HD Radio™ Broadcast System - 4th Generation

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INTRODUCTION

As HD Radio has achieved commercial acceptance, broadcasters are demanding more features in simpler, more robust and cost effective transmission solutions.

INTRODUCTION

Today, we will discuss the past and present HD Radio systems along with the state of development, challenges and solutions for providing the next-generation HD Radio Broadcast Systems.

INTRODUCTION

Advances in Digital Signal Processing technology are enabling developers and manufactures to reduce the cost, size and complexity of the HD Radio Broadcast system while providing increased flexibility, advanced features and zero-defect, mission-critical reliability that our customers demand.

INTRODUCTION

In the current generation HD Radio Broadcast System, all of the signal generation functions of audio intake, multiplexing, encoding and modulation require a separate Importer, Exporter and Exgine all, composed of diverse architectures.

INTRODUCTION

In the 4th Generation systems, these functions will be integrated into single, configurable embedded DSP based devices of similar architectures.

Additional functionality such as Hybrid Crest Factor Reduction, asymmetrical sideband generation and MER quality measurements will be integrated as part of the embedded system.

The Gen I HD Radio system was developed by USA Digital (one of the predecessor companies that merged to form iBiquity) around 1998 as a proof of concept system.

The Gen I exciter and its companion HD Radio Receiver were highly custom, single channel systems using fourteen Analog Devices SHARC Processors on a PC104 bus.

Complex, fragile and temperamental!

Used the AAC codec without Spectral Band Replication (SBR) for audio compression.

Throughout 2001 early IBOC testing at Xetron labs in Cincinnati and the original tests for the FCC Notice of proposed Rule Making (NPRM) used the Gen I systems.

Early over-the-air tests were at the University of Illinois FM station WILL in Champaign, IL using a modified Harris solid state VHF TV transmitter as the linear amplifier for the digital signal from the GEN I Exciter.

In 2000, iBiquity and Harris began discussing development of a 2nd Generation HD Radio Exciter as a potential reference design for commercialization.

GEN II PC BASED EXCITER

In 2001 iBiquity built the first Gen II IBOC Reference Exciter around a Pentium 4 processor.

GEN II PC BASED EXCITER

The GEN II Reference Exciter was LESS temperamental than its GEN I predecessor

GEN II PC BASED EXCITER

For the next four years the Gen II Reference Exciter became the workhorse of the HD Radio testing and early rollout efforts.

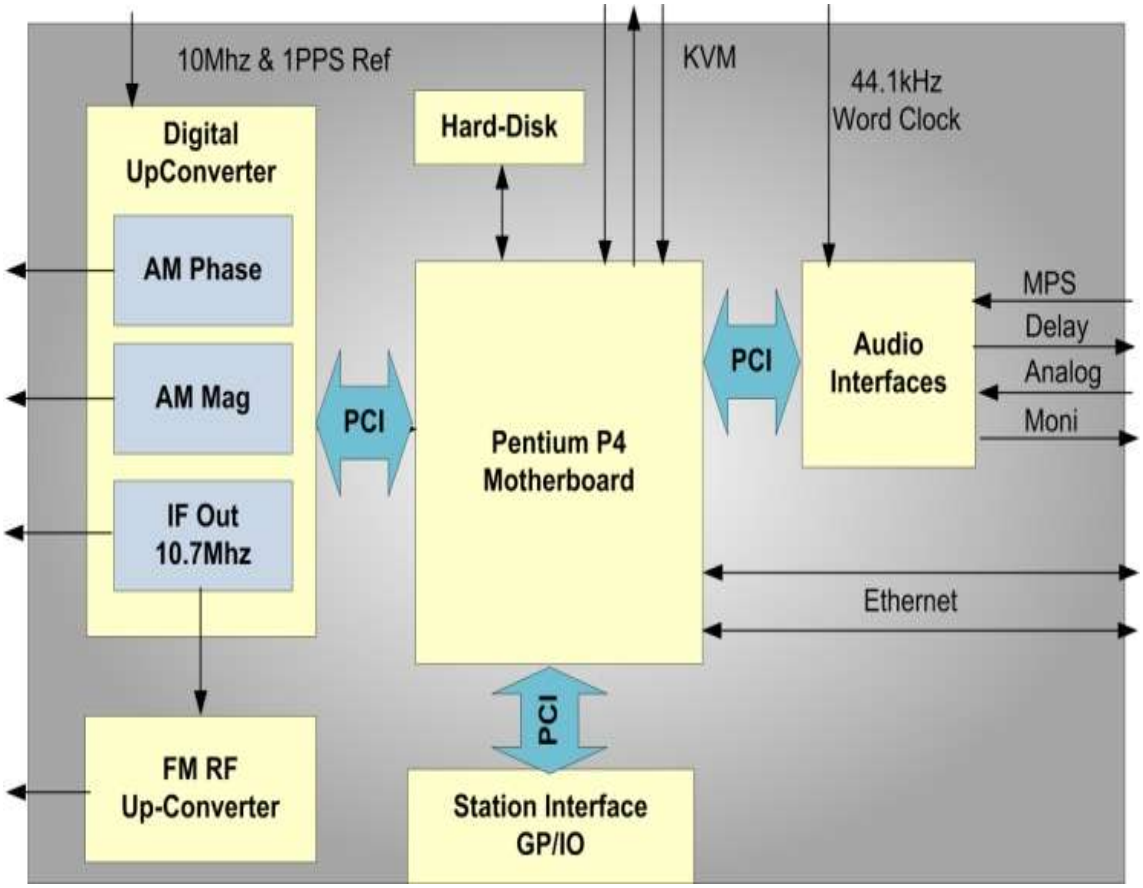
Some of the original exciters are still used in labs today

GEN II PC BASED EXCITER

The NRSC testing was all done using the GEN II Reference Exciter for development of the HD Radio Standards.

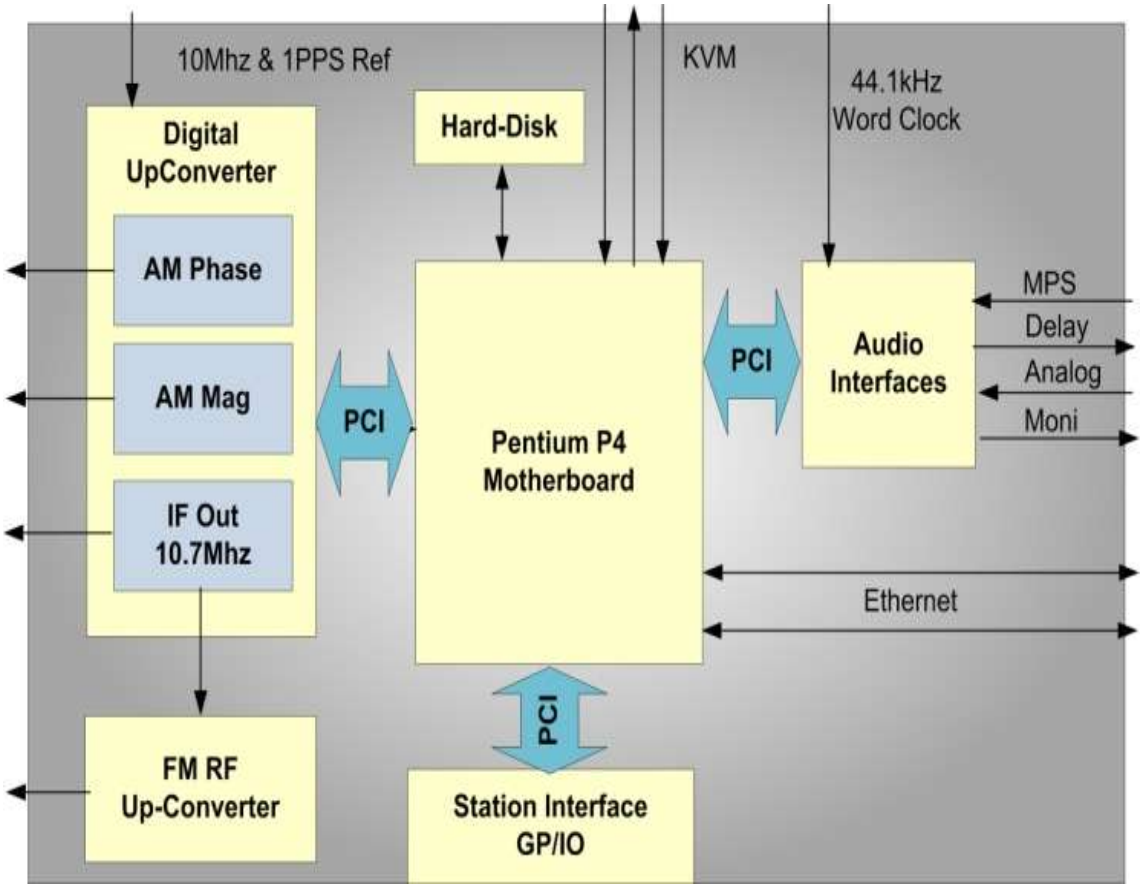
GEN II PC BASED EXCITER

The GEN II Exciter was monolithic, in that it contained all of the hardware and software necessary to create the on-channel FM HD-only RF signal or an AM+HD magnitude and phase signal from the audio inputs.



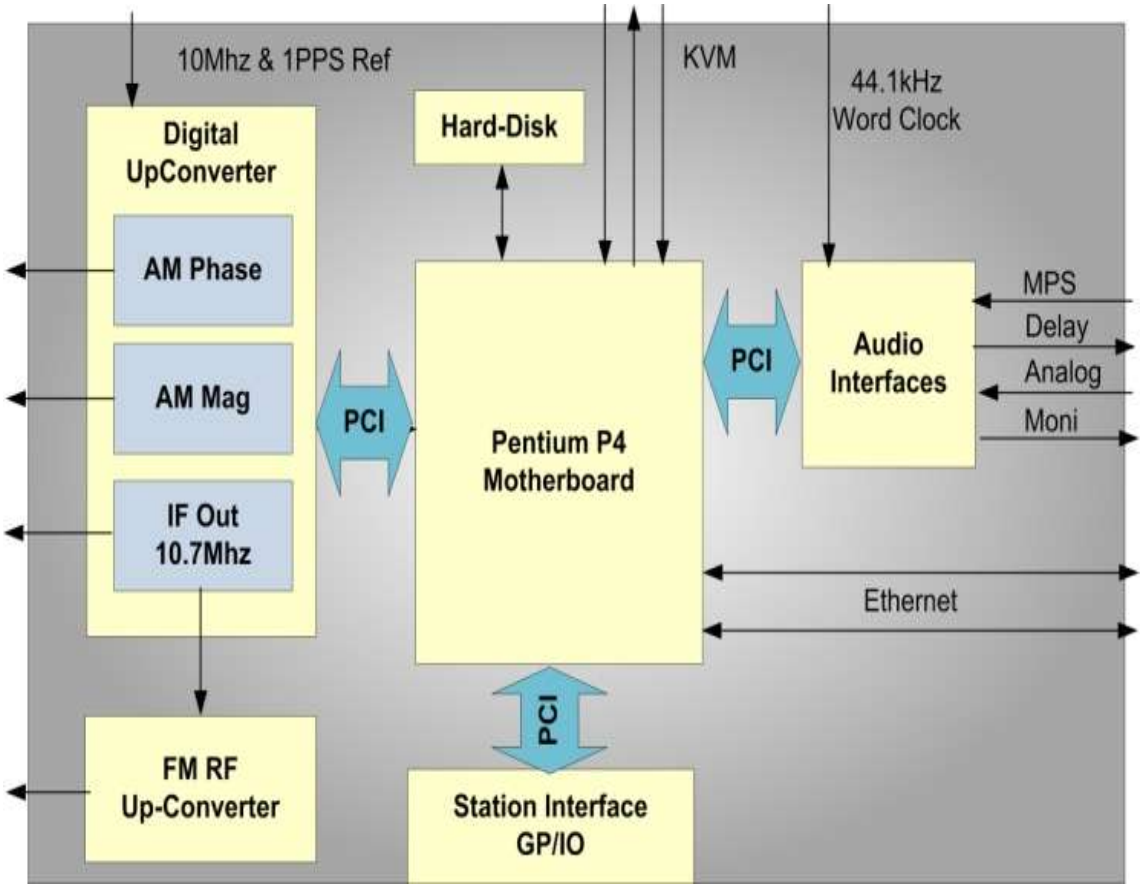
GEN II PC BASED EXCITER

The Gen II exciter consisted of a motherboard with a 3GHz Intel Pentium 4 processor, AES audio cards…



