Operating system selection recommendations for the NRC Segment Wave Generator Control System

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TITLE

OPERATING SYSTEM SELECTION RECOMMENDATIONS FOR THE NRC SEGMENT WAVE GENERATOR CONTROL SYSTEM
Final Report

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SUMMARY

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- Recommendation for a replacement VME chassis
- Investigation into the suitability of the Linux RTOS
- Confirmation of the availability of the BSP for the VMIC VMIVME 7050
- Provide a budget estimate for the RTOS

The VME chassis that are in use in the control systems today are compatible with the new hardware and could be reused. However, the chassis have been in use for over 10 years and replacement of the power supply, fans and backplane is justified.

The RTOS selection focuses on embedded Linux. Linux has attracted a great deal of interest over the past number of years and has evolved to both a desktop operating system and an embedded operating system. This report looks into the suitability of the operating system in an embedded design and the development tools that are available for use with Linux.

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1. Introduction

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The development of a board support package (BSP) for a CPU board requires special skills. This task can consume considerable time for complex boards. The operating system, the BSP and the CPU board must be considered as a group. If BSP support for a CPU board is not available for a given operating system, any savings in cost of the board, operating system and development tools can evaporate quickly.

Finally, the cost of the BSP, operating system and development tools for the control system upgrade are summarized.

2. VME Chassis Selection

There are a limited number of options for the VME chassis. Board manufacturers often offer their own family of chassis but there are few true chassis vendors. The best range of chassis options is offered by APW Electronic Solutions. Their Canadian representative is ElectroRep Solutions – the same distributor that supplied the VME chassis in use today.

The chassis in use today were assembled from parts by NRC staff. The chassis, power supply and fans were ordered from different vendors. The recommended strategy for the control system upgrade is to purchase the chassis as a unit with no assembly required. No other alternatives were considered in the selection of the chassis.

The control system hardware selected in the previous report specified the CPU board and the analog I/O boards. Given the improvements in density available today, the off-the-shelf, board-level hardware for an MCU controlling 32 segments with active wave absorption requires only 3 boards. This same MCU would require 9 boards in the current system.

The chassis option recommended is the APW VME SmartChassis. This product comes in a variety of configurations – horizontal or vertical; tabletop or rack mounted. These chassis all include card cage, backplane, power supply, cooling and wiring. Pricing was requested for 3 configurations. These are:

- 5-slot, horizontal chassis
- 12-slot, horizontal chassis (consideration for Davis Engineering)
- 12-slot vertical chassis (consideration for Davis Engineering)

Configuration	Product Specifications	Cost
5-slot horizontal SCHR5E160D050NSR	• 5 slot VME backplane • 350 watt power supply • no peripheral mounting • standard display • rackmount	$2,092
12-slot horizontal SCHR12E160D075NSR	• 12 slot VME backplane • 500 watt power supply • no peripheral mounting • standard display • rackmount	$2,587
12-slot vertical SCN12E160D075SSR	• 12 slot J2 configuration • 6U x 160mm card cage • no peripheral mounting • 500 watt power supply • removable fan tray with 3 90 CFM fans • standard display • rackmount	$3,025

The J2 configuration required is yet to be finalized. The packs in the chassis do not require a J2 backplane other than to access additional I/O on the CPU board. An extender card may be required to access the rear I/O.

3. Real-Time Linux

The use of Linux as a real-time operating system for embedded devices has increased dramatically over the last few years. Initial uses of Linux in real-time were either limited to soft real-time applications or used Linux kernels that were modified to provide real-time performance. This approach was necessary for Linux version 2.4.x since the kernel itself did not support real-time. However, Linux 2.6 was extended to include, among other enhancements, the modifications to support real-time. The first commercial distribution of real-time Linux was released in January 2004 by LinuxWorks.

In February 2004, Wind River, the developer of VxWorks, announced that it was partnering with Red Hat to develop Red Hat Linux for the embedded devices market. It is clear that much of the embedded development industry is quickly moving away from RTOS options that involve run-time licensing fees. It is also clear that Linux is a viable operating system for embedded devices.

