The IP04
Open telephony hardware for developing regions

The Free Telephony Project

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Free Telephony Project
Open Embedded Telephony

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1 Executive Summary

We have a vision. Anyone should be able to make a phone call to anyone else. Telephony should be regarded as a human right, not a privilege of the developed world. With the IP04, open hardware, and minimal capital cost, this vision is now possible.

This document describes the IP04, a low cost **open hardware** IP-PBX developed by the *Free Telephony Project*[1] for developing regions. The IP04 is a tiny, full function Asterisk-based IP-PBX with 4 analogue ports. It retails for around $400 but can be potentially be built and deployed to developing regions for under $100.

The **hardware design is free** as in speech. Anyone is welcome to copy, modify, and improve the hardware design, just like open software. Open hardware offers exciting new possibilities, for example dramatic end-user cost reductions; the potential for local manufacture; customisation to support developing world conditions such as low power and local languages; and flexibility, for example integration of solar charge controller and WiFi chip sets.

The IP04 is a **mature design** that is in volume production today. The next step is to deploy the technology for field trials to optimise the system and evaluate business models to support viral growth of the technology.

This document summarizes the IP04 project, including history of the product and key benefits for the developing world. Finally we present the outline of a plan for the next stage in the roll out of this technology: beta deployment of the 100 IP04 nodes.

1 Free Telephony Project, http://www.rowetel.com/ucasterisk

2 The IP04 Open Hardware IP-PBX

The IP04 is a 4 port IP-PBX that runs Asterisk and uClinux on a powerful embedded Blackfin processor[2]. To build an Asterisk IP-PBX you normally need a x86 PC plus PCI card for the analog ports. With the IP04 you get all of that functionality in a tiny, low cost, low power, silent box with no moving parts.

Unlike many other embedded processors, the Blackfin has enough DSP horsepower to handle multiple channels of echo cancellation and speech compression. This means that the IP04 is a complete IP-PBX with 4 analog ports. It is around 10 times as powerful as a WRT54G, yet consumes only a few watts. No PC required - not even for configuration!

The IP04 is an open hardware IP-PBX design. This means the design is available for anyone to modify, improve, or manufacture. As it runs uClinux and Asterisk (open source OS and IP-PBX application software) the software is also freely available.

For the developing world, open hardware offers many exciting opportunities, for example:

- The IP04 can be manufactured at near-cost price (sub $100 for a 4 port IP-PBX in Qty 1,000), and distributed through non-traditional methods (e.g. a NGO could arrange for manufacture of a batch and distribute through their channels). This is the same pricing model as the the OLPC, if we reduce the overheads the end-user price or IT hardware can be reduced by 75%.

- The IP04 hardware and software can be customised to suit local conditions, for example multi-lingual voice prompts can be installed to allow easy configuration and installation, or perhaps a simple user interface. The hardware could be combined with a wireless chipset and solar charge controller to produce a "turn key" solution to bring VOIP over WiFi to remote villages at extremely low cost.

3 The Free Telephony Project

The IP04 is the first product released by the *Free Telephony Project*. The Free Telephony project aims to release a range of open (free as in speech) reference designs for embedded (non x86) telephony products.

The project was started in 2005 by Dr. David Rowe, an Australian engineer who has 20 years experience in developing voice processing hardware and software. David founded, grew, and successfully exited www.voicetronix.com; a manufacturer of PCI based computer telephony hardware for Linux. He has a broad range of telephony hardware, software, DSP, and management experience and has held executive level positions in the sat-com industry (www.dspace.com).

In August 2005 David started porting Asterisk to the Blackfin processor, and a few months later had a basic version of Asterisk running on a STAMP development card.

2 Blackfin Linux Project, http://blackfin.uclinux.org

David was inspired by the Blackfin community who had released their development cards as "**open hardware**". So it was decided to follow this example and "open" the hardware designs. There are many people writing great open source software. However very few are making hardware or DSP code. David therefore decided to focus on those areas.

