Building a Distributed Satellite Ground Station Network

A Call To Arms

@hdznrrd @andreashornig @rel0c8 hackerspace global grid / constellation 28c3 2011 so hf, you'll shit bricks

Todays networks are evil.

They are based on old technology.

- Why don‘t we have fast connections everywhere?

They are based on old business models.

- Why do we have to pay by usage?

Basically, they are

- closed
- proprietary
- old-fashioned
- insecure

But things are changing, for the better.

All power has to be with the community.

All power has to be with the community.

- Science deserves a fair share.
- Users and providers have to be on the same level.
- Everyone shall benefit.
- We need distributed networks.

There‘s a lot of well established distributed networks.

There‘s a lot of well established distributed networks.

- IRC
- Skype (it‘s evil, but well established and distributed anyway)
- TOR
- BOINC and Seti@Home
- Peer 2 Peer Networks like Bittorrent, Bitcoin
- Freifunk / OLSR

Hackers want world domination.

This is the information age.

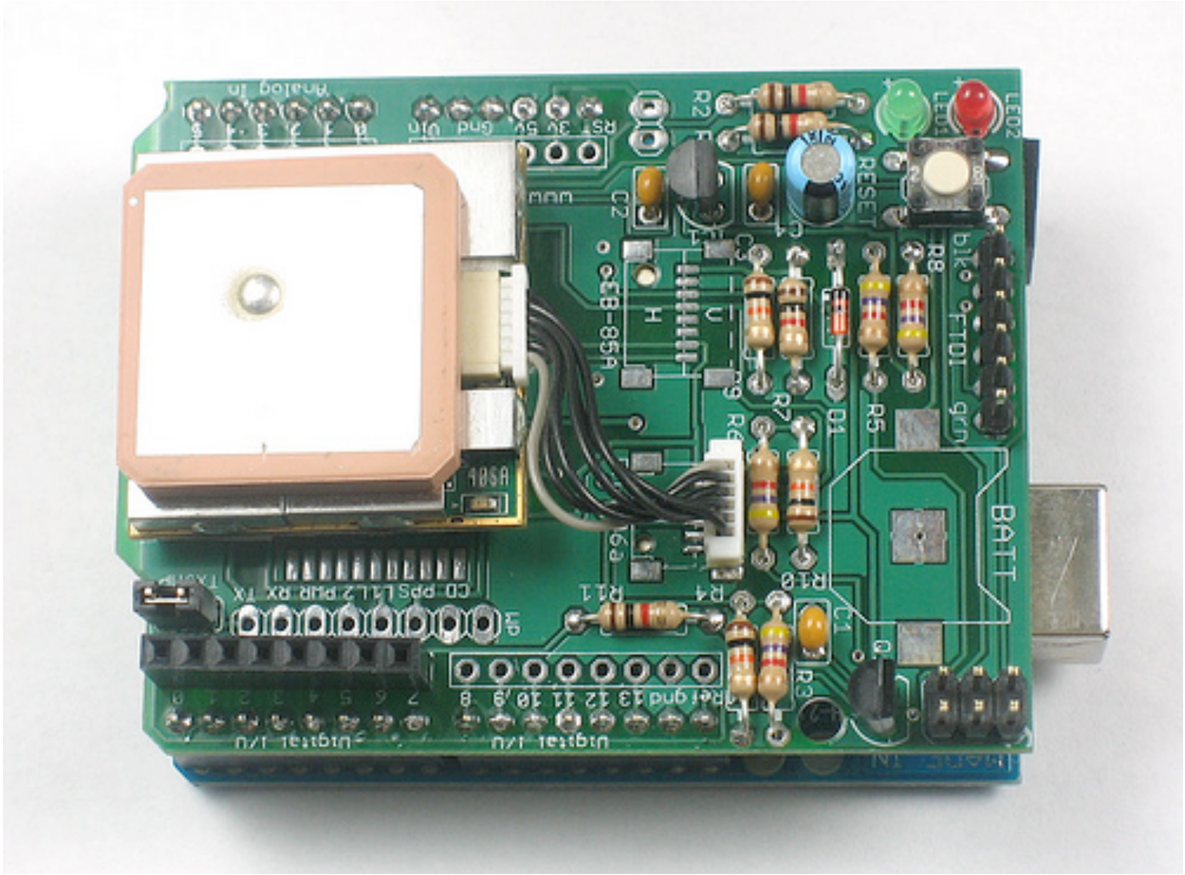
Therefore world domination is achieved by sharing information and making

fast, cheap, secure, reliable

network connections accesible.

You can join easily. Today.

It starts with a simple, small device



Building a Distributed Satellite Ground Station Network

A Call To Arms

@hdznrrd @andreashornig @rel0c8 hackerspace global grid / constellation 28c3 2011 so hf, you'll shit bricks

CCCamp11

Nick Farr et al: “Space! We haz a needs!” [h7]

Meanwhile on an express train to Berlin

Three hackers: “We haz a brainfart!” [h0]

The Goal

- Understand
- Build
- Own
- Open Source everything

Short Term Tasks

- Receive
- Decode
- Record & store

What we want/need to know

- Satellite communication protocols
- Antenna and HF design
- Analogue and digital filters
- Electronic design
- Embedded hard- and software
- Mathematics and cryptography

Where do we get started?

- Read Jeff Wofford's article "A programmer's greatest enemy" [h2]
  - Seriously.
- Break tasks down into very small sub-tasks
- Knowledge?
  - Purely optional.
  - I can say that from first hand experience because I didn't know anything about HF, antennas or radio communications

A ground station for... what?

- Everything!
  - "Eierlegende Wollmilchsau" sounds so much better than..."allround device"
- Of course that won't work
- Instead: build many small things and combine them to something bigger!
  - Works well for *NIX and Power Rangers

What's the most basic thing we need?

- Timing & Synchronization
- No point in measuring stuff in a distributed environment if you do not know the time accurately

Timing - What we want (1)

- High accuracy
  - Ideally something far better than a microsecond
- Some kind of easy to use interface
  - Need high accuracy timing? Just plug it in!
- Interchangeability & exchangability
  - Better timing source? No problem!

Timing - What we want (2)

- Bigger & better
  - More than one timing source? Would be nice!

Okay, a time source it is

- What do we have?
  - NTP
  - DCF77
  - GPS

NTP

- Meh, too simple
- Requires permanent internet connection
- Not very accurate either

DCF77

- Pros
  - At first glance very simple (59 bits per minute)
- Cons
  - Only works in (central) Europe
  - Antenna should be aligned with Frankfurt/Main
  - At second glance: we've found receivers often to be very delicate to touching, people being close by, people being too far away, low flying ponies, your longcat…

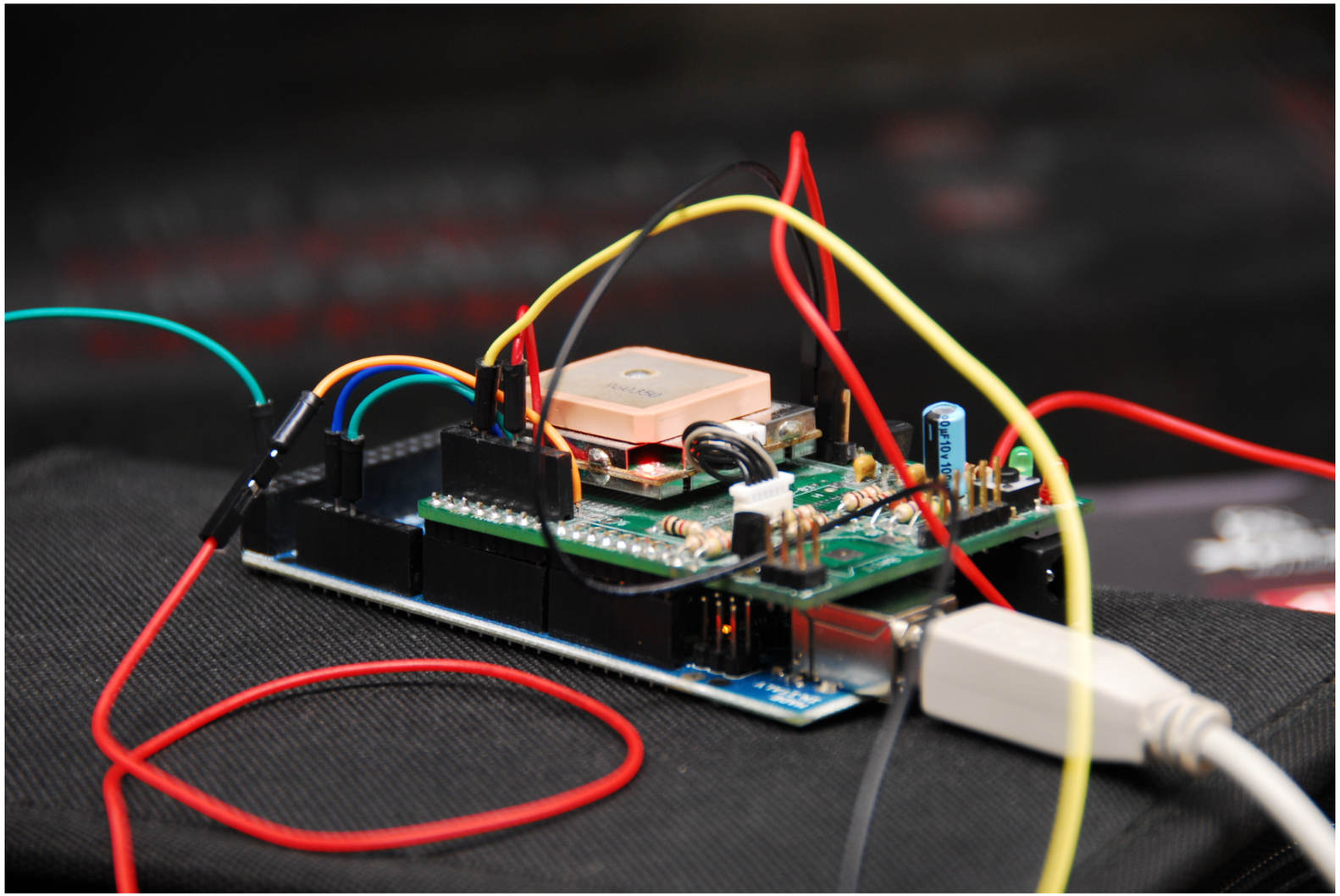
GPS (1)

