SPECTRUM OCCUPANCY MEASUREMENTS WITH LOW COST EQUIPMENT

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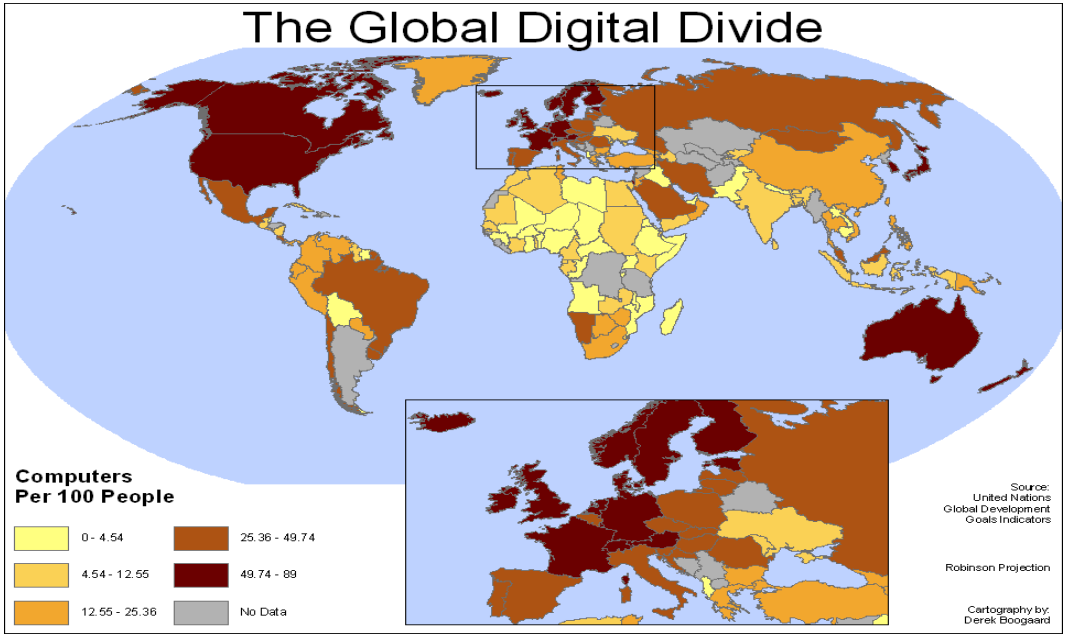
Efficient use of spectrum for the IT services demand

Problems:

- "**Spectrum holding**":
  who has the legal concession to broadcast, tends to preserve the legal rights on the frequencies, even if not uses them



- **technically inefficient use of the spectrum**

increases the gap between countries that can benefit from *Information Technology* Services and others that are practically excluded

Results of the Spectrum monitoring campaigns

The monitoring campaigns conducted to measure the Spectrum occupation have established that globally most of the spectrum is underused.

To evaluate the effective occupation, from the campaigns also emerged:

1. additional measurements are necessary in different locations, made for longer periods.
2. **Possibility to conduct campaigns are influenced by:**
   - **costs (of equipment),**
   - **the time required to perform the measurements**

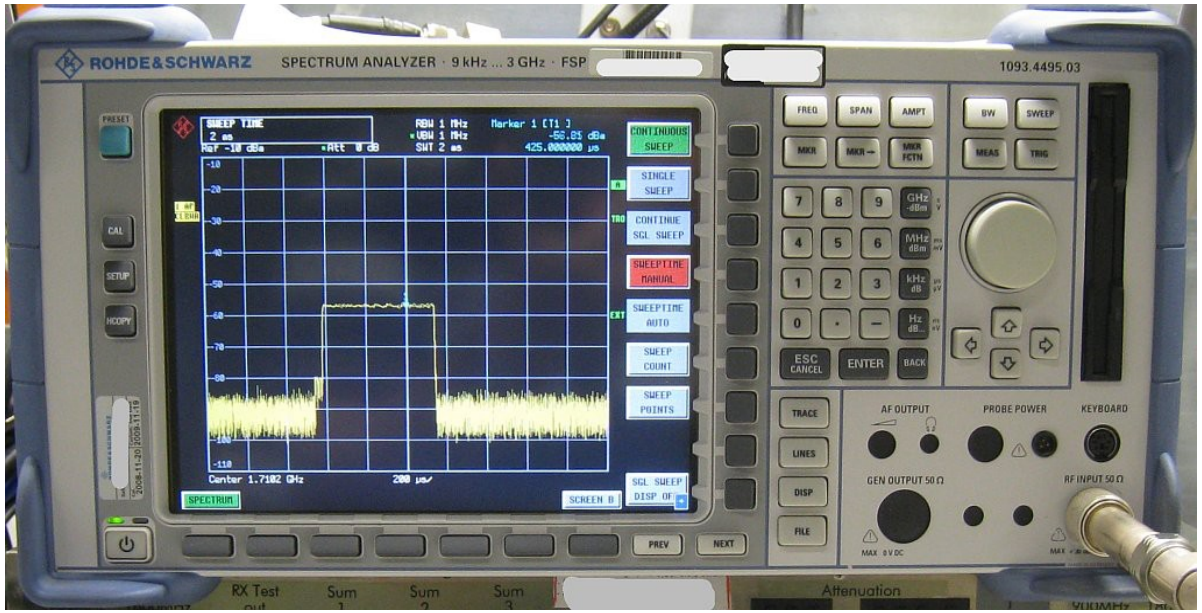
Use of TVWS frequencies

After the switchover from Analogue to Digital Terrestrial TV, the frequencies left free can be used to provide broadband network or other services in rural or remote areas

TV White Spaces have the greater potentiality of use in development countries

To build a monitoring system suitable to be used in development countries, ***the project must meet some requirements.***

Project Requirements for a TVWS Monitoring System



1. **Low cost:**

generally, high-end commercial spectrum analyzers are not available in University labs of Developing Countries, because bulky and expensive instrumens. Around the world, for budgets, some instruments can be easily acquired by Universities and organizations if the cost is not higher a few hundred dollars.

2. The system must operate for long time **battery powered**.

3. **Operate as much as possible independently:**
   it can be connected to a PC only for data transfers.
   For example, the acquisitions must be stored locally on SD memory cards.

4. **Data export:** the data must be saved in easily exportable formats for other processing.

5. **Easy to use:** the system must be used by non-technical staff. Unskilled staff should be able to easily select the frequencies of interest.

6. **Once turned on it must operate automatically,** without human intervention.

