Embedded Connectivity Summit 2004

Overview of PowerLine Modem Reference Design

DSCO

Launched by Motorola

freescale™
semiconductor

Power Line Modem

- Communication through power line

Overview

➤ The Power Line Modem (PLM) is the devices designed to communicate through the high voltage power line. It provides the low cost interconnectivity in homes or businesses at low speed data transmission rate over power line.

➤ This reference design demonstrates a complete hardware and software solution for power line communication by using Freescale's low cost DSP and Agilent's optical-based analog front end device which simplify circuitry with low component count thus lowering overall cost.
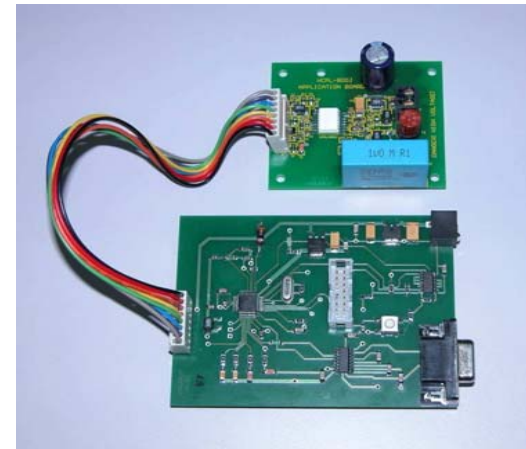
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semiconductor

Power line Modem

Target market and Applications
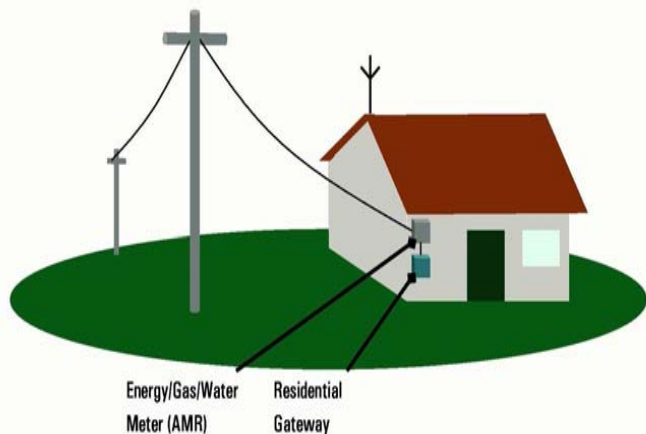
Freescale + Agilent = best Solution

Power Line Modem Basic
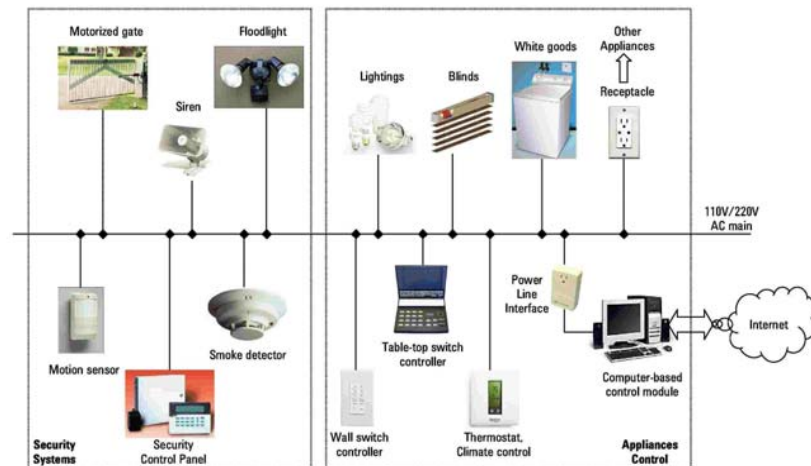
PLM Implementation

Powerline Modem Target Markets/Applications

Metering - Power Line Communication

Automated Meter Reading (AMR)
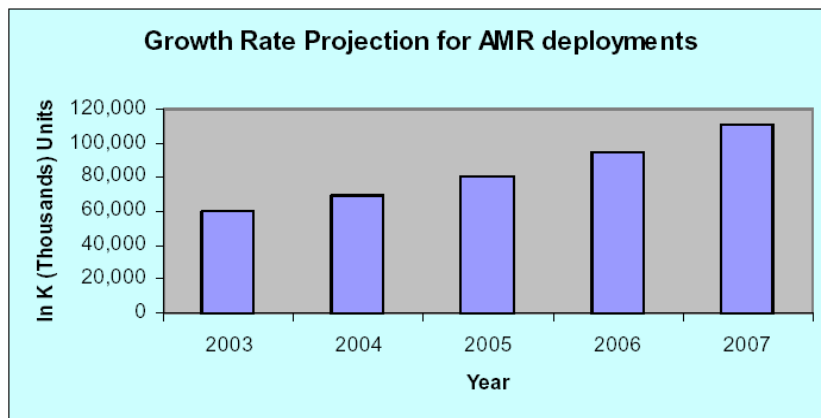• Energy Meters (Remote Units)
• Concentrators

Home Automation
• Home Appliances, e.g. Lightings, white goods, etc.
• Security/Alarm Systems

Slide 4

worldwide AMR Market Landscape

Market Size

Growth Rate Projection for AMR deployments

15-20% annual growth in AMR shipments - The Chartwell AMR Report 2003

Region	# Shipped	% Shipped	# Projects	% Projects
North America	49,311,372	80.4%	6,172	90.7%
Europe	7,428,817	12.1%	345	5.1%
Asia	3,892,839	6.4%	144	2.1%
Middle East	273,938	0.4%	26	0.4%
Central & South America	154,418	0.3%	49	0.7%
Australia/NZ	92,077	0.2%	29	0.4%
Misc.	87,199	0.1%	13	0.2%
Africa	55,553	0.1%	30	0.4%
Total:	61,296,213	100.0%	6,808	100.0%

Original data source from 2003 Scott Report on AMR Deployment

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AMR Technologies

- Powerline Carrier (PLC)
- Wireless
- Telephone line
- Others: dedicated wiring, twisted pair, etc.

Worldwide AMR Deployment (at Jan 1, 2003) millions					
	PLC	Wireless	Telephone	Others	Overall
N. America	5.5	41.0	2.8	0.0	49.3
Europe	6.0	0.8	0.3	0.3	7.4
Asia	3.1	0.0	0.8	0.0	3.9
ROW	0.1	0.2	0.0	0.4	0.7
Worldwide	14.7	42.0	3.9	0.7	61.3

Source: Scott Report 2003

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worldwide AMR Market Landscape (Cont'd)

A few comments:

- Worldwide AMR deployment exceeds 60 million units.
- About 25% of AMR systems worldwide are based on powerline technology with nearly 1000 projects currently running.
- North America is the biggest AMR market worldwide. However, RF is the preferred technology. Itron is the key metering system vendors.
- Europe is the biggest AMR market using powerline technology. Enel's project in Italy is the most well-known success story, which is based on Echelon solution.
- China and other developing countries in Asia are very aggressive in deployment of AMR. Powerline is one of the popular technologies under extensive field testing.

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Home Automation/Networking

Market domain ->Smart Home Network (Narrowband data rate <1 Mbps)

Typical applications:

• Home appliances (white goods)

• Simple home control (lighting, HVAC, etc.)

• Security and alarm systems

Home Automation/Networking Forecast

Smart Home Network Technologies:

- Powerline: X10, LonWorks®, proprietary protocols, etc.
- Wireless: ZigBee, Z-wave, Bluetooth, etc.
- Others: Phoneline, twisted pair, etc.

US Smart Home Network, Node Units by Transmission (thousands)						
	2001	2002	2003	2004	2005	2006
Powerline	6,654	10,018	15,808	23,800	32,915	49,812
Wireless	1,042	1,488	2,818	7,517	22,068	43,129
Other	470	666	1,564	6,313	16,626	32,909
Total	8,166	12,172	20,190	37,630	71,609	125,850

Source: In-Stat/MDR 2003

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Home Automation Forecast

A few comments:

- North America dominates the worldwide Smart Home Network market with millions of units shipped, mainly low-end powerline based X10 products.

- Echelon's LonWorks is gaining popularity in high-end Home Networking segments, e.g. home appliances.

- European and Asian home appliances and control system manufacturers are also very interested in Home Networking. Regional standardizations are formed.

- Low-end wireless technologies, e.g. ZigBee, are gaining ground in Smart Home Networks and competing directly with Powerline
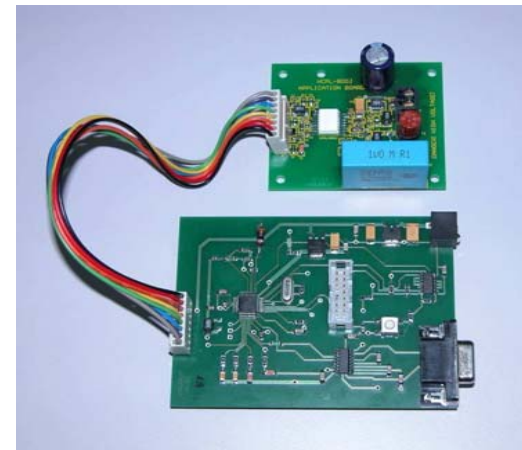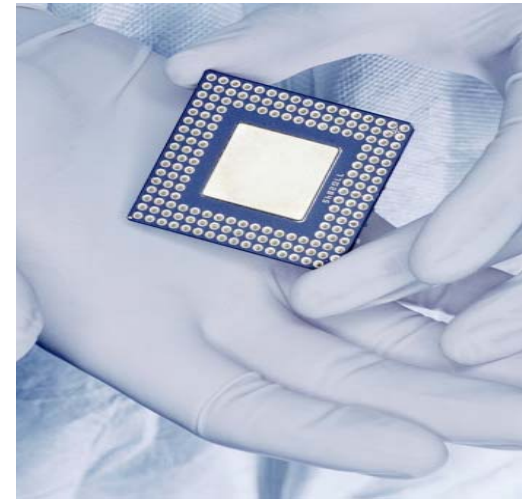
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Power line Modem