- Pros
  - There's existing hardware to do it.
  - You can receive it almost everywhere
  - It also tells you where you are
  - Super accurate (PPS pulse) and super effective

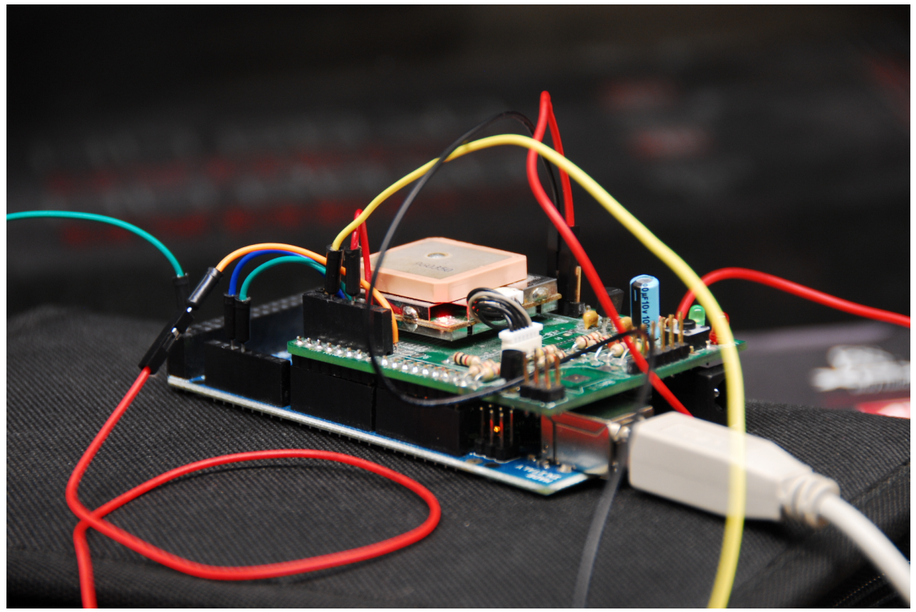
GPS (2)

- Cons
  - Not independent from current earth politics
  - Could be more accurate if current earth politics allowed for it to be
  - So HF, you shit bricks

GPS: Zero to hero in 10 seconds flat

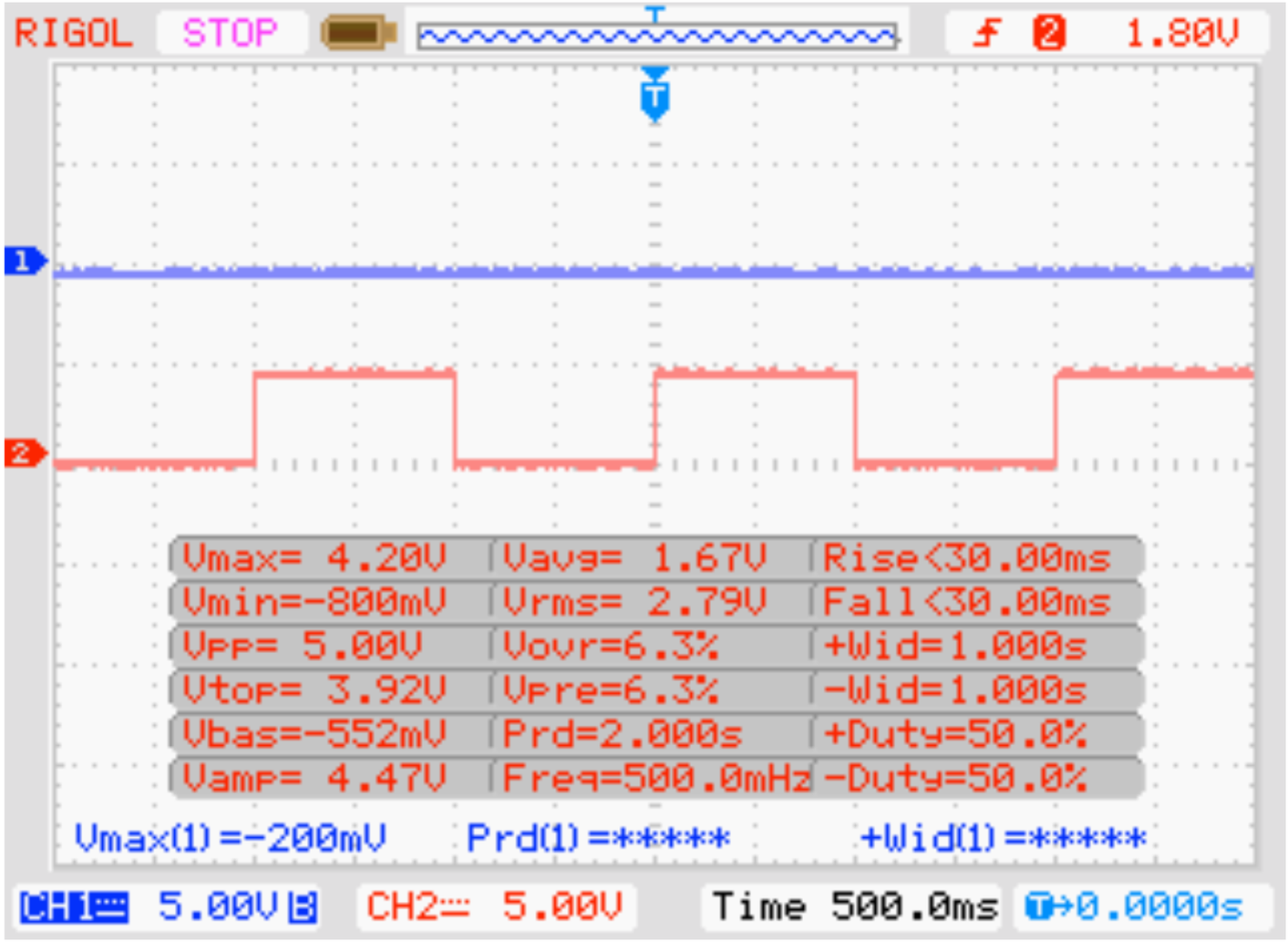


GPS: Zero to hero in 10 seconds flat



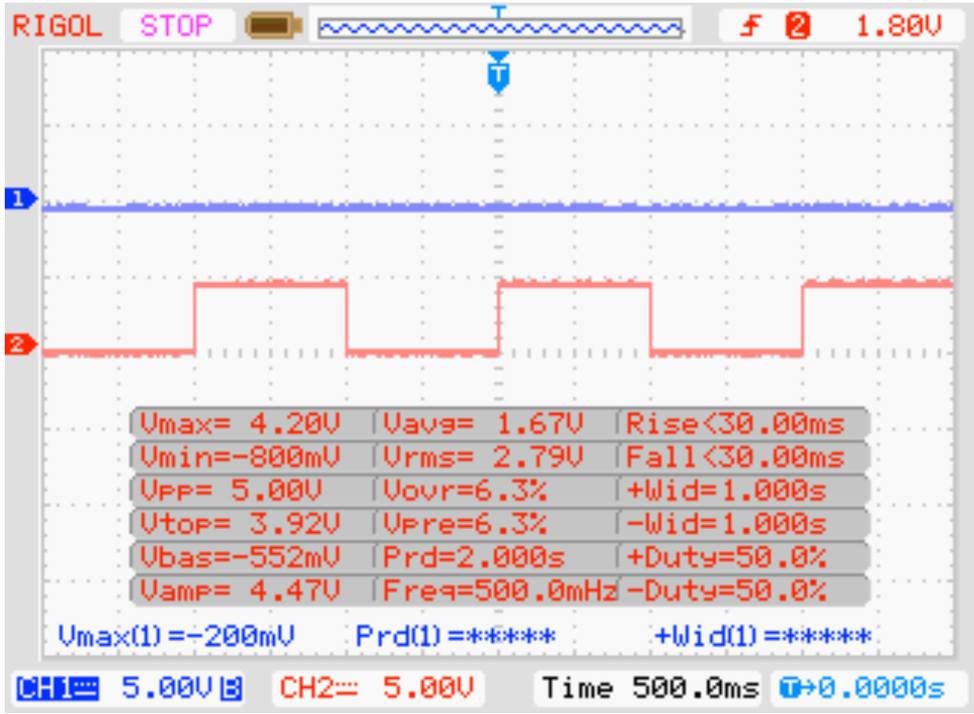
- Arduino Mega 2560 [h4]
  - 4 UARTs (oh boy)
  - More pins than you can shake a stick at
  - Blogcred^W community or something
- Adafruit GPS shield w/ EM-406 module [h5]
  - Because we've had that already (and it works!)

Accurate time? There's a pulse for that!

