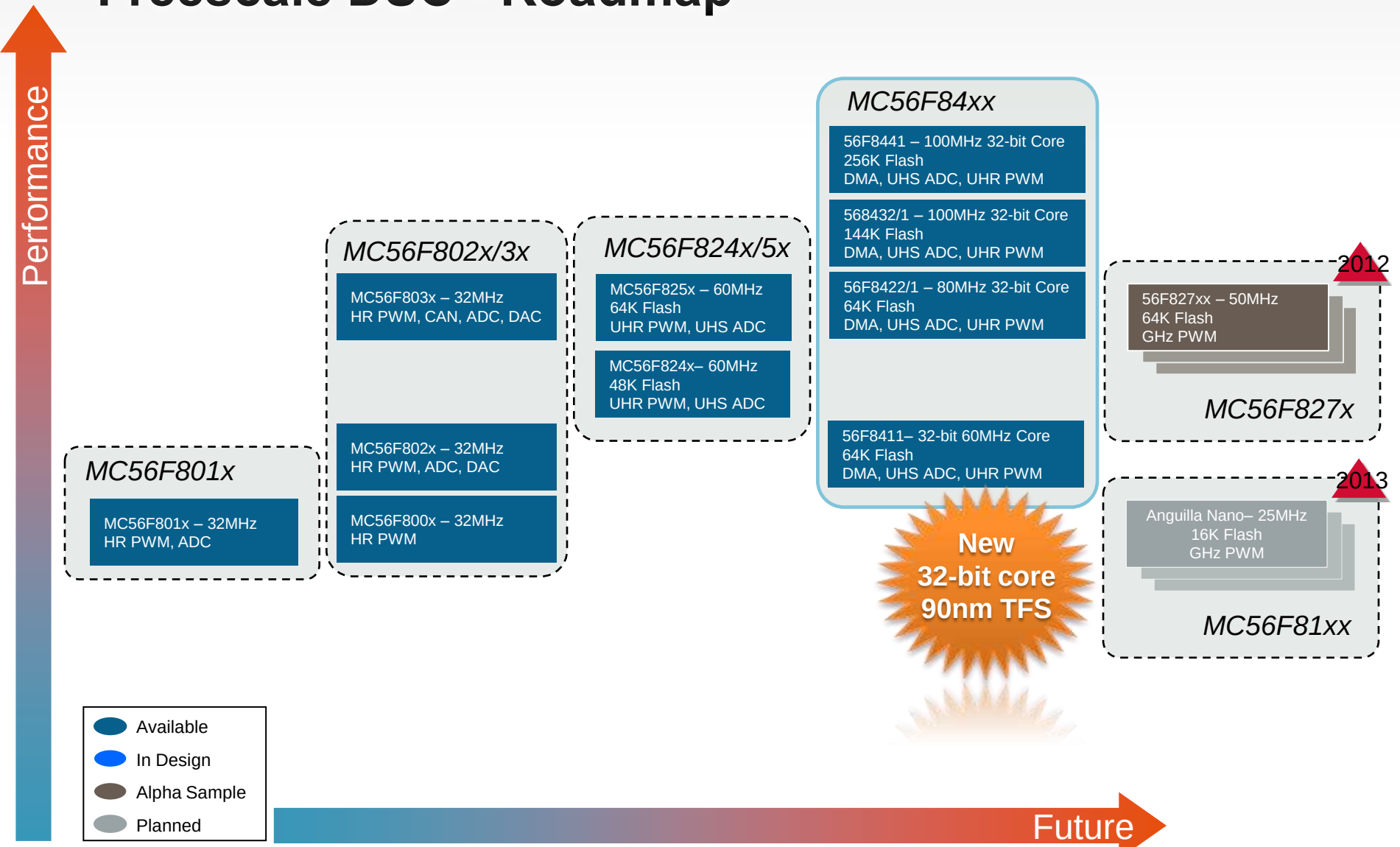


Traditional DSP Engine

- Designed for DSP Processing
- Designed for Matrix Operations
- Complex Programming
- Less Suitable for Control

- Instructions Optimized for Controller Code, DSP, Matrix Operations
- Compact Assembly and “C” Compiled Code Size
- Easy to Program
- Additional MIPS Headroom and extended addressing space

