



RTAI Port to MCF5329

Developer's manual

M5329/RTAI3.6.2

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A;out T7-s Do,ument

This document describes setting up and usage of RTAI for MCF5329 installed into μ Clinux embedded OS, and the changes in RTAI and Linux kernel source code, which allow using RTAI with MCF5329.

Au+-en, e

This document targets µClinux software developers using the MCF5329 processor.

! u33este+ Rea+-n3

- [1] MCF5329 Reference Manual Rev. 0
- [2] RTAI 3.4 User Manual Rev 0.3
- [3] Advanced Linux Programming. M. Mitchel, J. Oldham, A. Samuel

Definitions, Acronyms and Abbreviations

The following list defines the acronyms and abbreviations used in this document.

ADEOS	Adaptive Domain Environment for Operating Systems, a nanokernel used by RTAI
FEC	ColdFire Fast Ethernet Controller
FIFO	First Input First Output
HAL	Hardware Abstraction Layer
I-Pipe	Interrupt Pipeline
LED	Light-Emitting Diode
OS	Operating System
RDTSC	Read Time Stamp Counter – the function returning number of ticks from the system start.
RTAI	Real Time Application Interface
RTC	Real Time Clock
SRQ	System Request
UART	Universal Asynchronous Receiver/Transmitter
µClinux	Micro-Controller version of Linux OS for Embedded Applications

)* Introduction

This document describes the Real Time Application Interface (RTAI), ported to the MCF5329. RTAI is a Linux kernel extension, that allows preemption of the Linux kernel at any time in order to perform real time operations with interrupt latencies in the microseconds range. The standard Linux kernel can have latencies of several milliseconds.

The document is divided logically into five parts.

The first part contains a general overview of RTAI.

The second part contains the description of its installation and usage.

The third part describes the changes, which were made in the μ Clinux kernel 2.6.25 and Linux drivers. Mainly it contains information about modifications of the interrupt handling routines and timer routines.

The fourth part is a description of the changes made in the RTAI source code during porting.

The fifth part gives a short manual of creation of RTAI applications.

)* RTAI Features for MCF5329

- Correct execution of the real time tasks in periodic mode with the frequencies 3 kHz and less (In this mode real time task period have to be a multiple of the timer period).
- Correct execution of the real time tasks in oneshot mode with the frequencies 5 kHz and less (In this mode real time task period have to be a variable value based on the timer clock frequency).
- RTAI services are provided by 14 kernel modules, which allow hard real time, fully preemptive scheduling. These modules are: *rtai_hal*, *rtai_sched*, *rtai_lxrt*, *rtai_fifos*, *rtai_wd*, *rtai_msg*, *rtai_bits*, *rtai_mq*, *rtai_sem*, *rtai_netrpc*, *rtai_tbx*, *rtai_mbx*, *rtai_signal*, *rtai_tasklets*. Note that 15-th module, *rtai_usi*, contains no code, so there is no reason to use it.

)*2* RTAI's !erv-,es %verv-e0

This section briefly describes RTAI's real time services. They are provided via kernel modules, which can be loaded and unloaded using the standard Linux *insmod* and *rmmmod* commands. Although the *rtai_hal* and *rtai_sched*(or *rtai_lxrt*) modules are required every time any real time service is needed, all other modules are necessary only when their associated real time services are desired.

)*2*)* Mo+ule Itesed;h□ēd modredinloed aher□stR□siedo RT tes aher eO□air t edrable

It's the RTAI hardware abstraction layer used by other RTAI modules. It offers interrupt handling and timing functions.

)*2*2* Mo+ule

It's a real time, preemptive, priority-based scheduler, modified to work on MCF5329. It's simply a GNU/Linux co-scheduler. This means that it supports hard real time for all Linux schedulable objects like processes/threads/kthreads.

)*2*:RTAI)*2*PCF Mo+ule

It's a real time, preemptive, priority-based scheduler, modified to work on MCF5329. The *rtai_sched* instead supports not only hard real time for all Linux schedulable objects, like processes/threads/kthreads, but also for RTAI own kernel tasks, which are very light kernel space only schedulable objects proper to RTAI.

)*2*:RTAI tMPCF

) *2*1* Module

It's RTAI event flags functions.

) *2*2* Module

It's POSIX-like message queues.

) *2*9* Module

It's RTAI semaphore functions.