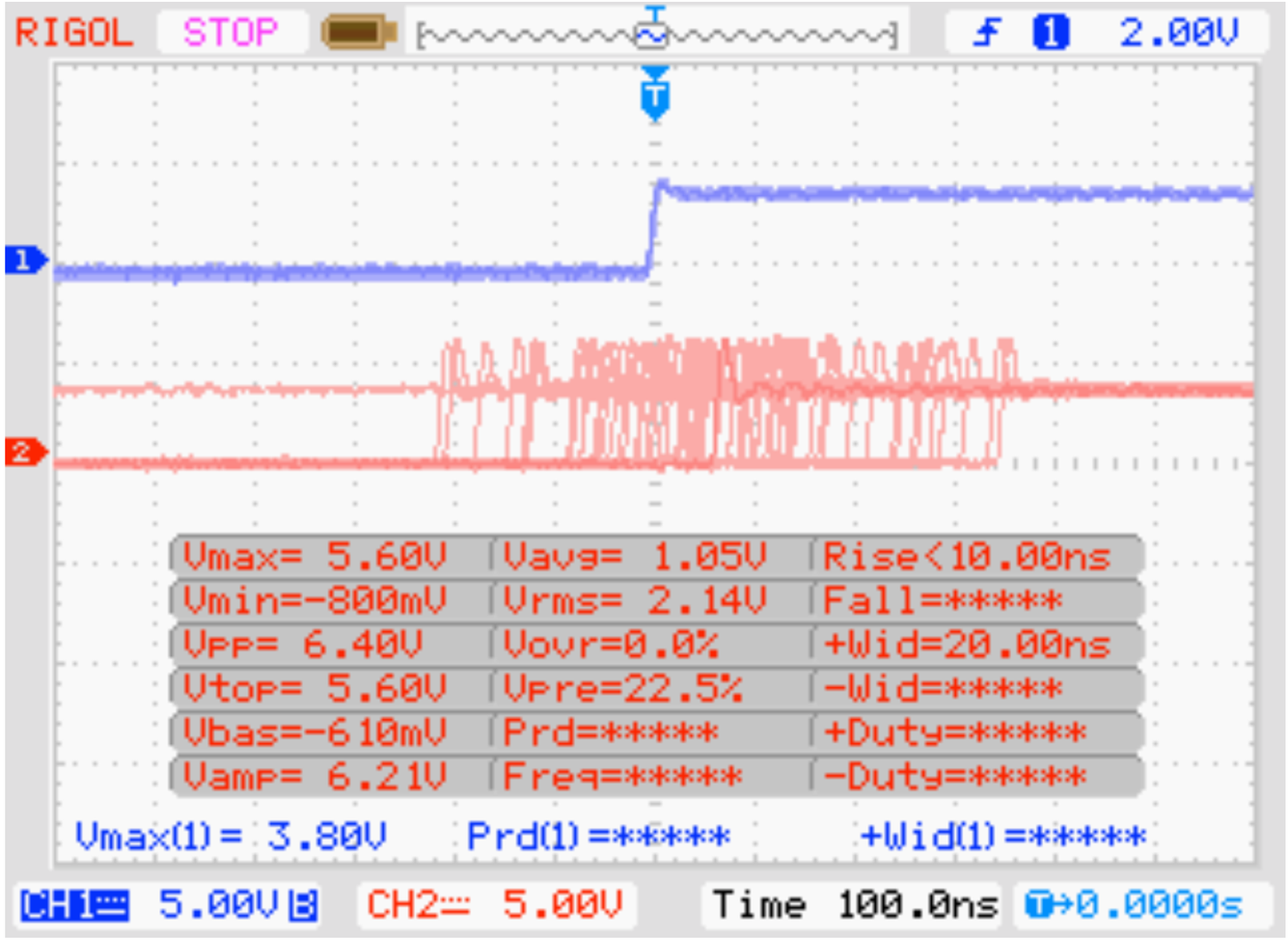


Accurate time? There's a pulse for that!

- PPS / Pulse Per Second
  - Much more accurate than what you get from reading NMEA over a serial connection
- Much more you say? Do tell more!

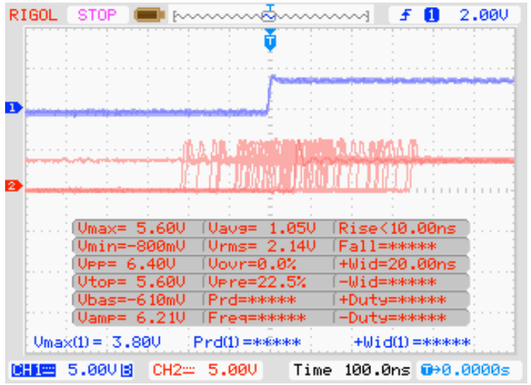


GPS Timing Accuracy



GPS Timing Accuracy

- +/- 200ns
  - not too shabby I'd say
- But wait, there's more!
  - 16 Mhz clock driving the uC. We could interpolate!
  - This is currently work in progress
- Caveat
  - We've measured relative accuracy of two receivers next to each other



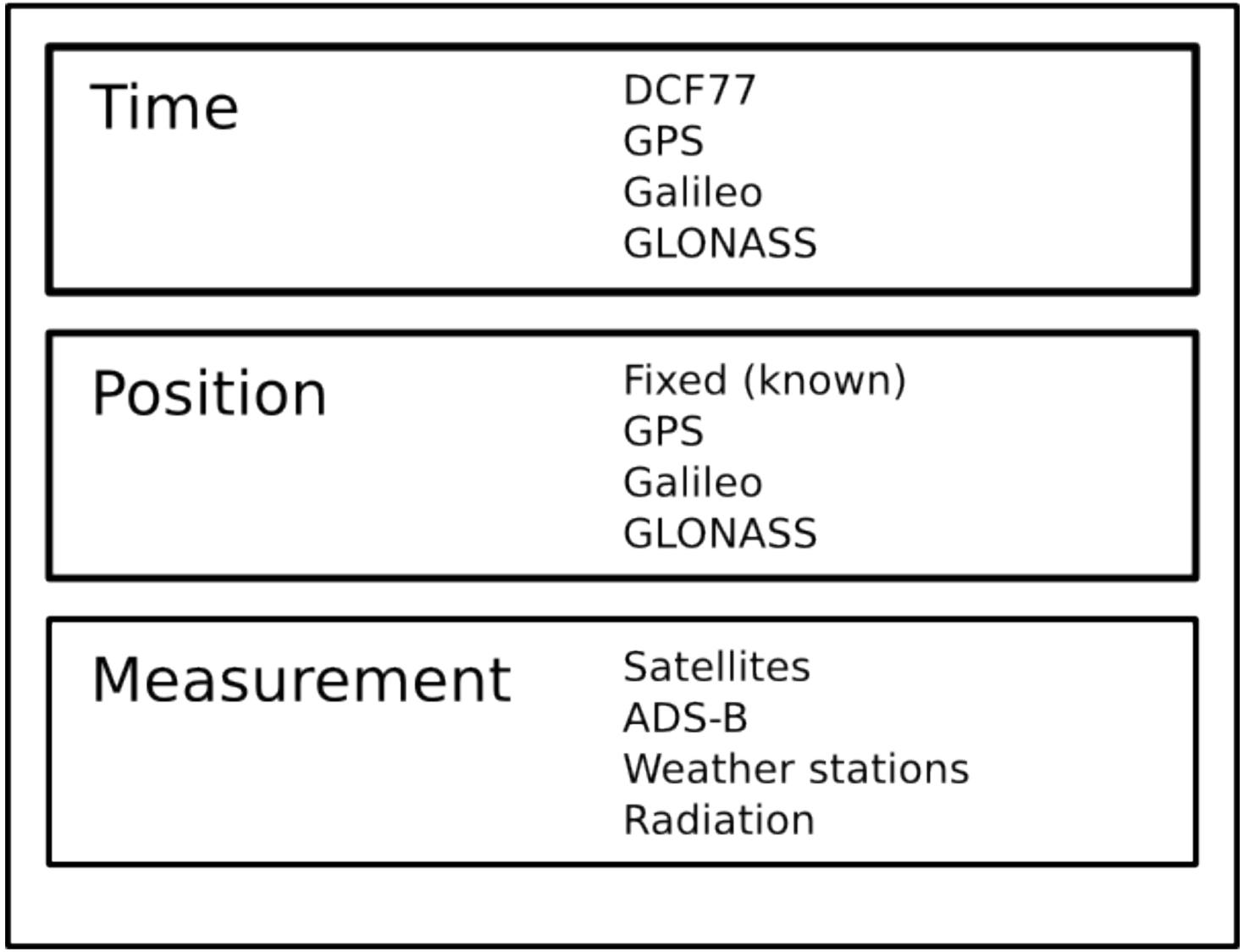
Defining a timing module

- Accurate time source
- Higher frequency clock to increase resolution
- Interface via I2C or interrupt + $something
  - Common interface with other modules
  - Different time sources can be easily adopted

Defining a positioning module

- Accurate position source
- Fixed stations can average position readings over time
- Different sources could be
  - GPS / GLONASS
  - Hard coded because you know where you are
  - Galileo, which was switched on a few days ago [h8]
- Again, a well defined module interface

Ground Station



What should be actually measured?

- Satellites?
  - Too complicated at this point
- Airplanes?
  - Challenge accepted!

ADS-B

- Pros
  - Includes planes call sign, GPS time, and position!
  - Gives us ground truth for verifying calculations and accuracy
- Cons
  - Signal sent at 1090 MHz
  - This is SHF (Scheiß hohe Frequenz)
  - SHF is nasty (which makes it awesome)

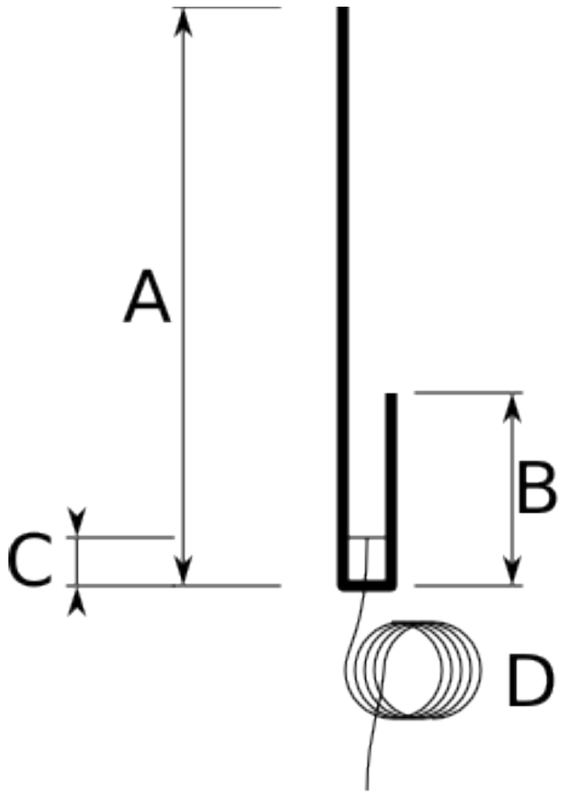
Dear HAMs...