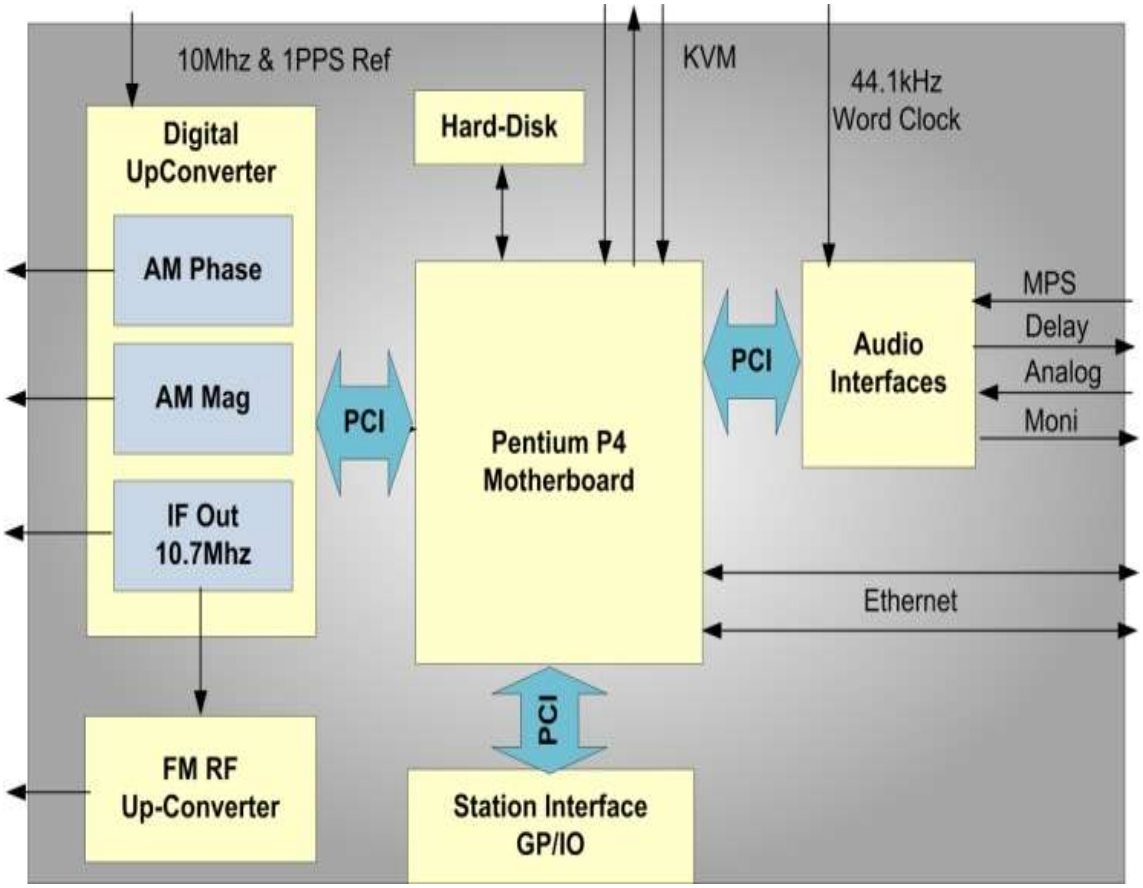
GEN II PC BASED EXCITER

…a digital up-converter (DUC), an RF up-converter (RFU), a Station Interface Card (SIC) for control, a hard drive and CD drive for software installation



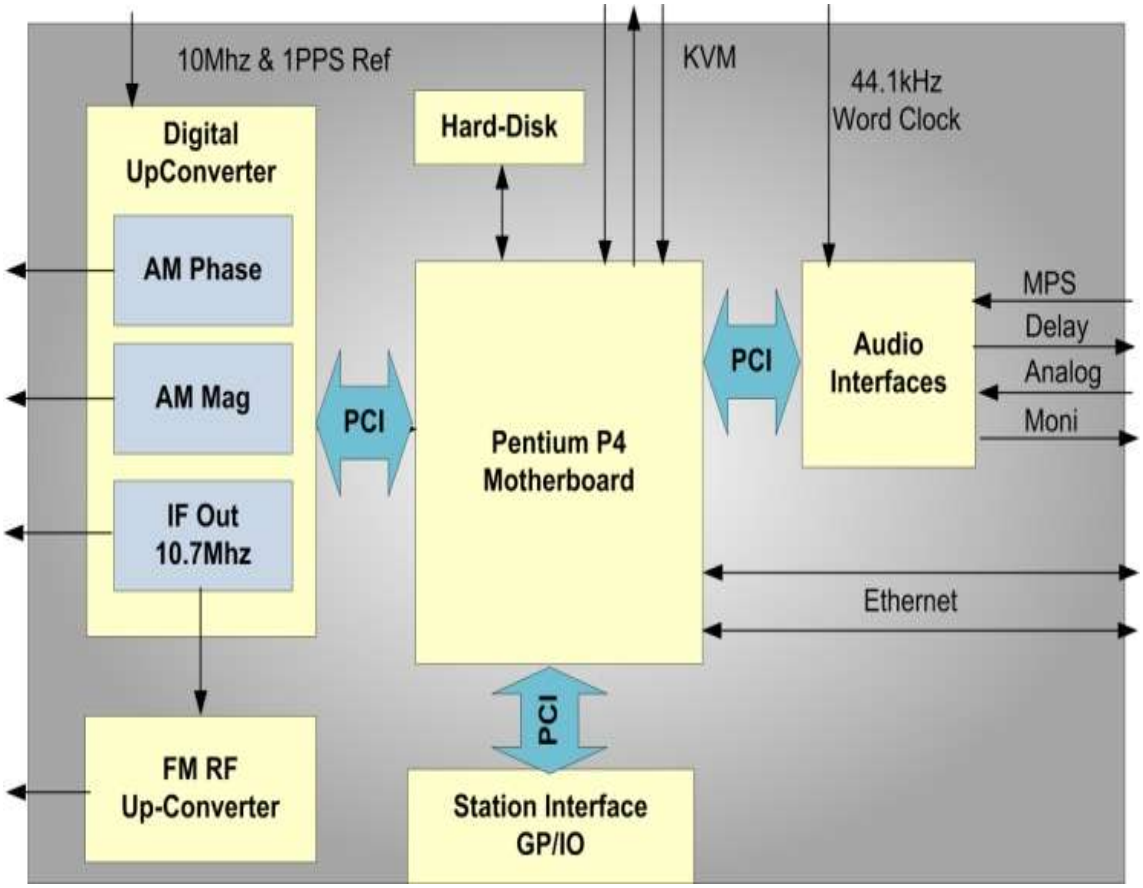
GEN II PC BASED EXCITER

It ran a Linux Mandrake operating system and the iBiquity Reference System Software (IRSS).



GEN II PC BASED EXCITER

Originally, the Gen II system employed the Bell labs/Lucent PAC codec but was later migrated to the current HD Codec (HDC), a multi-stream, MPEG4 derived codec with SBR that is still used today.

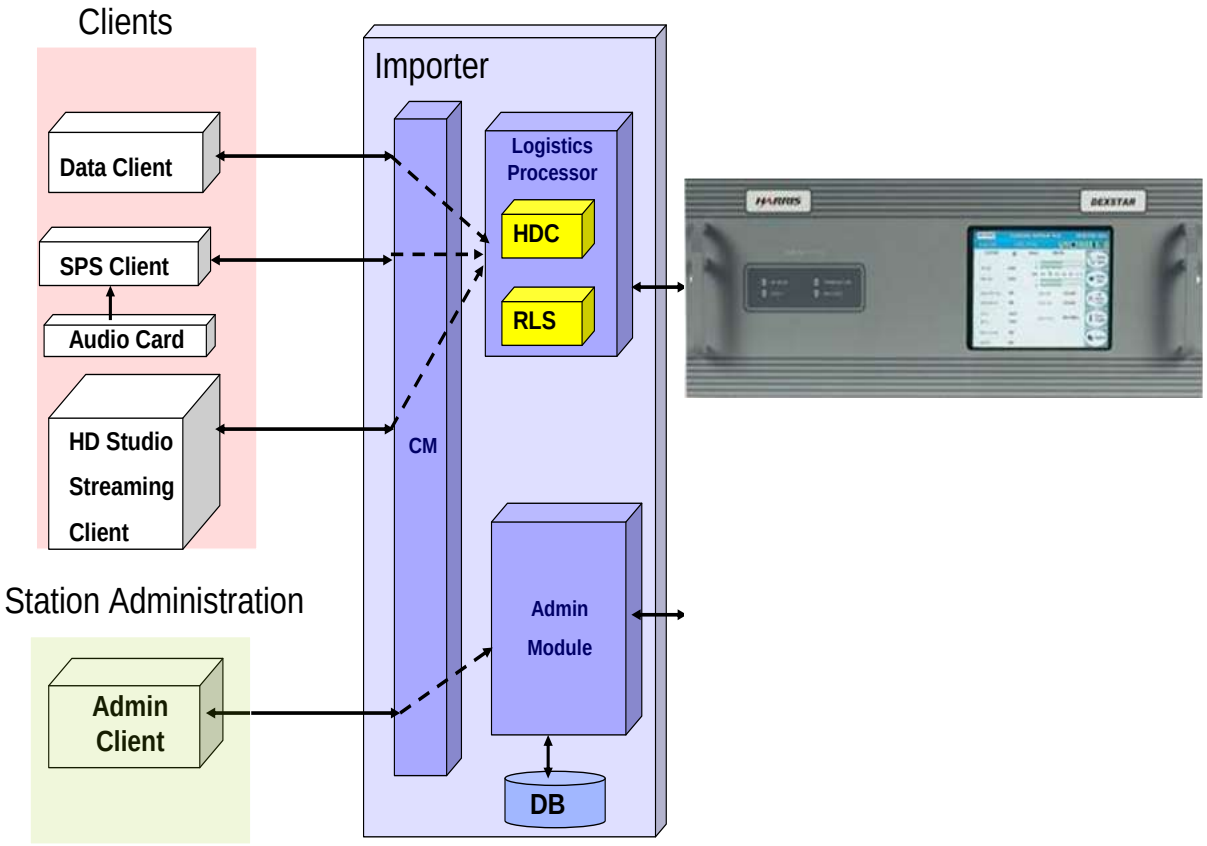


GEN II PC BASED EXCITER

In 2002, Harris introduced the Dexstar, the first commercially available Gen II HD Radio Exciter based on the iBiquity reference design with several user enhancements.

GEN II PROGRAM IMPORTER

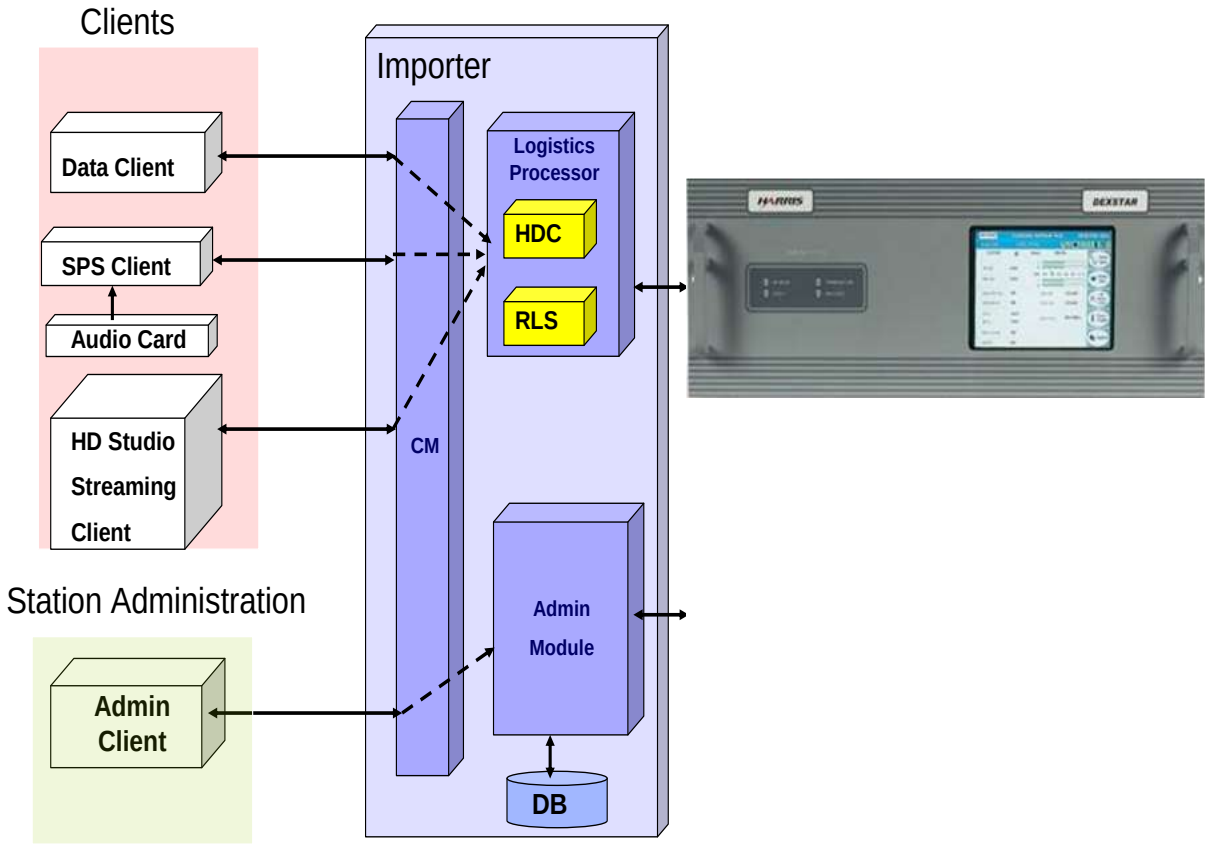
In 2002 iBiquity acquired the Command Audio Group and developed a Windows PC based advanced service multiplexer to provide multiple supplemental audio and data services.