Target market and Applications

Freescale + Agilent = best Solution

Power Line Modem Basic

PLM Implementation

PLC Modules Evolution History
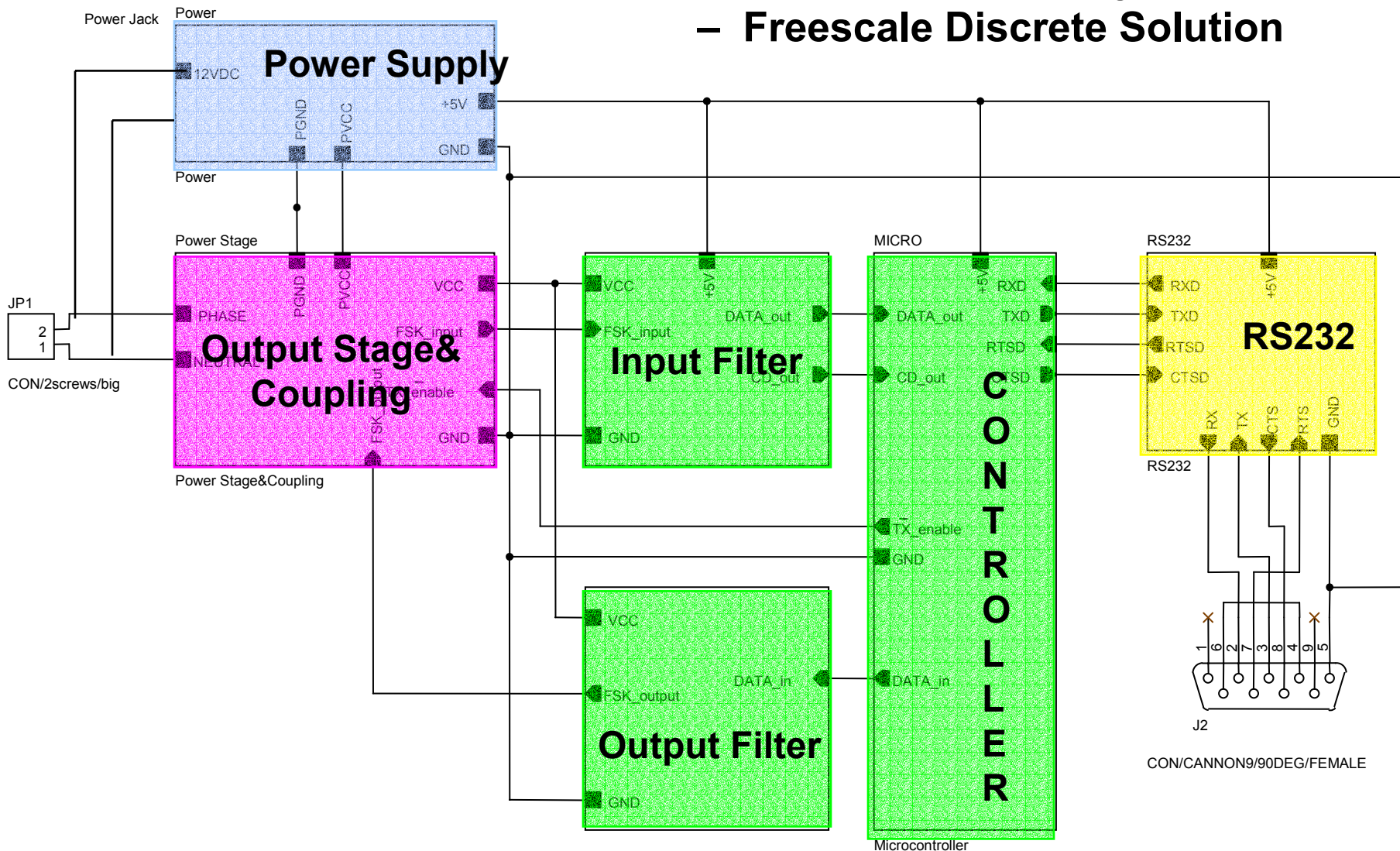
Discrete Solution (Freescale Solution)

- Modulation & demodulation done completely in SW of DSP
- FSK modulation used in the CELENEC EN 50065-1 "B" band (95-125 KHz) with 10 Kbps
- Transparent channel operation
- Transformation isolation => bulky and more expensive

Integrate Solution (Freescale + Agilent Solution)

- Modulation & demodulation done completely in SW of DSP
- FSK modulation used in the CELENEC EN 50065-1 "B" band (95-125 KHz) with 10 Kbps
- Transparent channel operation
- Optical-based Analog Front End => small size and low cost

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PLM Evolution History – Freescale Discrete Solution

PLM Evolution History
## – Freescale Discrete Solution

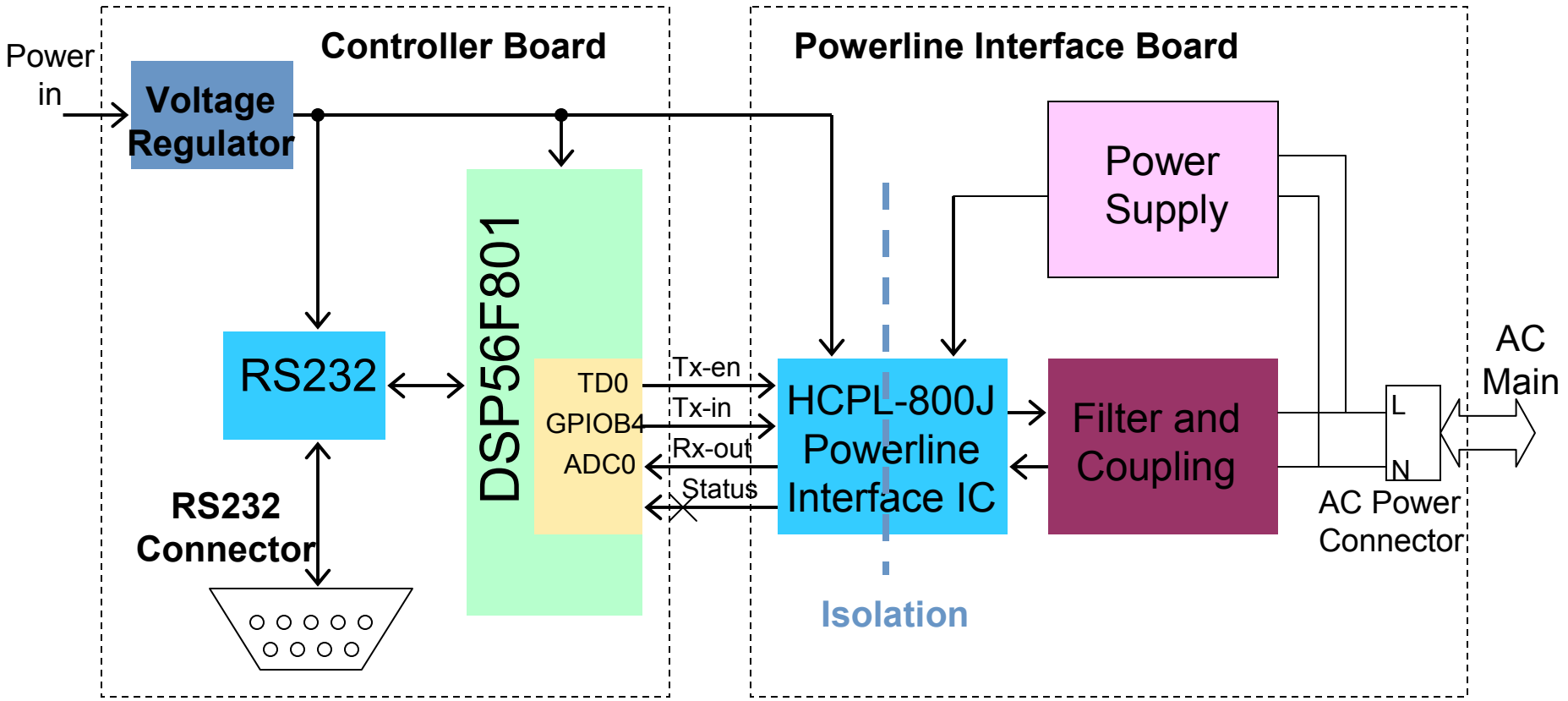# Power Line Modem (PLM) – Integrate Solution

-A Reference Design Based On Freescale DSP56F801/Agilent HCPL-800J

Features

- Single-chip PLM transceiver + DSP - Motorola DSP56F801
- Optically isolated powerline interface IC -Agilent HCPL-800J (no signal transformer required)
- 95 KHz-125 KHz FSK modulation /demodulation
- Data rate up to 10 Kbps
- RS-232 serial communication interface
- Low cost, simple, reliable design
- Suitable for CENELEC EN-50065-1 compliant design

Powerline Analog Front-end

DSP Powerline Modem

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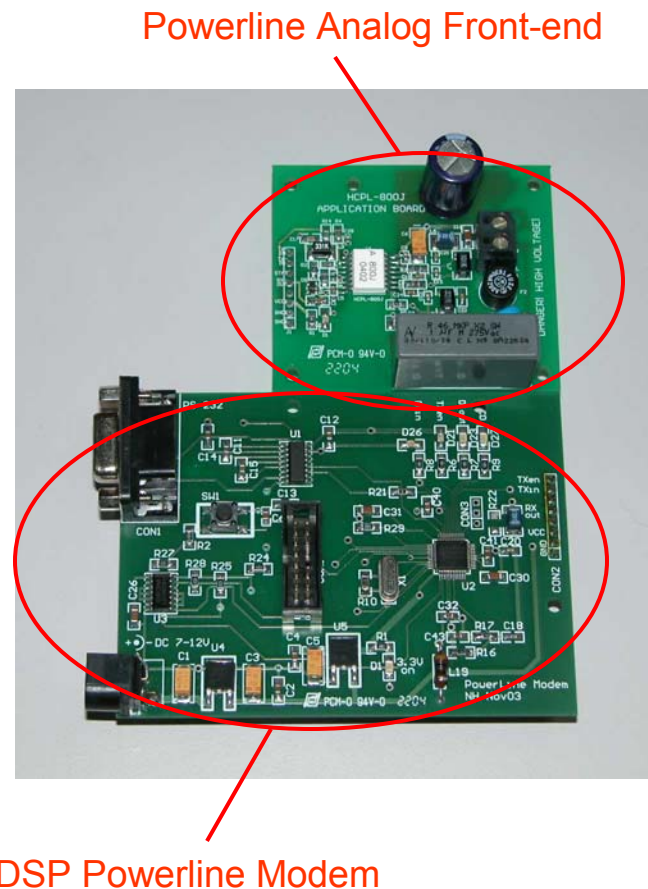
PLM Block Diagram

Benefits

PLM using Freescale's DSP and Agilent's Front-end device will enjoy the following benefits:

- ✓ Simplified circuitry with low component count thus lowering overall cost
  - ✓ **No need for isolation transformer reducing overall size and cost**
  - ✓ **No need for separate line driver which can be costly due of much higher rating thab what is required.**
  - ✓ **Safety features integrated: Over-current and under-voltage monitoring, over-temperature shutdown**
- ✓ Compliance to European CENELEC Standard EN50065-1 on harmonics emission. This inplies Konnex's compliance since Konnex adopts EN50065-1

Agilent is also the member of the following:

Konnex Association   **Power Line Communications**   **ECHONET**

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HCPL-800J Power Line DAA (Data Access Arrangement) IC

Key Features/Parameters:

- 1 App Output Driving Current
- -60 dB Overall TX Distortion
- Operating Frequency Up To 500 KHz
- Over-temperature Shutdown
- Under-voltage/Load Detection
- 5 V Power Supply
- Wide Operating Temp. Range –45 to 85°C
- Small Outline Package: SO16
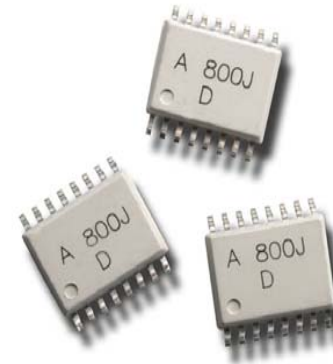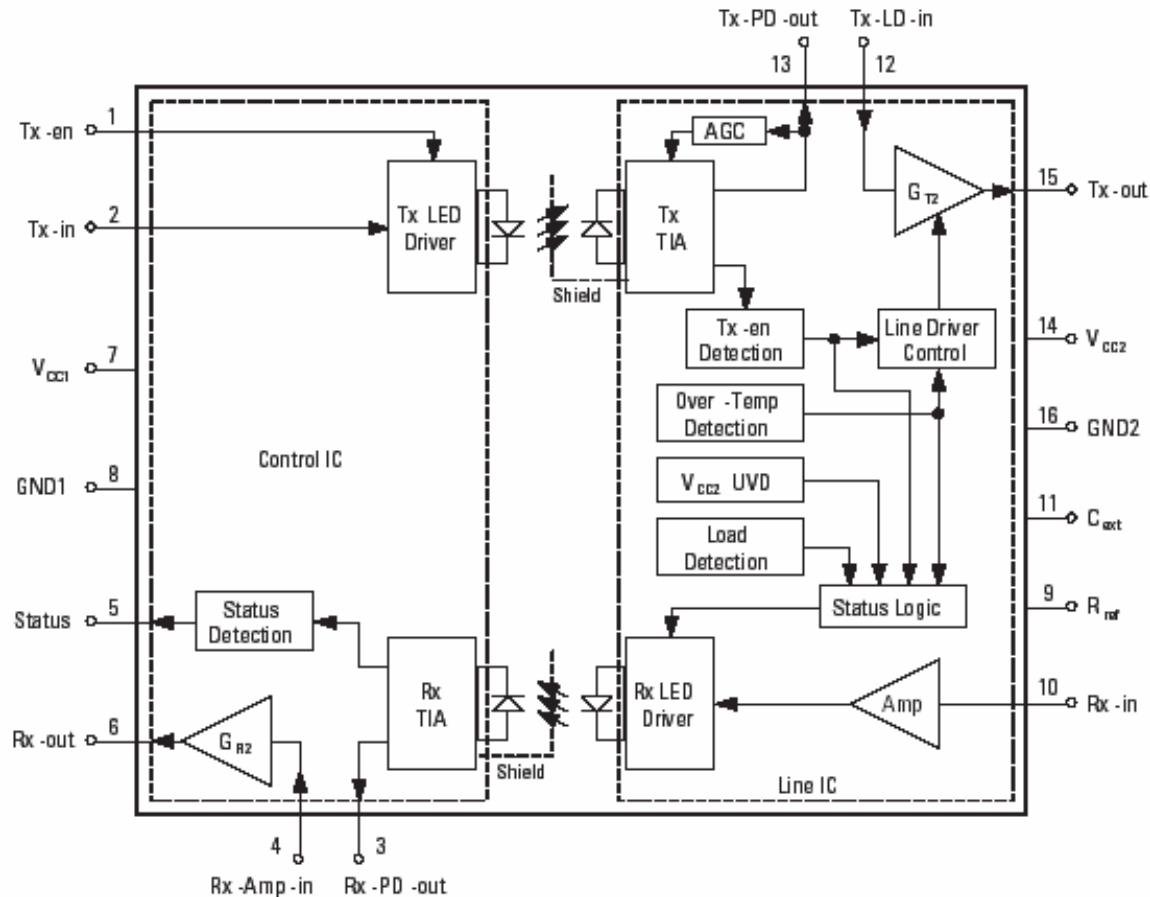
Standards Compliance

- EMI: CENELEC EN-50065-1, FCC
- Safety: UL, CSA, VDE/IEC

HCPL-800J Power Line DAA IC

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Block diagram of Agilent's HCPL-800J

➤ Highly integrated analog front-end solution for any narrowband powerline communication

Block Diagram

Simplicity – compact, reliable and very flexible

➢Wide narrowband carrier frequency range for power line communication.   Up to 450 KHz carrier frequency has been tested.
➢Carrier frequency is determined by the Low-pass/band-pass filters of TX and RX.

56F801 Functional Block Diagram
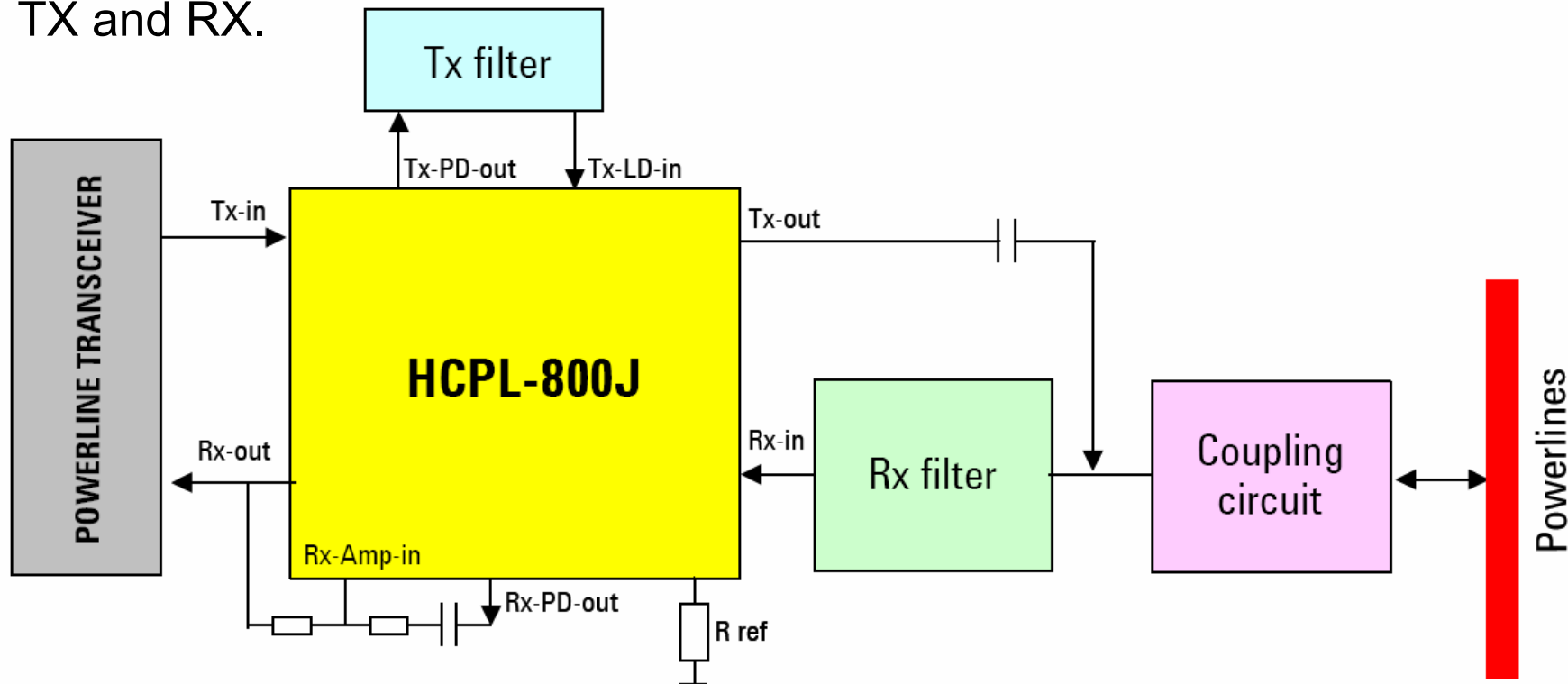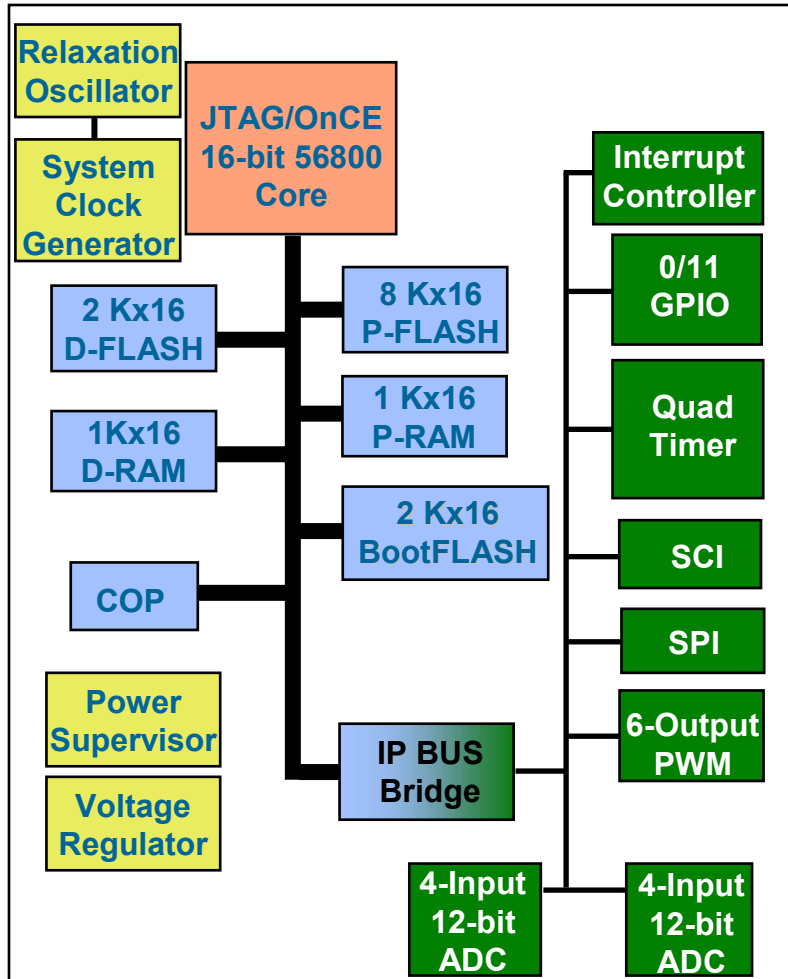
Package 44-pin LQFP

- ✓ 8 Kx16 Program Flash, 1Kx16 Program RAM
- ✓ 2 Kx16 Data Flash, 1Kx16 Data RAM
- ✓ 2 Kx16 BootFLASH
- ✓ Voltage regulator
- ✓ On-Chip Relaxation Oscillator (+/- 0.5% accuracy in room temperature) is available
- ✓ System Clock Generator
- ✓ Power Supervisor
- ✓ 6-Output PWM Module
- ✓ Two 4-Input 12-bit ADC
- ✓ 16-Bit Quad Timer
- ✓ COP Timer
- ✓ Multiple Serial Ports
- ✓ Up to 11 General Purpose I/OPins
- ✓ Vectored Interrupt Controller
- ✓ JTAG/OnCE™ Debug Port

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56800/E Hybrid Controller Roadmap

Features

56850 Series
Telecom/voice processors, RAM-based, 120 MMACS, Up to 80KB PRAM, 81–144 pins

56F8300 Series
Automotive & Industrial, Flash-based, 60 MMACS, 40-528KB PFlash, 48–160 pins

