

# Booting linux on ESP32s3

Sources:

- <https://github.com/jcmvbkbc/xtensa-dynconfig/tree/original>
- <https://github.com/jcmvbkbc/config-esp32s3>
- <https://github.com/jcmvbkbc/esp-idf/tree/linux-5.0.1>
- <https://github.com/jcmvbkbc/linux-xtensa/tree/xtensa-6.4-esp32>
- <https://github.com/jcmvbkbc/binutils-gdb-xtensa/tree/xtensa-2.40-fdpic>
- <https://github.com/jcmvbkbc/gcc-xtensa/tree/xtensa-14-fdpic>
- <https://github.com/jcmvbkbc/uclibc-ng-xtensa/tree/xtensa-fdpic>
- <https://github.com/jcmvbkbc/buildroot/tree/xtensa-2023.02-fdpic>
- <https://github.com/jcmvbkbc/crostoool-NG/tree/xtensa-fdpic>

Example kernel and rootfs images built from the above sources as well as a toolchain archive:  
<http://jcmvbkbc.spb.ru/~dumb/tmp/202305161729/>

## Build toolchain dynconfig library and export XTENSA\_GNU\_CONFIG for use by the toolchain

```
$ git clone https://github.com/jcmvbkbc/xtensa-dynconfig -b original
$ git clone https://github.com/jcmvbkbc/config-esp32s3 -o esp32s3
$ make -C xtensa-dynconfig ORIG=1 CONF_DIR=`pwd` esp32s3.so
$ export XTENSA_GNU_CONFIG=`pwd`/xtensa-dynconfig/esp32s3.so # make sure
this environment variable is set for all commands involving building or
using the toolchain
```

## Build the toolchain

Using crostoool-NG:

```
$ git clone https://github.com/jcmvbkbc/crostoool-NG.git -b xtensa-fdpic
$ pushd crostoool-NG
$ ./bootstrap && ./configure --enable-local && make
$ ./ct-ng xtensa-esp32s3-linux-uclibcdfpic
$ CT_PREFIX=`pwd`/builds nice ./ct-ng build
$ popd
```

It doesn't complete successfully ATM, failing with the following message, but it builds and installs everything that's important.

```
...
[INFO ] Installing final gcc compiler: done in 572.47s (at 29:47)
[INFO ] =====
[INFO ] Checking dynamic linker symlinks
[EXTRA] Checking dynamic linker for multilib ''
```

```
[ERROR] collect2: error: ld returned 1 exit status
[ERROR]
[ERROR] >>
[ERROR] >> Build failed in step 'Checking dynamic linker symlinks'
[ERROR] >>      called in step '(top-level)'
[ERROR] >>
[ERROR] >> Error happened in: CT_DoExecLog[scripts/functions@377]
[ERROR] >>      called from: CT__FixupLDS0[scripts/functions@1695]
[ERROR] >>      called from: CT_IterateMultilibs[scripts/functions@1608]
[ERROR] >>      called from: CT_MultilibFixupLDS0[scripts/functions@1761]
[ERROR] >>      called from: uClibc_ng_post_cc[scripts/build/libc/uClibc-
ng.sh@335]
[ERROR] >>      called from: do_libc_post_cc[scripts/build/libc.sh@38]
[ERROR] >>      called from: main[scripts/crosstool-NG.sh@697]
[ERROR] >>
...
```

Or manually:

```
$ git clone https://github.com/jcmvbkbc/binutils-gdb-xtensa -b xtensa-2.40-fdpic
$ git clone https://github.com/jcmvbkbc/gcc-xtensa -b xtensa-14-fdpic
$ git clone https://github.com/jcmvbkbc/linux-xtensa -b xtensa-6.4-esp32
$ git clone https://github.com/jcmvbkbc/uclibc-ng-xtensa -b xtensa-fdpic
$ mkdir build-xtensa-fdpic-toolchain-esp32s3 ; mkdir build-xtensa-fdpic-nothread-esp32s3
$ ( cd build-xtensa-fdpic-toolchain-esp32s3 ; rm -rf * ; FLAGS_FOR_TARGET='-mtext-section-literals -mfdpic -O2 -g -mforce-l32' nice ../build-xtensa-fdpic-toolchain.sh )
$ ( cd build-xtensa-fdpic-nothread-esp32s3 ; rm -rf * ; CROSS_COMPILE=`pwd`/../build-xtensa-fdpic-toolchain-esp32s3/root/bin/xtensa-linux-uclibcfdpic- TARGET_CFLAGS='-mauto-litpools -mforce-l32 -D_LARGEFILE64_SOURCE -D_FILE_OFFSET_BITS=64' ../build.sh )
$ ln -s `pwd`/build-xtensa-fdpic-nothread-esp32s3/sysroot build-xtensa-fdpic-toolchain-esp32s3/root/xtensa-linux-uclibcfdpic/
```