) *2*)4* Module

It's a module for network real time communications.

) *2*)*)* Module rta-=t;9

It's RTAI message queues.

) *2*)2* Module rta-=m;9

It's RTAI mailbox functions.

) *2*)3* Module

It's RTAI signal services.

) *2*) : * Module

It's an RTAI's implementation of tasklets. RTAI tasklets are used when functions are needed to be called from user- and kernel-space.

) *3* Related Files

The following files are relevant to RTAI:

- uClinux-dist-20080808.tar.bz2 – source code of the µClinux.
- rtai-3.6.2.tar.bz2 – RTAI 3.6.2 original package.

- m68k-uclinux-tools-20061214.sh - m68k-uclinux tool chain for μ Clinux and RTAI compilation.
- rtai3.6.2-mcf5329.patch – patch for RTAI to support MCF5329.
- uClinux-rtai-mcf5329_2.6.25.patch – patch for μ Clinux 2.6.25 kernel containing I-Pipe.

2* RTAI Installat-on an+ "sa3e

This chapter describes how to install and patch μ Clinux and RTAI, download image with μ Clinux and its real time extension for MCF5329. It also contains a general overview of RTAI and information about RTAI installation.

2*)* RTAI ' eneral %verv-e0

2*)*)* &ar+ real t-me

True multi-tasking operating systems, such as Linux, are adopted for use in increasingly complex systems, where the need for hard real time often becomes apparent. "Hard real time" can be found in the systems, which are dependent from guaranteed system responses of thousandths or millionths of a second. Since these control deadlines can never be missed, a hard real time system cannot use average case performance to compensate for worst-case performance.

2*)*2* RTAI an+ ot7er real t-me proje,ts

There are four primary variants of hard real time Linux available: RTLinux, Xenomai and RTAI.

RTLinux was developed at the New Mexico Institute of Technology by Michael Barabanov under the direction of Professor Victor Yodaiken. Real Time Application Interface (RTAI) was developed at the Dipartimento di Ingegneria Aerospaziale, Politecnico di Milano by Professor Paolo Mantegazza. One of the main advantages of RTAI is the support of periodic mode scheduling and its performance. Xenomai, that was launched in 2001 provides slightly worser performance comparing to RTAI.

2*)*3* RTAI -mplementat-on

For the real time Linux scheduler the Linux OS kernel is an idle task. Therefore Linux executes only when the real time tasks aren't running and the real time kernel isn't active. RTAI 3.6.2 uses ADEOS nanokernel for managing interrupts. ADEOS provides Interrupt Pipeline (called I-Pipe), that delivers interrupts to domains. One of domains is Linux, the second – RTAI. In hard real time mode (when there is a real time task running) Linux domain is in "stalled" state, which means it doesn't receive interrupts. So Linux kernel doesn't schedule, because timer interrupt never occurs. In

hard real time interrupts are delivered to RTAI scheduler, which manages RTAI tasks.

2*2* m. **256el/ Tool C7a-n !etup**

To install the m68k-uclinux tool chain for correct μ Clinux and RTAI compilation, the following steps must be accomplished:

1. Login as root
2. Run `m68k-uclinux-tools-20061214.sh`

2*3* 8Cl-nu9 an+ RTAI -nstallat-on* Pat,7-n3 an+ Comp-lat-on

To install and patch μ Clinux and RTAI, the following steps must be performed:

1. Copy `µClinux` archive (`uClinux-dist-20080808.tar.bz2`) into the `/opt/rta` directory (it developer wants to have `uClinux-dist` directory with `µClinux` in the other directory, the sequence of actions will be the same – only change of paths is needed).
2. Extract its content:

```
$ tar xf uClinux-dist-20080808.tar.bz2
```

3. Copy RTAI archive (`rtai-.6.2.tar.bz2`) into the `/opt/rtai` directory (location also can be changed)
4. Extract its content:

```
$ tar xf rtai-.6.2.tar.bz2
```

5. If the patches are stored in the `/opt/rtai/patches` directory, execute the following commands to patch `μClinux` and RTAI code:

```
$ cd /opt/rtai/rtai-.6.2
```

```
$ patch -p1 " /opt/rtai/patch!s/rtai .6.2-mcf# 2$.patch
```

```
$ cd /opt/rtai/uClinux-dist
```

```
$ patch -p1 " /opt/rtai/patch/s/uClinux-rtai-mcf# 2$%2.6.2#.patch
```

- ## 6. Configure the Linux kernel:

```
$ cd /opt/rtai/uClinux-dist
```

```
$ make menuconfig
```

It's possible to use `xconfig` and `config` if the developer prefers such way.