The Linux operating system was not originally designed to optimize the handling of events. It was, therefore, necessary to improve the event handling performance of Linux in order for it to be more suitable for real-time applications. There are two approaches to making the Linux 2.4 kernel suitable for real-time. One approach is to improve preemption and the second approach is to introduce a hardware abstraction layer to manage the interrupts on a system. Both techniques ensure that the kernel either does not become non-preemptible for extended periods of time or make the kernel itself preemptible. Companies such as MontaVista and TimeSys use the kernel patch to improve preemption. Companies such as FSM Labs and Denx Engineering use a hardware abstraction layer. Two competing products have been released for the hardware abstraction layer approach. The FSM Labs product is RTLinux and the Open Source product is Real-Time Application Interface (RTAI). The RTAI is a custom API that is used to provide hard real-time response with 2.4 kernels.

The kernel changes to improve preemption have been included in the 2.6 kernel. This makes it unnecessary to use the RTAI with the 2.6 kernel. However, work is continuing to develop an RTAI release that is compatible with the 2.6 kernel. This will allow software written for the 2.4 kernel to be ported to the 2.6 kernel. Also, designers who have experience using RTAI can continue their existing coding practices.

3.1. Linux Distributions

The requirements of this project clearly layout the need for a full-featured RTOS distribution. Only commercial distributions of Linux were considered since the overhead of putting together a custom distribution would quickly overshadow any savings in the cost of the distribution. The distributions considered are shown in the table below.

Company	Web Site	Product	Kernel Version	Processor Support
MontaVista Software	www.mvista.com	Professional Edition	2.4	PowerPC, ARM, MIPS, x86, Xscale, StrongARM
Denx Software Engineering	www.denx.de	ELDK Version 3.0	2.4	PowerPC, ARM, MIPS
TimeSys Corp.	www.timesys.com	TimeStorm	2.4 and 2.6	PowerPC, ARM, MIPS, x86, SPARC, XScale
Metrowerks Corp.	www.metrowerks.com		2.2	
FSM Labs	www.fsmlabs.com	RTLinuxPro	2.4.19	PowerPC, ARM, MIPS, x86,
LynuxWorks Corp.	www.lynuxworks.com	Blue Cat 5.0	2.4 and 2.6	PowerPC, ARM, MIPS, x86, SPARC, XScale
Red Sonic Inc.	www.redsonic.com	REDICE-Linux	2.4	x86

Table 1 - Linux Distributions Considered

Availability of the 2.6 kernel is an issue since none of the distributions have full support at the time of this report. The recommendation is to work in the 2.4 kernel environment making sure that the vendor will supply the upgrade path to the 2.6 kernel. While developing in the 2.4 environment, do not use the RTAI included with the system. If the events are not being handled appropriately then use the upgrade to the 2.6 kernel to “tweak” the system and bring the power of the preemptible kernel of 2.6 to bear on the issues.

3.1.1. MontaVista Software

The most established embedded Linux distribution, it only advertises 2.4 OS support. MontaVista indicates that they will migrate to version 2.6 when they feel that it is stable enough to proceed.

3.1.2. Denx Software Engineering

Denx provides a free distribution that supports the 2.4 kernel and a complete set of development tools. They have good reputation, they are associated with a successful engineering firm and they seem to have good long-term prospects. They also have better presence in the embedded world than many commercial products including some of the ones listed here.

The distribution is a simple 2.4 kernel with a complete set of tools well used by UNIX developers. It does have RTAI libraries in order to give the real-time performance required for this project. In a recent interview, Mr. Denx mentioned that the 2.6 kernel is quite unstable (in general, not specifically his product) for architectures other than x86. The Denx product will support 2.4 for a long time to come. Denx is not expecting 2.6 support for at least 6 months from the time of this report.

3.1.3. TimeSys Corporation

TimeSys advertises support for the 2.6 kernel but it appears to be only currently available on the x86 platform. Their product line is called TimeStorm. It has a broad set of products, produces patches and upgrades as part of the purchase price.