7. **Geolocation:** it should operate in motion, on a vehicle or by walking, collecting measurements of frequency and the geographical position with GPS .

8. **Open Source:** if the source code is released with Open Source licence, the system can be easily modified by other programmers.

http://wireless.ictp.it/

In Guglielmo Marconi Laboratory of ICTP, some projects has been developed to monitor White Space Frequencies with low cost apparatus.

1) the WhispPi monitoring system

WhispPi is a system composed of 4 parts:

1. **a Raspberry Pi**, a low-cost embedded PC with Linux, used to control the data acquisition
2. **An RFExplorer, a portable spectrum analyzer**, easy to use and low cost instrument. There are five models.
3. **A GPS with USB interface,** to collect the geographic position and the time of measurement.
4. **A small battery** that powers the Raspberry and the RFExplorer.

Cost estimate for the major components of WhispPi

Element	Estimated cost ($)	Source:
Raspberry PI	30 - 40	Adafruit, Raspberry Pi Model B+ 512MB
RFExplorer	120	http://rfexplorer.com/models/ (Price for 2.4G model)
Battery	25	Adafruit, 4400mAh - 5V @ 1A version
GPS receiver	20	Ebay

Total: 170 - 185 $ (only for the main components)

How to reduce the costs of the acquisition system?

RFExplorer is definitely the most expensive element.

... What alternatives can be found quickly???

Software-defined radio

https://en.wikipedia.org/wiki/Software-defined_radio

Software-defined radio (**SDR**) is a radio communication system where some hardware components (mixers, filters, amplifiers, modulators/demodulators, detectors, etc.) are instead implemented by software on a personal computer or embedded system.

...

It has been discovered that some common low-cost Digital Terrestrial TV tuner that use the Realtek RTL2832U component, can be transformed as a wide-band SDR receiver.

http://www.rtl-sdr.com/

RTL-SDR.COM

rtl-sdr.com

RTL-SDR (RTL2832U) and software defined radio news and projects. Also featuring Airspy, HackRF, FCD and more.

HOME | ABOUT RTL-SDR | QUICK START GUIDE | FEATURED ARTICLES | SOFTWARE | SIGNAL ID WIKI | FORUM | BUY RTL-SDR DONGLES | GUIDE BOOK | SUBMIT

AUGUST 28, 2015

GNU RADIO CONFERENCE 2015: PRESENTATIONS

NEW UPGRADED RTL-SDR
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What is RTL-SDR?

RTL-SDR is a very cheap software defined radio that uses a Digital Terrestrial TV tuner dongle based on the RTL2832U chipset.
With the combined efforts of Antti Palosaari, Eric Fry and Osmocom it was found that the signal I/Q data could be accessed directly, which allowed the DVB-T TV tuner to be converted into a wideband software defined radio via a new software driver.

Essentially, this means that a cheap $20 TV tuner USB dongle with the RTL2832U chip can be used as a computer based radio scanner. This capability would have cost hundreds or even thousands of dollars just a few years ago.
....

http://rtlsdr.org/#history_and_discovery_of_rtlsdr

Welcome to the rtlsdr.org wiki!

This Wiki is intended to collect all sorts of disparate information concerning the use of the so called RTLSDR. If you wish to add to this wiki please contact the Osmocom guys and ask for editing access rights to this site

History and Discovery of RTLSDR

It turns out that Antti Palosaari is perhaps not entirely responsible alone in getting credit for the discovery of Realtek 2832U tuners being used for SDR. The RTL2382U parts were always intended by design for SDR as the dongles come with closed SDR software in Windows for DAB+ and FM reception on the mini CD. I think the credit for uncovering of what the Windows software does lies with a fellow named Eric Fryoriginally sniffing the USB packets from the Windows application in FM and DAB mode way back in March of 2010.
He had hoped to get a DAB+ or FM receiver working in Linux (he had originally been providing unofficial support for Linux and this Quad Realtek DVB tuner). Eric and I discussed this privately at length and I made some reflections about this SDR feature in 2011 on the linux-tv mailing lists and discussed SDR potential on the associated #linux-tv IRC channel. Realtek had sent me some alpha FM SDR software for Linux with a promise of DAB+ to come. Antti's infamous email followed in early 2012. Very quickly the Realtek RTL2382U Linux driver and and some independent work byOsmocom (who were making their own E4000 based SDR) collided and in RTL-SDR as we know it exploded onto the scene.

http://www.realtek.com.tw/products/productsView.aspx?Langid=1&PFid=35&Level=4&Conn=3&ProdID=257

HOME > Products > Communications Network ICs > DTV Demodulators > DVB-T Demodulator (Terrestrial) > RTL2832U

RTL2832U: DVB-T COFDM Demodulator + USB 2.0

General Description

The RTL2832U is a high-performance DVB-T COFDM demodulator that supports a USB 2.0 interface. The RTL2832U complies with NorDig Unified 1.0.3, D-Book 5.0, and EN300 744 (ETSI Specification). It supports 2K or 8K mode with 6, 7, and 8MHz bandwidth. Modulation parameters, e.g., code rate, and guard interval, are automatically detected.

https://en.wikipedia.org/wiki/List_of_software-defined_radios

List of software-defined radios, from Wikipedia,

This article provides a list of commercially available **software-defined radio receivers**.

...The table shows 81 components.