Afterwards do the following selections:

```
!< /<roduct >!!<tion-*< < + ,r!!scal!
!< /<roduct >!!<tion-*,r!!scal! (<roducts + -# 2$.'/
0!<n!l/1ibrar2/3!faults >!!<tion-*0!<n!l '!<rsion + linux-2.6.x
0!<n!l/1ibrar2/3!faults >!!<tion-*libc '!<rsion + uClibc
0!<n!l/1ibrar2/3!faults >!!<tion-*Customiz! 0!<n!l >!!<tin&s + 2
0!<n!l/1ibrar2/3!faults >!!<tion-*Customiz! application/1ibrar2
>!!<tin&s + 2
```

Then save and exit. The second window “Kernel Configuration” will be shown. Here the following should be selected:

```
.nabl! loadabl! modul! support + 2
.nabl! loadabl! modul! support/-odul! unloadin& + 2
(roc!ssor t2p! and f!atur!s-*5nt!rrupt (ip!lin! + 2
```

Then save and exit. The third window “uClinux Distribution Configuration” will be shown. Here the following should be selected:

```
/us2box//us2box + 2
/us2box//us2box/linux -odul! 6tilit!s/inmod + 2
/us2box//us2box/linux -odul! 6tilit!s/lsmo + 2
/us2box//us2box/linux -odul! 6tilit!s/rmmod + 2
/us2box//us2box/linux -odul! 6tilit!s/)>upport 7!<rsion 2.6.x linux
k!<n!ls + 2
```

Then save and exit.

POSIX threading support is required to compile some RTAI testsuite files. To enable POSIX threading support configure uClibc:

```
$ cd uClibc
```

```
$ make menuconfig
```

In the configuration window set:

```
8!n!ral librar2 )!ttin&s/(9)5: ;hr!adin& )upport + 2
```

Then save and exit.

Go back to μ Clinux root directory:

```
$ cd /opt/rtai/uClinux-dist
```

7. Build μ Clinux:

```
$ make
```

8. Configure RTAI:

```
$ cd /opt/rtai/rtai-2.6.2
```

```
$ make 4<C+=m68knommu C<9))%C9-(51.+m68k-uclinux- menuconfig
```

In the configuration window set:

```
8!n!ral-*linux )ourc! ;r!! + /opt/rtai/uClinux-dist/linux-2.6.x
```

9. Build RTAI and copy modules to the target file system:

```
$ make
```

```
$ cd bas
```

```
$ install -d /opt/rtai/uClinux-dist/romfs/lib/modules/rtai
```

```
$ find -name *.ko -exec cp {} @ /opt/rtai/uClinux-dist/romfs/lib/modules/rtai \;
```

10. Then compile μ Clinux again:

```
$ cd /opt/rtai/uClinux-dist
```

```
$ make
```

11. Now it is possible to load and run μ Clinux using the d/68 monitor of the built-in ROMs. Use the dn command to load the image. And then type &o 40020000 to run it.

12. Now load RTAI modules and get information through /proc filesystem:

```
D insmod rtai%hal.ko
```

```
D insmod rtai%sch!d.ko
```

```
D insmod rtai%fifos.ko
```

... (and so on, all RTAI modules you need)

Go to /proc:

```
D cd /proc/rtai
```

```
D cat hal
```

```
>> <;45/m68knommuE
```

```
>> <!al-tim! 5<Fs us!d b2 <;45E non!
```

```
>> <;45 !xt!nsion trapsE
```

```
)G)<.F+0x2b
```

```
>> <;45 )G)<.Fs in us!E D1 D2
```

```
D cat sch!dul!r
```

```
<;45 1:<; <!al ;im! ;ask )ch!dul!r.
```

```
Calibrat!d C(6 ,r!Hu!nc2E 240000000 =z
```

```
Calibrat!d int!rrupt to sch!dul!r lat!nc2E 81$$1 ns
```

```
Calibrat!d on!shot tim!r s!tup%to%firin& tim!E 8008  
ns
```

Number of < C(6s in s2st!mE 1 Jsiz!d for 1K

<!al tim! kthr!ads in r!sor7oir Jcpu/DKE J0/1K

Number of forced hard/soft/hard transitionsE traps 0L
s2scalls 0

(riorit2 (!riodJnsK ,(6)i&)tat! C(6 ;ask =3/),
(53 <;%;4)0 > ;5-.