Program Importer Aggregates/manages the Multicast and data services for delivery to the Gen II Exciter via I2E Transport

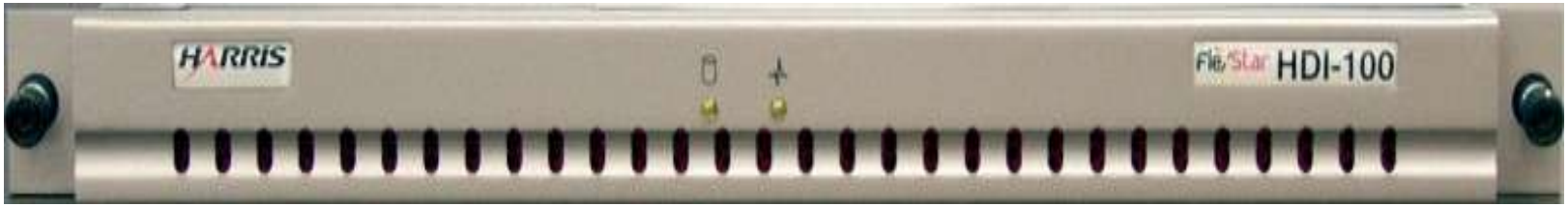
GEN II PROGRAM IMPORTER

NPR and Harris learned of this early work and began an effort to promote and commercialize the concept of HD Radio Multicasting as the Tomorrow Radio Project.



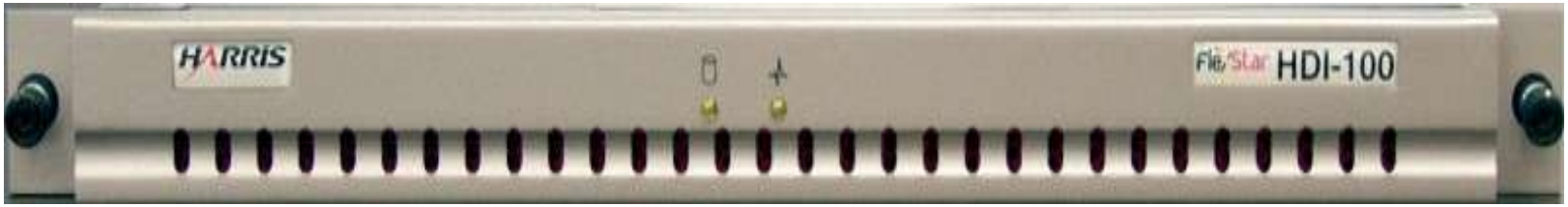
Program Importer Aggregates/manages the Multicast and data services for delivery to the Gen II Exciter via I2E Transport

GEN II PROGRAM IMPORTER



In 2003, Harris introduced the first commercial Program Importer running iBiquity Importer software on a Windows® based PC platform allowing stations to subdivide the available digital broadcast bandwidth into multiple streams of additional audio and data services.

GEN II PROGRAM IMPORTER



Two additional audio program services (HD2, HD3) were supported as well as ancillary data services such as iTunes Tagging, Artist Experience (Album Art and Graphics), news, weather and traffic data services.

GEN II PERIPHERAL DEVELOPMENTS

Several other important peripheral developments evolved during the Gen II era. Entirely new HD Radio specific systems were developed.

- Transmitter manufacturers began to employ class AB linearization in their digital power amplifiers with “on-the-fly FM/HD mode switching for better efficiency and power utilization.
- HD-specific linearized high-power transmitters such as the Harris HT-HD, Z16-HD for FM common amplification and DAX for AM.
- Common amplification and split-level combining for FM/HD were developed to lower the cost of HD Radio conversion and increase overall system efficiency.
- Fixed pre-correction for both AM and FM system to improve RF mask performance and power amplifier utilization was introduced by Harris and Broadcast Electronics.

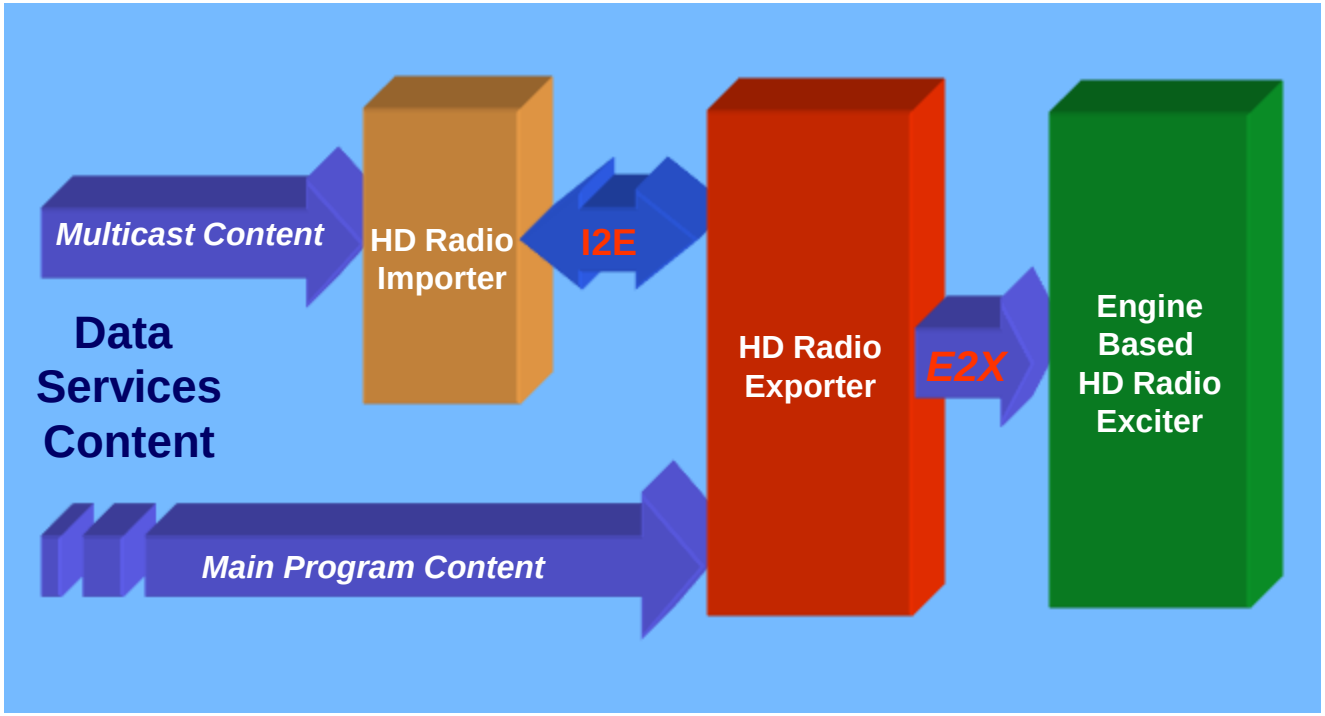
GEN II PERIPHERAL DEVELOPMENTS

Several other important peripheral developments evolved during the Gen II era. Entirely new HD Radio specific systems were developed.

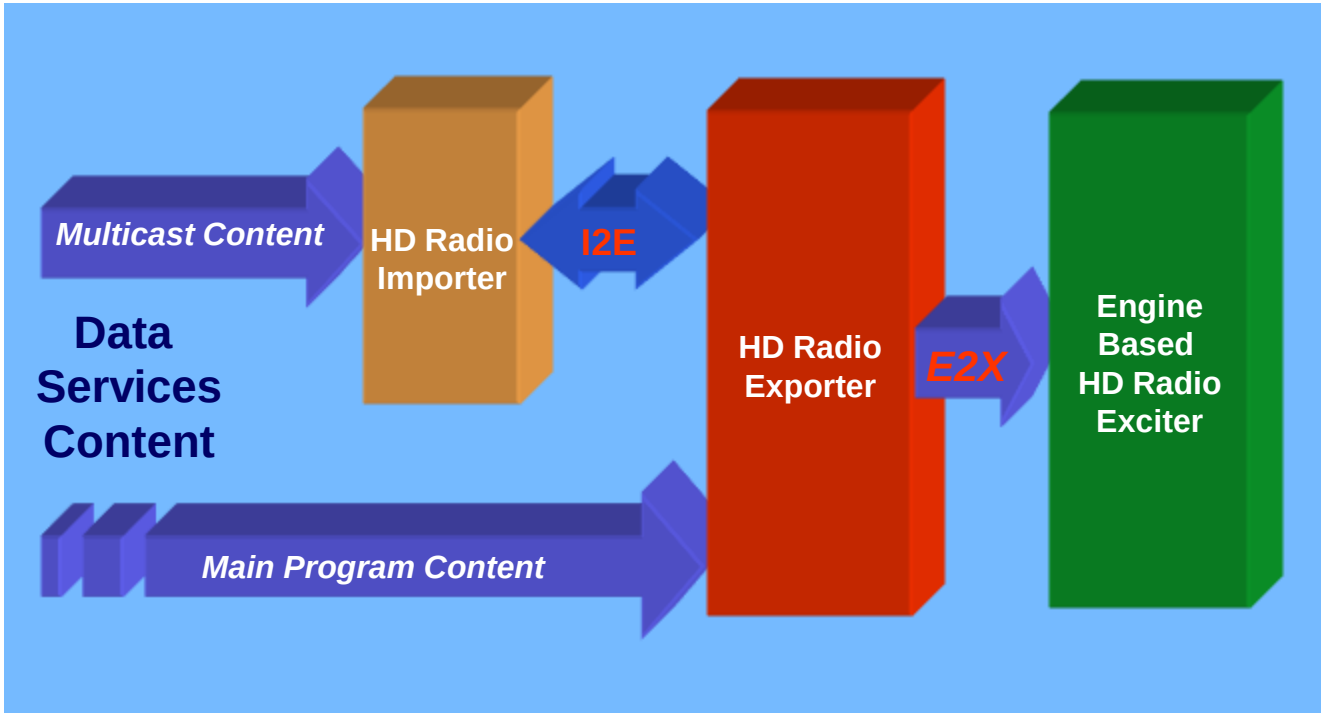
- Moseley introduced a new generation of STLs designed for HD Radio transport stream transport. The Starlink supports linear compressed and uncompressed stereo audio and up to 760kb/s bi-directional UDP Ethernet over T1.
- Codec pre-conditioning was introduced with the Harris NuStar Codec pre-processors significantly improving MPS audio performance at lower bitrates.
- DaySequerra introduced an off-air receiver/monitor offering HD Radio and FM analog modulation measurement and monitoring.
- Manufactures such as Kenwood, JVC, Polk Audio and Boston Acoustics introduced 2nd generation receivers that included PAD text and multicast capability.

GEN III: DISTRIBUTED ARCHITECTURE AND ADVANCED FEATURES

The monolithic exciter platform was suitable for many installations however, to maximize audio and data transport efficiency it was advantageous to split apart the HD Radio encoding functions from those of the OFDM waveform and RF generation.

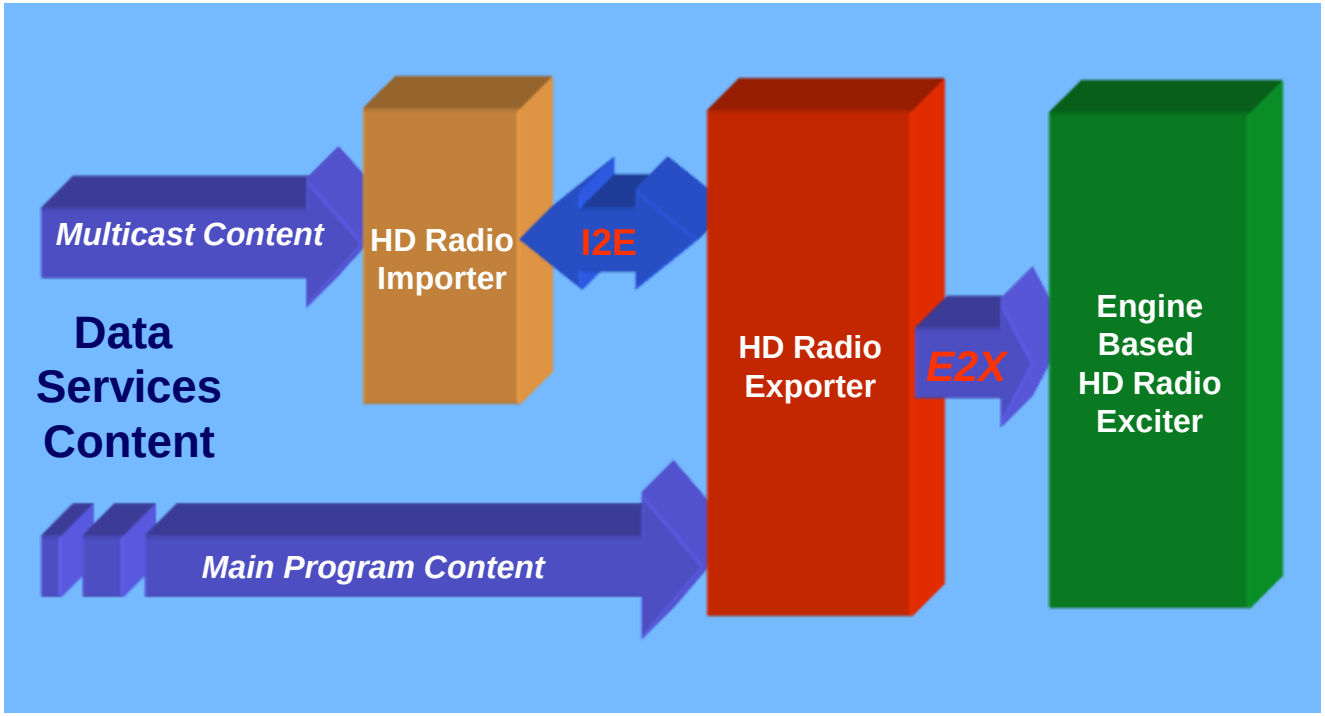


This prompted the development of the third generation HD Radio architecture and introduced the Program Exporter, and ” Exciter-Engine” or Exgine.