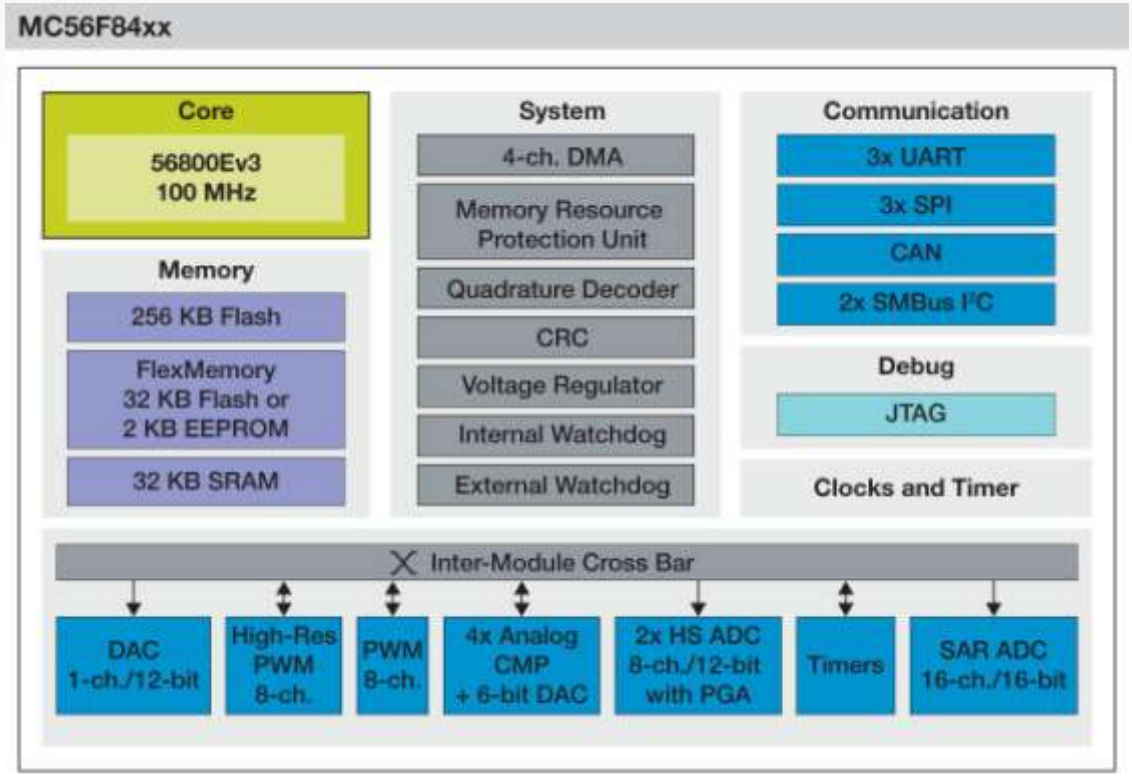
Freescale DSC - Roadmap



MC56F84xx

Exceptional Precision:

- High-res PWM with 312 pico-second resolution for accurate adjustment of the control loops
- 2x12-bit high speed ADCs with 3.3 Msps resolution reducing jitter on current and voltage reads
- 16ch 16b SAR ADC that enables external sensor inputs
- Four analog comparators with integrated 6-bit DACs that can enable emergency shut down of the PWMs
- Integrated PGAs to increase the accuracy of ADC conversions on small voltages and currents



Performance:

- 100 MHz/100 MIPS 32-bit core for fast control loop execution via single-cycle math computations and parallel moves
- Fractional arithmetic supported for greater accuracy
- DMA controller for reduced core intervention when shifting data from peripherals

Easy Implementation:

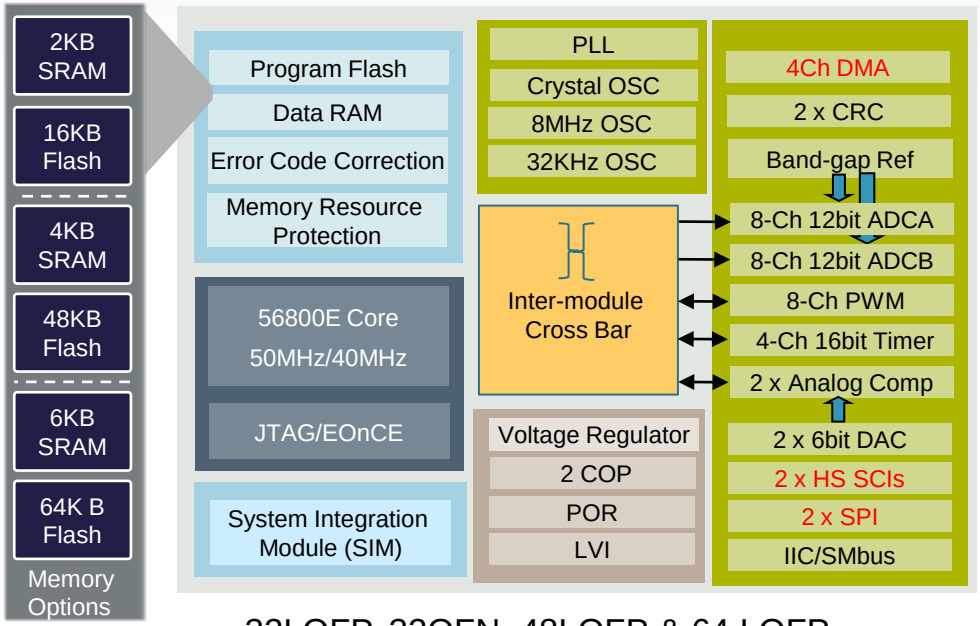
- 5V tolerant I/O for cost-effective board design
- Memory resource protection unit to ease safety certification
- Freescale FlexMemory for simplified data storage
- Market-focused software components, reference designs, and development tools for fast knowledge ramp up