- Why you so obscure?
- You love doing awesome hacking, so do we
- Yet a lot of documentation on the net is crap :(
  - We've probably just picked the wrong HAM
  - Anyway, here's some feedback ;)

Building an Antenna for ADS-B

- J-Pole [h9]
- Slim-Jim [h9,h6]

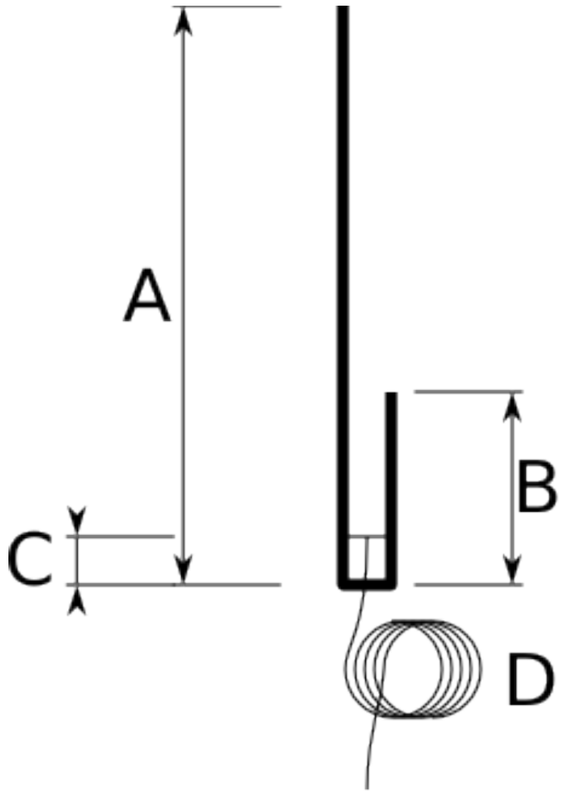
Building a J-Pole: Wrong



A = ~22 cm
B = ~6.5 cm
C = ~1cm
D = 4 turn balun

How to tune:
for each two nibbles taken away from A,
take one nibble away from B

Building a J-Pole: Correct



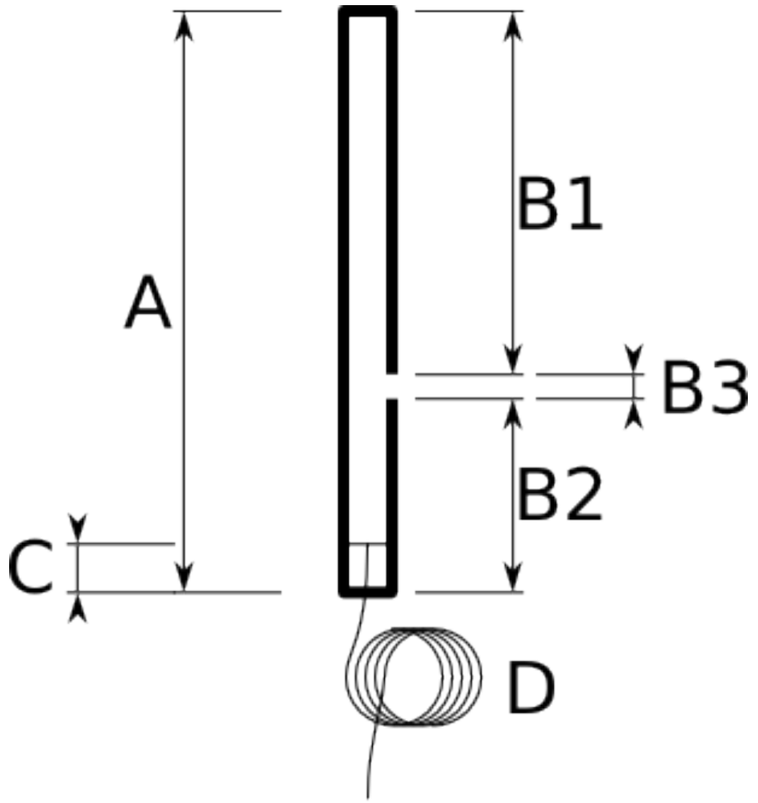
A = 3/4 λ
B = 1/4 λ
C = adjust to 50 Ω wave impedance between solder joints
D = 4 turn balun to keep coax line from becoming part of the radiator

How to tune:
nibble away bits on both arms while maintaining the (3/4 λ) / (1/4 λ) ratio

So, what should this tell us?

- Don't document what you did. Document why and how you did it!
- This is of course not an HAM issue (we just pick the wrong ones). There's plenty of hackers documenting their projects similarly. Okay, let's say almost all documentation of almost everyone just sucks ;)
- Documentation is work.
- Documentation will let us learn from each other, furthering everyones goals.

Building a Slim-Jim



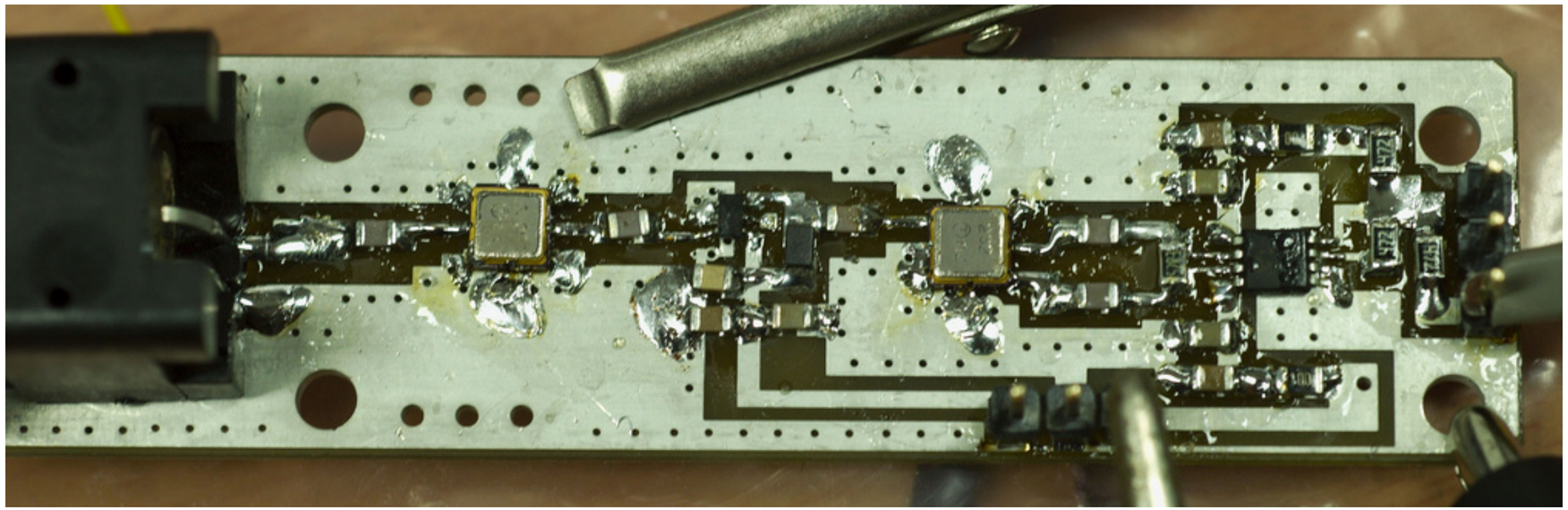
A = overall length
B1 = 1/2 λ
B2 = 1/4 λ
B3 = A-B1-B2
C = adjust to 50 Ω wave impedance between solder joints
D = 4 turn balun to keep coax line from becoming part of the radiator

First trials and failures

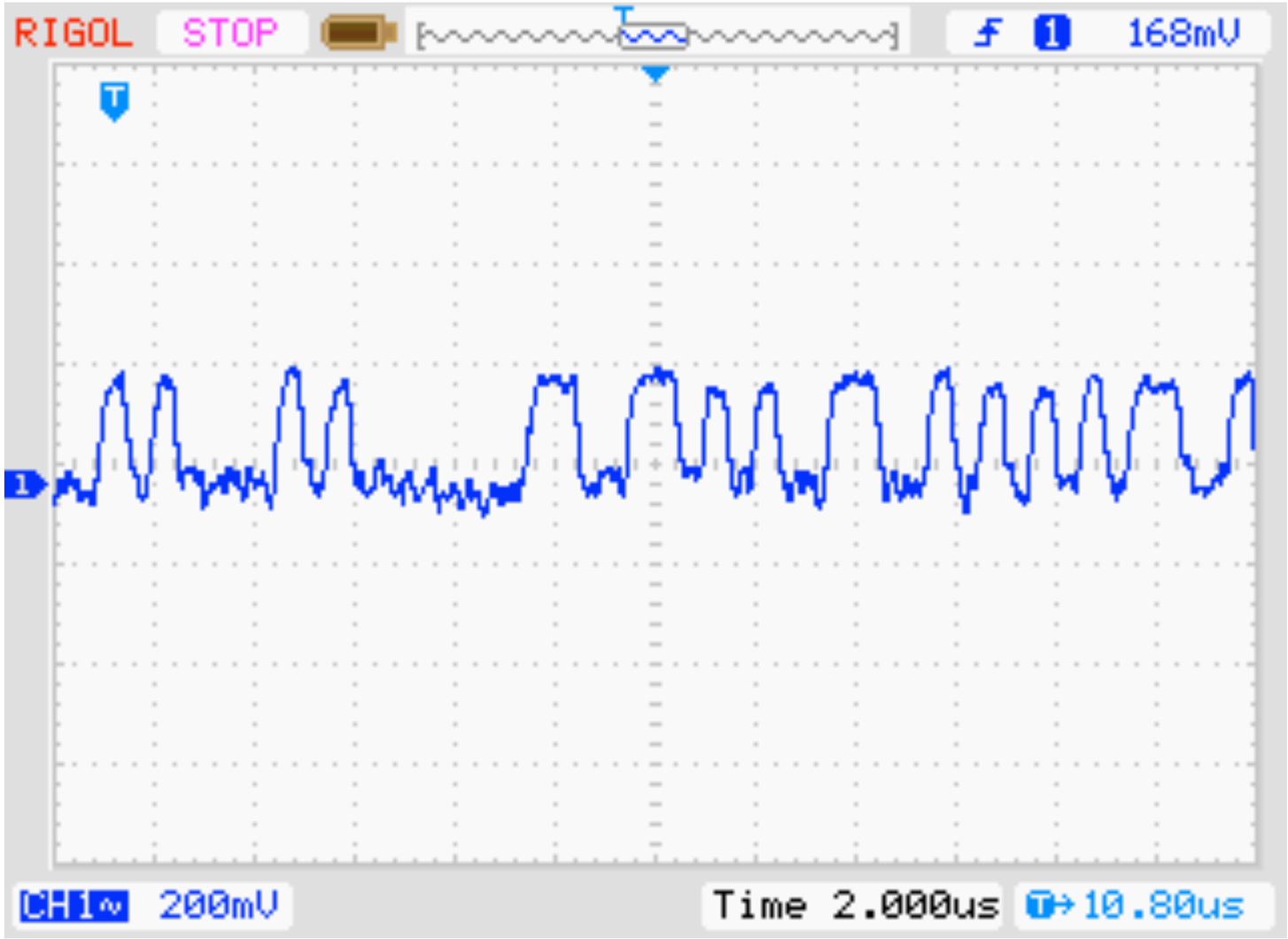
- TV Tuners? Works, if you have the right one that actually has a hardware “bug” you can use
- Sucks hard
- Documentation sucks harder