They currently only have 2.6 support on an Intel board. They plan to make the 2.6 version on the PowerPC available in a June/July timeframe. With an active account, the upgrade to 2.6 is free.

3.1.4. Mertrowerks

Appears to be a cross development system that only runs on Solaris or Windows and allows development for a Linux target. Also, the kernel version seems to be back around the 2.2 versions. This distribution will not be considered further.

3.1.5. FSM Labs

No formal response has been received from FSM. Their RTLinux distribution use a hardware abstraction layer approach to manage interrupts. They compete directly with standard distributions that are used with RTAI.

3.1.6. LynuxWorks Corporation

The LynuxWorks product is called Blue Cat version 5.0 which is the 2.6 version of their product. They have a BSP available for an Intel platform and a PPC architecture-specific BSP is available under certain licensing agreements.

They currently have 2.6 support for an Intel board. Their environment is essentially created as a command line environment but they priced in the cost of either CodeWarrior or Eclipse which makes it a GUI environment. The product Blue Cat 4.0 is the 2.4 kernel but it is not real-time. They do not add in RTAI so its essentially pure Linux. The product Blue Cat 5.0 is the 2.6 kernel and is their real-time Linux play. The BSP development that they include with their 5 pack includes the source code and there are no royalties associated with it.

3.1.7. Red Sonic Inc.

Product is called REDICE Linux and is available for the 2.4 kernel version. They have Intel support and do not support the PPC architecture. They did not mention if the PPC architecture will ever be supported. This distribution will not be considered further.

3.2. Development Environment

A development environment must include the tools required for efficient development. This must include at least the following:

- Code creation and editing tools
- Target management and cross-compiling tools
- Software debugging tools

Ideally, the development environment also includes the following:

- Repository system or support for a 3rd party repository system
- Kernel debugging tools

The development environment can be organized as a series of command-line tools that are called by the developer or the development environment can be integrated. The integrated development environment (IDE) is preferred by the majority of application developers since it allows the user to move seamlessly between the individual tools. Creating an IDE involves creating the framework for the development tools. Linux distributions tend to use a collection of individual tools (no IDE), proprietary IDEs, such as CodeWarrior, or the IBM Open Source tool called Eclipse. Eclipse is rapidly becoming the defacto standard with its plug-in architecture. Since it is a java application, Eclipse can run on many different platforms without an discernible change in its characteristics.

The table below shows the development environment included in the various distributions.

Company	IDE	Comment
MontaVista	Eclipse	
Denx	None	
TimeSys	Eclipse	
FSM	None	
LynuxWorks	CodeWarrior, Eclipse	CodeWarrior is a proprietary product from Metrowerks. They are moving towards Eclipse in the near future.

Table 2 - Development EnvironmentDevelopment

3.2.1. Code Creation and Editing

Tools for code creation and editing are used most often during a development cycle. A variety of tools exist from the simple but powerful vi to graphical editing tools such as emacs. Developers will generally have a preference and development environments typically allow a range of creation and editing tools to be used.

3.2.2. Target Management and Cross-Compiling

Cross-compiling involves compiling code on the development platform to be executed on the target platform. This is typically driven by a make utility that compiles all affected code modules and creates a downloadable executable. This executable is then copied to the target. In debug mode, the code copied to the target is connected to a debugger running on the development platform.

The Linux distributions generally include the Open Source gcc compiler, version 3.2 or more recent.

3.2.3. Software Debugging Tools

A variety of software debugging tools are available for use with the Linux distributions. These include command-line debuggers such as gdb and debuggers that have added a graphical interface on top of gdb, such as kdbg and ddd. All can be integrated into the Eclipse IDE or run separately. Note the kdbg is not the same as kgdb – kgdb is the source-level kernel debugger for Linux.

3.2.4. Repository Support

The main repository systems used under Linux is the CVS system. The telecomm defacto standard of Clearcase is also able to import/export to a CVS system so only support for CVS will be considered. CVS is an Open Source tool so all distributions have access to it. For IDEs built on Eclipse, the CVS plug-in allows the support for the repository to be built into the IDE.