ZS-1 [70],X-RAD[69],WinRadio WR-G31DCC[50],USRP X310[57],USRP X300[56],USRP N210[55],USRP N200[54],USRP B210[53],USRP B200[52],UmTRX[58],UHFSDR[51],ThinkRF WSA5000[12],SunSDR2[9],SoftRock-40[65],SoftRock RX Ensemble II[66],Soft66AD / Soft66ADD / Soft66LC4 / Soft66RTL[32],SDRX01B[10],SDRstick UDPSDR-HF2[5],SDRstick UDPSDR-HF1[6],SDRplay: Radio Spectrum Processor[31],SDR-LAB SDR04[79],SDR-IQ[38],SDR-IP[39],SDR-4+ [61],SDR-1[41],SDR(X) HF, VHF & UHF[64],SDR MK1.5 'Andrus'[59],SDR Minor[3],Realtek RTL2832U DVB-T tuner[63],RDP-100[68],Quadrus (DRU-244A and SRM-3000)[2],QS1R[48],PM-SDR[47],Perseus[28],Pappradio[30],Noctar[46],NetSDR[40],Myriad-RF 1[11],Mercury[67],Matchstiq[27],LD-1B[45],Kanga Finningley[49],Hunter SDR[60],HiQSDR[73],HackRF One[71],FUNcube Dongle[34],FUNcube Dongle Pro+[35],FLEX-6700R[22],FLEX-6700[21],FLEX-6500[23],FLEX-6300[24],FLEX-5000A,FLEX-3000,FLEX-1500[25],FiFi-SDR[36],Elektor SDR[42],Elektor AVR SDR[43],Elecraft KX3[20],ELAD FDM-S2[18],ELAD FDM-S1[17],ELAD FDM-DUO (Transceiver)[19],easySDR USB Dongle[33],DRB 30[44],Cross Country Wireless SDR receiver v. 3[62],Crimson[4],COM-3011[74],BladeRF[15],Bitshark Express RX[26],ASR-2300[16],ARSP / Wideband MIMO[72],Apache Labs ANAN-10[8],Apache Labs ANAN-100D,Apache Labs ANAN-100,AOR AR-2300[14],AirSpy[1],AFEDRI SDR[13],ADAT ADT-200A[7],AD-FMCOMMS5-EBZ[78],AD-FMCOMMS4-EBZ[77],AD-FMCOMMS3-EBZ[76],AD-FMCOMMS2-EBZ[75],

Name	Realtek RTL2832U DVB-T tuner[63]
Type	Pre-built with custom driver
Frequency range	24–1766 MHz (R820T tuner) (sensitivity drops off considerably outside this range, but can go 0–2,200 MHz (E4000 tuner with direct sampling mod))
Sampling rate	2.4 MHz (can go up to 3.2 MHz but drops samples)
Panadapters / Receivers	?
Host Interface	USB
Windows?	Yes
Linux?	Yes
Mac?	Yes
Base price (US$)	**8-10 $**

This is the first page where I see the component price:

is around $ 8-10

An example: RTLSDR - a poor ham's spectrum analyzer

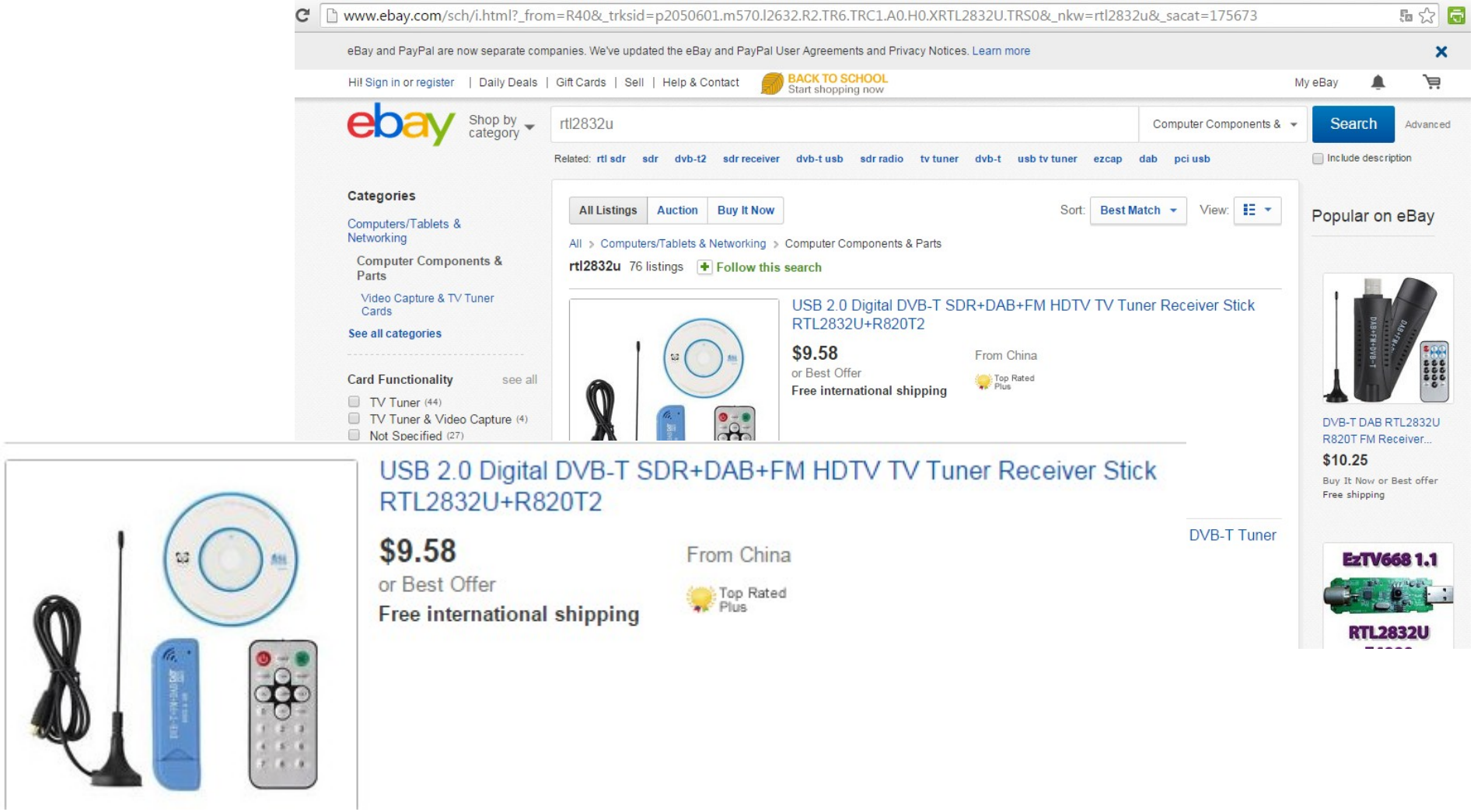
http://qsl.net/dl2wb/RTLSDR/rtlsdr.htm

- DVB-T Dongle Dexatek (Frequency range: 22 - 1100 Mhz)
- the dongle is connected with 1 m extension cable to a Windows Laptop.

- in Internet are reported many projects that use open source software to connect DVB-T dongles and build '***tiny cost***' spectrum analyzers
- Probably the dongle reported in project is no longer in production.

In order to build a cheapest TVWS datalogger, we evaluated the possibility to use similar dongles to build a "SDR Spectrum analyzer".