GEN III: DISTRIBUTED ARCHITECTURE AND ADVANCED FEATURES

Gen III is the standard HD Radio Broadcast System Architecture deployment with similar systems manufactured by Harris, Nautel, Broadcast Electronics and Continental Electronics.



GEN III EXPORTER

Like the Gen II Exciter, the Gen III Exporter contains the hardware and firmware necessary to handle all of the audio compression, Program Services Data (PSD) encoding and multiplexing but, unlike the Gen II Exciter, the Exporter does not perform the OFDM modulation or generate the on-channel RF signal.

First Generation HD Radio Exporter

Essentially, the Exporter is a Gen II exciter without the RFU and DUC sub-assemblies.

In fact, Harris's Gen II Exciter, the **Dexstar** can easily be converted into an Exporter maximizing the original equipment investment.

GEN III EXPORTER

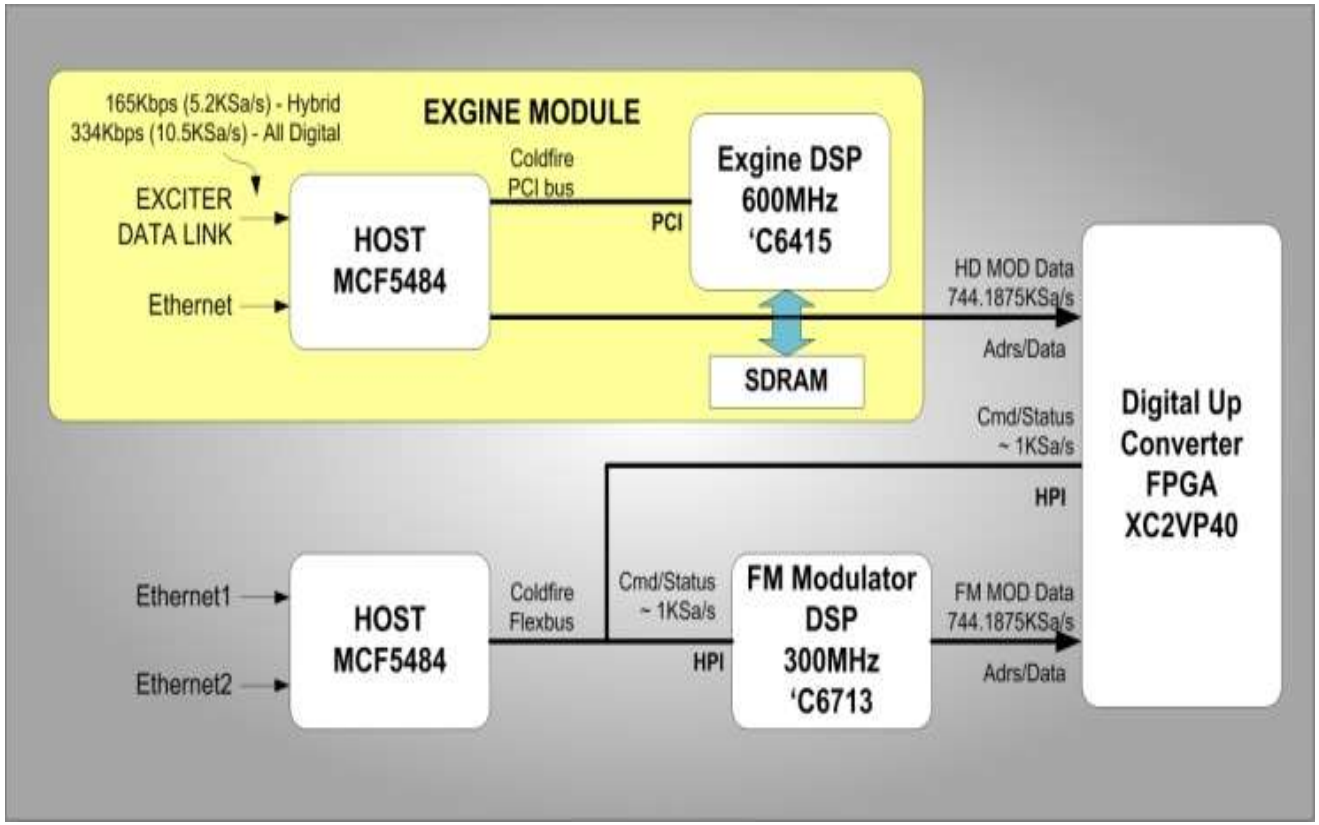
The Exporter sends the compressed digital audio and control information as an Ethernet bit stream called the E2X Data Link to the Gen III exciter at the transmitter site. This allows the encoding functions to be located at the studio along with the required audio processing

First Generation HD Radio Exporter

In its original GEN II implementation, the exporter was a PC running a Linux OS and the IRSS software.

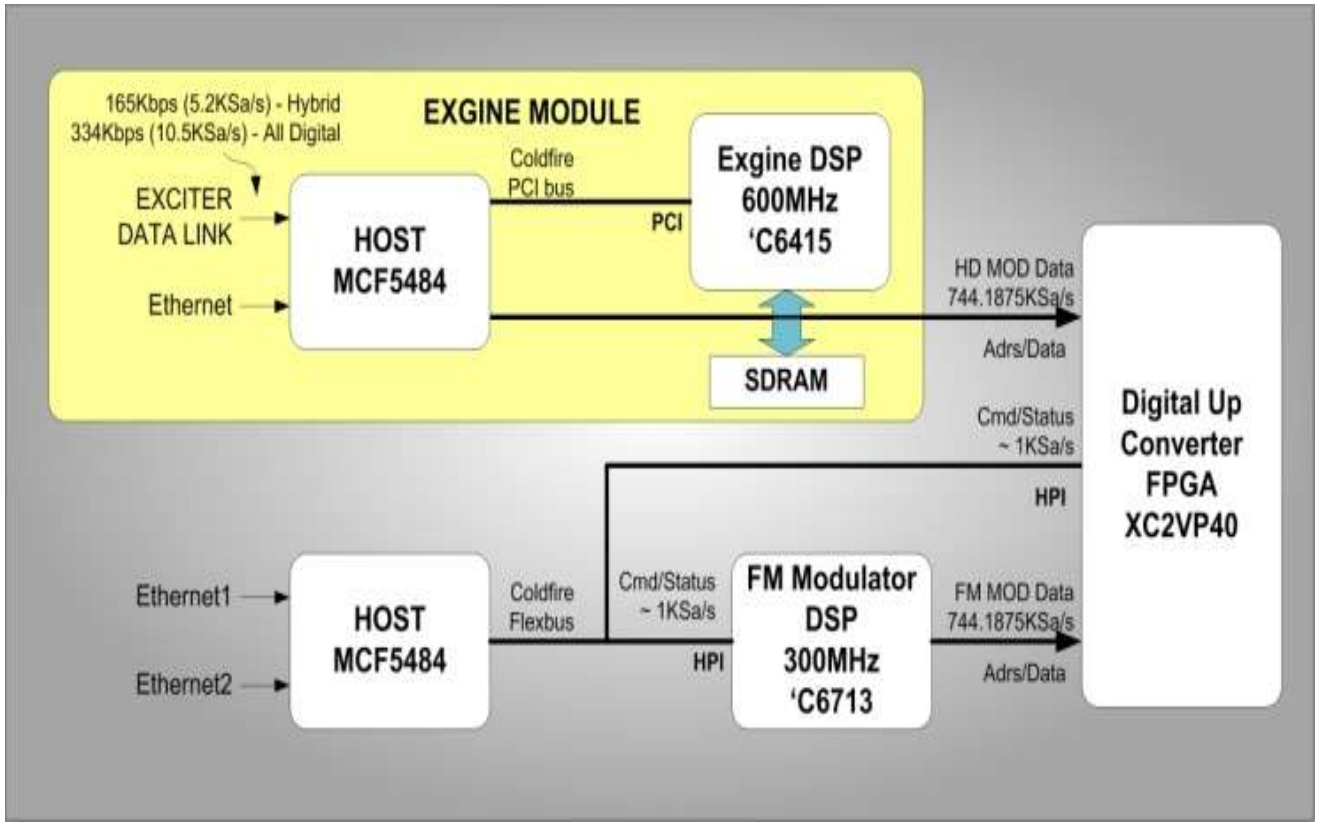
GEN III EXGINE

At the transmitter, a new subsystem called the Exciter Engine or Exgine accepts data from the E2X Link to produce the HD Radio OFDM waveform.



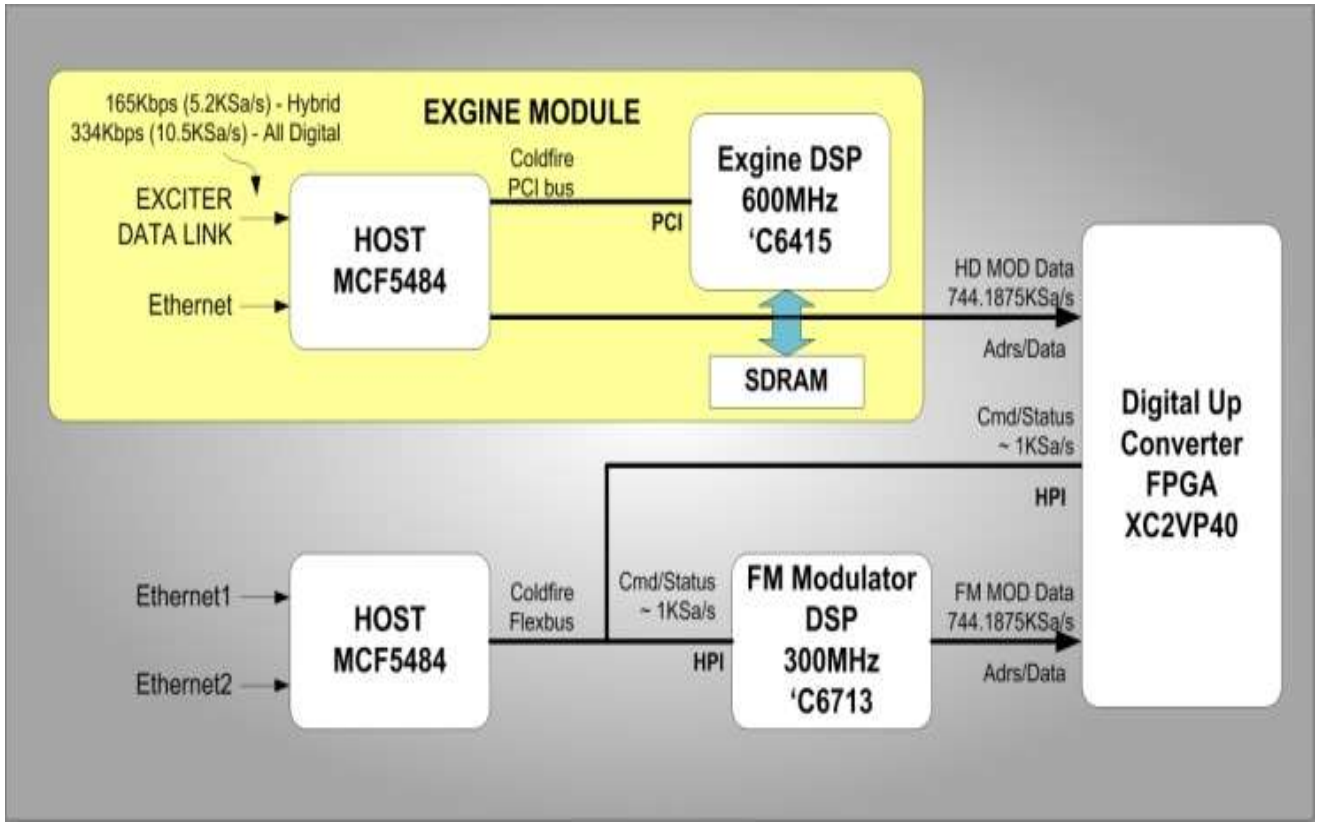
GEN III EXGINE

The Exgine consists of a host processor and a TI-C6415 processor along with SDRAM and Flash memory and enables the OFDM modulation to be executed on the Digital Signal Processor (DSP).