freescale™

MC56F84xx Advanced Features and Benefits

Features	Benefits
High-res PWM with 312 pico-second resolution	Provides precise and stable control across extended temperatures
Dual, low-power 12-bit ADC with built-in PGA sampling up to 3.3 mega samples per second (Msps)	Improves real-time control for an environmentally more efficient design
100 MHz/100 MIPS 32-bit core, optimized for digital signal processing	Increases the execution of the control loop
Program flash memory scales from 64 KB to 256 KB	Enables flexibility
Direct memory access (DMA)	Helps ensure fast data transfers without core interruption
Market-focused software components, reference designs and development tools designed by our experts, deployed via software tools and made available through our online experience	Simplifies and speeds system development
5V tolerant I/O	Offers flexibility and system cost reduction
Memory protection features	Restricts access to key modules, helping to ensure reliable solutions
Freescale FlexMemory EEPROM capability	Supports frequent event captures

MC56F827x



32LQFP, 32QFN, 48LQFP & 64 LQFP

Packages will be pin compatible with the MC56F824x/5x and Nevis

Run Current < 30mA (using control loop example code)

Breakthrough Features:

- High speed ADC @ 800ns conversion time
- Inter-module Cross bar
- DMA

- 56800E V3 Core @ 100MHz from cache (50MHz from flash)
- 2.7-3.6V Operation

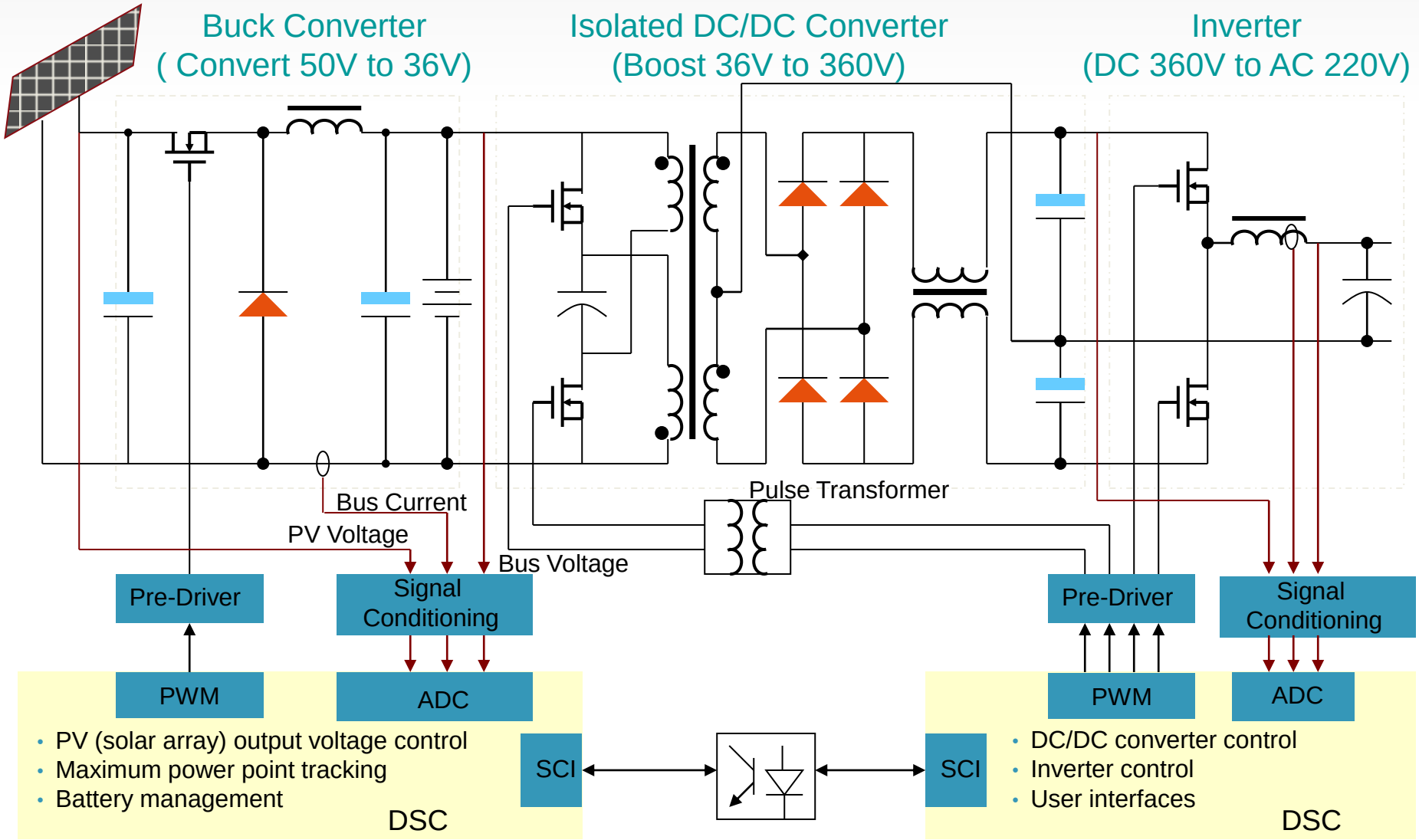
- Up to 64KB Program FLASH ,with Flash Security
- Up to 6KB Program/Data RAM
- Memory Resource Protection Unit
- Error code correction