Buy shit, get it done

- miniADSB receiver [h3]
- Pure SMT awesomeness
- Simply works!



Success!



Filtering and Amplifying the signal

- What we've learned so far: HF sucks hard, SHF sucks harder
- We get about 0.1 to 0.3 Volts from our receiver
- We need more => build a preamp and filters
- Through sucky documentation we now have a set of resonant circuits which are not filters which is kind of bad...

Decoding and Measurement

- ADSB is using Manchester coding (transmitting the clock signal together with the AM modulated signal)
- Oh #^$% it's the 28th and I haven't made any slides yet!

What we‘ll get along the way (1)

- Even if we're not yet talking to satellites, we get a lot out of this project early on
- High accuracy timing of $measurements
  - Weather
  - Airplanes
  - Radiation
  - Earthquakes
  - ...

What we'll get along the way (2)

- GPS receiving ground stations with known actual location
  - AGPS for the masses!
  - Know the GPS position of known-position locations to increase GPS accuracy
- Distributed time sources

Next up (1)

- Get both ADSB receivers working
- Set up two ground stations 100km apart
- Measure signals
- Calculate numbers

Next up (2)

- Become crazy from thinking about high frequency stuff all the time
- If it ain't working, try harder
- If it is working, build more!
- There will be dragons.

Collateral Damage (1)

- Contacts in the space & satellite community, both academic and commercial.
- Three HF antennas built
- Two ADS-B receivers
- Filters!... So many filters!
- Two Arduino/GPS setups

Collateral Damage (2)

- Got a GPS module made specifically for timing off eBay
- One hacker off to the far away land of FPGA design
- Lost a hacker to a serious case of horology [h1]
- Tons of fun!
- Too much to do for just us


NOKIA
NOKIA

How to contribute

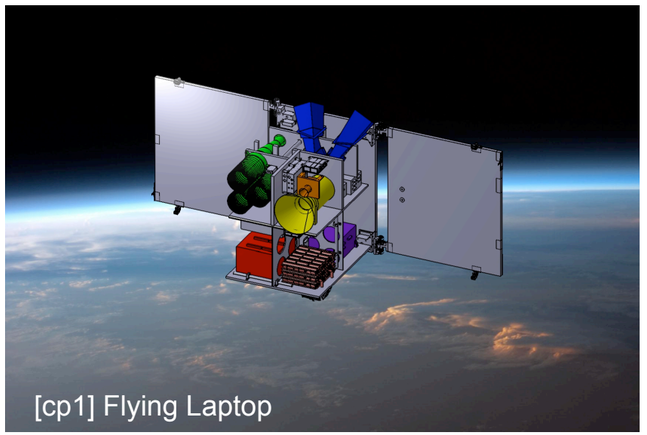
- Write code
- Provide computational power
- Build hardware
- Share expertise
- Set up a ground station!

And now a word from someone who actually has an application for all this!

loading Constellation ...

What the Frak are we doing?

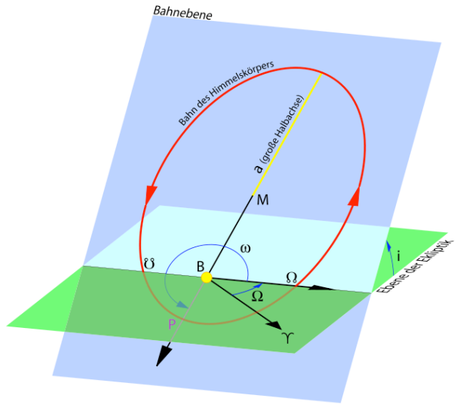
- Building a real space application
  - Telemetry and Tracking
  - Small Satellite Project "Flying Laptop" University of Stuttgart[c1-3] and more
  - Determine Orbital (Keplerian) Elements
  - Amateur Radio Community
  - External tracking and positioning!


[cp1] Flying Laptop

Universität Stuttgart

IRS

[c1-3][cp1]

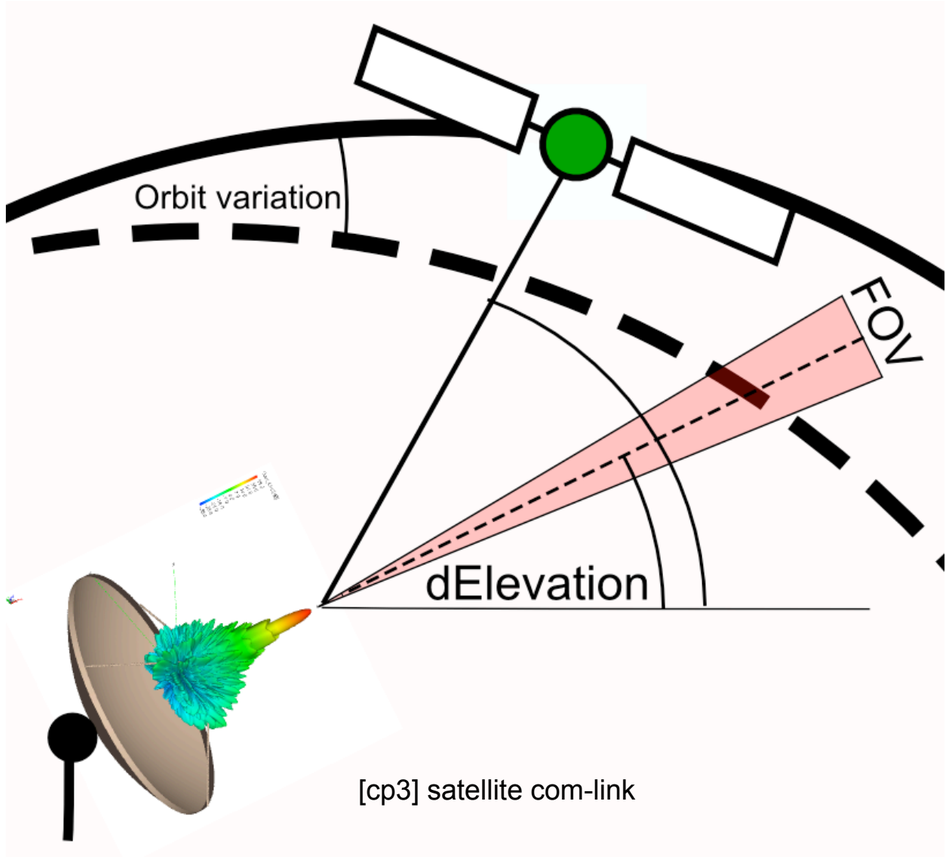


[cp2] Keplerian Elements


[cp1] IRS Ground Station

Why? Why not?

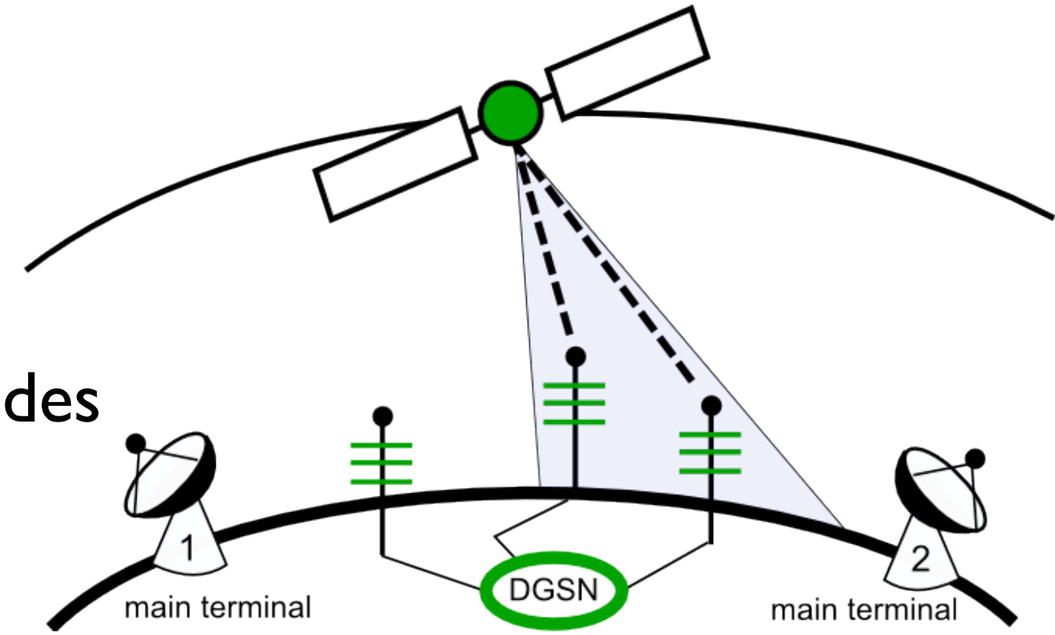
- Positioning:
  - Relatively fast positioning after orbit injection
  - Permanent and global tracking
  - Independent service



[cp3] satellite com-link

Why? Why not?