In 2006 David worked with some like minded developers to release open FXS/FXO analog hardware that could run on the STAMP card. In parallel, two talented Bulgarian engineers named Dimitar Penev and Ivan Danov developed and published an open hardware design for the BlackfinOne DSP motherboard. David combined the BlackfinOne design and the

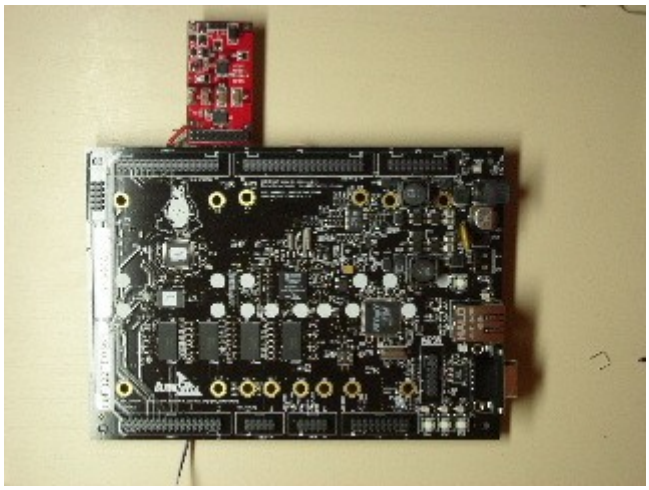

Figure 1: Early Blackfin-Asterisk prototype – a STAMP development card hacked to use a Digium FXO module!

FXS/FXO analog hardware to produce the IP04. Two Canadian software engineers, Wojtek Tryc and Pawel Pastuszak developed a convenient build system (Astfin) to generate the IP04 firmware. The IP04 project attracted the attention of Atcom[3], a commercial VOIP hardware manufacturer, who offered to build the product commercially in China. As with other open source projects, many other developers have also contributed.

Several hundred IP04s have now been manufactured and sold (up to November 2006). The design is tested and stable, and many companies are using the IP04 as a reference design for their own products. This success combined with the open hardware design will stimulate competition, encourage mass production and therefore act to further reduce the end-user price.

3.1 Community development model

It should be stressed that the IP04 is a community effort, with many people contributing. In no particular order: the Astfin[4] & BlackfinOne teams, uClinux[5], Analog Devices Blackfin team, the Asterisk community, and Atcom.

3 Atcom, http://www.atcom.cn/
4 Astfin http://astfin.org
5 uClinux http://blackfin.uclinux.org

4 IP04 Design

This section provides technical details of how the IP04 hardware and software works.

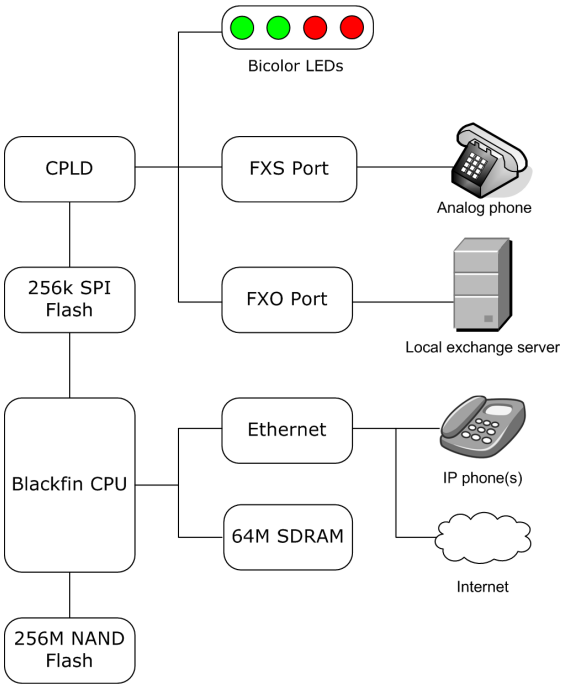

Figure 2: IP04 Hardware Architecture

When power is applied, the Blackfin boot ROM starts reading from the 256k SPI flash chip. The program it loads is called *u-boot*, a powerful boot loader that has been ported to the Blackfin by the Analog Devices Blackfin team. U-boot has a command line interface that lets you load other programs from flash or via Ethernet. In normal operation it automatically loads and executes the uClinux kernel.

A 256M NAND flash chips is used as the main storage for the IP04. NAND flash has the advantage of high density and low cost. It's the same hardware that is used in your MP3 player, so prices have plummeted over recent years. However the Blackfin boot ROM can't read the NAND flash directly, which is why we need the SPI flash chip and u-boot to support the start up process. Compared to many embedded Linux systems, the IP04 requires quite a lot of flash storage (around 16M minimum) to store the Asterisk executable and audio prompts.

After booting the kernel runs out of SDRAM, and the NAND flash is mapped to the root filesystem. We also use a portion of the SDRAM for temporary files, e.g. /tmp.

The IP04 runs Asterisk and the uClinux operating system. Asterisk was relatively easy to port to the Blackfin, thanks to the similarities of uClinux to the Linux operating system, and the maturity of the Blackfin gcc toolchain. The Astfin[6] build system is used - a system of nested Makefiles and patches that simplifies the complex build process required for the IP04.