GEN III EXGINE

The Exgine subsystem accepts the E2X data from Exporter through the Exciter Data Link. The DSP performs the coding of the digital portion of the HD Radio waveform. It is the passed to the Exciter's Digital Up-Converter



GEN III EXGINE

Harris' Gen III Exgine Card with Host Audio Extraction

In 2003 iBiquity developed and released the Exgine embedded code base libraries for the Texas Instruments C64 family of DSP devices

GEN III EXGINE

Harris' Gen III Exgine Card with Host Audio Extraction

Manufacturers developed their own host-micro/TI-C64xx hardware Exgine solutions.

For iBiquity and the manufacturers, the Exgine was a significant effort and a key development in the advancement of HD Radio

GEN III EXGINE

Harris' Gen III Exgine Card with Host Audio Extraction

In March 2005 Harris was the first to introduce the Gen III Exgine based exciter, the Flexstar HDx

Harris' Exgine based HD Radio Flexstar™ Exciter

GEN III EMBEDDED EXPORTER

- In 2006, NAB Fastroad representatives approached several of the broadcast equipment manufacturers to help identify the most costly and troublesome elements of the HD Radio system in order to promote wider adoption.
- The high cost of the Exporter (built on a highly modified computer) was seen as a roadblock to wider HD Radio implementation.
- It was determined that development of an improved HD Radio Program Exporter using embedded DSP technology could reduce the cost of HD Radio implementation while simplifying the system and increasing reliability.

- **The third Generation HD Radio architecture was rife with innovative development and an important step in the maturation of the technology by:**
  - Providing a means of multiplexing additional program and data service content into the available bandwidth.
  - Providing a more robust HD Radio generation platform
  - Reducing the cost and complexity and STL bandwidth requirements of providing main and secondary audio programming and advanced application services into a single multiplexed data stream that could be carried over a single, relatively low bandwidth IP connection.
  - Simplifying the configuration, monitoring, control and troubleshooting of the HD Radio system by making it more accessible to engineers.

GEN III EMBEDDED EXPORTER

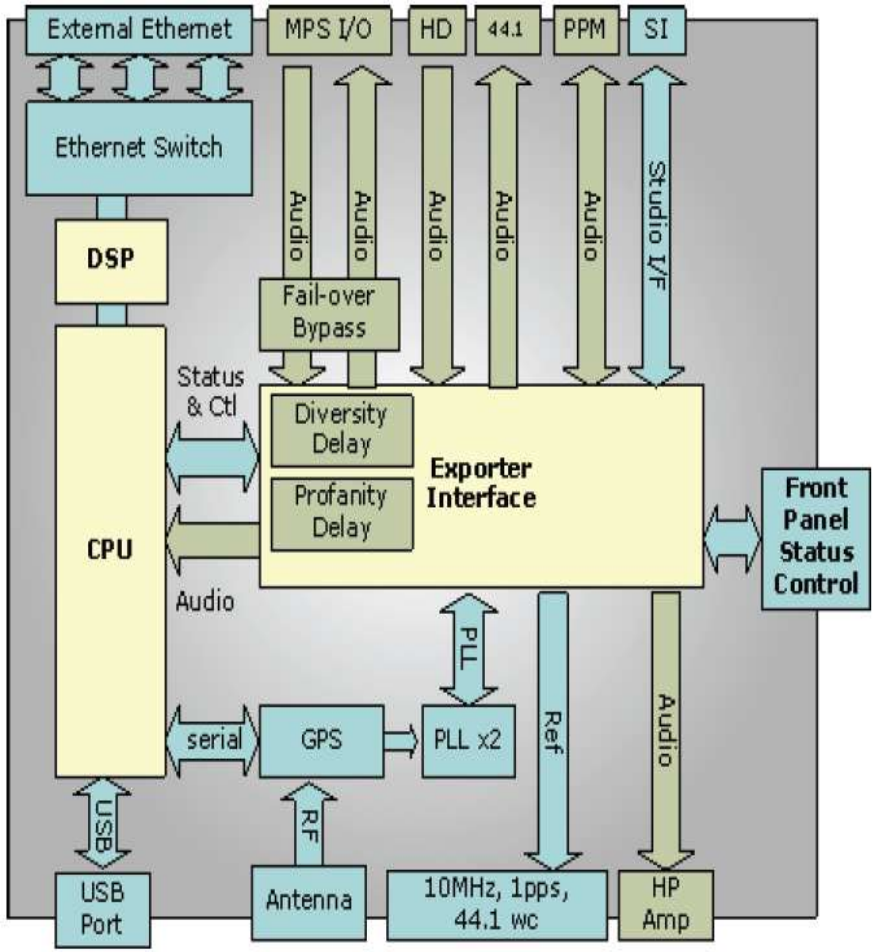
- With financial support from the NAB's Fastroad Technology Office, iBiquity Digital developed the necessary software libraries and APIs that could be implemented on either a C67 DSP or an x 86 processor under windows or Linux.
- iBiquity release the Embedded Exporter's libraries to the manufacturers in March 2007
- Several broadcast equipment manufacturers were supported by the NAB to encourage development of their own exporter solutions incorporating the new iBiquity code.
- These efforts resulted in the Gen III HD Radio "Embedded" Exporter.

- Harris along with Nautel, Broadcast Electronics and Continental introduced their Embedded Exporter at the **2008 NAB Conference**

Harris' HDE200 HD Radio Embedded Exporter

GEN III EMBEDDED EXPORTER

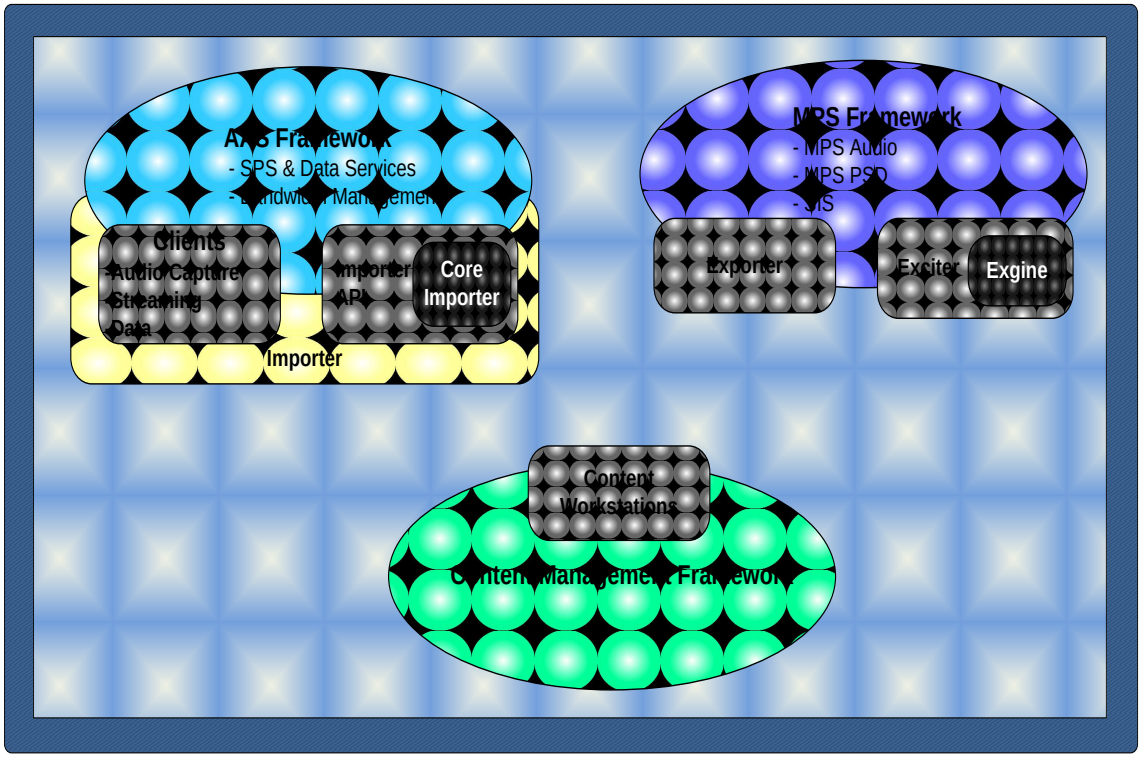
- The “embedded” HD Radio Program Exporter provided a simple, powerful hardware/software platform offering improved reliability and ease-of-use at a significantly lower cost over first and second generation products and was another significant step in the maturation of the technology.
  - Harris’ implementation of the embedded exporter uses an ARM 9 microcontroller CPU as the “Host Controller”
  - The HD Radio codec and data encoding algorithms are all processed within the unit’s TI-C67 floating point DSP.
  - No hard-drive, no-fans, no audio cards



GEN III FRAMEWORK BASED ARCHITECTURE

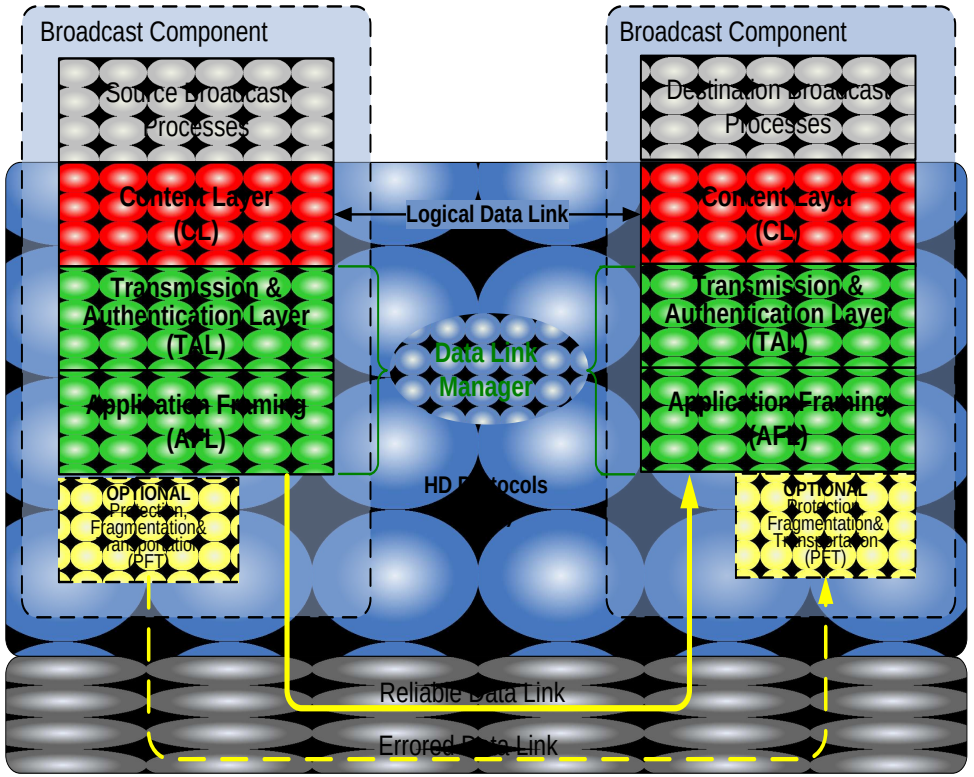
With the release of Framework version 4 supporting the embedded Exporter in Gen III, the internal workings of the HD Radio Broadcast System were significantly re-designed and divided into three distinct frameworks:

- The Main Program Service (MPS) Framework.
- The Advanced Applications Service (AAS) Framework.
- HD Content Management Services (CMS) Framework



GEN III HD PROTOCOL

- At the heart of the Gen III HD Radio System advanced functionality and capabilities is the HD Protocol (HDP).
- HDP unifies the communications between all of the various HD Radio components and provides support for content creation and distribution as well as command and control across the entire HD Radio system from local, centralized and/or remote locations.
- Implementation of the HP protocol necessitated rewriting virtually every software component of the HD Radio system making version 4 incompatible with all previous releases.
- HDP is now the standard communications protocol used throughout the HD Radio broadcast system



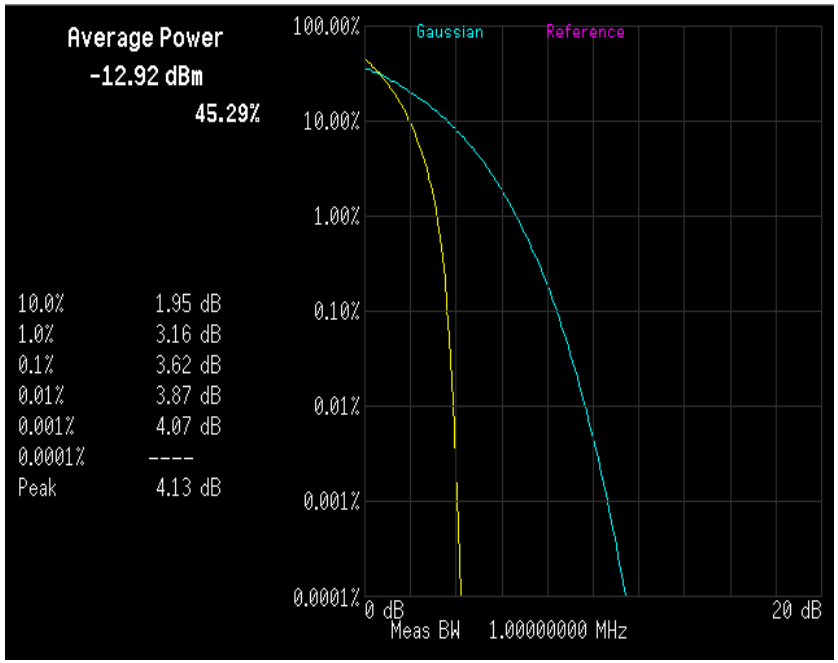
GEN III PERIPHERAL DEVELOPMENTS

Continuing development efforts by equipment manufacturers and vendors are leveraging the GEN III architecture to provide more features/functionality, flexibility, robustness and ease of setup and maintenance.