- Communication:
  - receiving sat-data in data-dump mode
  - in between black regions of main GS nodes
  - possibility to command satellites



[cp4] data-dump mode

„Almost nothing is more expensive than data-rates in $pace!“

Why? Why not?

- To serve man...!
  - with telemetry and tracking of satellites
  - derivates beyond current objectives
  - science platform

There are all kinds of groundstations

Raisting Satellite Earth Station, Germany.

[cp5]

There are all kinds of groundstations

Raisting Satellite Earth Station, Germany.

[cp5]

HGG Groundstation,
Berlin-Neukölln, Germany

[cp6]

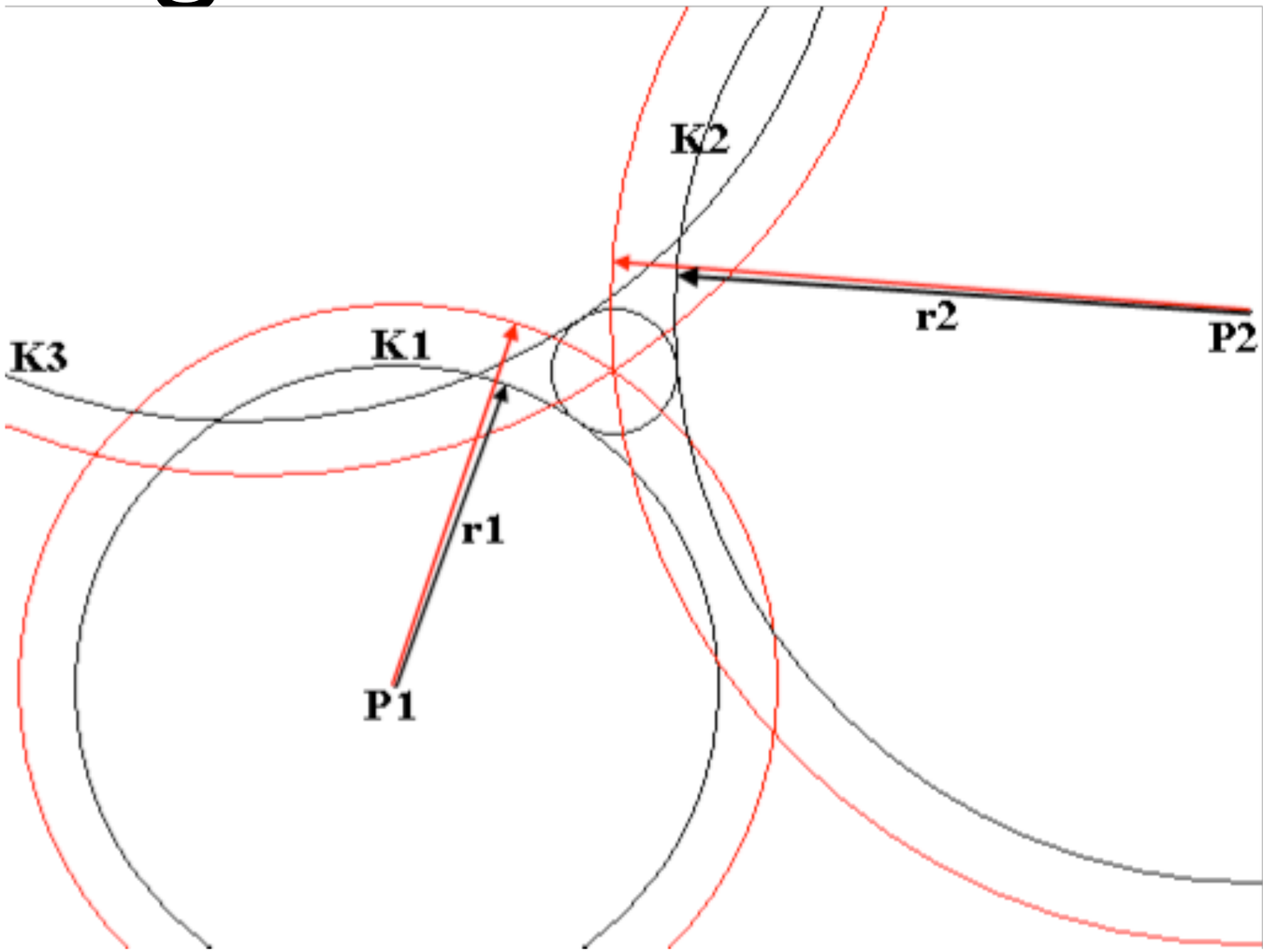
It starts with four dots

volunteers

[cp7]

Mathmagic 1

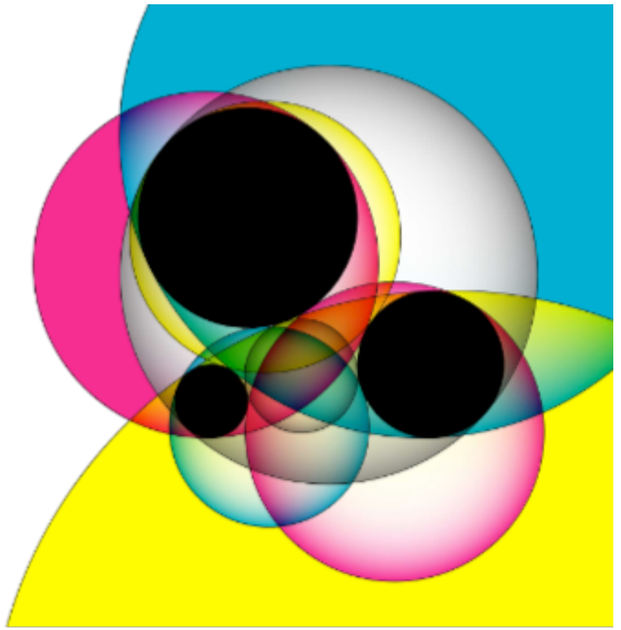
- Positioning via Pseudoranging
  (you can't beat the speed of light!)
- Beacon Signal to receiver stations
  "reverse GPS"
- At least 4 receiver stations,
  because it's 3D!
- Matrix Fun!



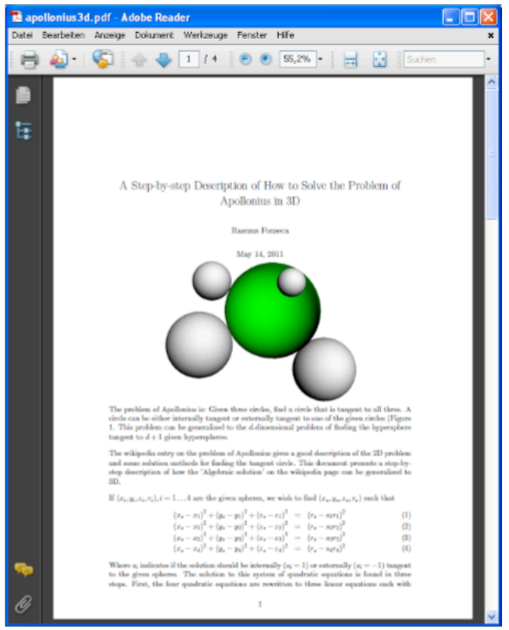
[cp8] pseudoranging

Mathmagic 1

- Apollonius of Perga had a problem once (ca. 262 BC – ca. 190 BC) [c4]
- We take available math and solutions from him & the Internet



[cp9] apollonius solutions 2d



[cp10] apollonius solutions 3d

It won‘t end with 4 dots!

volunteers

[cp7]

It won‘t end with 4 dots!

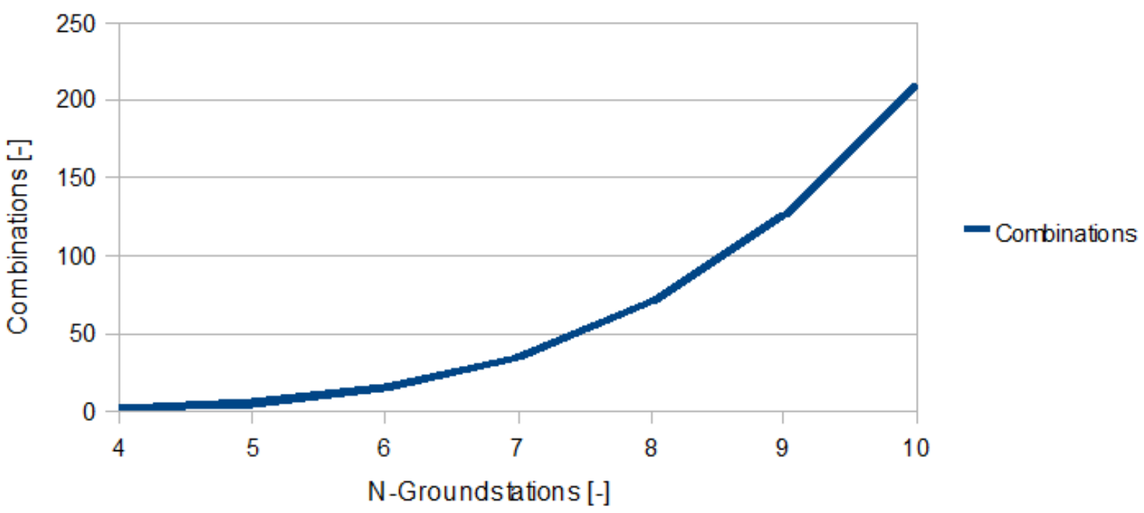
[cp7]