build-xtensa-fdpic-toolchain.sh:

```
#!/bin/bash -ex

src_base=$(dirname $(readlink -f "$0"))
binutils_src="$src_base/binutils-gdb"
gcc_src="$src_base/gcc"

target=${TARGET:-xtensa-linux-uclibcfdpic}
base=`pwd`

_FLAGS_FOR_TARGET=${FLAGS_FOR_TARGET:--mtext-section-literals -mfdpic -O2 -g}
```

```

mkdir binutils && (
    cd binutils
    "$binutils_src/configure" --prefix="$base/root" \
        --target=$target \
        --disable-shared --disable-werror --disable-gdb --disable-
gdbstub \
        CFLAGS='-O0 -g'

    make -j8
    make -j8 install
)

mkdir gcc && (
    cd gcc
    "$gcc_src/configure" --prefix="$base/root" \
        --target=$target \
        --with-sysroot="$base/root/$target/sysroot" \
        --enable-languages=c \
        --disable-shared \
        --enable-__cxa_atexit \
        --enable-tls --disable-threads \
        --without-headers --with-newlib \
        CFLAGS_FOR_TARGET="$_FLAGS_FOR_TARGET" \
        CXXFLAGS_FOR_TARGET="$_FLAGS_FOR_TARGET" \
        CFLAGS='-O0 -g' \
        CXXFLAGS='-O0 -g'

    make -j8 all-gcc
    make -j8 all-target-libgcc
    make -j8 install-gcc
    make -j8 install-target-libgcc
)

```

build.sh:

```

#!/bin/bash -ex

if [ $1 = "-r" ]; then
    reconfigure=1
fi
base=$(dirname $(readlink -f "$0"))
export CROSS_COMPILE=${CROSS_COMPILE:-xtensa-dc233c-elf-}
export TARGET_CFLAGS="${TARGET_CFLAGS:--mlongcalls -mauto-litpools -
D_LARGEFILE64_SOURCE -D_FILE_OFFSET_BITS=64}"

if [ ! -d build-linux ]; then
    cur=`pwd`
    mkdir -p build-linux
    cd build-linux
    make -C $base/linux ARCH=xtensa O=`pwd` defconfig
    make -C $base/linux ARCH=xtensa O=`pwd` INSTALL_HDR_PATH="$cur" -j8

```

```
headers_install
    cd ..
fi

#base=$(dirname "$0")
if [ -z "$reconfigure" ]; then
    [ -f .config ] || make -C $base/uclibc-ng ARCH=xtensa O=`pwd`
    KERNEL_HEADERS=`pwd`/include UCLIBC_EXTRA_CFLAGS="${TARGET_CFLAGS}"
    defconfig
else
    make -C $base/uclibc-ng ARCH=xtensa O=`pwd`
    KERNEL_HEADERS=`pwd`/include UCLIBC_EXTRA_CFLAGS="${TARGET_CFLAGS}"
    menuconfig
fi

make -C $base/uclibc-ng ARCH=xtensa O=`pwd` KERNEL_HEADERS=`pwd`/include
UCLIBC_EXTRA_CFLAGS="${TARGET_CFLAGS}" -j8 "$@"
make -C $base/uclibc-ng ARCH=xtensa O=`pwd` KERNEL_HEADERS=`pwd`/include
UCLIBC_EXTRA_CFLAGS="${TARGET_CFLAGS}" DESTDIR=`pwd`/sysroot install
```

## Build the rootfs

```
$ git clone https://github.com/jcmvbkbc/buildroot -b xtensa-2023.02-fdpic
$ nice make -C buildroot O=`pwd`/build-xtensa-2023.02-fdpic-esp32s3
qemu_xtensa_kc705_xip_defconfig
$ # adjust external toolchain location to the one built above
$ nice make -C buildroot O=`pwd`/build-xtensa-2023.02-fdpic-esp32s3
```