3.2.5. Kernel Debugging Tools

A kernel debugger is a source level debugger that can be used for debugging the Linux kernel. This is not to be confused with the ICE styled tools as in Powertap, BDM or VisionICE. These tools can do the job of a kernel debug tool but are supplemented with hardware and are beyond the scope of this report.

Kgdb is used along with gdb to debug the Linux kernel. Kgdb makes it possible to place breakpoints in kernel code, step through the code and observe variables. The use of kgdb requires two machines – the target and the host development platform. The host must be connected to the target through a serial line – a null-modem cable which connects their serial ports.

Kgdb is a kernel patch. It has to be applied to a Linux kernel to enable kernel debugging. Kgdb is available for i386, x86_64, PPC and s390 architectures.

Kgdb has only recently been available for the 2.6 kernel. Documentation on the website indicates that support for 2.6 is limited to development versions only. Support for PPC with Linux 2.6 is listed as experimental.

3.3. Distribution Costs

Company	Cost (USD)	Comment
MontaVista	No response	
Denx	Free	All s/w is from the GNU or OpenSource repositories.
TimeSys	Std Edition $2990 w/1 year support Prof. Edition $3640 with 1 year support Design Edition $5590 with 1 year support	PPC 750 BSP is not available until June/July in the 2.6 kernel. Each of these “Editions” increase in price by 30% in order to maintain a 1 year Active account. This is needed to be able to receive patches and upgrades, notably an upgrade from 2.4 to 2.6.
FSM	No response	
LynuxWorks	$11495 [1]with 1 year of support per developer $20,000 [2]with 1 year of support per 5 developers	To license their IDE CodeWarrior, it costs $2500/developer. If the client wants to use the new support for Eclipse it is $2995/developer. With the 5-developer pack, the cost is $7500. The company is moving towards Eclipse in the future. This cost includes 1 year of support.

Table 3 - Linux Distribution Costs

Two of the vendors have not responded with pricing information. This makes it impossible to assess their product costs and capabilities with respect to the other distributions considered. The analysis and costs outlined above reveals that the TimeSys product has the best combination of supported, available tools and low cost. The price per developer for LynuxWorks is the lowest cost if there are at least 5 developers; there will not be 5 developers on this project.

[1] The total cost for a single seat developers license is $8500 (license for SDK) + $2995 (Eclipse license) = $11495.00/developer.
[2] The 5 pack as they refer to it is 20,000 (license for SDK) + $7500 (Eclipse) = $27,500.00 for 5 developers which is $5500.00/developer. This includes 1 year of support plus the development of a custom BSP.

3.4. Summary

Real-time performance is possible with Linux. For Linux kernel version 2.4, the choices are:

1. A commercial distribution including a kernel with an integrated preemptive patch. Vendors will charge for either the kernel and/or the development tools. The choices here are MontaVista, TimeSys and FSM Labs. TimeSys is the least expensive of these options.
2. A commercially supported version of the standard kernel with Open Source RTAI for real-time. Vendors typically do not charge for this option but the responsibility for assembling the pieces rests with the developer. For a fee, support will be provided. The choices here are Denx Software Engineering or the standard Open Source repositories.

For Linux kernel version 2.6, the real-time performance is built in. However, there are issues with the stability of the 2.6 kernel on the PowerPC architecture and some tools (e.g. kernel debugger) are not considered robust. It will take some time for these issues to be resolved. Options for the 2.6 kernel are:

1. Use a standard 2.6 distribution with a development environment developed from assembled from components. These would all be free of charge but the responsibility for assembling the pieces rests with the developer.
2. Use a standard 2.6 distribution but purchase support and the development tools from a vendor. The choices here are TimeSys and LynuxWorks.

The Denx product is a free distribution but it is only available on the PPC architecture, it is only available on the 2.4 kernel and the development environment would be created by downloading a selection of tools – all of which are available free of charge. The Denx distribution has a very good reputation and the RTAI is reputed to be very well tested. It is the clear alternative to an all-in-one commercial product. If an IDE was desired for the Denx distribution, one could be created using the Eclipse framework.