;5-.3

<.43G

2*:* RTAI testsuite -installation

To install and launch RTAI testsuite, some additional steps must be performed:

1. `gn!ral-*/uild <;45 t!stsuit!` option must be selected when configuring RTAI.
2. After building testsuite files must be copied to the target filesystem:

```
$ 6C%<;%;.)/+/opt/rtai/uClinux-dist/romfs/rtai-t!stsuit!
```

```
$ install -d $6C%<;%;.)/k!rn/lat!nc2
```

```
$ install -d $6C%<;%;.)/k!rn/pr!!mpt
```

```
$ install -d $6C%<;%;.)/k!rn/sMitch!s
```

```
$ install -d $6C%<;%;.)/us!r/lat!nc2
```

```
$ install -d $6C%<;%;.)/us!r/pr!!mpt
```

```

$ install -d $C%<;%>./us!r/sMItch!s
$ cd /opt/rtai/rtai- .6.2/t!stsuit!
$ cp k!rn/lat!nc2/lat!nc2%rt.ko $C%<;%>./k!rn/lat!nc2/
$ cp k!rn/lat!nc2/displa2 $C%<;%>./k!rn/lat!nc2/
$ cp k!rn/pr!!mpt/pr!!mpt%rt.ko $C%<;%>./k!rn/pr!!mpt/
$ cp k!rn/pr!!mpt/displa2 $C%<;%>./k!rn/pr!!mpt/
$ cp k!rn/sMItch!s/sMItch!s%rt.ko $C%<;%>./k!rn/sMItch!s/
$ cp us!r/lat!nc2/lat!nc2 $C%<;%>./us!r/lat!nc2/
$ cp us!r/lat!nc2/displa2 $C%<;%>./us!r/lat!nc2/
$ cp us!r/pr!!mpt/pr!!mpt $C%<;%>./us!r/pr!!mpt/
$ cp us!r/pr!!mpt/displa2 $C%<;%>./us!r/pr!!mpt/
$ cp us!r/sMItch!s/sMItch!s $C%<;%>./us!r/sMItch!s/

```

3. Testsuite uses RTAI FIFOs, so FIFO device files should be created:

```

$ touch /opt/rtai/uClinux-dist/romfs/d!7/Nrtf0LCL1#0L0
$ touch /opt/rtai/uClinux-dist/romfs/d!7/Nrtf1LCL1#0L1
$ touch /opt/rtai/uClinux-dist/romfs/d!7/Nrtf2LCL1#0L2
$ touch /opt/rtai/uClinux-dist/romfs/d!7/Nrtf LCL1#0L

```

4. Rebuild μ Clinux

```

$ cd /opt/rtai/uClinux-dist
$ mak!

```

5. Now it is possible to load and run μ Clinux using the d/68 monitor of the built-in ROMs. Use the dn command to load the image. And then type &o 40020000 to run it.

6. When μ Clinux is launched on the board, insert required modules:

```

D insmod rtai%hal.ko

```



```

D insmod rtai%sch!d.ko
D insmod rtai%s!m.ko
D insmod rtai%fifos.ko
D insmod rtai%mbx.ko
D insmod rtai%ms&.ko
D cd /rtai-t!stsuit!

```

7. Launch RTAI tests:

Kernel-space *latency* test in oneshot mode:

```

D cd k!rn/lat!nc2
D insmod lat!nc2%rt.ko
D ./displa2

```

Latency test will be displaying its results, until you press Ctrl+C.

```

D rmmod lat!nc2%rt.ko
D cd ../..

```

Kernel-space *latency* test in periodic mode:

```

D cd k!rn/lat!nc2
D insmod lat!nc2%rt.ko tim!r%mod!+1
D ./displa2

```

Latency test will be displaying its results, until you press Ctrl+C.

```

D rmmod lat!nc2%rt.ko
D cd ../..