56F8100 Series
Industrial, Flash-based, 40 MMACS, 40-528KB PFlash, 48–160 pins

56F820 Series
General Purpose, Flash-based, 40 MMACS, 64 -130KB PFlash, 100–128 pins

56F8000 Series
Automotive & Industrial, Flash-based, 32 MMACS, 12-16KB PFlash, 28-32 pins

56F800 Series
Industrial controllers, Flash-based, 30-40 MMACS, 20-128KB PFlash, 32–160 pins
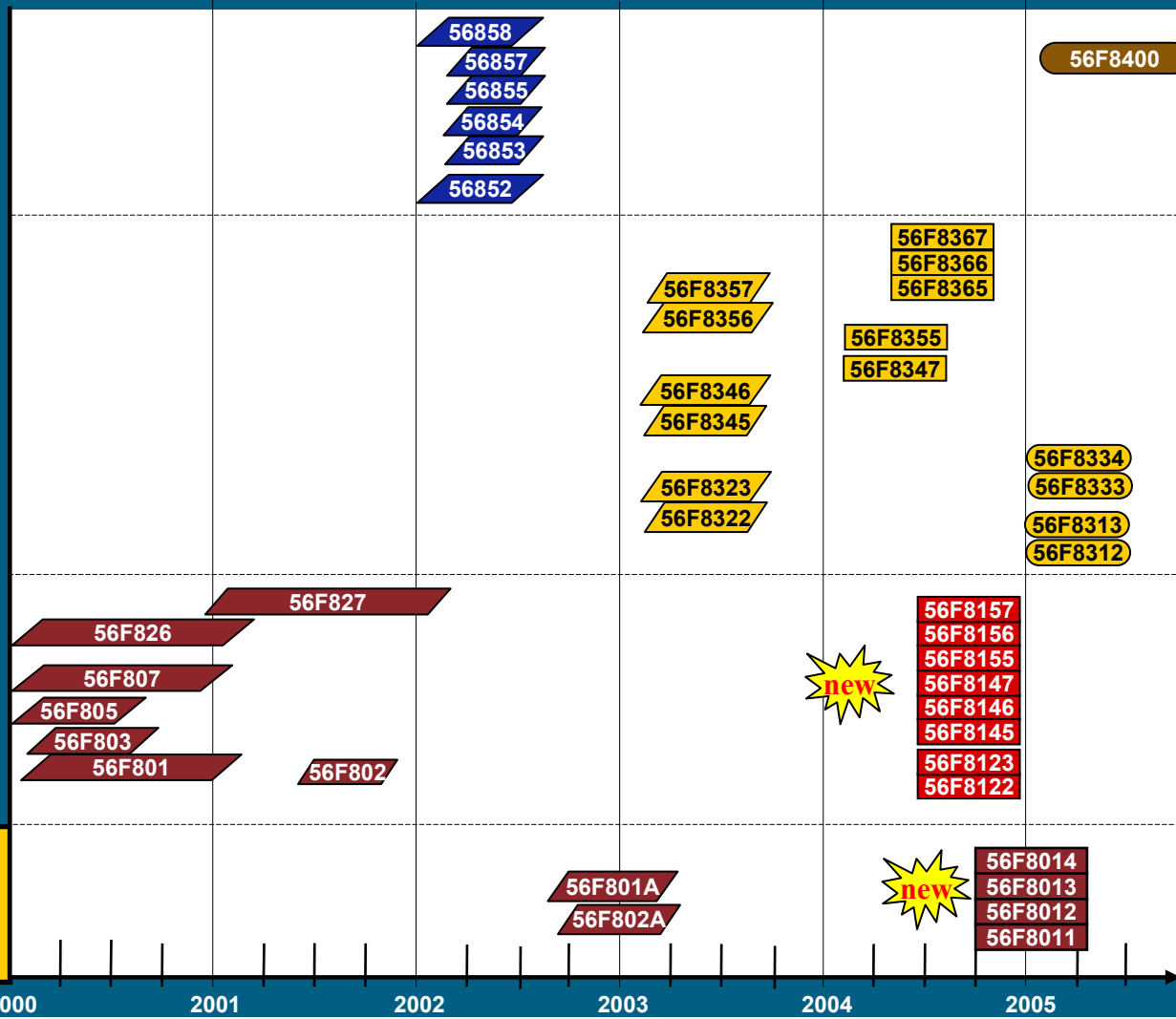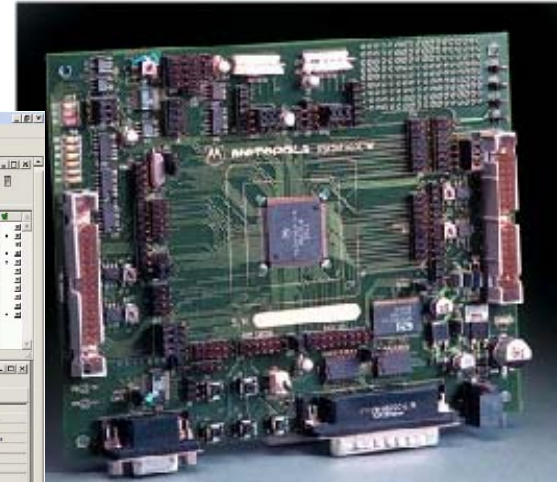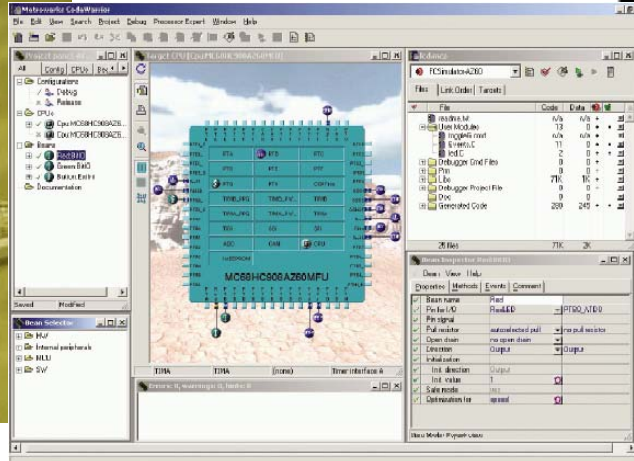
Legend:
- Proposal
- Planning
- Execution
- Production

- 0.18μ, 56800E 120 MMACS
- 0.18μ, 56800E 120 MMACS
- 0.25μ, 56800E 60 MMACS
- 0.25μ, 56800E 40 MMACS
- 0.25μ, 56800 30/40 MMACS

Timeline: 2000, 2001, 2002, 2003, 2004, 2005

Parts shown:
- 56858, 56857, 56855, 56854, 56853, 56852
- 56F8400
- 56F8367, 56F8366, 56F8365
- 56F8357, 56F8356
- 56F8355, 56F8347
- 56F8346, 56F8345
- 56F8334, 56F8333
- 56F8323, 56F8322
- 56F8313, 56F8312
- 56F827, 56F826
- 56F807, 56F805, 56F803, 56F801, 56F802
- 56F8157, 56F8156, 56F8155, 56F8147, 56F8146, 56F8145, 56F8123, 56F8122 (new)
- 56F8014, 56F8013, 56F8012, 56F8011 (new)
- 56F801A, 56F802A

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The Complete Development Environment

CodeWarrior™ for 56800/E

CodeWarrior for Freescale 56800/E is a windows based visual IDE that includes an optimizing C compiler, assembler and linker, project management system, editor and code navigation system, debugger, simulator, scripting, source control, and third party plug in interface.

Processor Expert™

Processor Expert (PE) provides a Rapid Application Design (RAD) tool that combines easy-to-use component-based software application creation with an expert knowledge system. PE is fully integrated with the CodeWarrior for 56800/E.

Hardware Tools

The 56800/E solutions are supported with a complete set of evaluation modules which supply all required items for rapid evaluation and software and hardware development. In addition several command converter options exist for customer target system debugger connection.

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Processor Expert Overview
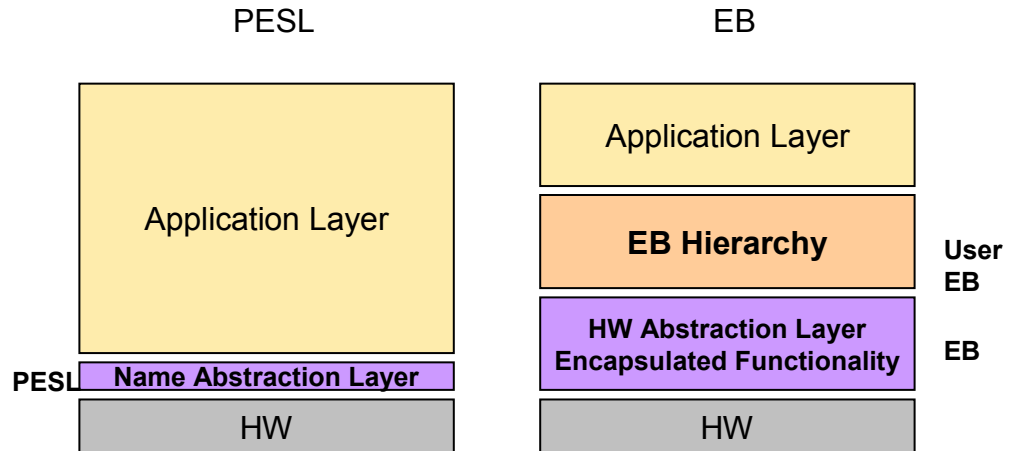
Processor Expert™

- Supports rapid application development
- Enables component oriented programming
- Provides expert advice if necessary
- Delivers instant functionality of generated code
- Provides tested ready-to-use code

Key Abstraction Technologies

- **PESL**
  - Processor Expert System Library
  - Peripheral oriented
- **EB – an abstraction provider**
  - Embedded Beans
  - Functionality oriented
  - Real *components* for building of an application

How Features of PE are Achieved

- Developed by experienced programmers of embedded systems
- Expert knowledge system is working on the background of PE and checks all the settings
- Provides context help and access to CPU/MCU vendor documentation
- All EB delivered by UNIS are tested according to ISO testing procedures (UNIS is ISO certified company)

PESL

EB

Application Layer	Application Layer
	EB Hierarchy
PESL **Name Abstraction Layer**	**HW Abstraction Layer Encapsulated Functionality**
HW	HW

User EB

EB

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Processor Expert Features

Available across 8/16-bit product lines
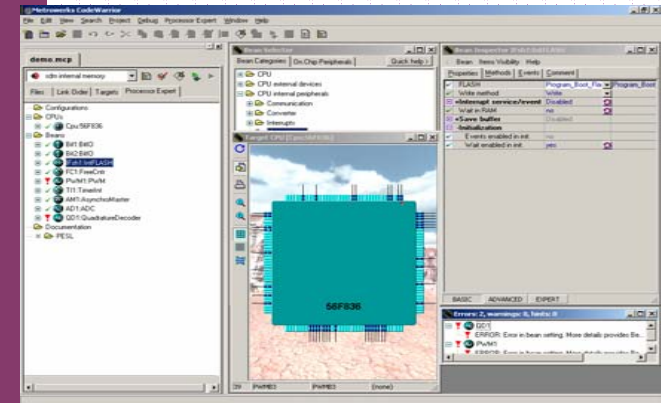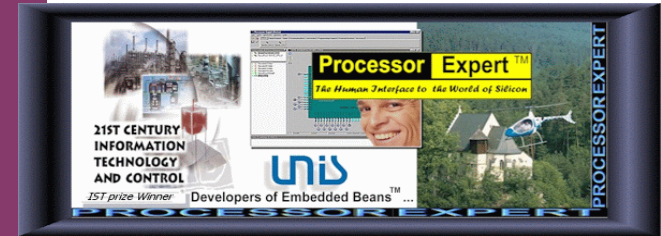
Rapid application development