4. BSP Availability

The Board Support Package (BSP) turns a board-level product into a platform on which a real-time application can be delivered. BSPs include the following components:

- Device drivers
- Root file system
- Utilities
- Documentation

If the BSP is provided as part of a commercial Linux distribution, it includes the kernel. If the BSP is provided by the board manufacturer, the BSP must be integrated with a Linux kernel.

The BSP is tightly coupled to the CPU and the other hardware devices on the board. Given the recent release of the Linux 2.6 kernel, this is a difficult time for board vendors since their existing BSPs developed for the 2.4 kernel may not run on the 2.6 kernel without modification. It will take some time as the industry migrates from 2.4 to 2.6. There are also issues relating to the use of the 2.6 kernel with the PPC architecture. Indications are that it will take until June or July of 2004 to resolve the stability issues that have been found. Currently, the 2.6 kernel is only supported on the Intel x86 architecture.

The hardware analysis report recommends the VMIC VMEVMI 7050 CPU board. This board is based on the IBM PPC 750FX or 750GX processor. This is a difficult combination to support on the 2.6 kernel at this time. VMIC is working on a Linux 2.6 BSP, but their current estimate is that they will not complete the work until August 2004. If development of the control system upgrade is to start before the VMIC BSP is available for the 7050, a custom BSP will need to be developed. Depending on the state of integration of the 2.6 kernel on the PPC architecture, this will, at best, be a challenging task.

There are three options that can be considered. These are:

1. Delay the project until the BSP is available and stable,
2. Develop the BSP and
3. Select another CPU board.

The choice of when to begin the project is clearly up to NRC. It does not seem reasonable to delay the project to wait for the BSP. However, if the timing of the start of development is such that the BSP is available, the 7050 remains the recommended board.

Development of a custom BSP for the board on the 2.6 kernel is not a viable option at this time. There are issues yet to be resolved with Linux kernel 2.6 and the PPC architecture. Once these issues have been resolved, the choice to proceed will be based on the availability of the following:

- BSP for any PPC 750 based CPU board on Linux 2.6
- Availability of device drivers for all hardware devices on the board

If these building blocks are available, it is reasonable to assume that the BSP could be developed in a reasonable amount of time. It is also possible to develop the BSP on the Linux 2.4 kernel with the RTAI extensions. This would provide a stable platform on which to develop the BSP. It is likely that the necessary 2.4 compatible drivers can be found and that the BSP can be developed.

The obvious choice for another CPU board is the top non-PPC board from the hardware analysis. In this case, the second highest ranked board is an option. The specifications for the top two CPU board options from the hardware report are repeated in the table below. Key differences between the top recommendation (7050) and the second place recommendation (7700) are:

- The 7700 uses the Intel Celeron processor. This is a low-voltage, low-power, x86 architecture processor
- All necessary I/O connectors are available on the front panel of the 7700
- The 7700 does not support gigE
- A Linux BSP is available for the 7700 (Linux 2.4)

Model	**VMIVME-7050-2000**	**VMIVME-7700-121**	**Comments**
Rank	1	2	
Age (yrs)	0.5	0	both are less than a year
Cost (US$)	$2,756	$2,601	
Processor	PPC 750FX/GX	Intel Celeron	PowerPC option runs cooler
Speed (GHz)	1.00	0.65	
Front Panel Access	1 serial, 2 Ethernet	2 serial, 2 Ethernet	**7050:** either the terminal or the synch signal will need to use the rear P2 connector
Ethernet Speed	2 gigE	2 10/100 MbitE	**7700:** no gigE
Board Support Packages	VxWorks: released	VxWorks: May-04	
	Linux: late summer	Linux: released	
	LynxOS: released	QNX: released	
		Windows: released	
PMC sites	2	1	need 1 (for digital I/O)
Memory	512 MB SDRAM, 64.5 MB chip flash, 32K NVRAM	512 MB SDRAM, 128 MB compactFlash, 32K NVRAM	
I/O	2 serial I/O; dual gigE	2 serial I/O; 2 USB; 2 10/100 BT	
Power Req (max)	3.8A @ 5V, 1.2 mA @ +12V	3.5A @ 5V, 1mA @ +/-12V	
Bonus Features	watchdog timer	watchdog timer	Could be used to force a reboot if s/w locks up
	temp sense		Could be used to detect overheating (fan failure)
	compactFlash	compactFlash (part of main memory)	**7050:** Allows flash to be added if necessary. **7700:** uses compactFlash for booting so flash memory could be increased on it as well
	built-in self test (BIST)		Could integrate tests on RAM, COM ports and LAN into control s/w
		Enet boot	BIOS directly supports software boot from a server. Would require additional effort on other boards
	voltage sense	byte-swapping h/w, on-board video controller, mouse & keyboard I/f	Cool, but not useful