We bought on Ebay different models of compatible dongles, at least with the same declared features. GO to www.ebay.com and search ***rtl2832u***



Results (for now ...):

1. we bought dongles that have been proven incompatible with the **RTL-SDR software** (required to build the "SDR spectrum analyzer")
2. often, commercial characteristics of the dongle reports a wrong type of chip used (***newer type of components, less expensive, "cut down" only as tuner for digital terrestrial TV***).
3. often the supplied antenna was not of good quality, and so include the construction of electronics
4. Measurements performed with similar dongles can report big differences (this is not acceptable for our application).

...For now we have not found a possible alternative to RFExplorer.

Looking forward to find:

1. a spectrum analyzer with a good cost / performance ratio and less expensive than RFExplorer
2. Digital Terrestrial TV Dongles or similar devices, that have a sufficient quality to realize a low cost TVWS data logger.

To reduce the cost of the new project, we decided to continue to adopt RFExplorer and to focus on other points.

Is possible to build a data logger using RFExplorer connected to an Android system?

Android smartphones and tablets have excellent features to make data acquisition systems.

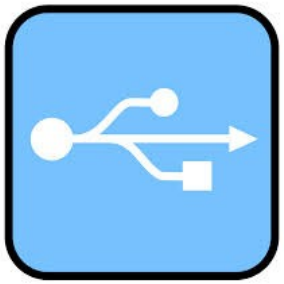
- Android is is an open source, integrated software platform based on Linux kernel.
- Are popular systems, with various price ranges
- In 2014, the market share of Android smartphones and tablets was around 85%.

- Most Android devices include microSD slot and can read microSD cards
- Android devices can include GPS, video cameras, touchscreens, accelerometers, gyroscopes, barometers, magnetometers, dedicated gaming controls, proximity and pressure sensors, thermometers, etc..
- Android supports various connectivity technologies, including GSM/EDGE, Wi-Fi, Bluetooth, etc..

Is possible to connect external devices to an Android unit ?

We studied the problem, and the answer was: YES …

Android USB On-The-Go



http://developer.android.com/guide/topics/connectivity/usb/host.html

- USB On-The-Go (USB OTG or OTG) is a ***specification first used in late 2001 that allows USB devices*** such as digital audio players or mobile phones ***to act as a host***,
- allow other USB devices such as USB flash drives, digital cameras, mice or keyboards to be attached to an USB OTG.

When a device is plugged into the USB bus

1. ***the master device, or host, sets up communications with the device.***
2. The host's software enables or does the needed data handling
3. The host is responsible for all data transfers over the bus

Android USB Host Mode

- USB Host Mode support was introduced in Android version 3.1 (Honeycomb), so if you have Android 3.1, or newer installed on your device then you should have the necessary support for it in your OS.
- Android 4 adds additional USB and On-The-Go support.
- Many third-party ROMs (unofficial version of Android) add support for USB Host Mode to phones that have the hardware support, but don't have the necessary OS or driver support in the official operating system release.

To use an attached USB device you need to have:

Software Requirements on the Android System:

1. ***Android operating system***: the system has installed an OS that supports USB Host Mode (Ver. 3.1 or higher)
2. ***Software Drivers***: the system has loaded USB Host Mode drivers and the drivers for the USB device that is plugged in.

Hardware Requirements:

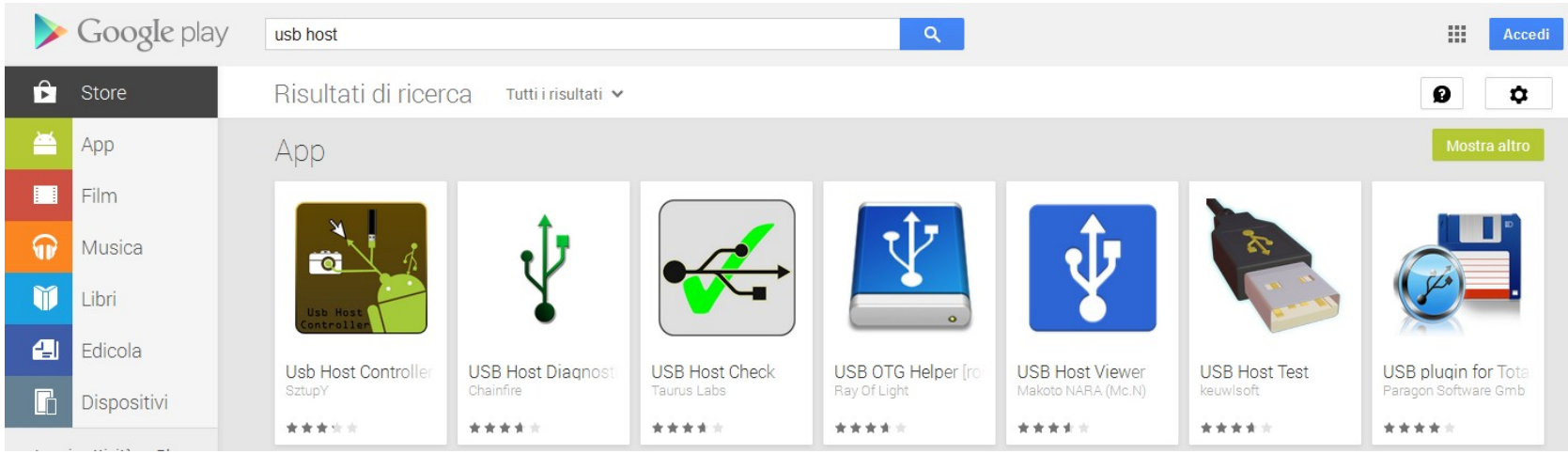
1. the Android device (eg phone or tablet) that has built-in hardware support for USB Host Mode
2. An USB OTG (USB On-The-Go) cable

Problem: USB Host is not supported.