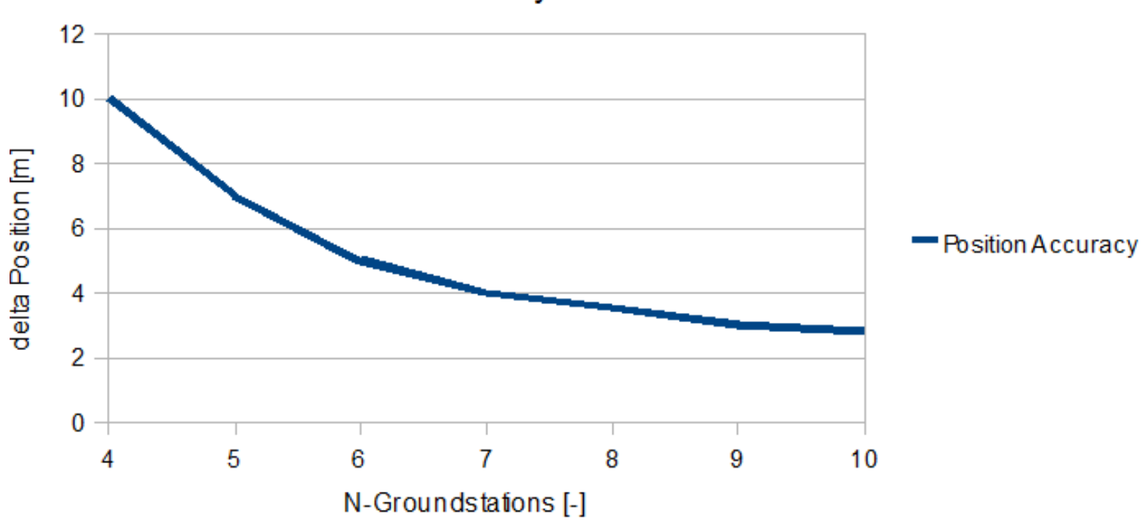
Mathmagic 2

- Enhancement of accuracy through multi receiver points.
- Combinatorical problem
- Deterministic n!/((n-k)!-k!)
  n=groundstations, k=needed groundstations (graph)

Mathmagic 2

trade-off:
Complexity vs. Accuracy





Infrastructure Constellation Platform

- Turning an existing distributed computing infrastructure into a sensor grid!

- Constellation Platform

  - student group

  - DGLR young academic groups

  - applied science & use-oriented aerospace project

  - interdisciplinary collaboration

Constellation

DEUTSCHE GESELLSCHAFT FÜR LUFT- UND RAUMFAHRT - LILIENTHAL OBERTH E.V.
Wissenschaftlich-Technische Vereinigung

Rechenkraft.net e.V.
Verein zur Förderung von Bildung, Forschung und Wissenschaft durch Einsatz vernetzter Computer

Selfnet e.V.

shack
stuttgart hackerspace

Infrastructure Constellation Platform

	HLRS (Uni Stuttgart)[c10]	Constellation
Units	**113,472 Cores**	**5,239 Computers**
Computing-Power	**831.40 TFLOPS**	**2.2 TFLOPS**
Costs	**22.5 (+10) M€, *1**	**300 €**
Top500.org (11/2011) [c11]	**12 (Congratulations!)**	**-**

[cp11]

For classification:
intel Centrino Core Duo (mobile, T2050) 1.6ghz: 4,8 GFOPS [4]

***1 equipment acquisition + 5 years operation**

Infrastructure Constellation Platform

	HLRS (Uni Stuttgart)[c10]	Constellation
Units	**113,472 Cores**	**5,239 Computers**
Computing-Power	**831.40 TFLOPS**	**2.2 TFLOPS**
Costs	**22.5 (+10) M€, *1**	**300 €**
Top500.org (11/2011) [c11]	**12 (Congratulations!)**	**-**

[cp11]


[c5]

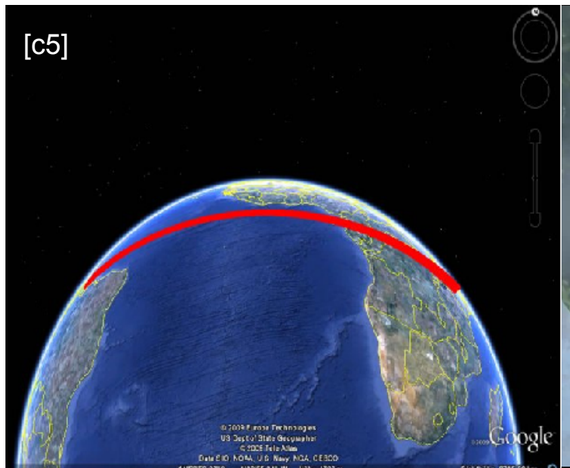
For classification:
intel Centrino Core Duo (mobile, T2050) 1.6ghz: 4,8 GFOPS [4]

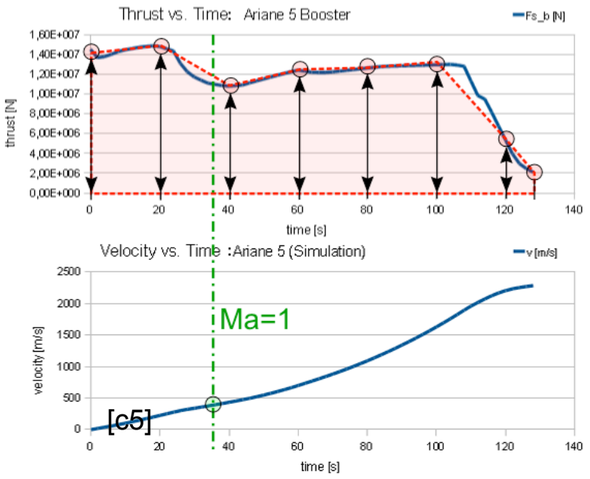
***1 equipment acquisition + 5 years operation**

Constellation Infrastructure
The Power of Many

Distributed Computing (DC)

- with BOINC
- 1995 users, 5230 host-PCs, 249 teams, 66 countries, 103.8M Credits (13.12.2011)
- currently processing TrackJack,
  an ascent trajectory optimizer
  (HyEnD's hybrid engined sounding rocket)[c14]





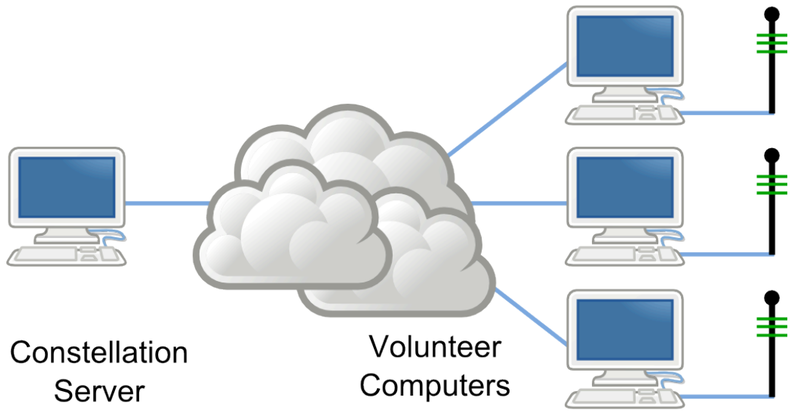
Constellation Infrastructure
The Power of Many

Distributed Ground Station Network (DGSN)

- distributed computing system as basis for DGSN
  just plug in DGSN hardware
- sensor data processed in home on DC
- hosting raw and processed data in data-base

YOU CAN START RIGHT NOW!

aerospace*research*.*net*/Constellation

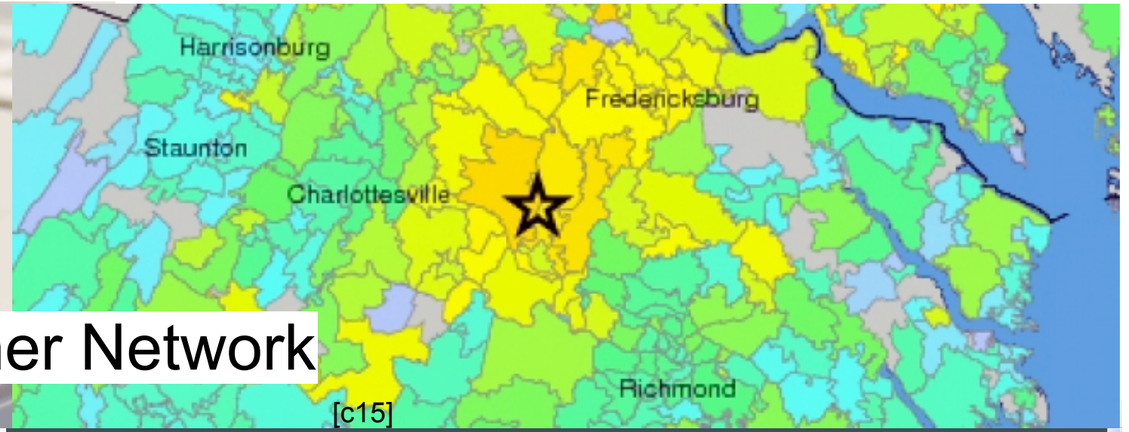


[cp14] DGSN schematic

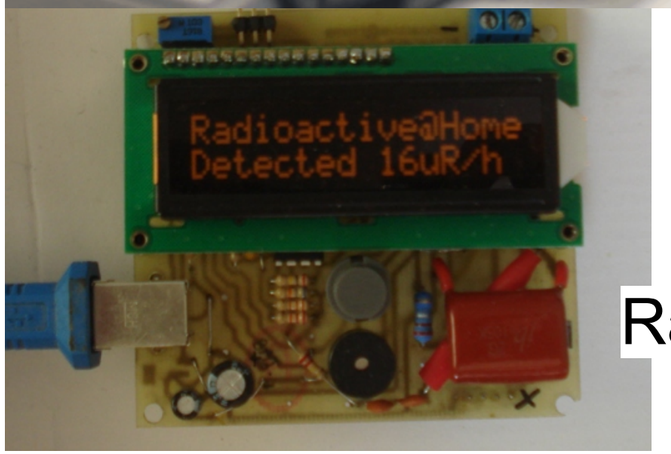
Constellation Infrastructure
The Power of Many