Expert configuration system

Instant functionality of generated code

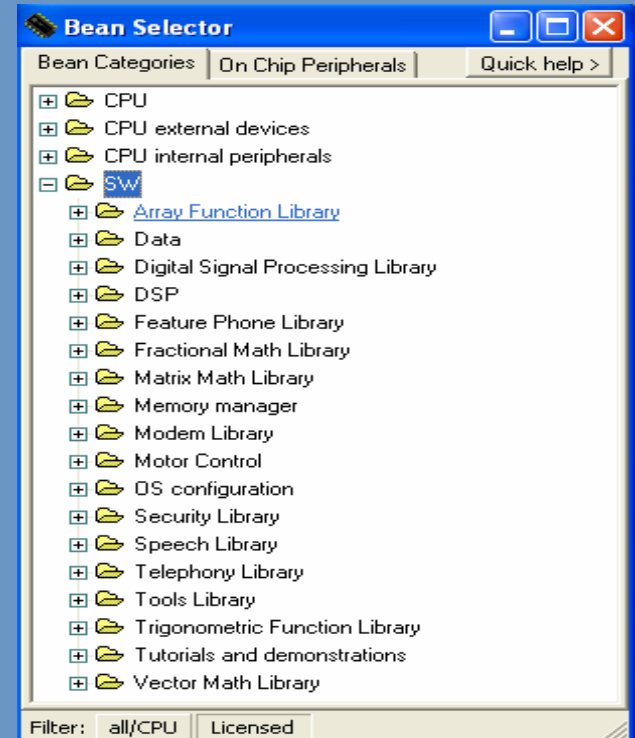Two Peripheral programming levels

- Embedded Beans
- PESL

Application Specific Algorithm Libraries

- All SDK algorithm libraries ported

Tested and ready-to-use code

Application Specific Algorithm Libraries

Memory Manager
- Dynamic allocation

Feature Phone Library
- CallerID type 1&2, CallerID Parser, Generic Echo Cancellor

DSP Library
- FIR, IIR, FFT, Auto Correlation, Bit Reversal

Telephony Libraries
- AEC, AGC, Caller ID,
- CAS, CPT, CTG, DTMF
- G165, G168, G711
- G723, G726, G729

Modem Libraries
- V.8bis, V.21, V.22bis, V.42bis

Security Libraries
- RSA, DES, 3DES,

Motor Control
- BLDC, ACIM, SR motor specific algorithms
- General purpose algorithms

Math Libraries
- Matrix, Fractional, Vector
- Trigonometric

Tools Library
- Cycle Count, FIFO, FileIO, Test

Bean Selector

Bean Categories | On Chip Peripherals | Quick help >

- CPU
- CPU external devices
- CPU internal peripherals
- SW
  - Array Function Library
  - Data
  - Digital Signal Processing Library
  - DSP
  - Feature Phone Library
  - Fractional Math Library
  - Matrix Math Library
  - Memory manager
  - Modem Library
  - Motor Control
  - OS configuration
  - Security Library
  - Speech Library
  - Telephony Library
  - Tools Library
  - Trigonometric Function Library
  - Tutorials and demonstrations
  - Vector Math Library

Filter: all/CPU | Licensed

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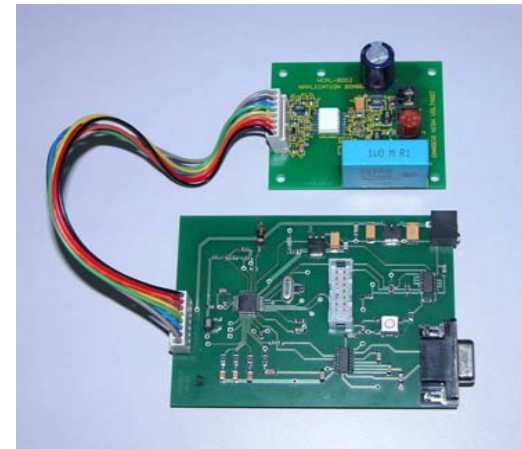
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Power line Modem

Target Market and Applications

Freescale + Agilent = Best Solution

Power Line Modem Basic

PLM Implementation

Power Line Modem Basic

- The PLM is the devices designed to communicate through the Power line

  - **Provide low cost interconnectivity in homes or businesses**

  - **Low speed data transmission rate over power line**

  - **Applications include: Home appliances; HVAC; lighting control; low-speed communication control; signal and information displays; fire and security alarm systems.**

- Transmitting and receiving digital signals over 120/230-VAC power line using carrier frequencies

  - **Europe CENELE: 3 KHz – 148.5 KHz**

  - **The U.S. FCC: 45 KHz – 450 KHz**

  - **Japan PLC: 10 KHz – 450 KHz**

- The applications and frequencies are VERY different from the Broadband over Power Line (BPL) networking technologies, which are designed to:

  - **Provide networking and internet access at up to 10 Mbps over electrical power line**

  - **Operating frequencies in 1 MHz – 10 MHz range**

Typical Frequency-Shift keying (FSK) PLM
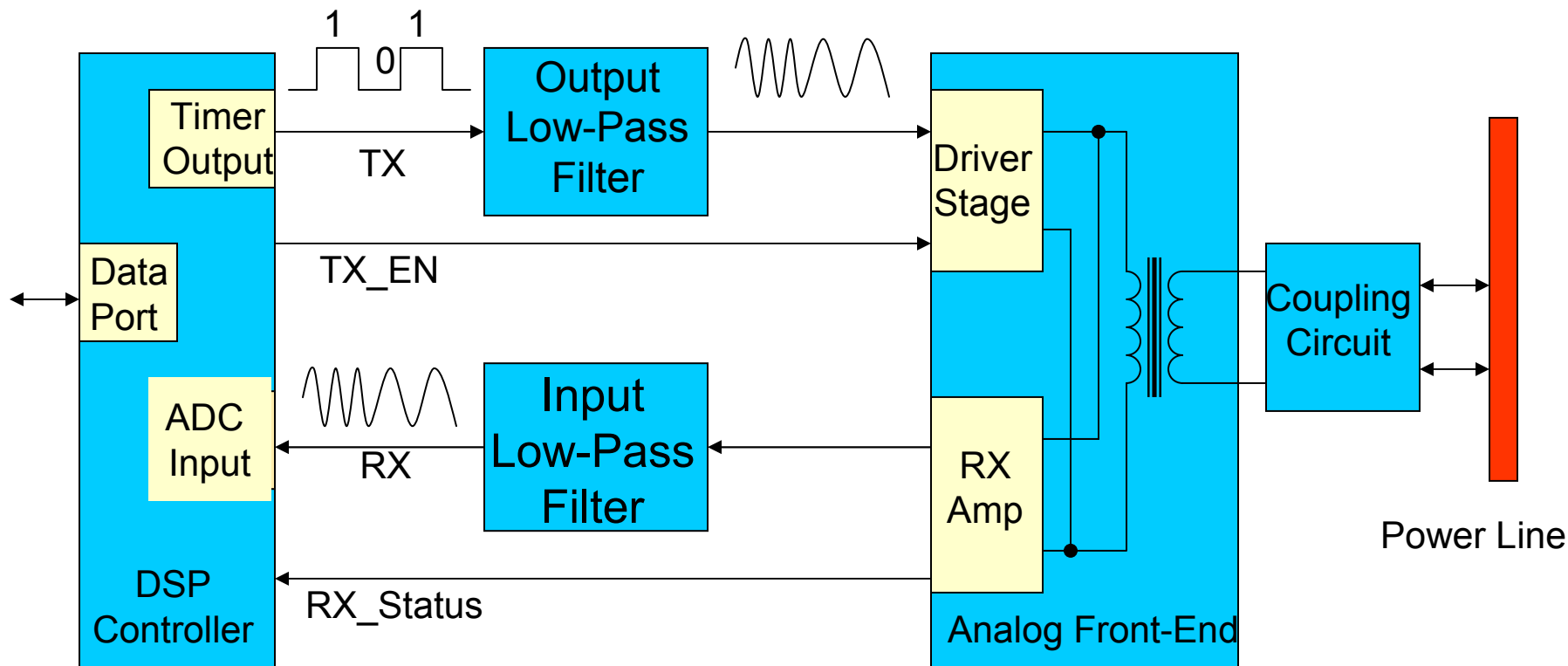
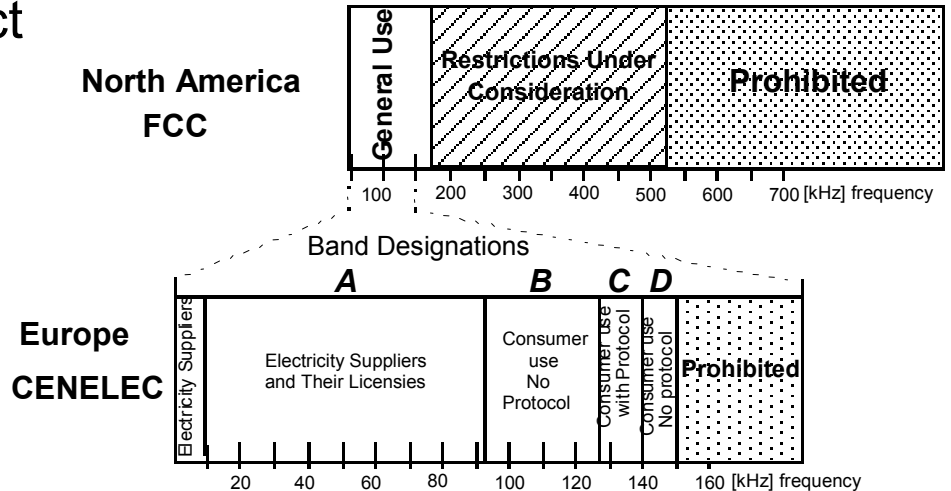# Frequency-Shift Keying (FSK)

- **(FSK) The use of <u>frequency modulation</u> to transmit digital data, i.e. two different <u>carrier</u> frequencies are used to represent zero and one.**