```

Kernel-space *preempt* test:

```

D cd k!rn/pr!!mpt
D insmod pr!!mpt%rt.ko
D ./displa2

```

Preempt test will be displaying its results, until you press Ctrl+C.

```
D rmmod pr!mpt%rt.ko
```

```
D cd ../../
```

Kernel-space *switches* test:

```
D cd k!rn/sMitch!s
```

```
D insmod sMitch!s%rt.ko
```

Switches test will be displaying its results after few seconds.

```
D rmmod sMitch!s%rt.ko
```

```
D cd ../../
```

User-space *latency* test in oneshot mode:

```
D cd us!r/lat!nc2
```

```
D ./lat!nc20
```

```
D ./displa2
```

Latency test will be displaying its results, until you press ENTER.

```
D cd ../../
```

User-space *latency* test in periodic mode:

You will need to modify latency test, rebuild RTAI and μ Clinux and launch μ Clinux on the board again.

First, in the following file

```
/opt/rtai/rtai-.6.2/t!stsuit!/us!r/lat!nc2/lat!nc2.c
```

change line 38 from

```
Dd!fin! ;5-.<%-93. 0
```

to

```
Dd!fin! ;5-.<%-93. 1
```

After it rebuild RTAI:

```
$ cd /opt/rtai/rtai- .6.2
```

```
$ mak!
```

Then copy updated `lat!nc2` executable to the romfs:

```
$ 6C%<;%;. );+/opt/rtai/uClinux-dist/romfs/rtai-t!stsuit!
```

```
$ cp /opt/rtai/rtai- .6.2/t!stsuit!/us!r/lat!nc2/lat!nc2  
/opt/rtai/uClinux-dist/romfs/rtai-t!stsuit!/us!r/lat!nc2/
```

And rebuild `μClinux`:

```
$ cd /opt/rtai/uClinux-dist
```

```
$ mak!
```

Then load and run `μClinux` using the `d/68` monitor of the built-in ROMs. Use the `dn` command to load the image. And then type `&o 40020000` to run it.

Insert required modules again:

```
D insmod rtai%hal.ko
```

```
D insmod rtai%sch!d.ko
```

```
D insmod rtai%s!m.ko
```

```
D insmod rtai%fifos.ko
```

```
D insmod rtai%mbx.ko
```

```
D insmod rtai%ms&.ko
```

```
D cd /rtai-t!stsuit!
```

And finally launch user-space latency test in periodic mode:

```
D cd us!r/lat!nc2
```

```
D ./lat!nc20
```

```
D ./displa2
```

Latency test will be displaying its results, until you press ENTER.

```
D cd ../..
```

User-space *preempt* test:

```
D cd us!r/pr!!mpt
```

```
D ./pr!!mpt0
```

```
D ./displa2
```

Preempt test will be displaying its results, until you press Ctrl+C twice.

```
D cd ../..
```

User-space *switches* test:

```
D cd us!r/sMi tch!s
```

```
D ./sMi tch!s
```

Switches test will be displaying its results after few seconds.

Note: The description for each test can be found in README file in the test directory.

3* C7an3es -n t7e 8Cl-nu9 an+ l6P-pe ! our,e
Co+e

Both μ Clinux and I-Pipe source code has been changed during porting. Changes affect architecture-dependent part. I-Pipe was ported to the m68knommu architecture.

1. The `return` function from `arch/m68knommu/platform/coldfire/entry.S` was modified to call `._614;._%<99;%5<.;` macro. It was made to process syscalls correctly with the I-Pipe;
2. The `s2st!m%call` function from `arch/m68knommu/platform/coldfire/entry.S` was modified to call `C4;C=%<99;%)G)C411` macro. It was made to deliver syscall to the I-Pipe;
3. The `trap` function from `arch/m68knommu/kernel/entry.S` was modified to call `%%ipip!%handl!%!xc!ptionJK` function. It was made to deliver exceptions to the I-Pipe;
4. The `inthandl!r` function from `arch/m68knommu/platform/5307/entry.S` was modified to call `ipip!%irH%handl!rJK` function instead of Linux interrupt handler. It was made to deliver interrupts to the I-Pipe;
5. All interrupt enabling/disabling routines from `include/asm-m68knommu/system.h` were modified to use the I-Pipe stall/unstall domain functions instead of hardware interrupt managing. The functions with `%hm` suffix which implement hardware interrupts enabling/disabling were added;
6. The `rad%tim!r%cntJK` function was added to `arch/m68knommu/platform/coldfire/timers.c`. This function calculates the number of timer ticks passed from the timer initialization. It is used to implement the `rdtscJK` function in the `m68knommu` RTAI part;
7. The `ack%linux%icr0JK` function was added to `arch/m68knommu/kernel/ipipe.c`. It was made to perform correct acknowledgment of the FEC and UART interrupt routines in the I-Pipe;
8. The `,< .F` macro definition was modified in `arch/m68knommu/platform/coldfire/timers.c` to equal to `-C,%/6)C10`. It was made because of another timer frequency;