## Build and flash the bootloader, flash kernel and rootfs images

```
$ git clone https://github.com/jcmvbkbc/esp-idf -b linux-5.0.1
$ pushd esp-idf
$ . export.sh
$ cd examples/get-started/linux_boot
$ idf.py set-target esp32s3
$ idf.py build
$ idf.py flash
$ popd
$ parttool.py -p /dev/ttyUSB0 write_partition --partition-name linux --input
xip-esp32s3-esp32s3/arch/xtensa/boot/xipImage
$ parttool.py -p /dev/ttyUSB0 write_partition --partition-name rootfs --
input build-xtensa-2023.02-fdpic-esp32s3/images/rootfs.cramfs
```

## The result

```
ESP-ROM:esp32s3-20210327
Build:Mar 27 2021
rst:0x1 (POWERON),boot:0x8 (SPI_FAST_FLASH_BOOT)
SPIWP:0xee
mode:DI0, clock div:1
load:0x3fce3810,len:0x10a0
load:0x403c9700,len:0xa24
load:0x403cc700,len:0x2d04
entry 0x403c988c
I (73) octal_psram: vendor id      : 0x0d (AP)
I (73) octal_psram: dev id        : 0x02 (generation 3)
I (74) octal_psram: density       : 0x03 (64 Mbit)
I (78) octal_psram: good-die      : 0x01 (Pass)
I (83) octal_psram: Latency       : 0x01 (Fixed)
I (89) octal_psram: VCC           : 0x01 (3V)
I (93) octal_psram: SRF           : 0x01 (Fast Refresh)
I (99) octal_psram: BurstType     : 0x01 (Hybrid Wrap)
I (105) octal_psram: BurstLen     : 0x01 (32 Byte)
I (110) octal_psram: Readlatency  : 0x02 (10 cycles@Fixed)
I (117) octal_psram: DriveStrength: 0x00 (1/1)
I (122) esp_psram: Found 8MB PSRAM device
I (126) esp_psram: Speed: 80MHz
I (130) cpu_start: Pro cpu up.
I (134) cpu_start: Starting app cpu, entry point is 0x40375344
I (0) cpu_start: App cpu up.
I (593) esp_psram: SPI SRAM memory test OK
I (602) cpu_start: Pro cpu start user code
I (602) cpu_start: cpu freq: 160000000 Hz
I (602) cpu_start: Application information:
I (605) cpu_start: Project name:   linux_boot
I (610) cpu_start: App version:    v5.0.1-4-g680509ab40d1
I (617) cpu_start: Compile time:   May 7 2023 16:29:12
I (623) cpu_start: ELF file SHA256: a110e4309915b853...
I (629) cpu_start: ESP-IDF:       v5.0.1-4-g680509ab40d1
I (635) cpu_start: Min chip rev:   v0.0
I (640) cpu_start: Max chip rev:   v0.99
I (644) cpu_start: Chip rev:       v0.1
I (649) heap_init: Initializing. RAM available for dynamic allocation:
I (656) heap_init: At 3FC958C0 len 00053E50 (335 KiB): D/IRAM
I (663) heap_init: At 3FCE9710 len 00005724 (21 KiB): STACK/DRAM
I (669) heap_init: At 3FCF0000 len 00008000 (32 KiB): DRAM
I (676) heap_init: At 600FE010 len 00001FF0 (7 KiB): RTCRAM
I (682) esp_psram: Adding pool of 8192K of PSRAM memory to heap allocator
I (690) spi_flash: detected chip: generic
I (694) spi_flash: flash io: dio
I (699) cpu_start: Starting scheduler on PRO CPU.
I (0) cpu_start: Starting scheduler on APP CPU.
I (719) esp_psram: Reserving pool of 32K of internal memory for DMA/internal
allocations
ptr = 0x42830000
ptr = 0x42b30000
```

```
[ 0.000000] Ignoring boot parameters at (ptrval)
[ 0.000000] Linux version 6.3.0-00022-g5d8354462a70 (jcmvbkbc@octofox)
(xtensa-dc233c-elf-gcc (GCC) 13.1.0, GNU ld (GNU Binutils) 2.40) #39 PREEMPT
Sun May 7 16:35:44 PDT 2023
[ 0.000000] config ID: c2f0fffe:23090f1f
[ 0.000000] earlycon: esp32uart0 at MMI032 0x60000000 (options
'115200n8')
[ 0.000000] printk: bootconsole [esp32uart0] enabled
[ 0.000000] *****
[ 0.000000] ** NOTICE NOTICE NOTICE NOTICE NOTICE NOTICE NOTICE **