- **FSK was originally used to transmit <u>teleprinter</u> messages by radio (<u>RTTY</u>) but can be used for most other types of radio and land-line digital telegraphy. More than two frequencies can be used to increase transmission rates.**
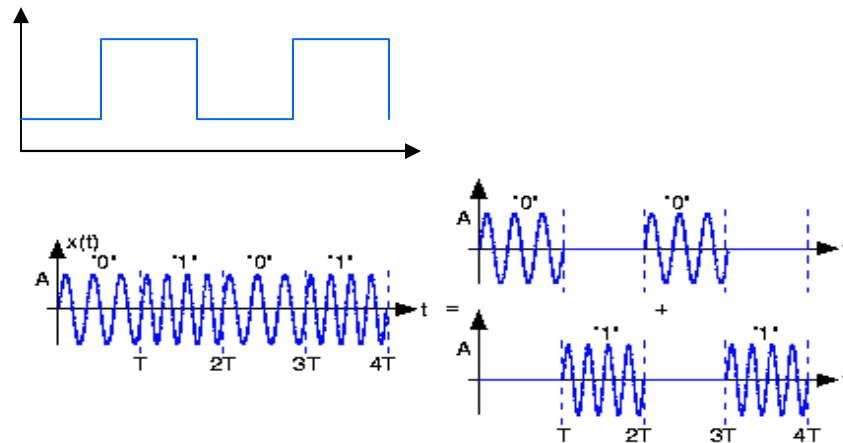
PLM Reference Design Basic Requirement

Basic technical requirements:

- Low cost; low speed, compact size

- Based on the software control

- FSK modulation used in CELENEC EN 50065-1 "B" band (95-125 KHz)

- Transparent channel operation

- Half-duplex mode of communication

- 10 Kbps communication speed

North America FCC

General Use | Restrictions Under Consideration | Prohibited

100 200 300 400 500 600 700 [kHz] frequency

Band Designations

A   B   C   D

Europe CENELEC

Electricity Suppliers | Electricity Suppliers and Their Licensies | Consumer use No Protocol | Consumer use with Protocol | Consumer use No protocol | Prohibited

20 40 60 80 100 120 140 160 [kHz] frequency

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Another technical requirements

- 16 bits *Cyclic Redundancy Check (CRC)* is used to verify the integrity of every transmitted frame

- *Encryption / Decryption* ensures the security of the transmitted data. The PLM board software utilizes *The Tiny Encryption Algorithm (TEA)*.

- *Forward Error Correction (FEC)* uses added redundancy information in order to correct the errors which occurred during the transmission. Quite straightforward method of FEC called *Linear Block Codes* is used. Added redundancy is characterized by expression (7, 4).

- *Interleaving* is another technique which should assure better consistency of the transmitted data. It simply modify the sequence of bits of frame to be transmit in defined way.
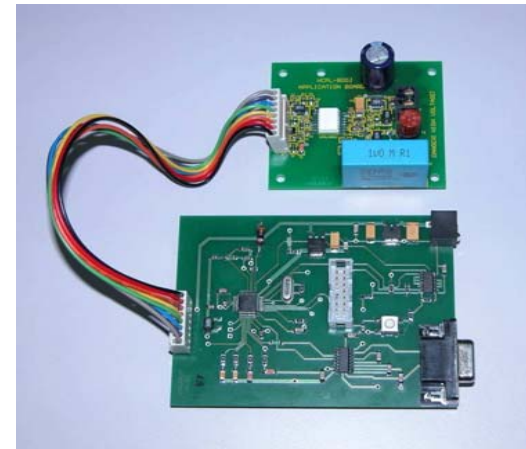
Power line Modem

Target Market and Applications

Freescale + Agilent = Best Solution

**Power Line Modem Basic**

PLM Implementation

Power Line Modem Structure

- **DSP Controller- DSP56F801**
  - ✓ Provide Signal Modulation/ Demodulation using FSK method
  - ✓ Cyclic Redundancy Code (CRC) calculation
  - ✓ Forward Error Correction (FEC) calculation
  - ✓ Encryption/ Decryption
  - ✓ Interleaving transmmission
- **Analog Front-end**
  - ✓ Signal Insulation for high voltage
  - ✓ Surge voltage immunity
  - ✓ Minimize line attenuation
  - ✓ Immunity to Electromagnetic Interface
  - ✓ Electromagnetic Compatibility
- **Transmit Filter – Two stage filter circuit**
  - ✓ First stage – A resonat band-pass filter
  - ✓ Second stage – Four pole band pass filter
- **Receive Filter**
  - ✓ First stage – Remove band noise at frequencies less than the 100Khz
  - ✓ Second stage – a low pass filter to further attenuate high frequency noise
- **Power-line coupling Capacitor**
  - ✓ Block mains frequencies for transceiver circuits
- **Power Line Side Power Supply**
 - ✓ Provide power for high voltage side

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Stage I TX Filter Frequency Response
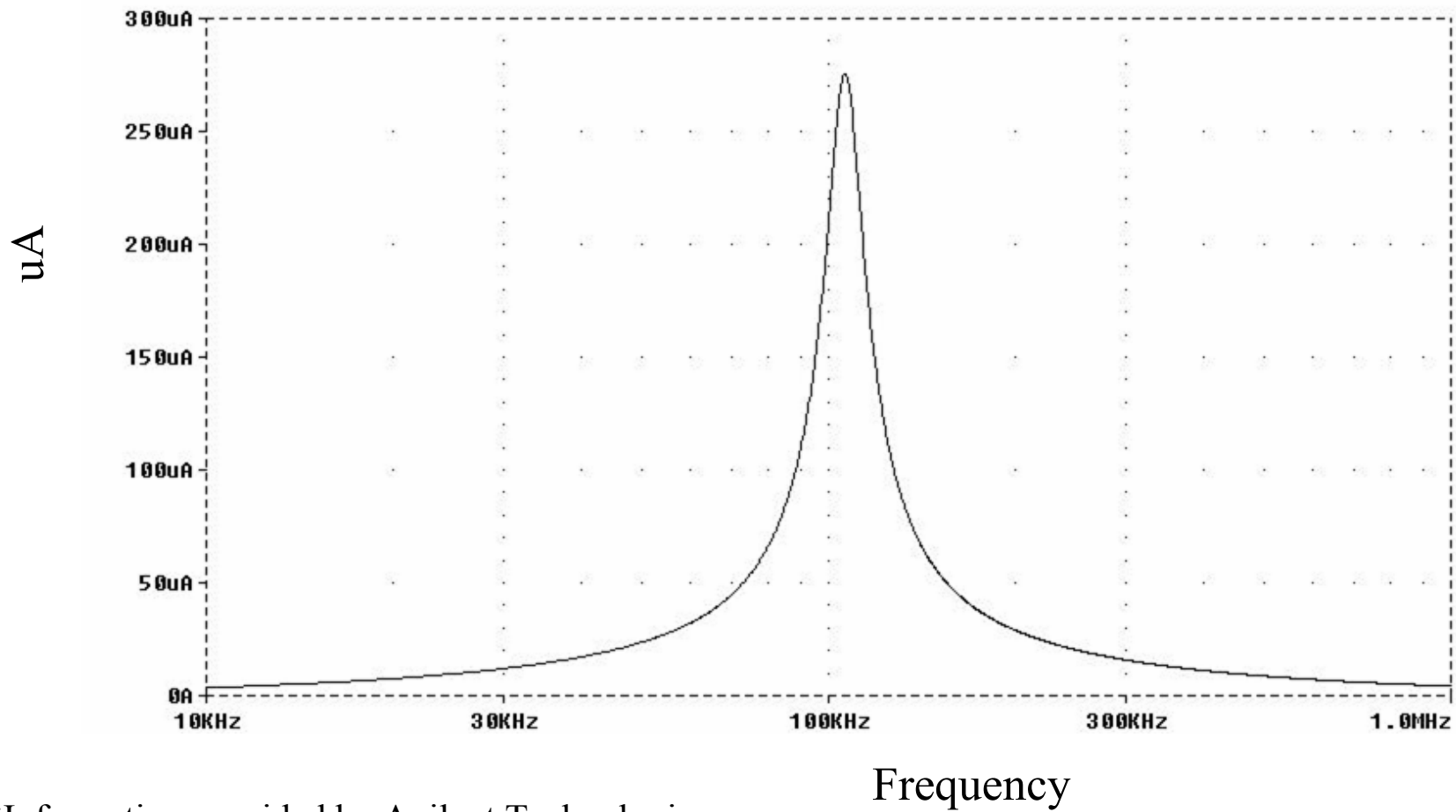
*Information provided by Agilent Technologies