6 Astfin, http://astfin.org/

Some changes to Asterisk were required to account for the lack of FPU and MMU on the Blackfin, for example porting of DTMF routines from floating point to fixed point. The standard Asterisk PCI card FXS/FXO port device drivers were ported to the Blackfin. Due to the richness of the Blackfins peripherals (e.g. TDM serial and SPI ports), the Blackfin device drivers are actually simpler compared to their PCI equivalents.

The 4 analog ports can be flexibly configured using single port FXS/FXO modules. The IP04 auto-detects the module type when it powers up and helpful LEDs indicate what flavour (FXS or FXO) each port is.

Use of the IP04 is similar to any other Asterisk box. You can telnet in, modify config files, or even use the new Asterisk GUI. Setting up the IP04 is easier than a x86 PC based Asterisk system: you don't need to install Asterisk, or even Linux. The IP04 comes pre-loaded with Asterisk and uClinux. Plug it in and in a few seconds you can make calls. With the IP04 you get dial tone out of the box!

4.1 Open Hardware Design

The IP04 is an open hardware project. The Blackfin portion of the design is based on the BlackfinOne DSP motherboard[7], and the FXO/FXS interfaces derived from Silicon Labs reference designs. The use of open hardware techniques helped bring the design together quickly and with minimum effort.

The specific benefit of open hardware is lower R&D costs. This has been the experience with the IP04 project - we have developed a leading edge IP-PBX design with a modest investment of effort, simply by working together with other open hardware and software developers.

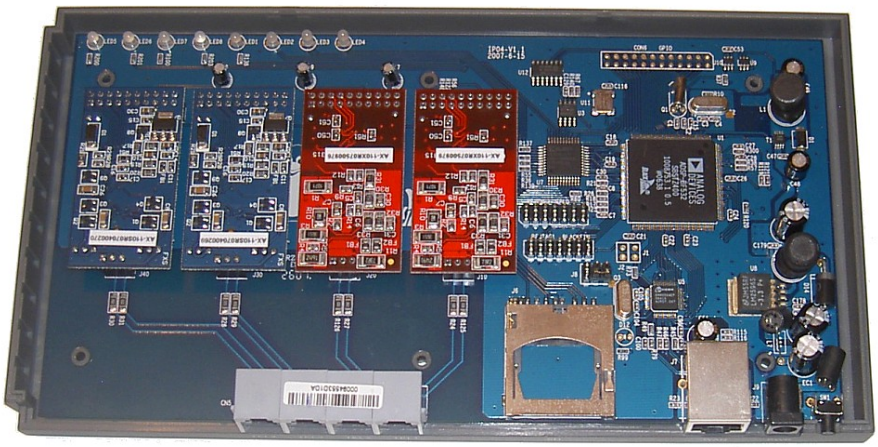

Figure 3: IP04 design manufactured by ATCOM.

Bug counts have been very low and development cycles very fast due to re-use of existing open hardware modules. The IP04 was booting uClinux and making phone calls using Asterisk **1 week** after the solder had cooled on the first prototype. This is practically unheard of in hardware development. The IP04 reached production 3 months later and the design has proven to be reliable and stable.
Similar tools and techniques to open software are used for open hardware development. For

7 BlackfinOne Project, http://blackfin.uclinux.org/gf/project/bf1

example the team uses SVN to store and share schematic and PCB files, as well as the software components of the IP04. The team is spread throughout the world, so chat, Skype, and email were used to coordinate hardware development and debugging. Blog posts have been used to document and share IP04 development instead of the traditional engineering log book.

Open hardware is a 21st Century technique to help solve a timeless problem – connecting the world.

5 Competitor Analysis

The IP04 is a leading edge embedded IP-PBX, equivalent to anything developed by traditional (closed development) commercial companies. The open hardware pedigree means that the hardware has been reviewed by "many eyes". This means (just like open software) that the IP04 is likely to be more stable and have higher quality compare to "closed" products.

It should be noted that the IP04 is one of the first embedded Asterisk "Appliance" type devices to be offered for commercial sale – community based development (open hardware and software) gave the development team a time-to-market edge.

Note also that with the right "business model" (e.g. NGO support for distribution, volume manufacture), the IP04 can be deployed for as low as $100 per unit, around 5% of the price of competing devices (e.g. the Asterisk Appliance) with equivalent functionality!