Table 4 - Top CPU Board Choices

5. Conclusions

Linux is a suitable candidate for use in the segmented wave generator.

Commercial distributions of Linux either come with a tool chain in an Integrated Development Environment (IDE) or an IDE can be created using Eclipse and Open Source tools.

Linux kernel version 2.4 with either the pre-emption patch or RTAI is suitable for embedded, real-time devices.

Linux kernel version 2.6 includes the pre-emption patch making the standard distribution suitable for real-time.

The 2.6 kernel is only stable on the x86 architecture at this time.

If the PowerPC architecture is used, the best alternative in the short term is to build on the Denx Linux kernel 2.4 distribution with their RTAI distribution.

6. Recommendations

Use the SmartChassis, 5-slot horizontal chassis, part number SCHR5E160D050NSR as the replacement chassis for the control system.

The correct development path to take depends on the stability of Linux kernel version 2.6 on the PowerPC and the state of development of the BSP for the VMEVMI 7050 (PPC) at the time that development is started.

Best option, but not likely:

If 2.6 is stable on the PowerPC and the BSP is available for the 7050 from VMIC:

- Select the 7050 CPU board
- Select a standard distribution for the 2.6 kernel
- Download the Eclipse IDE framework and plug-in tools to create an IDE
- Integrate the kernel and the BSP
- Begin development

There will be no charge for the BSP, the kernel or the development tools. It will take some time to set up the IDE and to integrate the BSP with the kernel. The effort in assembling the tools can be reduced if a development environment is purchased. In this case, the TimeSys environment is the most suitable.

Best option for the 7050 board but more initial effort:

If a stable 2.6 kernel with BSP is not available for the 7050 and the decision is made to develop a BSP based on the 2.4 kernel with RTAI extensions:

- Attempt to get a board on loan from VMIC
- Download the BSPs from various sources that have support for the hardware devices and CPU on the 7050.
- Download a standard distribution for the 2.4 kernel and the RTAI extensions from the Denx website
- Download the Eclipse IDE framework and plug-in tools to create an IDE
- Develop the BSP by integrating components from a suite of other BSPs
- Begin application development

There will be no charge for the BSP, the kernel or the development tools. It will take some time to set up the IDE and to develop the BSP.

Lowest risk option with lowest initial effort:

If a stable 2.6 kernel with BSP is not available for the 7050 and the decision is made to move to the 7700 board:

- Start development using the VMIC VMEVMI 7700 (x86-based) board
- Attempt to get a board on loan from VMIC
- Download the BSP from VMIC
- Download a standard distribution for the 2.4 kernel
- Download the Eclipse IDE framework and plug-in tools to create an IDE
- Integrate the kernel and the BSP
- Begin development
- Migrate to the 2.6 kernel when the 2.6 kernel version of the BSP is released

There will be no charge for the BSP, the kernel or the development tools. It will take some time to set up the IDE and to integrate the BSP with the kernel.

Note that the 7700-based option is not a hard real time solution until the kernel is migrated to version 2.6. If a real-time system is to be built on kernel version 2.4, the TimeSys commercial distribution should be used. In this case, the designer version of the tools should be selected at a cost of $5590 (USD). Since TimeSys does not support the 7700 directly, it will still be necessary to integrate the VMIC BSP with the TimeSys kernel.