Stage II TX Filter Frequency Response

μA

Frequency

*Information provided by Agilent Technologies

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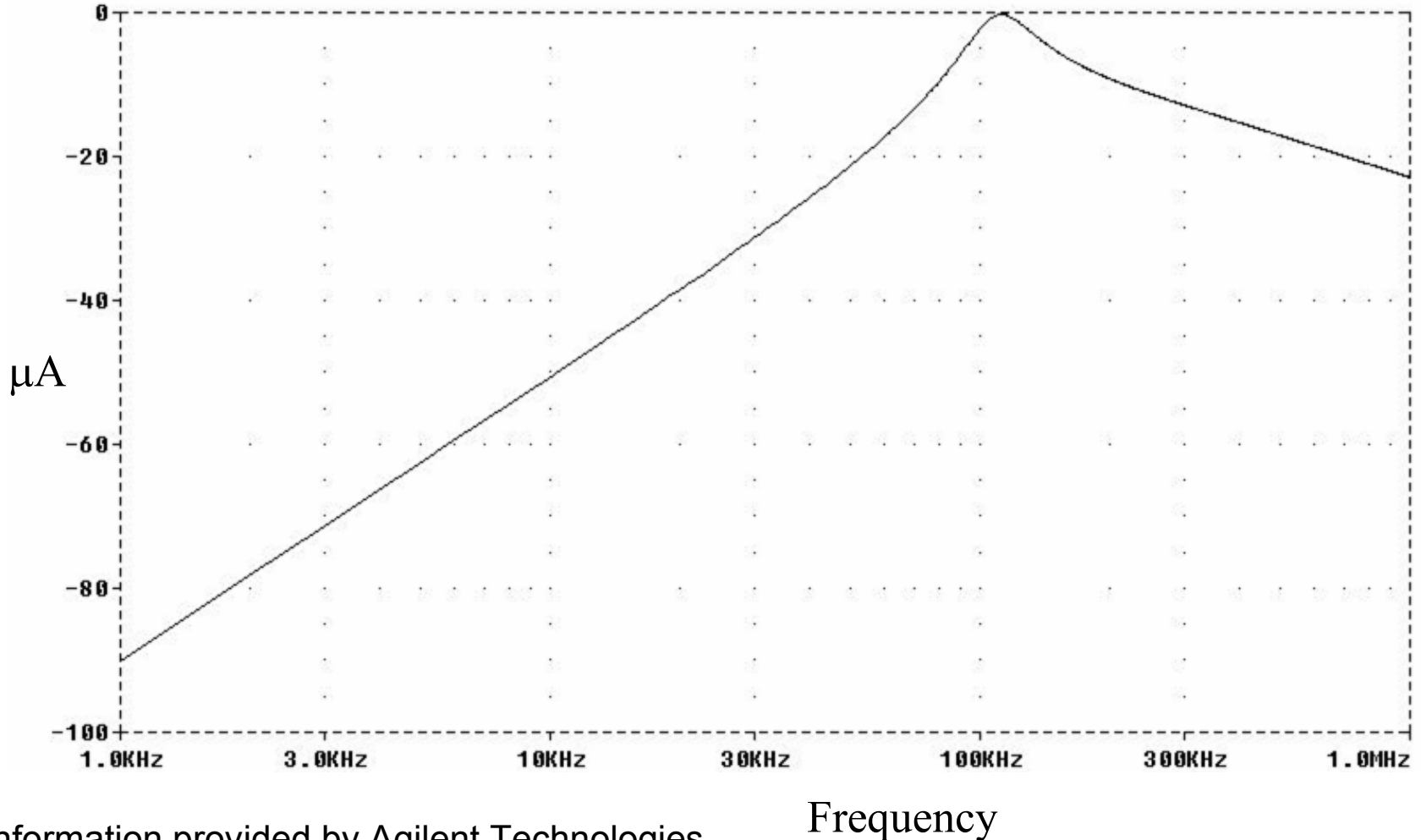Launched by Motorola
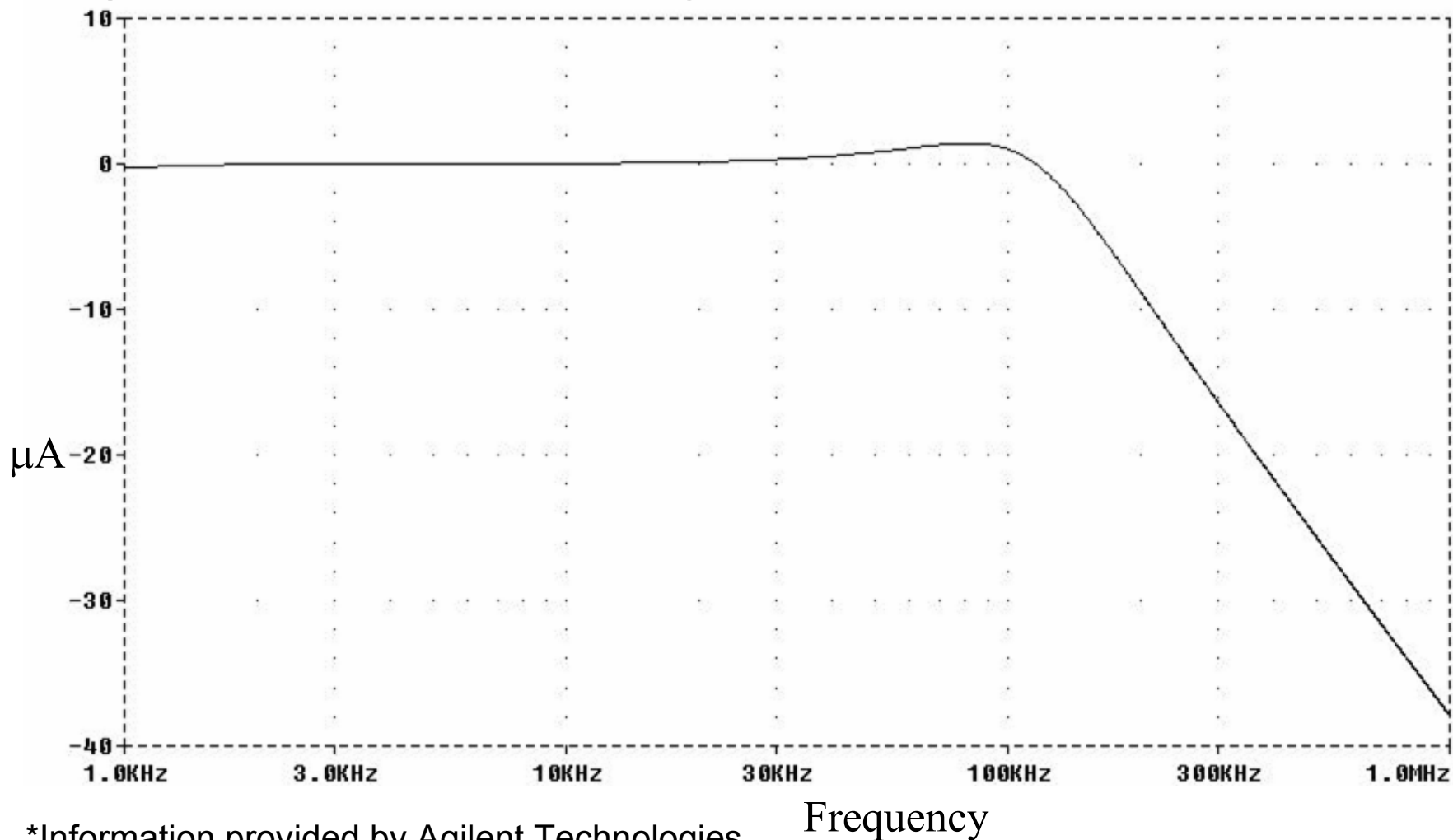**freescale**
semiconductor
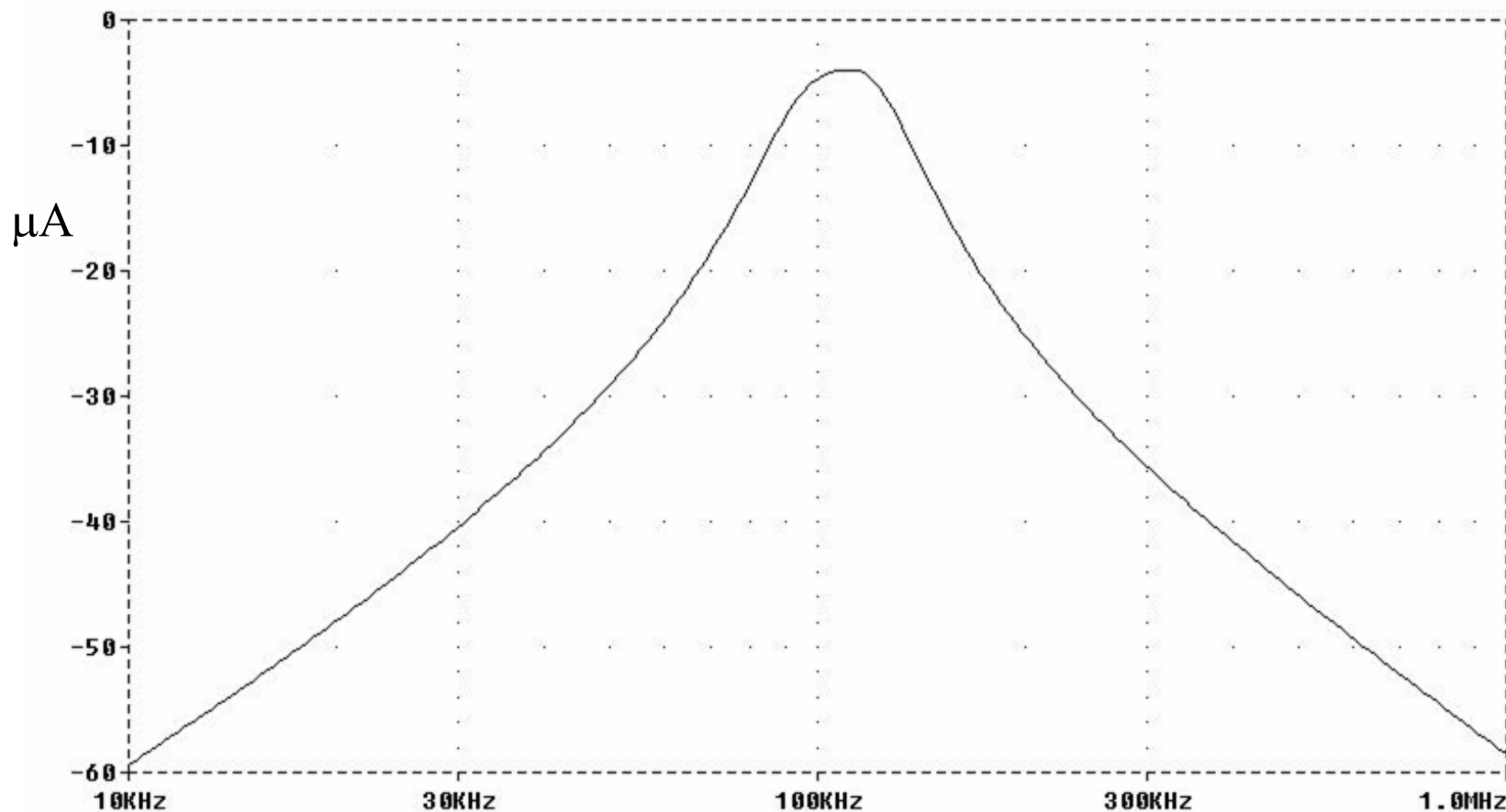
Stage I RX Filter Frequency Response