- Real-time Adaptive Pre-correction (RTAC™) in Harris' Flexstar Exciter offers additional improvement in RF mask performance and power amplifier utilization.
- Higher power, more efficient FM transmitters such as the Harris HPX and Flexiva families and the Nautel NV series are providing wideband solutions up to 40 kilowatts of FM+HD common amplification systems.
- The Harris HDLink offers multiple audio streams and Ethernet connectivity leveraging Intraplex™ technology over a standard, licensed 450MHz Broadcast STL channel.
- Audio processors supporting dual processing paths for FM analog and HD MPS as well as internal diversity delay and automatic time alignment are available from Omnia, Orban and others.
- EAS systems from Sage, TFT and Digital Alert Systems are supporting multiple broadcast streams
- Nearly 100 different HD Radio receivers are available at retail with nearly 6 million HD Radio receivers in the marketplace. 22 automakers including Ford, Cadillac, Hyundai, and Mazda will incorporate HD Radio in over 100 models available by year end with more than 50 included as standard equipment.
- Insignia and Cydle HD Radio players, JVC in-car navigation /HD Radios, and several auto manufacturers' OEM in-dash systems now support Artist Experience (Album art and other visual graphics) being broadcast by Clear Channel and Greater Media stations in an ever growing number of markets.
- iTunes tagging and Artist Experience aggregation are available from Broadcast Electronics/TRE, Emmis Interactive /TagStation and Jump2Go
- Multi-stream, multi-protocol play-out automation support is available for audio and metadata from play-out systems manufacturers like Enco, Broadcast Electronics/TRE and RCS/NextGen.
- Garmin nüvi GPS employs HD Radio Technology to provide real time traffic updates

GEN IV THE NEXT STEPS

- GEN IV Exgine Architecture to include:
  - **Hybrid Crest Factor Reduction** for improved power amplifier utilization and efficiency through the use of intelligent clipping and restoration of the digital signal accounting for vector summation of the FM analog signal with the digital carriers within the Exgine

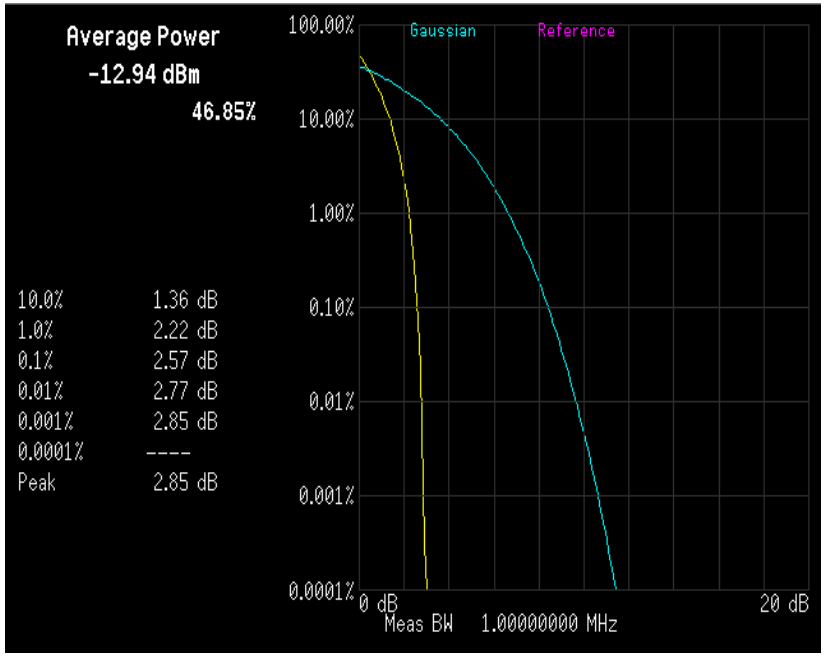


PAR for -10dBc OFDM pattern generator HD + FM with standard CFR – at .01% of the time the PAR = 3.87dB

GEN IV THE NEXT STEPS

- GEN IV Exgine Architecture to include:
  - **Hybrid Crest Factor Reduction** in the Exgine providing seven iterations of advanced HCFR, can to realize a 0.6db improvement over standard CFR resulting in a 16% improvement in transmitter power utilization at -14 dBc, injection in MP1 mode.

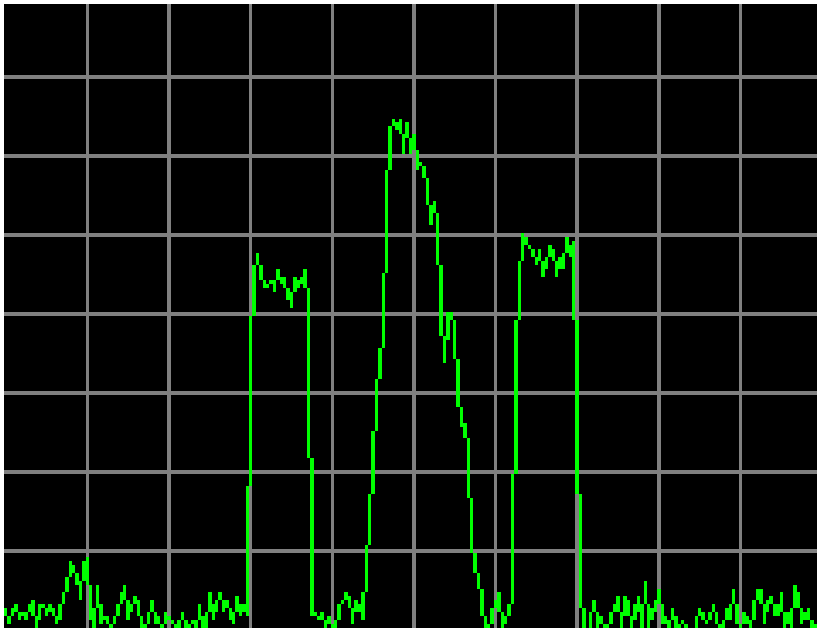
At -10dBc, this technique yields an even more impressive 1.2 dB of peak reduction and a 31% improvement in utilization while harmonizing the CFR and asymmetrical sideband generation and, maintaining an MER of 14dB.



GEN IV THE NEXT STEPS

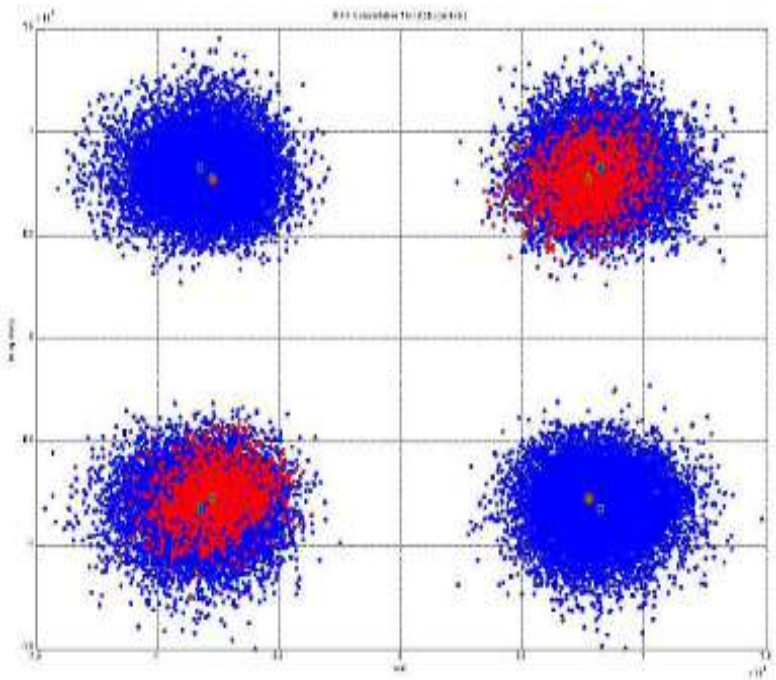
- GEN IV Exgine Architecture to include:
  - **Asymmetrical Sideband Generation** to allow stations to increase their HD sideband power above -14dBc on one side of the channel while protecting the adjacent channel on other side from interference

CFR and Asymmetrical Sideband manipulation are currently accomplished with external signal processing after the OFDM modulation process.
This is considered inefficient and imprecise. A far better approach is to manage these functions together within the modulation processes of the Exgine as the OFDM waveform is created.



GEN IV THE NEXT STEPS

- GEN IV Exgine Architecture to include:
  - **Modulation Error Vector (MER) Calculation** to provide a clear measurement of the digital signal-to-noise ratio for data-bearing and reference carriers allowing station engineers to adjust the system for minimum distortion, preserving the equalization correction margin in the receiver by giving "grayscale" diagnostic view of system problems. MER is averaged across all data carriers and is required to be greater than 14 dB .



MER Constellation ~ 14dB – Cd/No = 64 dB-Hz

- One Physical Design Implementation
  - **HD** Exgine for FM.
  - **HD** for AM
  - **DRM+** Modulator
  - **DRM30** Modulator
  - **Next generation Exporter**
  - **Next generation Importer**

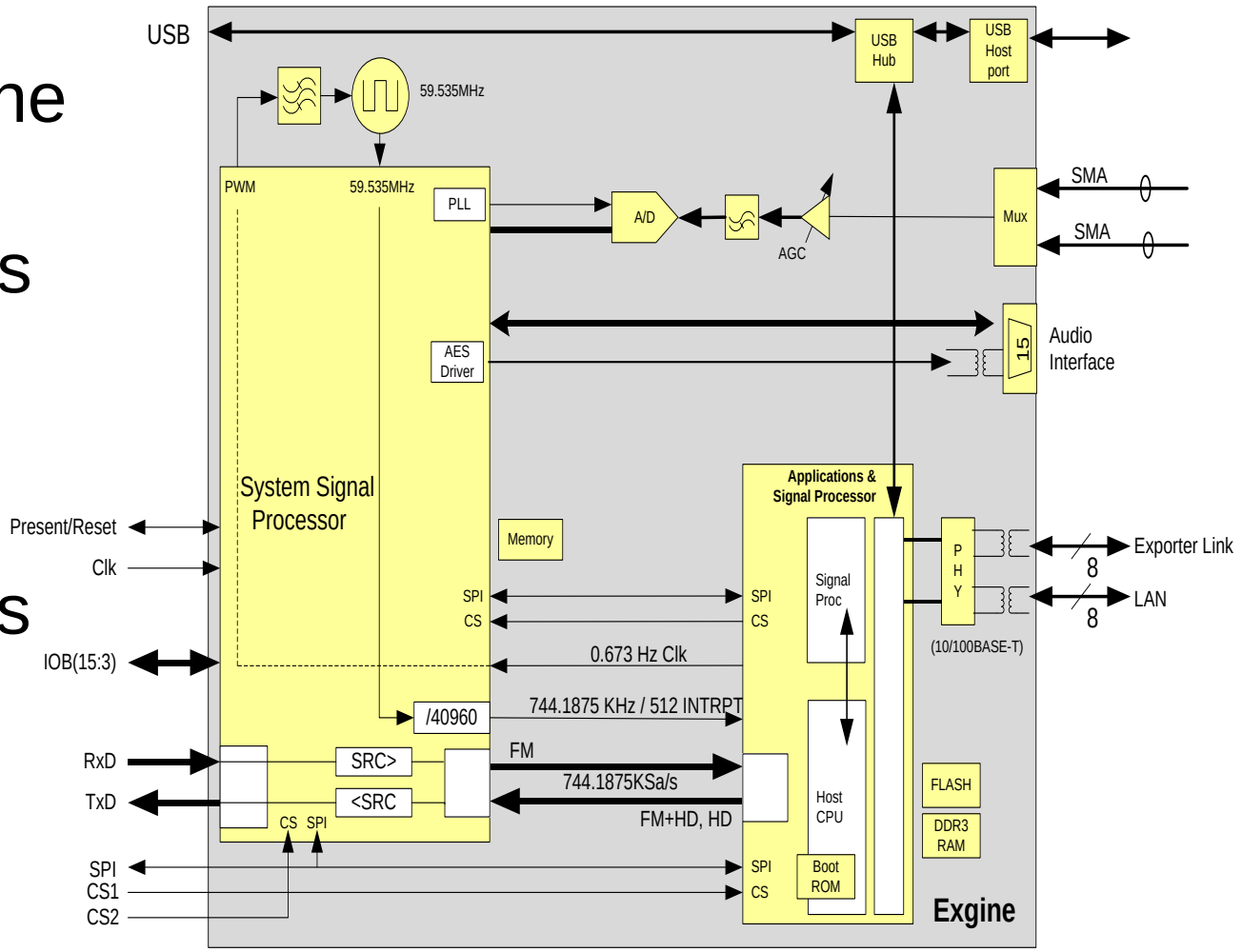
- Values
  - Performance
  - Time to Market
  - Reference design that all vendors can leverage.
  - Sustainable Software & Firmware Updates
  - Cost