POSSIBLE CAUSES:

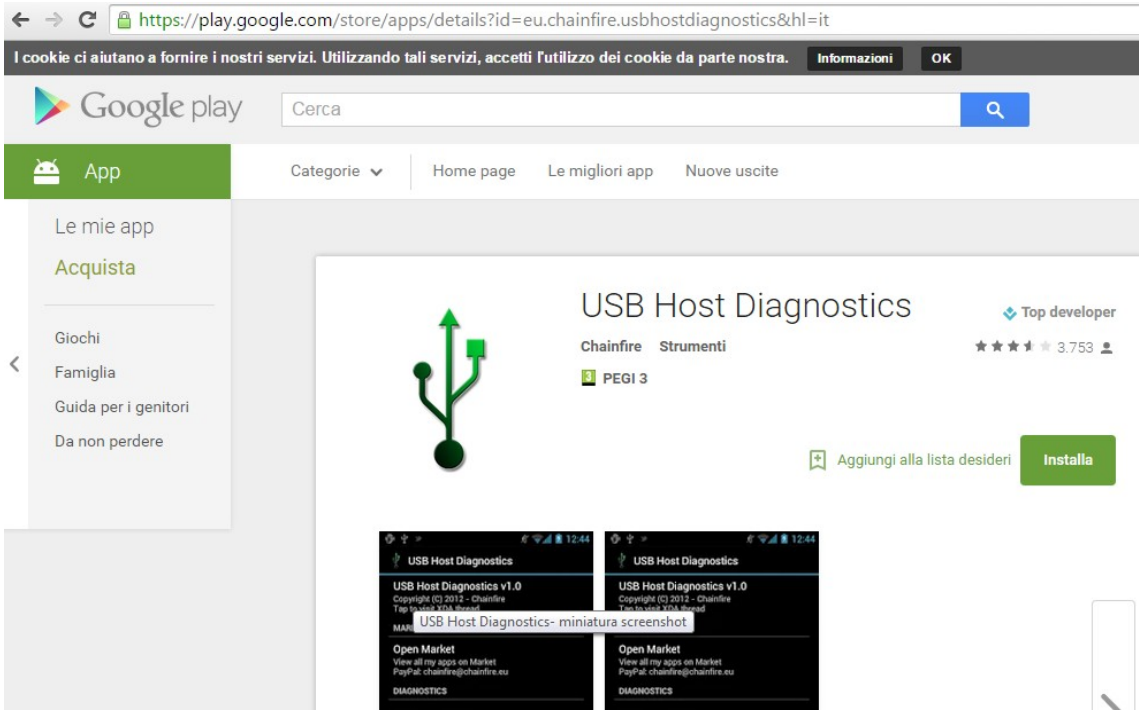
- **limits imposed on the hardware project** (to reduce the costs of the Android unit).
- **blocks imposed by the producer at software level**

How to verify that the device supports USB Host?



https://play.google.com/store/search?q=usb%20host&hl=it

To know if your Android device is compatible with the USB Host functionality, just search on Android Market one of many available APP

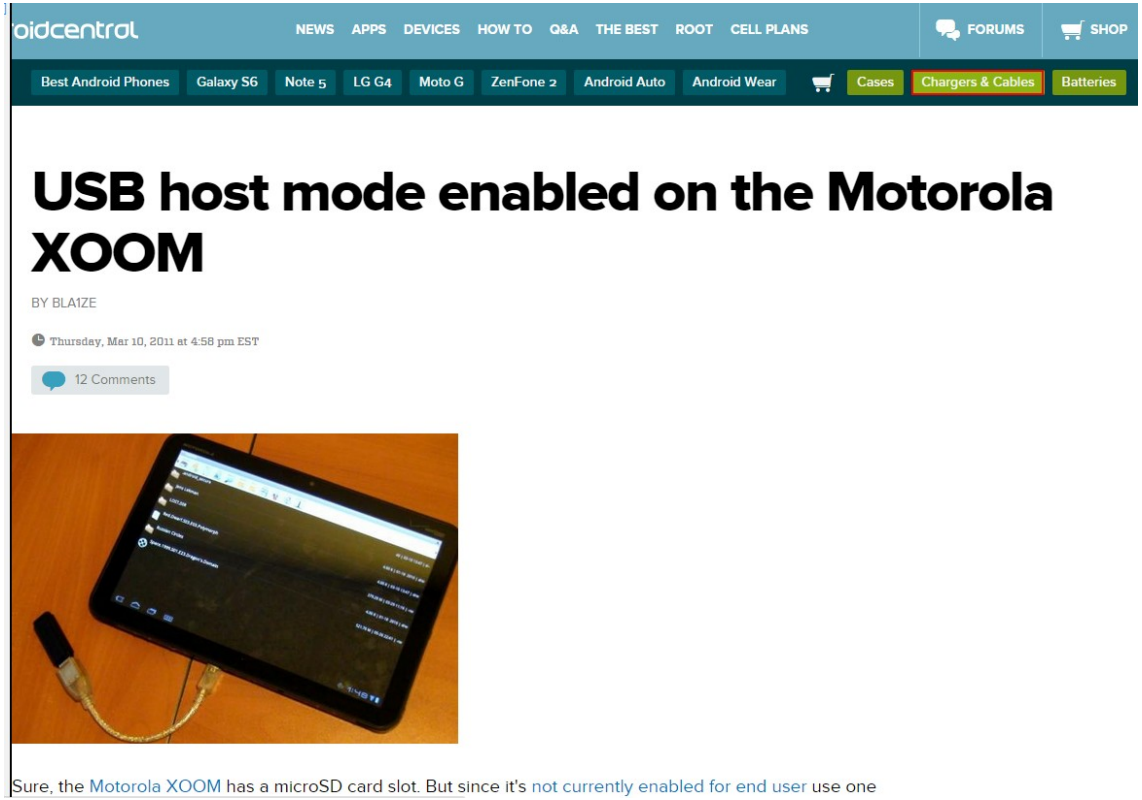


USB Host Diagnostics determines your device's USB host capabilities.

USB host is a very powerful feature of recent Android based smartphones and tablets, but on many firmwares (both stock and custom) the feature is somewhat broken.

For example, at launch the Galaxy Nexus told all the apps and the Market that it supported USB host, but USB host did not actually work (this was fixed in the Android 4.0.2 update).

If the USB Host is not enabled by the operating system?



1. Search to internet a tutorials to enable USB host in your models.

http://www.androidcentral.com/usb-host-mode-enabled-motorola-xoom

http://geeknizer.com/enable-usb-host-controller-on-android/

You are here: Home ▸ Enable USB-Host Controller on any Android [Samsung, HTC, Motorola]

Enable USB-Host Controller on any Android [Samsung, HTC, Motorola]

Author: Tarandeep Singh on February 2, 2012

USB Host controller device profile enables your device to **detect and attach other USB peripherals**. E.g. with an Android Phone with USB host controller, you can connect USB pen drive, USB mass storage, external Printers, keyboards, mouse and what not.