- Up to 100 MHz Peripherals – Timers, PWMs and SCIs

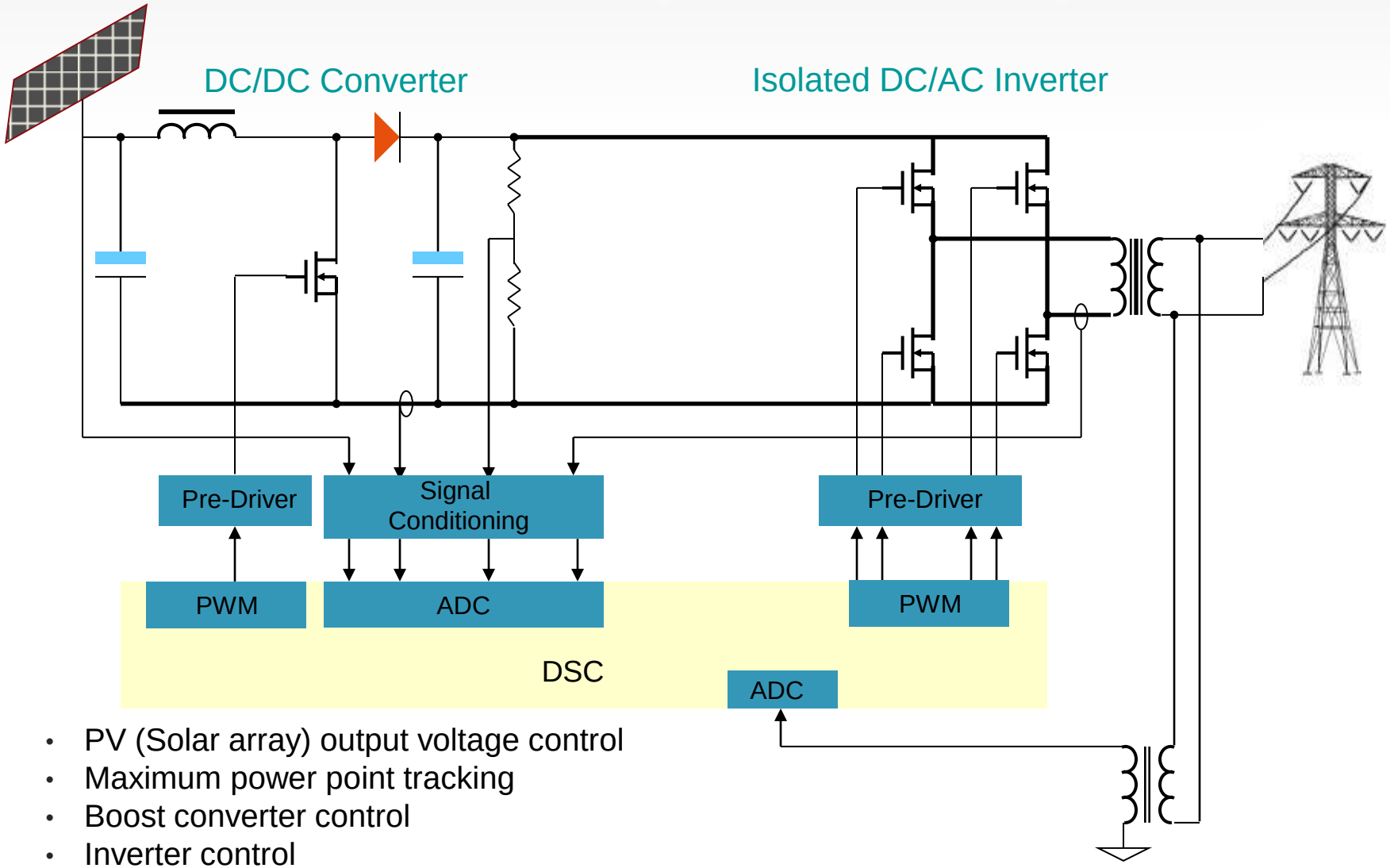
- Eight Channel Enhanced PWM (100MHz)
- (Inclusion of Nano Edge PWM under investigation)
  - Up to four programmable fault protection input
  - Dead-time insertion
  - Input Capture function
- 2 x12-bit ADCs with total 16 Inputs,
  - 800ns conversion rate
  - Band-gap reference
- 2 x Comparators with a 6bit Voltage reference
- 2 x CRC Generator
- 2 x COP with Multiple clock sources (Watchdog)
- 4 x 16-bit Enhanced Multifunction Programmable Timers
- 2 x High Speed SCI
- 2 x SPI
- 1x I^2C/SMbus Communications Interface
- Four channel DMA controller
- Inter Module cross-bar
- Software Programmable Phase Locked Loop
- Multiple Clock sources
  - External Crystal/Resonator Oscillator
  - 8MHz/400KHz Tunable Internal Relaxation Oscillator
  - 32KHz Internal RC relaxation Oscillator
- 5v Tolerant IO