9. The `mcf_tmr_tick_JK` function from *arch/m68knommu/platform/coldfire/timers.c* was modified by deleting timer acknowledgment, because now it is performed from the I-Pipe;
10. The `mcf_tmr_readclk_JK` function from *arch/m68knommu/platform/coldfire/timers.c* was modified to use `read_timer_cnt_JK` function;
11. The `hM_timer_init_JK` function from *arch/m68knommu/platform/coldfire/timers.c* was modified to initialize timer to work with better timer precision;
12. The `ack_linux_tmr_JK` function was added to *arch/m68knommu/platform/coldfire/timers.c* to perform correct timer interrupt acknowledgment in I-Pipe;
13. The `mcf_interrupt_JK` function from *drivers/serial/mfc.c* was modified to enable UART interrupt. It was made to perform correct UART interrupt acknowledgment;
14. The `falcon_interrupt_JK` function from *drivers/net/fec.c* was modified to enable FEC interrupt. It was made to perform correct FEC interrupt acknowledgment.

:* C7an3es -n RTAI ! our,e Co+e

RTAI source code has been changed during porting. Changes affect both architecture-independent and architecture-dependent parts.

Main changes in RTAI code are described here.

:*)* RTAI &AL C7an3es

In RTAI HAL (file */base/arch/m68knommu/hal.c*) the following changes were made:

1. Timer code was changed to work with ColdFire timer. First system timer is used by both RTAI for scheduling real time processes and Linux when RTAI scheduler is inactive.
2. *rdtscJK* function implementation is now based on *r!ad%tim!r%cntJK* kernel function. Thus RDTSC functionality is emulated by ColdFire timer.

```
lon& lon& rdtscJK
@
    r!turn    r!ad%tim!r%cntJK > Jtun!d.cpu%fr!H / ;5-.<%,<.FKC
A
```