XDA developer sztupy's USB Host Controller takes advantage of native OTG Host functionality (available in many high-end Android devices) makes it easily accessible for the end user. The app is capable of showing the connected usb devices, and lets you mount external harddisks and connect

2. ***or make the root,*** to get Administrative permissions

https://en.wikipedia.org/wiki/Rooting_(Android_OS)

Rooting (Android OS)

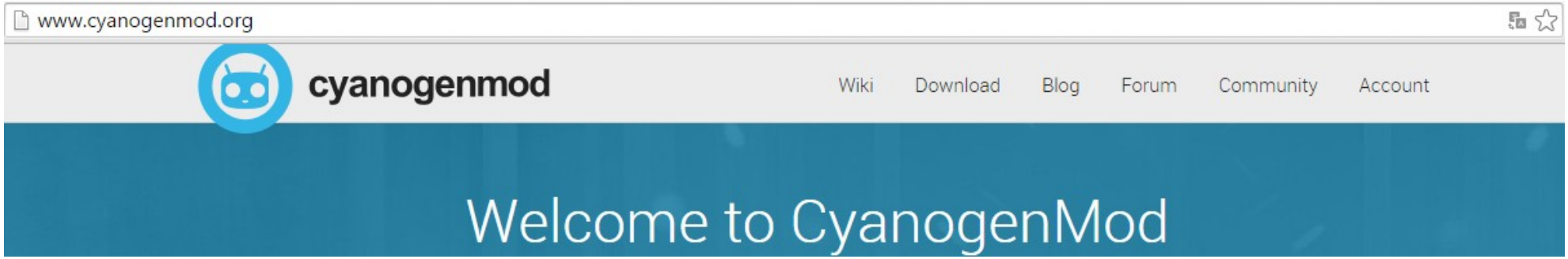
From Wikipedia, the free encyclopedia

Android uses the Linux kernel, rooting an Android device gives similar access to administrative (superuser) permissions as on Linux or any other Unix-like operating system

Rooting gives the ability (or permission) to alter or replace system applications and settings, run specialized apps that require administrator-level permissions, or perform other operations that are otherwise inaccessible to a normal Android user.

3. *Install "alternative" Android firmware*

Example. CyanogenMod, www.cyanogenmod.org,



https://en.wikipedia.org/wiki/CyanogenMod

CyanogenMod, is an open-source operating system for smartphones andtablet computers, based on the Android mobile platform.
It is developed as free and open source software based on the official releases of Android by Google, with added original and third-party code.

We need to pay attention to these operations:

All actions that bypass the blocks or limitations imposed by the manufacturer, will void the warranty!!!

An Android logger: the RfTrack monitoring system

The system consists of four parts:

The handheld spectrum analyzer RFExplorer,

a tablet or Smartphone Android, equipped with a USB host (vital !!) and GPS.

One USB OTG cable, to permit linking RFExplorer as a USB peripheral to Android.

The RfTrack application, that acquires data provided by RFExplorer through the USB port.

Compared to WhispPi, the costs of the monitoring system tend to decrease?

1. **<u>remains the central component:</u>** the spectrum analyzer RFExplorer
2. Currently, an Android tablet with GPS and appropriate characteristics, can be bought in supermarkets at about 70 euros.
3. ***The use of your own Android smartphone is possible:*** *it is crucial that in the system can be activated the USB host.*
4. RFExplorer must be connected through a USB OTG host cable (On The Go), which costs about 4 Euro (eg. Amazon)

The response is: YES …

Advantages for developers of programming for Android

- Android is available from Google, free of licenses or royalties
- The Android documentation is well structured and organized.
- Android smartphones are extremely popular: For this, on Internet there are various community to send queries and get online answers (for example, http://stackoverflow.com/).
- The installation of whole environment to develop Android applications is possible on any OS - Windows, Linux or Mac (for IOS, only in Mac computers).
- Android uses the standardized and open programming language

Java. Java is generally an easy language to pick up especially if you have had experience in OOP.

- for data storage purposes, in Android is used SQLite, a lightweight relational database.
- The Android SDK and the development tools like Eclipse or Android studio are easy to use and have a smaller learning curve.
- Finally, the process of uploading applications to the Android Market is extremely easy.

The RfTrack datalog file format

The first objectives to meet for the logger was:

- make a simple but robust logging system
- data must be read and written by other programs, such as scripts running on Linux systems.

The first choice: write data acquisition in CSV files

At least in the beginning, text files are easier to get started with and are expected to work reasonably well.

- A comma-separated values (CSV) file stores numbers and text in plain text.
- Each line of the file is a data record.
- Each record consists of one or more fields, separated by delimiters (typically a single reserved character such as comma, semicolon, or tab)

- it is human-readable with a standard text editor.
- is plain text using a character set such as ASCII, various Unicode character sets (e.g. UTF-8), etc..

The first version of rftrack saves in CSV file records that contain this information:

- acquisition time
- latitude and longitude of position GPS
- frequency and dBm values read from spectrum analyzer RFExplorer

Pictures taken during a measurement campaign in Zambia

- in May of 2014 was released the first version of RfTrack
- It's been proven in the field, used in some measurement campaigns abroad.
- The sources are available in a GitHub repository.

The actual version of RfTrack: the acquisition data are saved in a SqLite Database

In the next version of RfTrack, the objectives of the project are increased.

To meet the requirements, now the data are saved in a database, from which it is quite easy to import the data.

Actually, RfTrack application saves the acquisitions in Sqlite databases.

SQLite is a database system that implements a lightweight version of SQL, standard interactive and programming language for getting information from and updating a database.

Client/server SQL database engines such as MySQL, Oracle, PostgreSQL implement a shared repository of enterprise data.	• Sqlite doesn't require a special database server • It's just a direct filesystem engine that uses SQL syntax.