- Industrial temperature:-40C to 105C @ 50MHz
- AEC – 100 Level 2

Solar Inverter Solution (Less than 1kW)

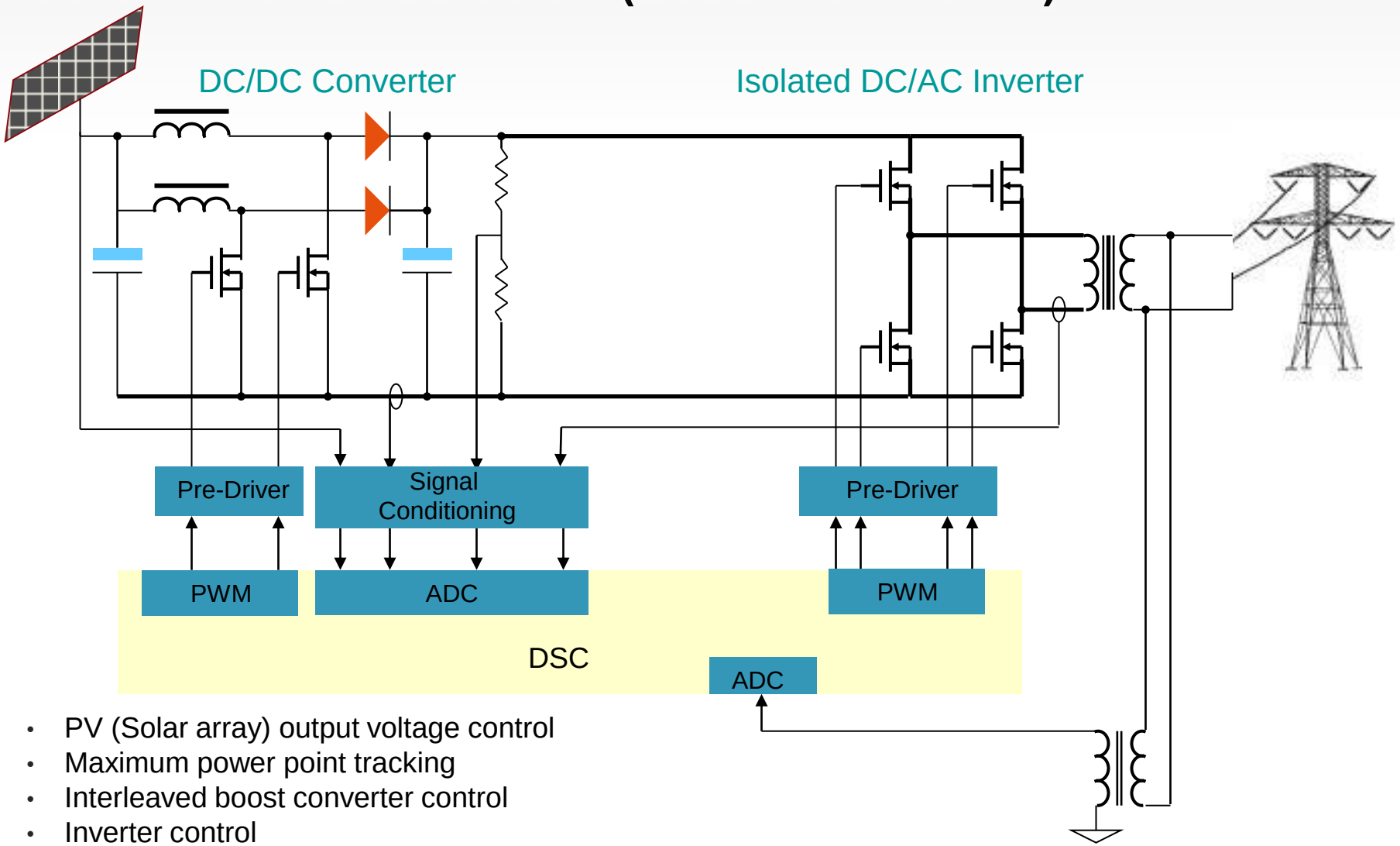


Solar Inverter Solution (Less than 3kW)