NEXT GENERATION HARDWARE PLATFORM

- The TI-C64 processor used in the current Exgine does not have the processing power required for the future applications envisioned.
- To accommodate these new features and functionalities, a new DSP and development environment will need to be architected.
- To accommodate the additional signal processing required for HCFR, asymmetrical sideband manipulation and MER calculation, a new, much more powerful, solution needs to be implemented in the Exgine
- Several devices and architectures are being evaluated for the next generation HD Radio systems
  - Dual ARM , FPGA
  - DSP+ARM
  - Dedicated ARM + C66 Multicore DSP
  - C66 Multicore DSP with an internal OS
- Many Pros and Cons to each…
- Moore's Law is in full effect… The technology and possibilities are changing at break-neck speed

NEXT GENERATION HARDWARE PLATFORM CONCEPT

The approach being taken for the hardware implementation is an FPGA based signal processor with integrated ARM applications processors

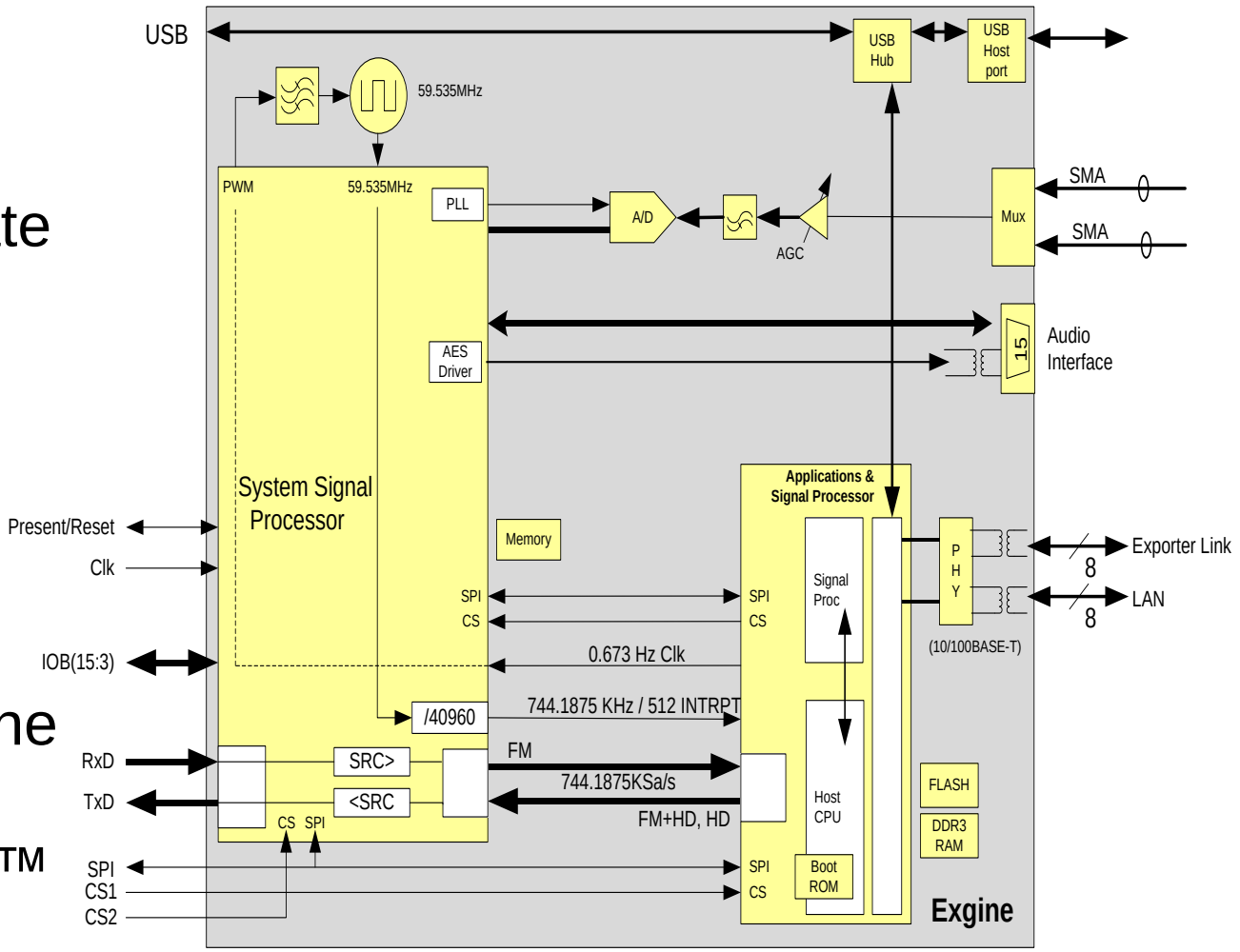


NEXT GENERATION HARDWARE PLATFORM CONCEPT

iBiquity and the equipment manufacturers are working to accelerate development of the Gen IV Exgine

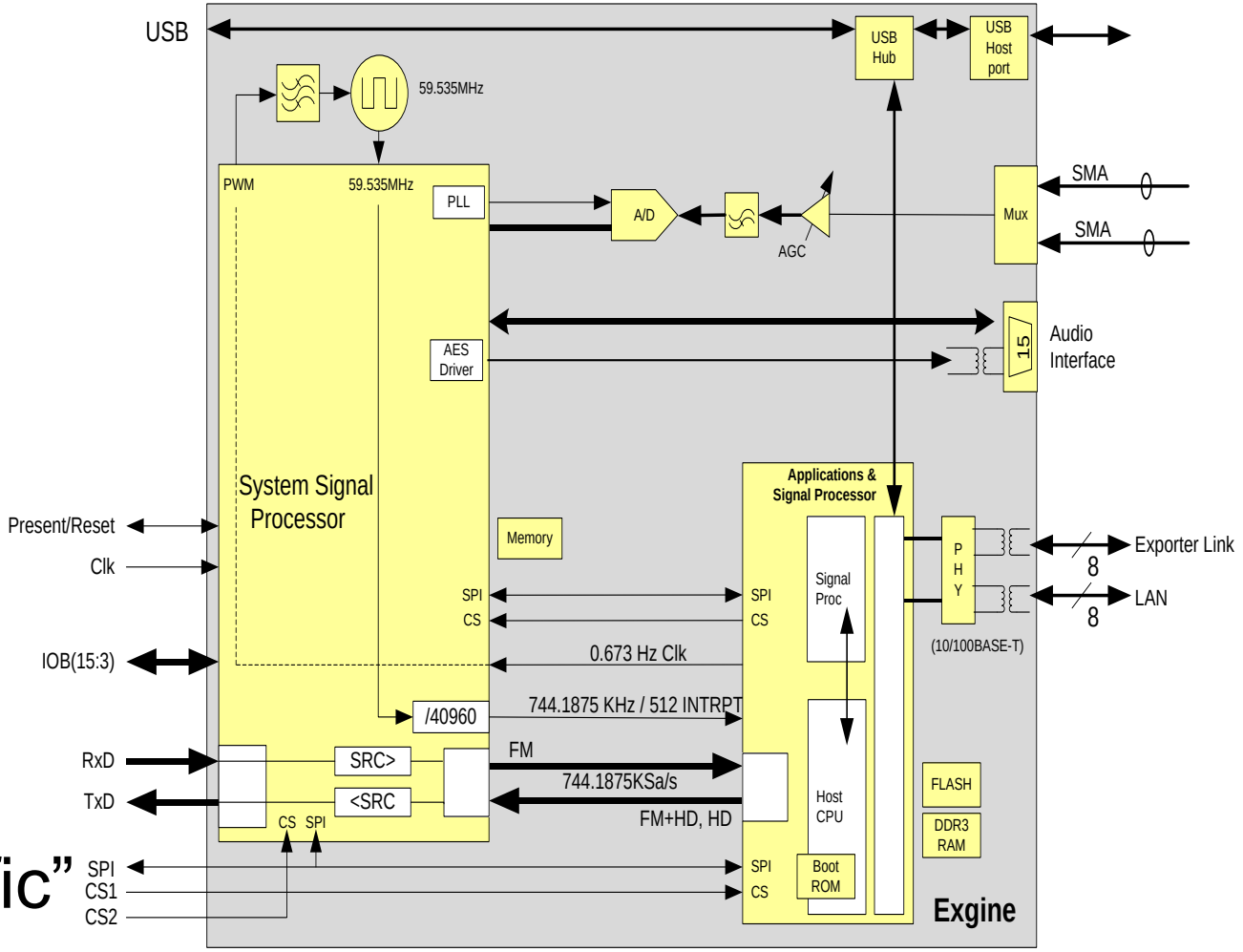
First prototypes are now working in the labs

First shipments of the Gen IV systems in Harris' new Flexiva™ are expected by Spring 2013