3. RTAI SRQ dispatcher code was adopted to MCF5329. SRQ dispatcher is a function that is called as a trap handler from user space to access RTAI functionality. The result of a syscall is always a 64-bit value, but it's meaning depends on a specific syscall.

```
//P! ha7!E d0 - srHL d1 - ar&sL d2 - r!t7al
asmlinka&! int    rtai%s2scall%dispatch!r    J%%7olatil!    struct
pt%r!&s ptK
@
    int cpuidC
    //unsi&n!d lon& lsr + pt.src
    lon& lon& r!sultC
    //5,%5)%4%6)5%)<F%C411%5;Jpt.d0L pt.d1L Jlon& lon&>Kpt.d2L
lsrL 0KC
    if Jusi%)<F%callJpt.d0L pt.d1L Or!sultL pt.srKK
        r!turn 0C
    r!sult      +      pt.d0      *      <;45%I<%)<F)      Q
rtai%lxrt%dispatch!rJpt.d0L      pt.d1L      J7oid      >KOptK      E
rtai%usrH%dispatch!rJpt.d0L pt.d1KC
```

```

pt.d2 + r!sult 0 0x,,,,,,,,,C
pt.d + Jr!sult ** 2KC
if Jr!in%hrt%mod!Jcpuid + rtai%cpuidJKKK @
    hal%t!st%and%fast%flush%pip!lin!JcpuidKC
    r!turn 1C
A
r!turn 0C
A

Dd!fin! )4'.%<.8 B
    Smo7!      D0x2T00LUsrBnBtS      /> disabl! intrs >/ B
    Sbtst      D#LUsPNJ2KBnBtS        /> from us!rQ >/ B
    Sbn!s      6fBnBtS                /> noL skip >/ B
    Smo7!l     USpLSM%uspBnBtS        /> sa7! us!r sp
>/ B
    SaddyHl    D8LSM%uspBnBtS        /> r!mo7! !xc!ption >/ B
    Smo7!l     sM%kspLUsPNBnBtS      /> k!rn!l sp >/ B
    SsubHl     D8LUsPNBnBtS          /> room for !xc!ption >/
B
    Scrlrl     UspN-BnBtS             /> stkadv >/ B
    Smo7!l     Ud0LUsPN-BnBtS        /> ori& d0 >/ B
    Smo7!l     Ud0LUsPN-BnBtS        /> d0 >/ B
    Sl!a UspNJ- 2KLUsPNBnBtS        /> spac! for 8 r!&s >/ B
    Smo7!ml    Ud1-Ud#/Ua0-Ua2LUsPNBnBtS B
    Smo7!l     sM%usPLua0BnBtS        /> &!t usp >/ B
    Smo7!l     Ua0N-LUsPNJ48KBnBtS    /> cop2 !xc!ption
program count!r J(;%(C+48K>/ B
    Smo7!l     Ua0N-LUsPNJ44KBnBtS /> cop2 !xc!ption
format/7!ctor/sr J(;%,9<-4;''.C+44K>/ B
    Sbra TfBnBtS B
    S6EBnBtS B
    Scrlrl     UspN-BnBtS             /> stkadv >/ B
    Smo7!l     Ud0LUsPN-BnBtS        /> ori& d0 >/ B
    Smo7!l     Ud0LUsPN-BnBtS        /> d0 >/ B
    Sl!a UspNJ- 2KLUsPNBnBtS        /> spac! for 8 r!&s >/ B
    Smo7!ml    Ud1-Ud#/Ua0-Ua2LUsPNBnBtS B
    STEBnBtS B
    Smo7!      D0x2000LUsrBnBtS

Dd!fin! <);<%<.8 B
    Sbtst      D#LUsPNJ46KBnBtS      /> &oin& us!rQ
J(;%)<+46K>/ B
    Sbn!s      8fBnBtS                /> noL skip >/ B
    Smo7!      D0x2T00LUsrBnBtS      /> disabl! intrs >/ B
    Smo7!l     sM%usPLua0BnBtS        /> &!t usp >/ B
    Smo7!l     UspNJ48KLua0N-BnBtS    /> cop2 !xc!ption
program count!r J(;%(C+48K>/ B

```



```

    Smo7!!    UspNJ44KLua0N-BnBtS />          cop2          !xc!ption
format/7!ctor/sr J(;% ,9<-4;' .C+44K>/ B
    Smo7!ml    UspNLUd1-Ud#/Ua0-Ua2BnBtS B
    Sl!a UspNJ 2KLUSpBnBtS          /> spac! for 8 r!&s >/ B
    Smo7!!    UspNWLUD0BnBtS B
    SaddHl    D4LUSpBnBtS          /> ori& d0 >/ B
    Saddl     UspNWLUSpBnBtS          /> stkadv >/ B
    SaddHl    D8LUSpBnBtS          /> r!mo7! !xc!ption >/ B
    Smo7!!    UspLSM%kspBnBtS          /> sa7! ksp >/ B
    SsubHl    D8LSM%uspBnBtS          /> s!t !xc!ption >/ B
    Smo7!!    sm%usplUSpBnBtS          /> r!stor! usp >/ B
    Srt!BnBtS B
    S8EBnBtS B
    Smo7!ml    UspNLUd1-Ud#/Ua0-Ua2BnBtS B
    Sl!a UspNJ 2KLUSpBnBtS          /> spac! for 8 r!&s >/ B
    Smo7!!    UspNWLUD0BnBtS B
    SaddHl    D4LUSpBnBtS          /> ori& d0 >/ B
    Saddl     UspNWLUSpBnBtS          /> stkadv >/ B
    Srt!S

```

```

Dd!fin! 3.,5I.%'.C;9<.3%5)<Jnam!L funk B
%%asm%% J B
    )G-/91%I4-.%);<Jnam!K SEBnBtS B
    )4' .%<.8 B
    SVsr S)G-/91%I4-.%);<JfunkSBnBtS B
    <);<%<.8KC

```

```

7oid rtai%u7!c%handl!rJ7oidKC
3.,5I.%'.C;9<.3%5)<Jrtai%u7!c%handl!rL
rtai%s2scall%dispatch!rKC

```

This code switches stack from user-space stack to kernel-space when RTAI syscall occurs and switches back at syscall return. Stack switching code is similar to Linux syscalls implementation, because this RTAI code is based on it.