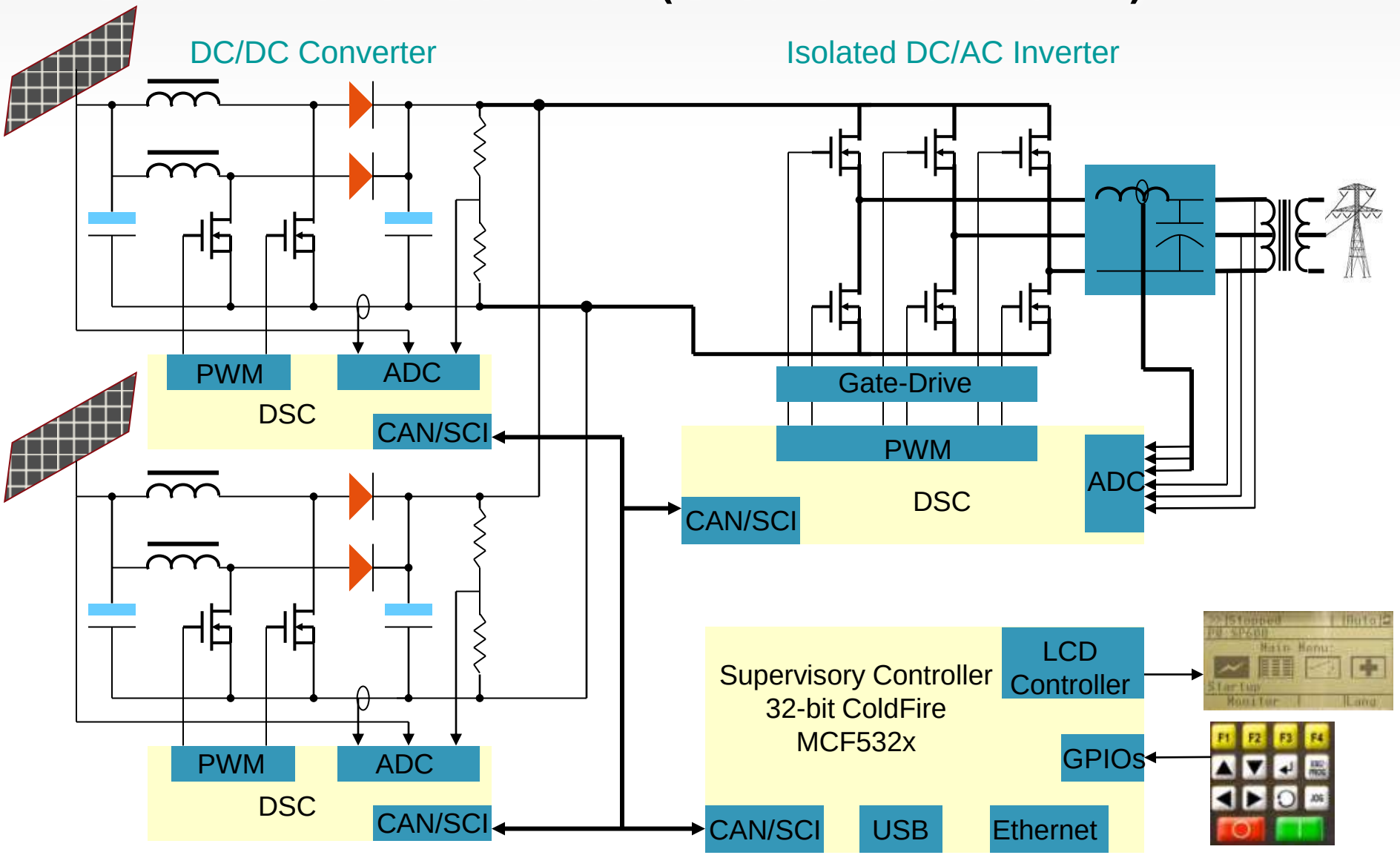
- PV (Solar array) output voltage control
- Maximum power point tracking
- Boost converter control
- Inverter control
- User interfaces