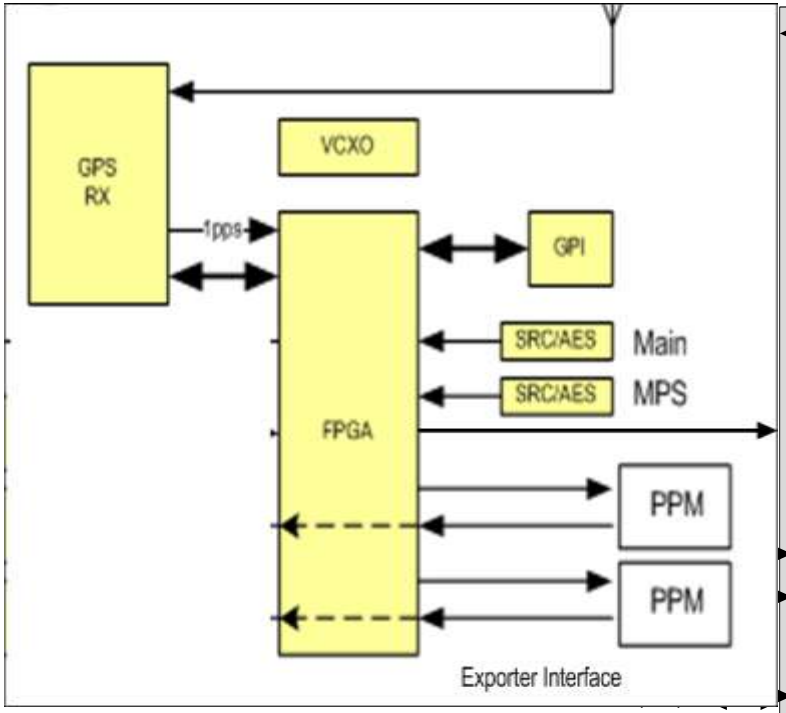


NEXT GENERATION HARDWARE PLATFORM CONCEPT

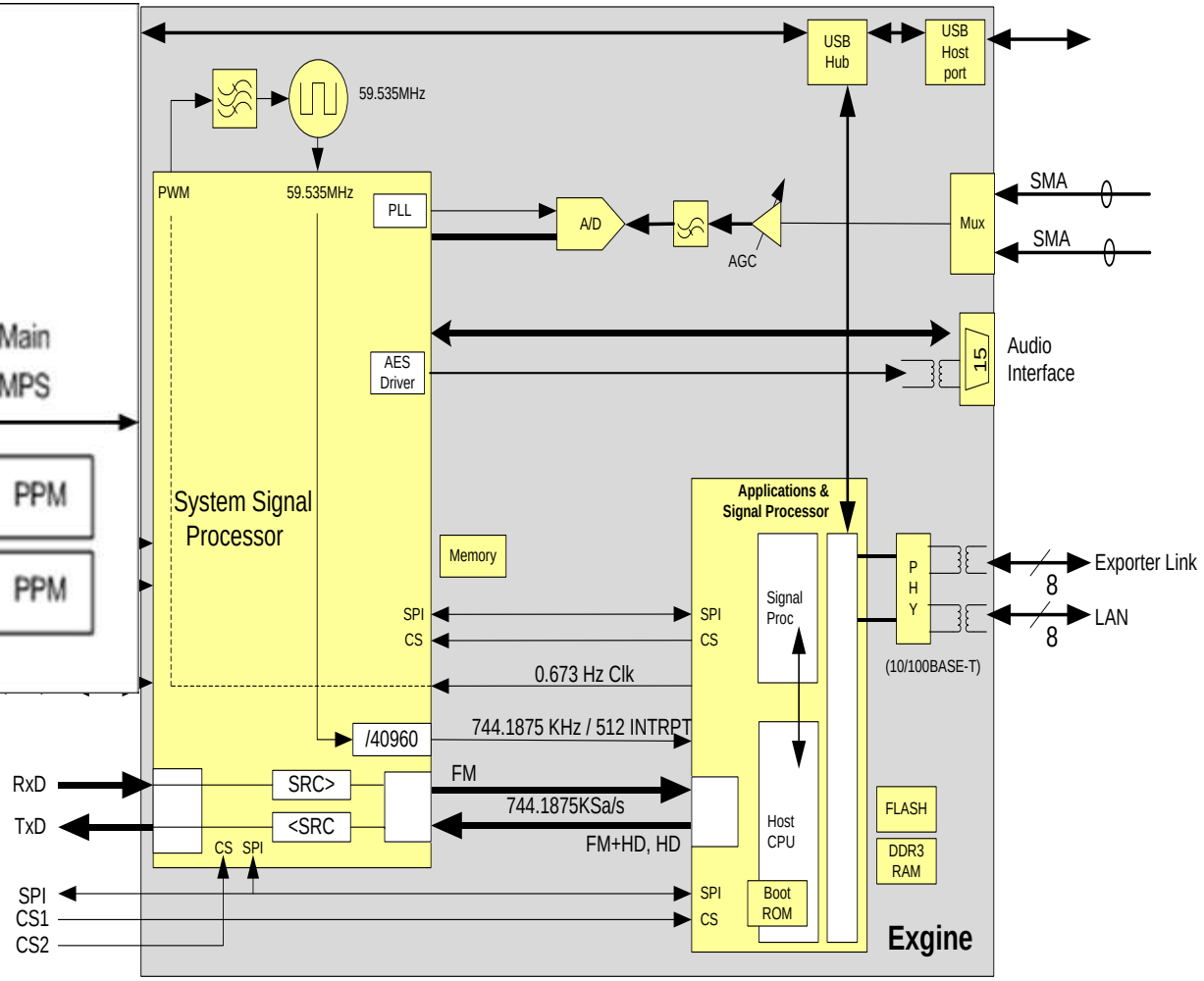
- With an additional "mission specific" interfaces, the same hardware becomes ….



NEXT GENERATION HARDWARE PLATFORM CONCEPT

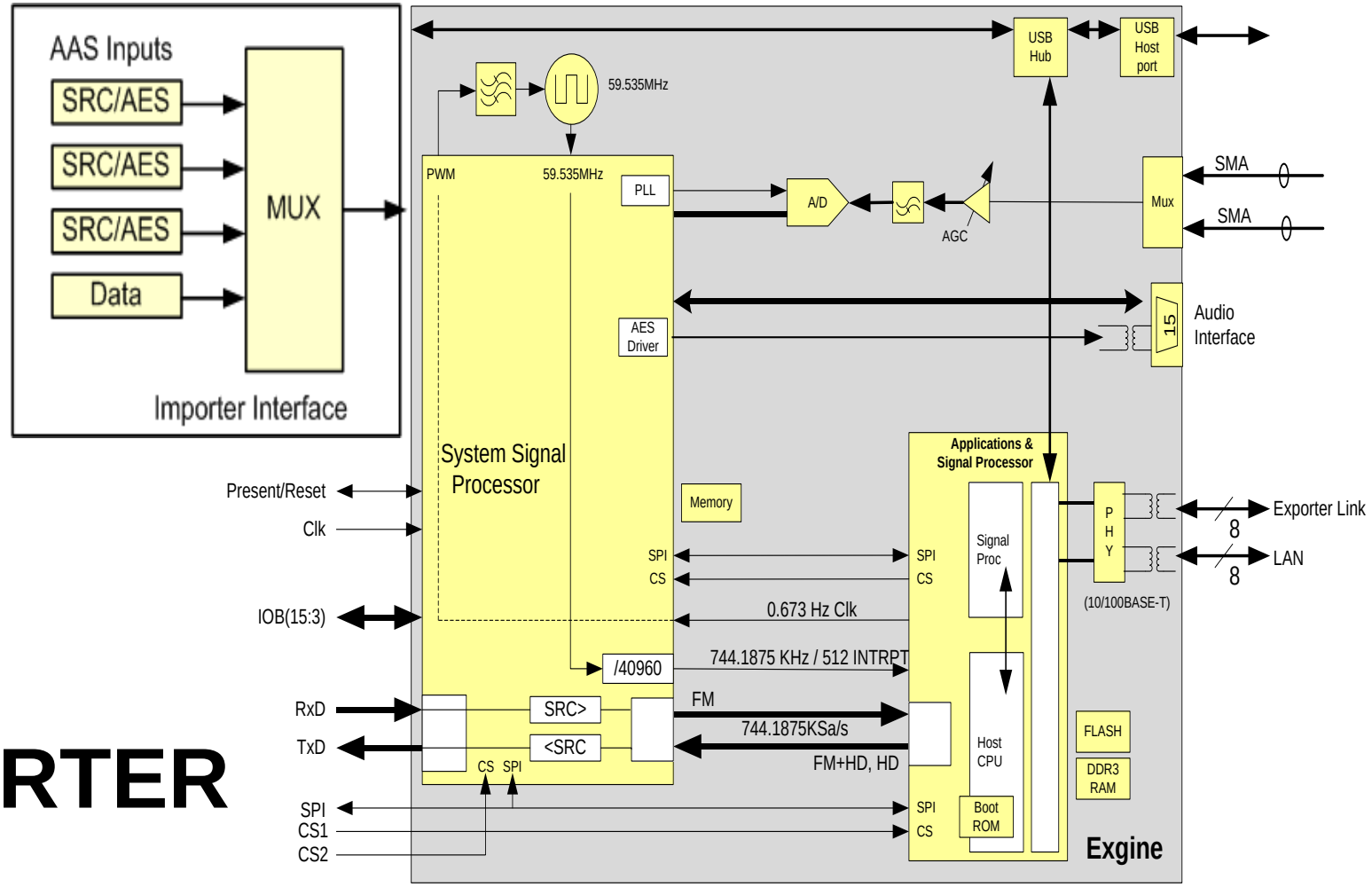


- **AN EXPORTER**

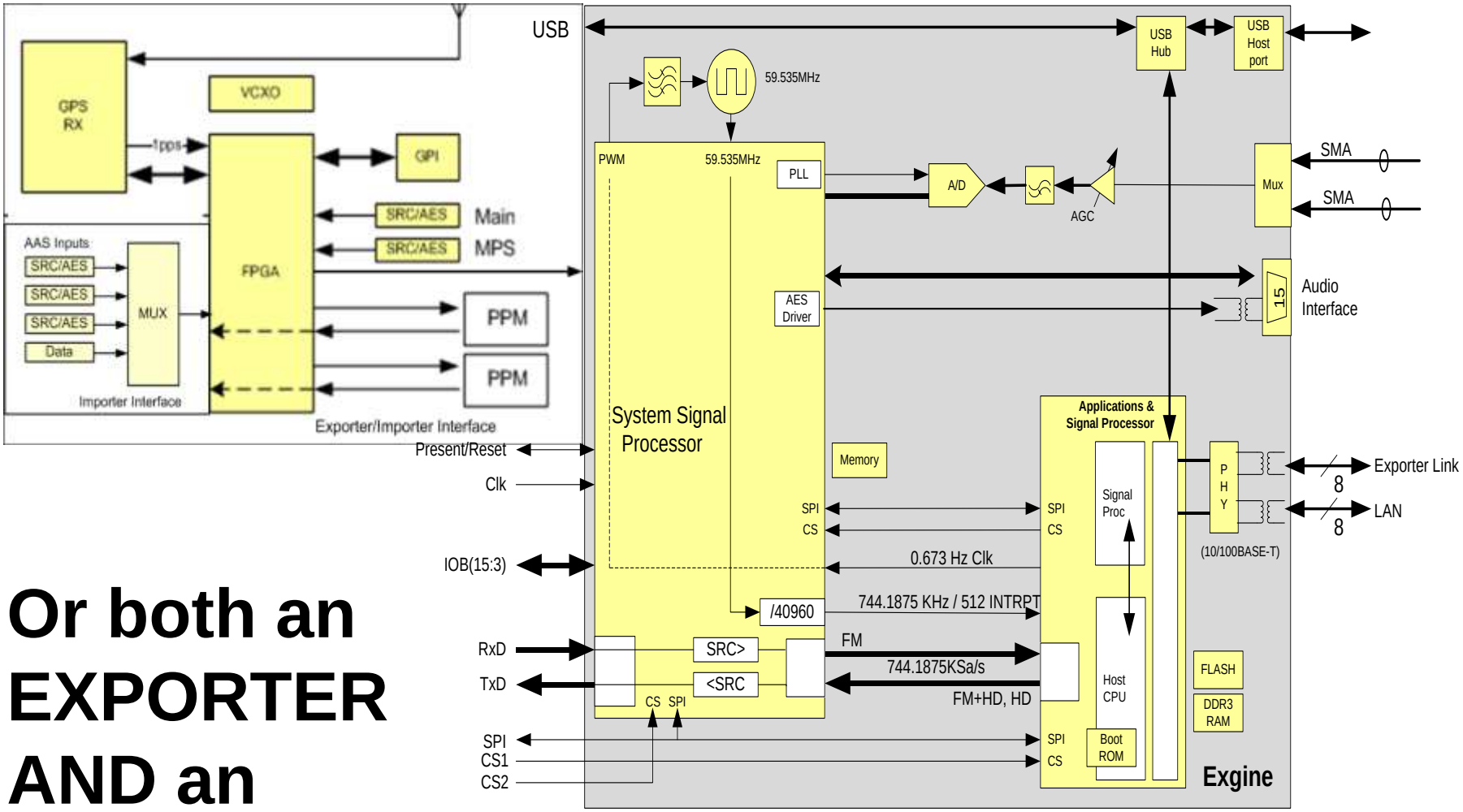


NEXT GENERATION HARDWARE PLATFORM CONCEPT

- **AN IMPORTER**



NEXT GENERATION HARDWARE PLATFORM CONCEPT



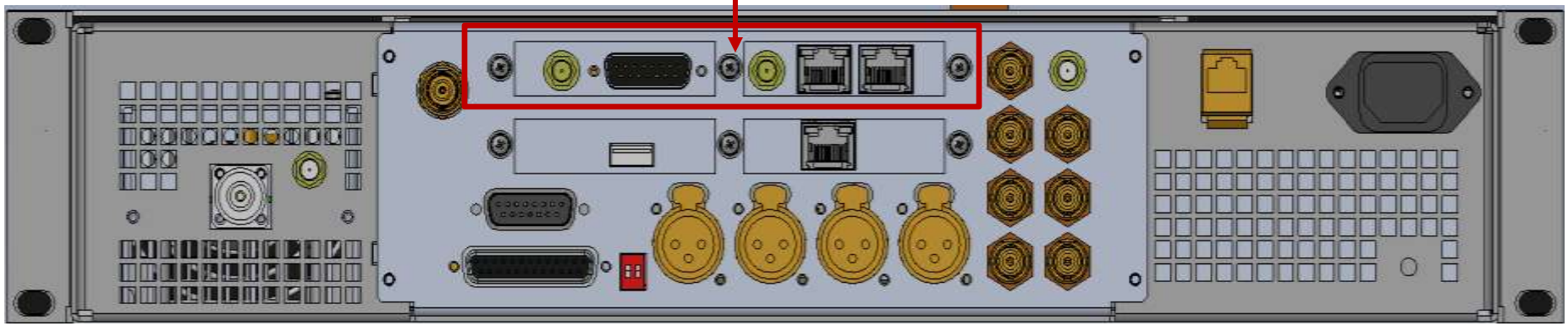
- **Or both an EXPORTER AND an IMPORTER**

Flexiva™ FAX50/FAX150 Exciter with Gen IV Exgine

Gen IV Exgine Features:

- Dual Ethernet Ports
- Asymmetrical Sidebands
- HCFR
- MER Measurement
- Host Audio Extraction
- Diversity Delay
- Remote Control
- Integrated RTAC
- Spectrum Display
- HD SFN

Gen IV Exgine Option Card



Gen IV HD Radio Architecture further integrates HD Radio Advanced Services to enhance the user experience and create new revenue streams

Artist Experience

iTunes® Tagging

Traffic Services

Journaline®

Electronic Program Guide

Conclusion

- HD Radio technology and the broadcasters' business models' have now reached a level of maturity that demands even more robust and cost effective solutions for deployment and operation.
- Over the three generations of HD Radio system development, there have been many innovations as developers and manufacturers have leveraged the latest cutting-edge technology. Some of these advances have been in response to identified needs in the marketplace while others are expanding the capabilities and challenging us to explore yet-untapped mediums and potential new revenue streams.
- 4th generation HD Radio systems will offer new features and capabilities that will push the boundaries of our current broadcast models, offering new opportunities and at the same time, becoming the reliable, efficient and cost effective broadcast system of the future.

ACKNOWLEDGEMENTS

- HD Radio™ is a trademark of IBiquity Digital Corporation, Columbia, Maryland
- Flexstar™ Dexstar™ and RTAC™ are trademarks of Harris Corporation, Melbourne, FL
- Windows® is a registered trademark of the Microsoft Corporation, Redmond, WA
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THANK YOU!

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