*Information provided by Agilent Technologies

Stage II RX Filter Frequency Response

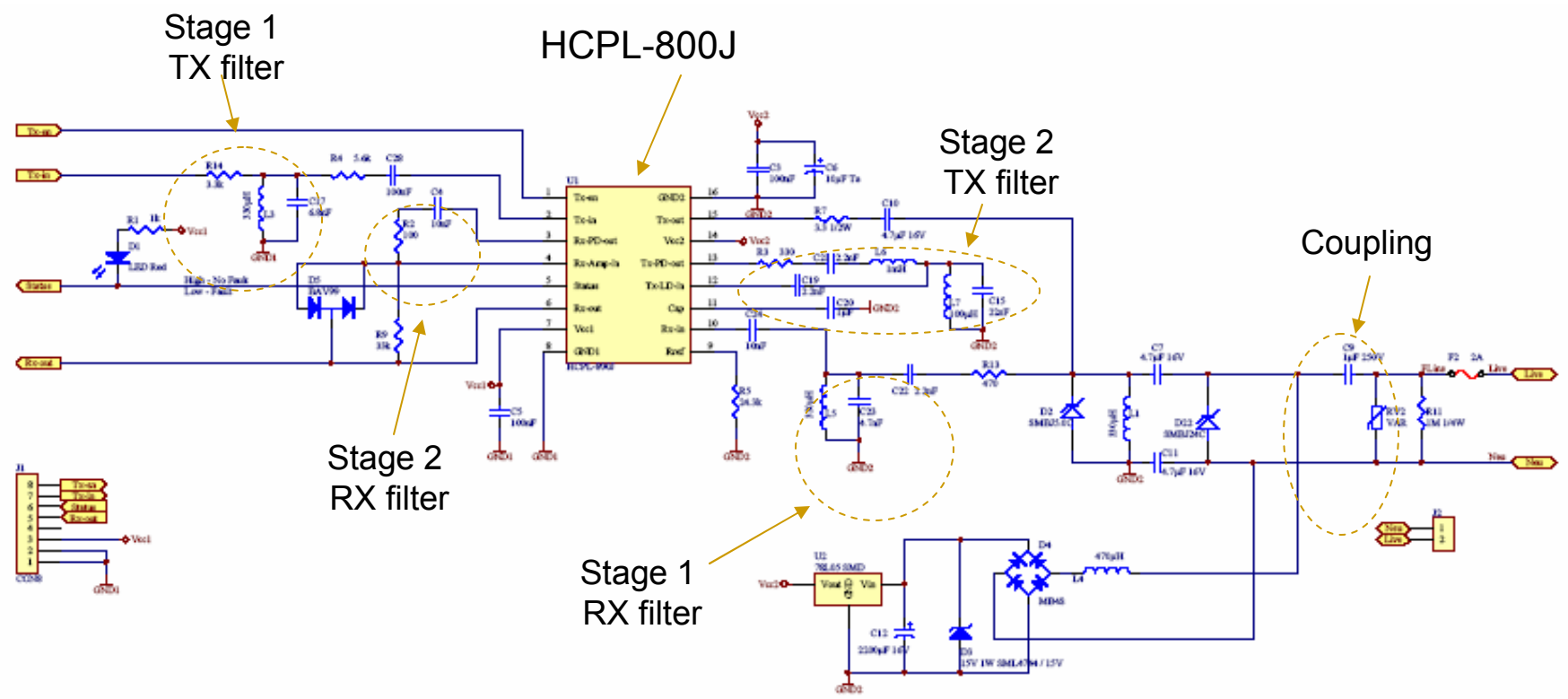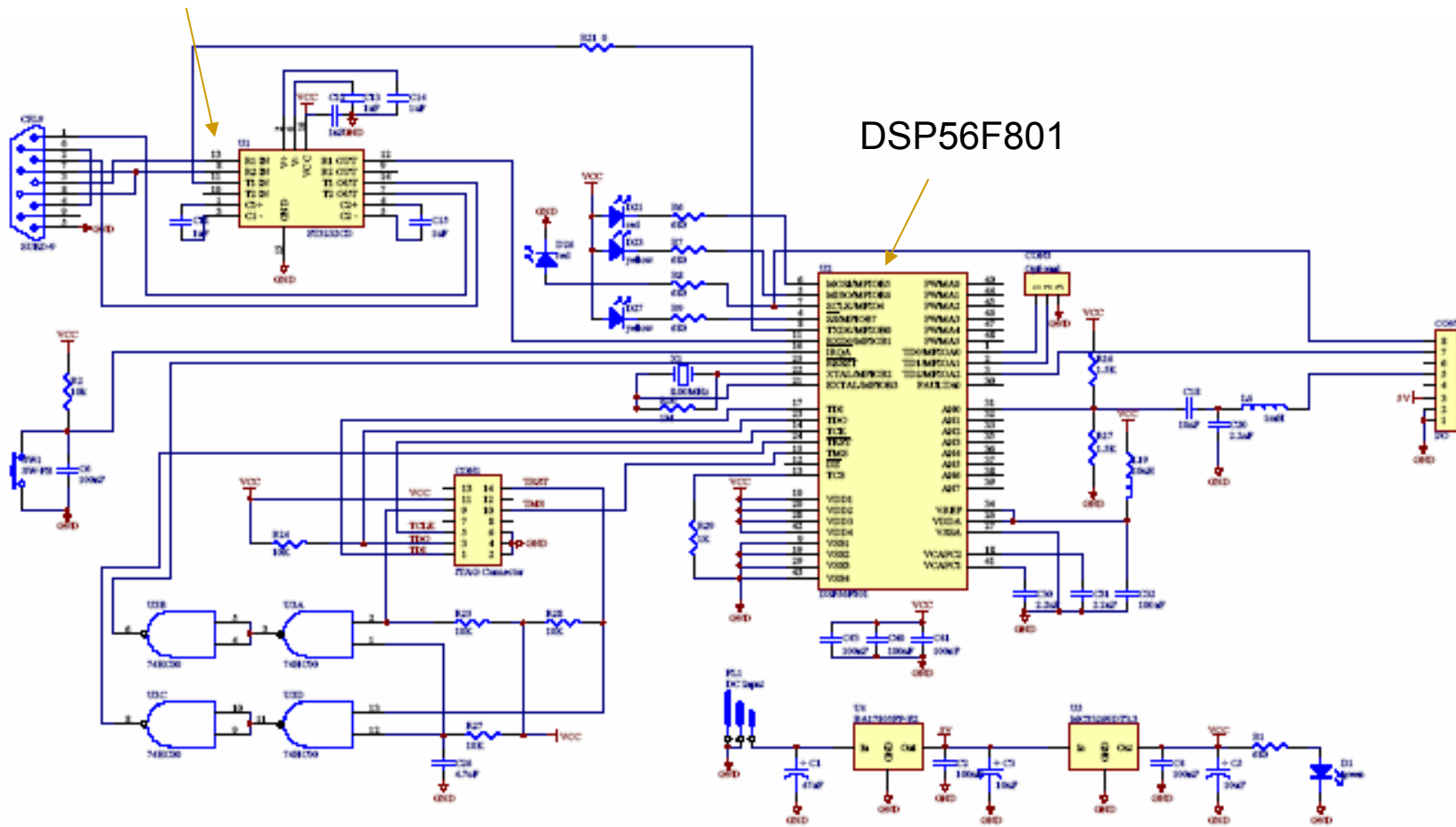*Information provided by Agilent Technologies

PLM Schematic 1

Stage 1 TX filter

HCPL-800J

Stage 2 TX filter

Coupling

Stage 2 RX filter

Stage 1 RX filter

PLM Schematic 2

JTAG Converter

DSP56F801

DSP controller resources usage
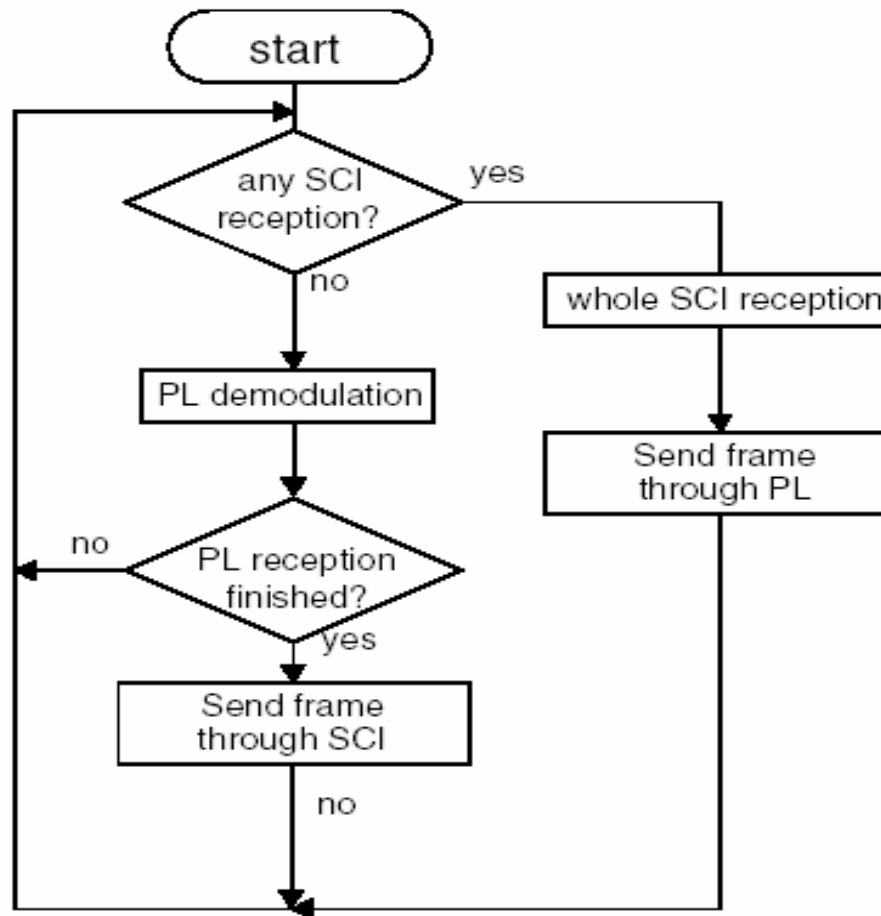
Memory usage of DSP56F801

- **Program flash (P.FLASH): 69% memory free**
- **Data (X.RAM): 32% memory free**
- **Data flash (X.FLASH): 56% memory free**
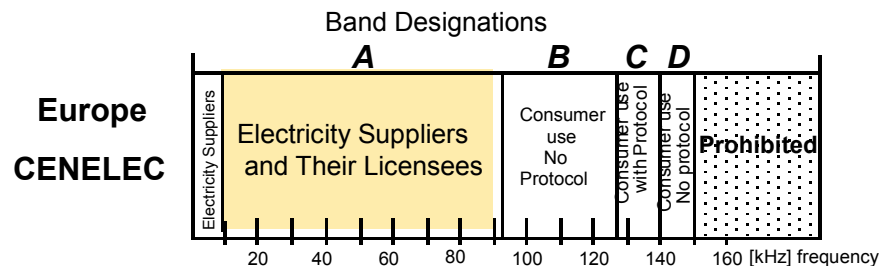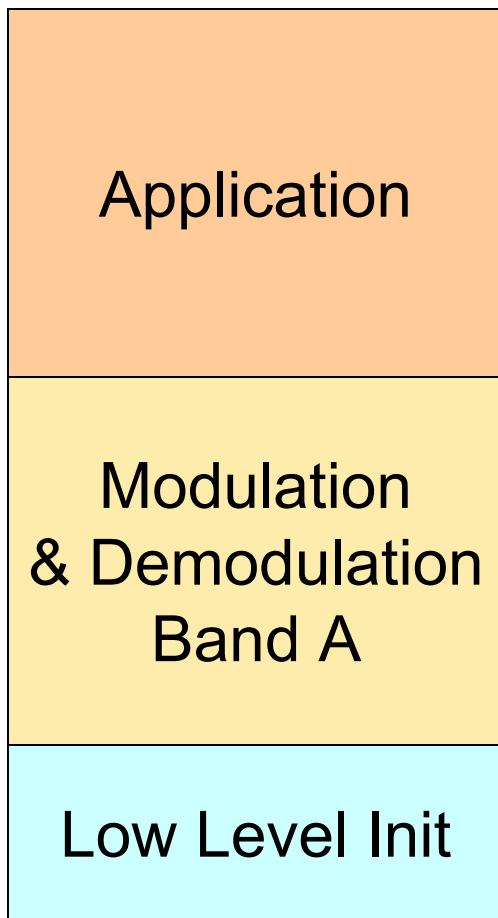
Pin usage of DSP56F801

- **Analog input AN0 (7 of 8 analog pins free)**
- **5 digital I/O pins used**

Note: When Power Line reception routine is in progress, almost all the DSP computation power is fully utilized.

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Software Block Diagram

PLC Module - band A->B->C modifications
software

Application
Modulation & Demodulation Band A
Low Level Init

Band Designations

Europe

CENELEC

A B C D

Electricity Suppliers

Electricity Suppliers and Their Licensees

Consumer use No Protocol

Consumer use with Protocol

Consumer use No protocol

Prohibited

20   40   60   80   100   120   140   160 [kHz] frequency

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Conclusion

Combine Freescale's DSP controller and Agilent's Optical-based Analog Front End, this reference design demonstrates complete hardware implementations using the DSP56F801 and HCPL-800J as well as software implementations using the CodeWarrior™ software tools. Demonstrate the benefits of these complete solutions for the industrial, security, commercial and other markets.

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