Solar Inverter Solution (Less than 10kW)



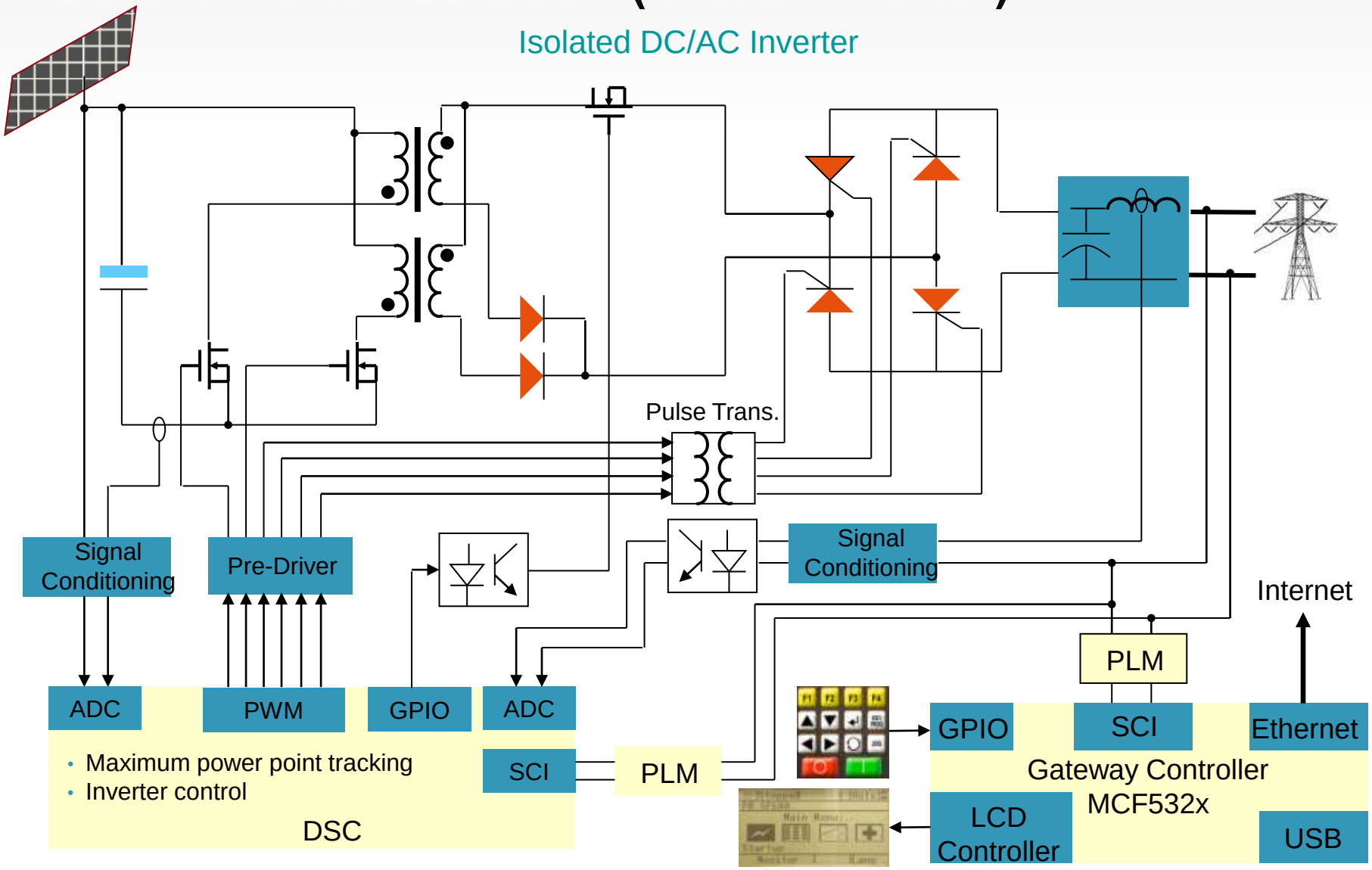
- PV (Solar array) output voltage control
- Maximum power point tracking
- Interleaved boost converter control
- Inverter control
- User interfaces