Product	**Arch**	**HW**	**SW**	**Interfaces**	**Power**	**Features**	**Status (Nov 2007)**	**Price (USD)**
IP04	Blackfin	Open	Open	1 Ethernet 4 FXS/FXO	very low	MMC card	Production	450
IP08	Blackfin	Open	Open	2 Ethernet 8 FXS/FXO	very low	MMC card USB	Prototype	N/A
Asterisk Appliance	Blackfin	Closed	Open	5 Ethernet (4 LAN, 1 WAN) 8 FXS/FXO	low	HW echo, CF card	Production	1259 (VoIP only) 1859 (4 FXO)
Vdex-40	Mindspeed	Closed	Open	1 Ethernet 4 FXO	low	HW echo	Evaluation	695
Trixbox	x86	Closed	Open	Any with expansions	high	4 line LCD	Production	1499 (4 FXOs)
Magiclink	Blackfin	Closed	??	2 Ethernet 4/8 FXO	very low	based on IP04	Evaluation	899 (1+)
Astfin	Blackfin	Open	Open	1 Ethernet 1 PRI 1 BR4	low	MMC card, HW echo option	Prototype	N/A
PIKA	AMCC Power PC	Closed	Closed	1 Ethernet 1 USB 4 FXS/FXO	low		Evaluation	1200

Table 1: Comparative chart of Asterisk-based appliances

6 VOIP and GSM – Partners not Competitors

In this section we address the question of "Why VOIP?" given the popularity of GSM in developing countries.

Just like 1st world telephone networks, VOIP and GSM can complement each other. In the 1st world we tend to use mobile phones for short phone calls in situations where portability is important. For longer duration phone calls, or for areas without mobile coverage we use traditional land line or VOIP. These same models can apply to the developing world. In fact VOIP models may offer GSM providers opportunities to expand their network and billed air time.

First, lets examine the novel features of VOIP. Unlike cellular networks, a VOIP network can be deployed on a small scale at at low capital and operating costs. For a few $100, a village can install a VOIP over WiFi node that supports say 4 telephones and links to a nearby village via WiFi. This can then provide unlimited, untimed phone calls at virtually zero recurring cost. As more villages are added, a mesh network will evolve. As a bonus, it builds out a data backbone – the WiFi link can be used to support Intranet type applications like chat, email, and web access.

However the problem of connectivity with the PSTN and GSM networks remains. Using GSM-VOIP gateways, the mesh network can be connected to and interoperate with the GSM network. A calling card system could be added to the IP04 firmware to manage billing. Such a network could also be used to extend the range of a GSM network, for example in the case that only one end of the WiFi-VOIP mesh network has strong GSM signals.

7 Business Models in developing countries

Open hardware opens up exciting new "business" models, for example developing countries could start their own local industry - building advanced telephone systems for cost price. This is far more attractive than buying technology from a first-world profit-oriented business that must charge a 75% mark up to cover their overheads. This business model is used for the one laptop per child project. A $100 laptop is possible if you remove the overheads, use community input and sponsorship for R&D and build volume. Now, with the IP04, a solar powered $100 IP-PBX suitable for the developing world is also possible. Such a device could bring telephony to remote villages using WiFi links for trunking.

Another benefit is that the hardware can be built locally in developing countries (remember the hardware design is free) overcoming import tariff problems and building local industry. Combining these elements means lots of people getting connected cheaply. That is a very good thing for the world.

To help deploy VOIP in the developing world, specific business models for the IP04 are required. This will promote "viral" growth and sustainability of the technology.

Here are some ideas:

- Existing **Internet Cafe's** can add voice capability
- Integration of a billing system into the IP04 firmware to allow operations with pre-paid **calling cards**.
- **Communication within organisations**. Consider a university which has WiFi based Intranet but no fixed landlines. Rather than using GSM handset for inter-office calls, VOIP over WiFi can be used.
- **Local call mesh network**. Statistics show that 60% of all phone calls are local. A group of villages several km apart could be linked by Wifi, and IP04s deployed to build a small local "mesh" telephone network. Voice works for the illiterate, so IP04 deployment may actually stimulate WiFi link roll out, which can then be used as a back bone for Internet connection and web/text based services like email and chat. One end of the mesh could be connected to the PSTN or GSM network.

8 Next Steps

We suggest one or more field trial deployments designed to test the hardware and business models.

The plan should include the following activities:

- Find sponsor: venture, donor or private philanthropist
- Identify general recipient requirements
- Identify training needs and local support
- Study the regulatory aspects
- Identify and manage risks
- Choose a site and identify who would benefit the most from telephony
- Design a production environment including the possibility of building the units locally.
- Develop a localized software version, focus on usability, e.g. ease of installation, ease of maintenance.
- Develop local training materials
- Develop a business model and integrate it with the technology
- Field implementation and training including
  - Hardware assembling
  - VoIP networking
  - Energy support
  - Business models
- Involve the community
- Document the findings