For example, SQLite databases can be found in software running in Embedded devices and the internet of things

- SQLite is a compact library written in C: with all features enabled, the library size can be less than 500KiB
- A complete SQL database with multiple tables, indices, triggers, and views, is contained in a single disk file.
- the SQLite databases no requires administration

https://www.sqlite.org/whentouse.html

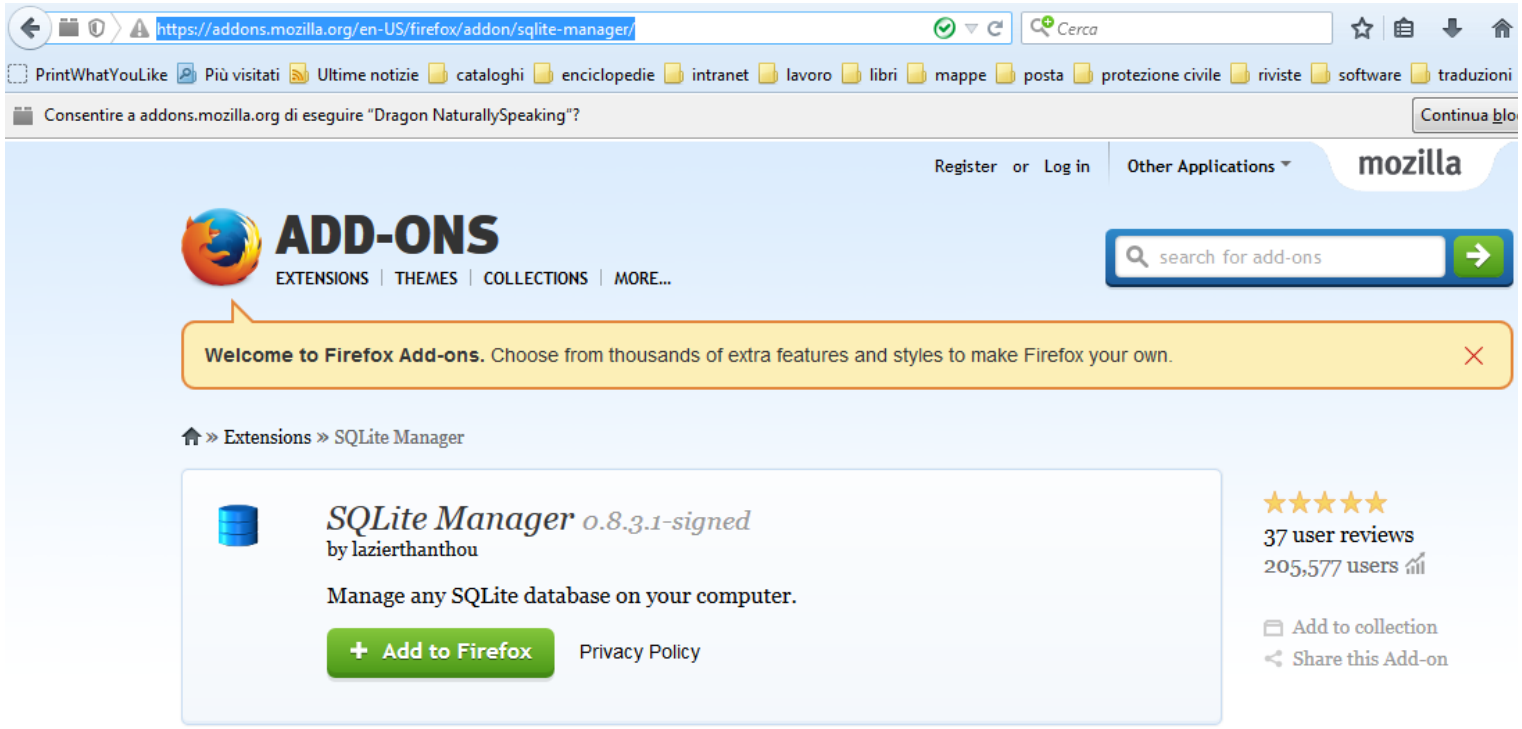
… SQLite is a good fit for use in cellphones, televisions, game consoles, cameras, thermostats, automobiles, machine tools, airplanes, remote

sensors, drones, medical devices, and robots: the "internet of things".

Free SqLite amministration toos

A SqLite database can be managed inside a Browser

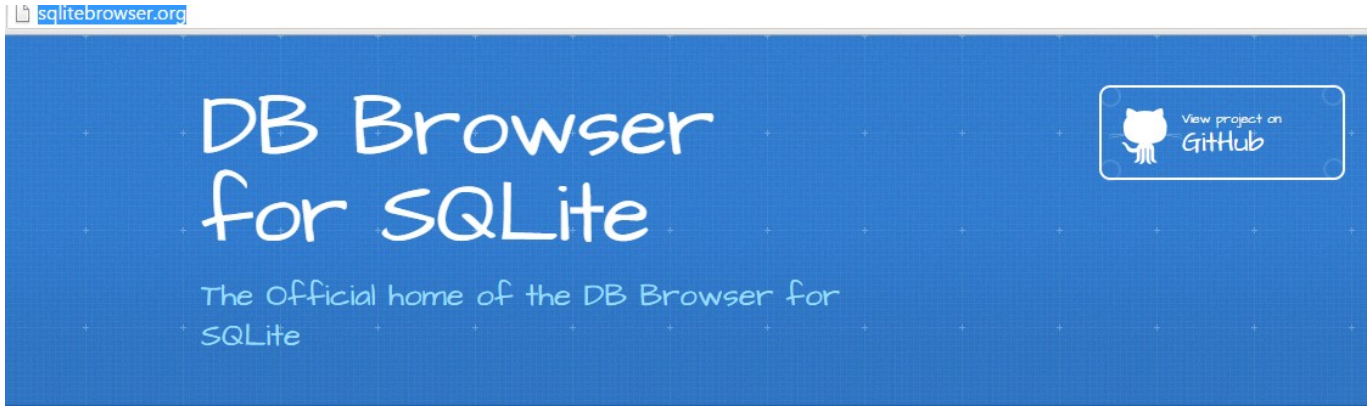
https://addons.mozilla.org/en-US/firefox/addon/sqlite-manager/



https://chrome.google.com/webstore/detail/sqlite-database-browser-b/jlpbdkmaomigeneadlamehkfchdmojgg

… and handled with multi-platform opensource tools

http://sqlitebrowser.org/



DB Browser for SQLite is an visual, open source tool to create, design, and edit database files compatible with SQLite.

It is for users and developers wanting to create databases, search, and edit data. It uses a familiar spreadsheet-like interface, and you don't need to learn complicated SQL commands.