Solar Inverter Solution (Greater than 10kW)



Solar Inverter Solution (Micro Inverter)

Isolated DC/AC Inverter



2012 Inverter Ref Designs

Applications / Reference Designs		
MC56F801x/2x	**Solar Panel Inverter using MPPT**	Available
MC56F824x/5x	**Solar Micro-inverter – MPPT, 31-65VDC, 200W output, 94% efficiency, EU regulations**	Available
PXS Family	**Grid Tied Solar Inverter w/Ethernet Demo (3-Phase)**	Available

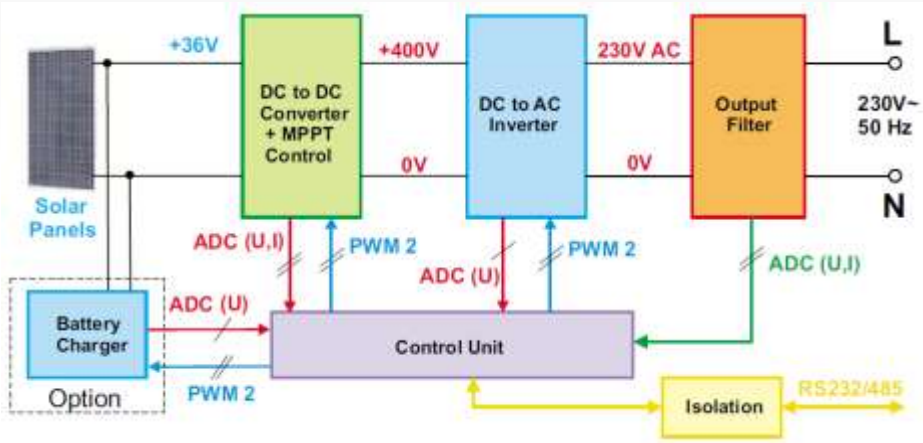
Solar Panel Inverter Demo

Target Devices/Platforms:

- DSC controlled DC to AC Inverters
- MC56F8025
- Solar Energy Harvesting
- UPS

Applications Usage:

- As DEMO application for the solar energy to power line conversion
- Small power line source for home usage
- Functions as UPS when battery connected



Application Features:

- DC to AC Inverter for solar panel is DSC controlled inverter with battery charger option
- Nominal input voltage is 36V – it represents one 36V panel, or two 18V panels in series, or three lead-acid batteries in series – each of 12V
- Output power is max 400VA / 230V AC / 50Hz
- Can work as grid connected or no
- The MPPT algorithm is implemented to maximize output power from the solar panel
- High frequency power transformer is used to maintain isolation between solar panels and grid connected power line
- The switching frequency is up to 50kHz
- The DC-DC up-converter and full bridge topology is used for the AC voltage generation
- Fault protection implemented – over-current, short-circuit and input under-voltage
- Isolated serial link RS-485 used for connection to whole system

Summary

- Solar market continues to gain greater share of the renewables market (decreasing cost/kWh)
- Market supports range of inverter architectures to support commercial and residential deployment activities
- Freescale offers flexible and scalable DSC portfolio to address all types of inverter solutions from several hundred watts to 10 kW and above

Freescale on Kaixin
Tag yourself in photos and upload your own!

Weibo?
Please use hashtag **#FTF2012#**

Session materials will be posted @ www.freescale.com/FTF

freescale™

For More Information

- Freescale Solutions
  - Freescale DSC Home Page
    - www.freescale.com/dsc
  - Digital Power Home Page
    - www.freescale.com/digitalpower


freescale™