[ 0.000000] **
[ 0.000000] ** This system shows unhashed kernel memory addresses **
[ 0.000000] ** via the console, logs, and other interfaces. This **
[ 0.000000] ** might reduce the security of your system. **
[ 0.000000] **
[ 0.000000] ** If you see this message and you are not debugging **
[ 0.000000] ** the kernel, report this immediately to your system **
[ 0.000000] ** administrator! **
[ 0.000000] **
[ 0.000000] ** NOTICE NOTICE NOTICE NOTICE NOTICE NOTICE NOTICE **
[ 0.000000] *****
[ 0.000000] Zone ranges:
[ 0.000000] Normal [mem 0x000000003c030000-0x000000003c82ffff]
[ 0.000000] Movable zone start for each node
[ 0.000000] Early memory node ranges
[ 0.000000] node 0: [mem 0x000000003c030000-0x000000003c82ffff]
[ 0.000000] Initmem setup node 0 [mem
0x000000003c030000-0x000000003c82ffff]
[ 0.000000] pcpu-alloc: s0 r0 d32768 u32768 alloc=1*32768
[ 0.000000] pcpu-alloc: [0] 0
[ 0.000000] Built 1 zonelists, mobility grouping off. Total pages: 2032
[ 0.000000] Kernel command line:
earlycon=esp32uart,mmio32,0x60000000,115200n8 console=ttyS0,115200n8 debug
rw root=mtd:data no_hash_pointers
[ 0.000000] Dentry cache hash table entries: 1024 (order: 0, 4096 bytes,
linear)
[ 0.000000] Inode-cache hash table entries: 1024 (order: 0, 4096 bytes,
linear)
[ 0.000000] mem auto-init: stack:off, heap alloc:off, heap free:off
[ 0.000000] virtual kernel memory layout:
[ 0.000000] lowmem : 0x3c030000 - 0x3c830000 ( 8 MB)
[ 0.000000] .text : 0x42830000 - 0x429e0d28 ( 1731 kB)
[ 0.000000] .rodata : 0x429e1000 - 0x42a1f000 ( 248 kB)
[ 0.000000] .data : 0x3c030000 - 0x3c0a9420 ( 485 kB)
[ 0.000000] .init : 0x3c0a9420 - 0x3c0adf00 ( 18 kB)
[ 0.000000] .bss : 0x3c0adf00 - 0x3c0e1988 ( 206 kB)
[ 0.000000] Memory: 7332K/8192K available (1731K kernel code, 485K
rwdata, 248K rodata, 88K init, 206K bss, 860K reserved, 0K cma-reserved)
[ 0.000000] SLUB: HWalig=16, Order=0-3, MinObjects=0, CPUs=1, Nodes=1
```

```
[ 0.000000] rcu: Preemptible hierarchical RCU implementation.
[ 0.000000] rcu: RCU calculated value of scheduler-enlistment delay is 10
jiffies.
[ 0.000000] NR_IRQS: 33
[ 0.000000] rcu: srcu_init: Setting srcu_struct sizes based on
contention.
[ 0.000000] clocksource: ccount: mask: 0xffffffff max_cycles: 0xffffffff,
max_idle_ns: 11945377789 ns
[ 0.000086] sched_clock: 32 bits at 160MHz, resolution 6ns, wraps every
13421772796ns
[ 0.008110] Calibrating delay loop (skipped)... 160.00 BogoMIPS preset
[ 0.014370] pid_max: default: 4096 minimum: 301
[ 0.021337] Mount-cache hash table entries: 1024 (order: 0, 4096 bytes,
linear)
[ 0.026541] Mountpoint-cache hash table entries: 1024 (order: 0, 4096
bytes, linear)
[ 0.077044] rcu: Hierarchical SRCU implementation.
[ 0.077673] rcu: Max phase no-delay instances is 1000.
[ 0.091972] devtmpfs: initialized
[ 0.115533] clocksource: jiffies: mask: 0xffffffff max_cycles:
0xffffffff, max_idle_ns: 19112604462750000 ns
[ 0.116804] futex hash table entries: 16 (order: -5, 192 bytes, linear)
[ 0.139676] NET: Registered PF_NETLINK/PF_ROUTE protocol family
[ 0.156790] platform soc: Fixed dependency cycle(s) with
/soc/intc@600c2000
[ 0.219233] clocksource: Switched to clocksource ccount
[ 0.266507] NET: Registered PF_INET protocol family
[ 0.274408] IP idents hash table entries: 2048 (order: 2, 16384 bytes,