Controls and wizards available DB Browser for SQLite:

- Create and compact database files
- Create, define, modify and delete tables
- Create, define and delete indexes
- Records: Search, Browse, Edit, Add and Delete
- Import and export records as text
- Import and export tables from/to CSV files
- Import and export databases from/to SQL dump files
- Issue SQL queries and inspect the results
- Examine a log of all SQL commands issued by the application

Run on: Windows, Linux, Mac

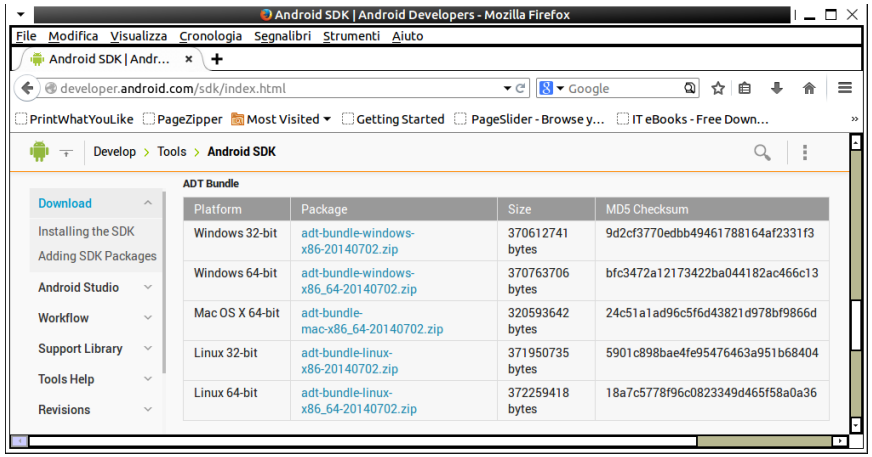
Tools used to develop RfTrack

The software is developed on a laptop with Ubuntu Ver. 14.04.

Software Tools

http://developer.android.com/sdk/index.html

ADT (Android Developer Tools) Bundle: It includes the essential Android SDK components and a version of the Eclipse IDE with built-in ADT



Software Tools

https://www.virtualbox.org/

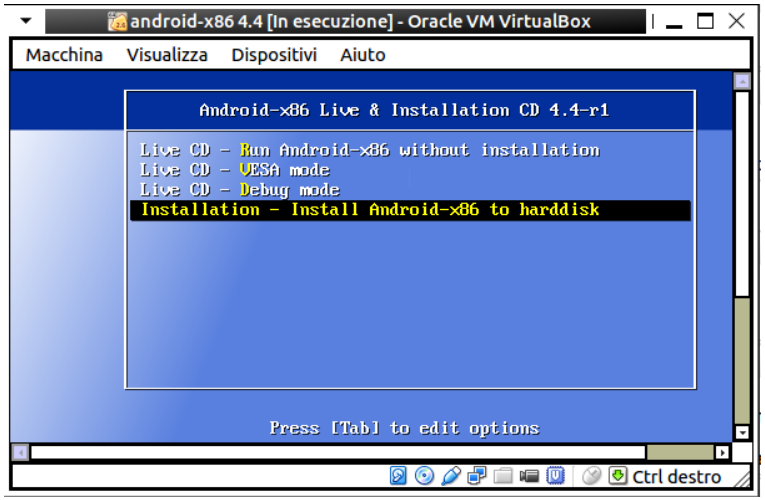
Oracle VM VirtualBox, open source software that run and create virtual machines

Software Tools

http://www.android-x86.org/download

For debugging, it was a very useful a virtual machine with Android 4.4 installed in VirtualBox.

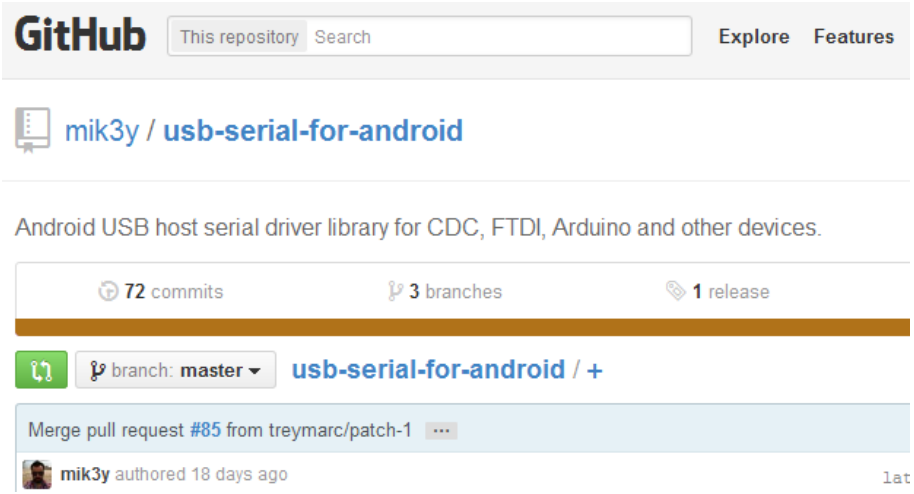
4.4 Kitkat : android-x86-4.4-r1.iso



Libraries

For the development have been used almost exclusively Android SDK libraries (eg: GPS reading, access to the file system, etc.).

To communicate with RFExplorer, has been used the library

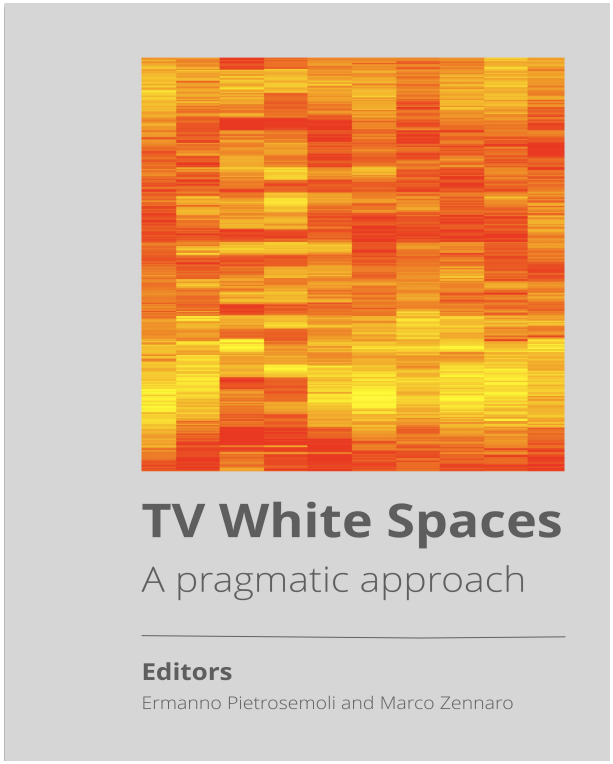


Usb-serial-for-android: driver library for communication with Arduinos and other USB serial hardware on Android, using the Android USB Host API available on Android 3.1+.

https://github.com/mik3y/usb-serial-for-android

References

http://wireless.ictp.it/tvws/book/



TV White Spaces

A pragmatic approach

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