- Two functions from *rtai_atomic.h* (`atomic%exch&JK` and `atomic%cmpxch&JK`) were changed to use RTAI traps. The following trap code was added to the HAL:

```

7oid rtai%cmpxch&%trap%handl!rJ7oidKC
%%asm%% J B
    Srtai%cmpxch&%trap%handl!rEBnBtS B
    Smo7!    D0x2T00LUSrBnBtS B
    Smo7!!    Ua1NL Ud0BnBtS B
    Scmpl     Ud0LUd2BnBtS B
    Sbn!s     1fBnBtS B
    Smo7!!    Ud LUa1NBnBtS B

```

```

    S1EBnBtS B
    Srt!SKC

```

```

void rtai%xch&%trap%handl!rJ7oidKC

```

```

%%asm%% J B

```

```

    Srtai%xch&%trap%handl!rEBnBtS B

```

```

    Smo7! D0x2T00LUsrBnBtS B

```

```

    Smo7!! Ua1NL Ud0BnBtS B

```

```

    Smo7!! Ud2LUa1NBnBtS B

```

```

    Srt!SKC

```

```

...

```

```

    rtai%xch&%trap%7!c +

```

```

    rtai%s!t%&at!%7!ctorJ<;45%:C=8%;<4(%)G)%'.C;9<L 1#L L

```

```

    Ortai%xch&%trap%handl!rKCrtaixch&%trap%7!c +

```

```

    rtai%s!t%&at!%7!ctorJ<;45%C-( :C=8%;<4(%)G)%'.C;9<L 1#L L

```

```

    Ortai%cmpxch&%trap%handl!rKC

```

5. `rt%s!t%tim!r%d!la2JK` function from `rtai_hal.h` was changed to work with ColdFire timer and was made cache-aware to avoid timer TCN overruns (i.e. when TCN is further then TRR).

:*2* RTC Removal

RTAI port for MCF5329 doesn't allow to use an RTC as a time source, so all related code was removed.

:*3* RTAI LEDs !upport

`rtai_leds` module hasn't been ported, because LED functionality doesn't depend on RTAI. If you need to use LEDs for debugging you will need to write a code that is specific to your LEDs and hardware it is based on.

5. Programming with RTAI.

This section gives some information about creation of RTAI applications.

The following acronyms were used in this section:

<uClinux> - μ Clinux root directory

<rtai> - RTAI root directory

<filename> - name code of file that should be built (without extension).

This section describes building of written RTAI application or module, it doesn't cover any programming information.

For help in RTAI API please refer to RTAI Doxygen documentation or RTAI programming manuals.

5*) Create user-space RTAI programs

To compile **<filename>.c** in user-space that uses some exportations from **liblxt** library:

1. Change the current directory to the directory with **<filename>.c**;
2. Compile **<filename>.c** to the object file **<filename>.o**:

```
$ m68k-uclinux-&cc -3=4'.%C9I,58%= -5. -  
5<uClinux>/linux-2.6.x/include! -3C9I,58%6C15I6: -3%%5I%<;45%%  
-5<rtai>/bas!/include! -5<rtai> -m# 0T -PaL-m# 0T -c -o  
<filename>.o <filename>.c
```

3. Link **<filename>.o** to the executable **<filename>**:

```
$ m68k-uclinux-&cc -m# 0T -PaL-m# 0T -PL-!lf2flt -o  
<filename> <filename>.o <rtai>/bas!/sch!d/liblxt/liblxt.a  
-lpthr!ad
```

4. If there were no errors, then in the current folder **<filename>** executable will appear. Then it can be added to the romfs of μ Clinux.

5.2 Creating a kernel-space RTAI module

1. To compile kernel-space RTAI-based module `<filename>.c` for MCF5329, the next steps should be done:
2. Change the current directory to the directory with `<filename>.c`;
3. Create `Makefile` file and put the next lines into it:

```
rtai%srcdir!!E+<rtai>

.:;C,148)W+-5$Jrtai%srcdir!!K -5$
Jrtai%srcdir!!K/bas//include

obj-m E+ <filename>.o
```

4. Launch the make utility:

```
$ make -C <uclinux> &+$(P3 module)
```

5. If there were no errors, `<filename>.ko` kernel module will appear in the current folder. Then it can be added to the romfs of μ CLinux.