linear)
[ 0.294920] tcp_listen_portaddr_hash hash table entries: 1024 (order: 0,
4096 bytes, linear)
[ 0.296128] Table-perturb hash table entries: 65536 (order: 6, 262144
bytes, linear)
[ 0.303770] TCP established hash table entries: 1024 (order: 0, 4096
bytes, linear)
[ 0.309855] TCP bind hash table entries: 1024 (order: 1, 8192 bytes,
linear)
[ 0.315629] TCP: Hash tables configured (established 1024 bind 1024)
[ 0.326107] UDP hash table entries: 256 (order: 0, 4096 bytes, linear)
[ 0.329877] UDP-Lite hash table entries: 256 (order: 0, 4096 bytes,
linear)
[ 0.340029] NET: Registered PF_UNIX/PF_LOCAL protocol family
[ 0.361833] workingset: timestamp_bits=30 max_order=11 bucket_order=0
[ 2.712542] 60000000.serial: ttyS0 at MMIO 0x60000000 (irq = 1, base_baud
= 0) is a ESP32 UART
[ 2.714408] printk: console [ttyS0] enabled
[ 2.714408] printk: console [ttyS0] enabled
[ 2.720147] printk: bootconsole [esp32uart0] disabled
[ 2.720147] printk: bootconsole [esp32uart0] disabled
[ 2.759786] physmap-flash 42830000.flash: physmap platform flash device:
[mem 0x42830000-0x4302ffff]
```

```
[ 2.761481] 2 fixed-partitions partitions found on MTD device
42830000.flash
[ 2.765620] Creating 2 MTD partitions on "42830000.flash":
[ 2.772746] 0x00000000000000-0x00000003000000 : "linux"
[ 2.787049] 0x00000003000000-0x00000008800000 : "data"
[ 2.787809] mtd: partition "data" extends beyond the end of device
"42830000.flash" -- size truncated to 0x500000
[ 2.814687] NET: Registered PF_PACKET protocol family
[ 3.044471] cramfs: checking physical address 0x42b30000 for linear
cramfs image
[ 3.045351] cramfs: linear cramfs image on mtd:data appears to be 1808 KB
in size
[ 3.052366] VFS: Mounted root (cramfs filesystem) readonly on device
31:1.
[ 3.057890] devtmpfs: mounted
[ 3.062212] Freeing unused kernel image (initmem) memory: 12K
[ 3.064482] This architecture does not have kernel memory protection.
[ 3.072536] Run /sbin/init as init process
[ 3.074991]     with arguments:
[ 3.077870]         /sbin/init
[ 3.081602]     with environment:
[ 3.083725]         HOME=/
[ 3.086028]         TERM=linux
Starting syslogd: OK
Starting klogd: OK
Running sysctl: OK
seedrng: can't create directory '/var/lib/seedrng': Read-only file system
Starting network: OK

Welcome to Buildroot
buildroot login: root
~ # cat /proc/cpuinfo
CPU count      : 1
CPU list       : 0
vendor_id      : Tensilica
model          : Xtensa LX7.0.12
core ID        : LX7_ESP32_S3_MP
build ID       : 0x90f1f
config ID      : c2f0fffe:23090f1f
byte order     : little
cpu MHz        : 160.00
bogomips      : 320.00
flags          : nmi debug ocd density boolean loop nsa minmax sext clamps
mac16 mul16 mul32 mul32h fpu s32cli
physical aregs : 64
misc regs     : 4
ibreak        : 2
dbreak        : 2
num ints      : 32
```

```
ext ints      : 26
int levels    : 6
timers        : 3
debug level   : 6
icache line size: 4
icache ways   : 1
icache size   : 0
icache flags  :
dcache line size: 16
dcache ways   : 1
dcache size   : 0
dcache flags  :
~ # free
available     total      used      free      shared  buff/cache
Mem:          7344      3264      3444         0        636
3208
~ #
```

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Last update: **2023/05/20 02:50**