Distributed Sensor Grid => Yesterday‘s news

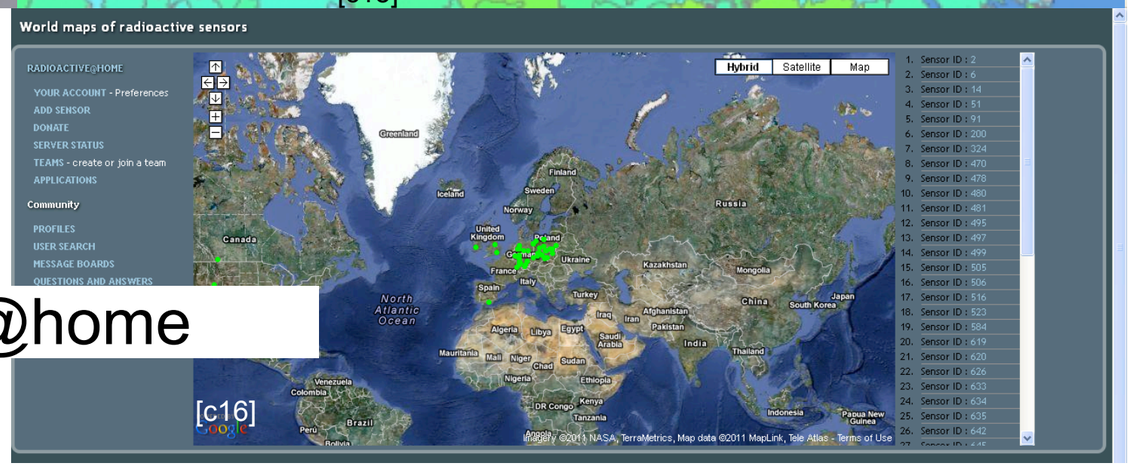
Quake Catcher Network



[c15]



Radioactive@home



[c16]

Infrastructure Expansion

[cp7]

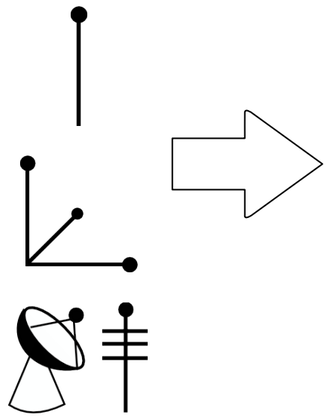
Infrastructure Expansion

volunteers
amateur radio
institutes

[cp7]

Infrastructure Expansion

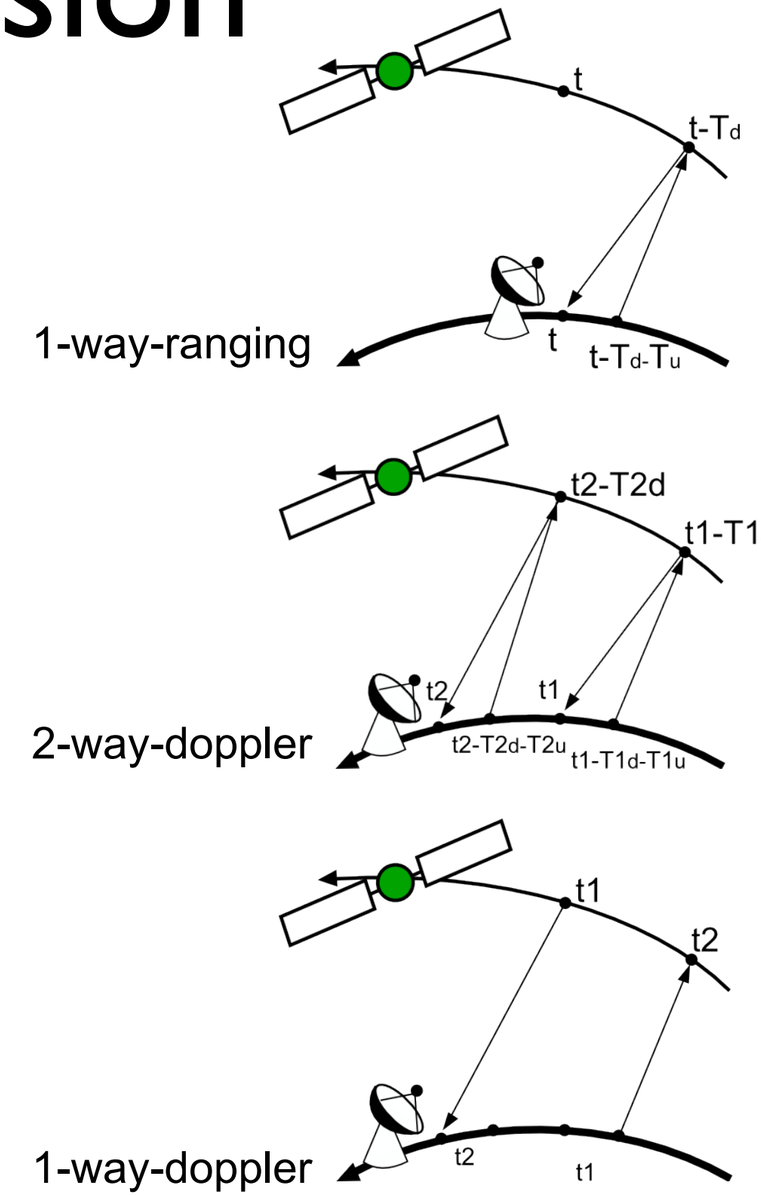
- Antenna Modes
  - fixed single antenna
  - fixed triple directional
  - motorized single directional
- hybrid antenna
- global sensor grid (n>1000)



- Volunteer Level
  - average joe & his balcony
  - amateur radio operator
  - institutes and organizations

Infrastructure Expansion

- More mathmagic:
  - One way ranging and Two way doppler
  - One way doppler [DORIS]
    ("Satellite orbits"; Oliver Montenbruck; Eberhard Gill)[c17]
  - Multiway ranging & doppler
  - Dopplershift
    (Dr. Yuji SAKAMOTO, Tohoku University, Japan)[c18]
  - … you name it!



Why do it?

- For science, you monster!
- And of course for more ...

System classification

Existing Navigation and Tracking Services

On-Board:

- Intertial Measurement System
- space-based satellite navigation system,
  - GPS by the U.S. Department of Defense (DoD)[c19]
  - Glonass transferred from Ministry of Defence to Russia's civilian space agency Roscosmos[c20]

When your satellite gets lost,
you're position data get lost, too.

System classification

Existing Navigation and Tracking Services

External:

- Governmental and Agency Services
  - NORAD+USSTRATCOM [c21-22]
  - European Space Tracking (ESTRACK) [c23]
- DORIS by the French Space Agency (CNES) [c24]

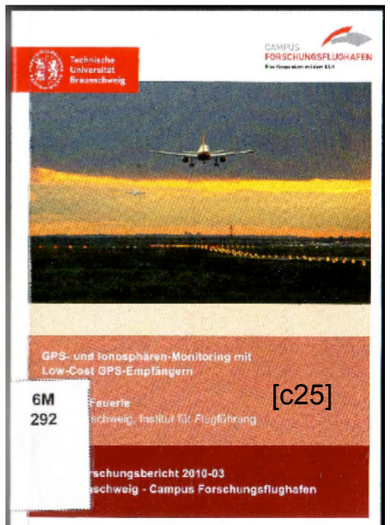
=> different function, under different management

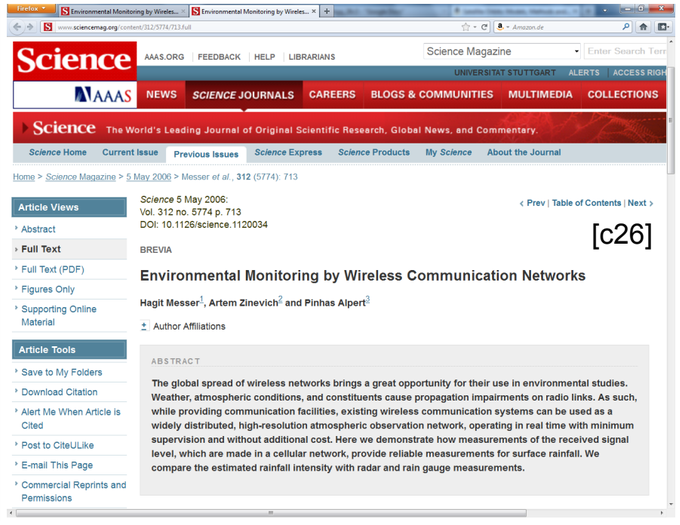
... DGSN could become new player with decentralized responsibilities

Hacking in/for science

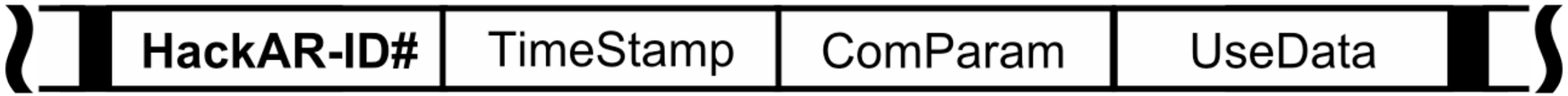
what else could DGSN do?

- Atmospheric measurements (Thomas Feuerle)[c25]
- GPS accuracy measurements (Thomas Feuerle)[c25]
- Environmental monitoring by wireless communication nets
  (Hagit Messer, Artem Zinevich and Pinhas Alpert)[c26]
- Thunderstorm strikes & cells (Blitzortung.org)[c27]
- Nuclear detonation detection (Daniel N. Baker)[c28]





Beacon on board



- Transmitting
- Protocol
- Datarate
- ID like *OSCAR* *(Orbital Satellite Carrying Amateur Radio)*

AEROSPACE LAB
Jugendforschungszentrum Herrenberg-Gäu

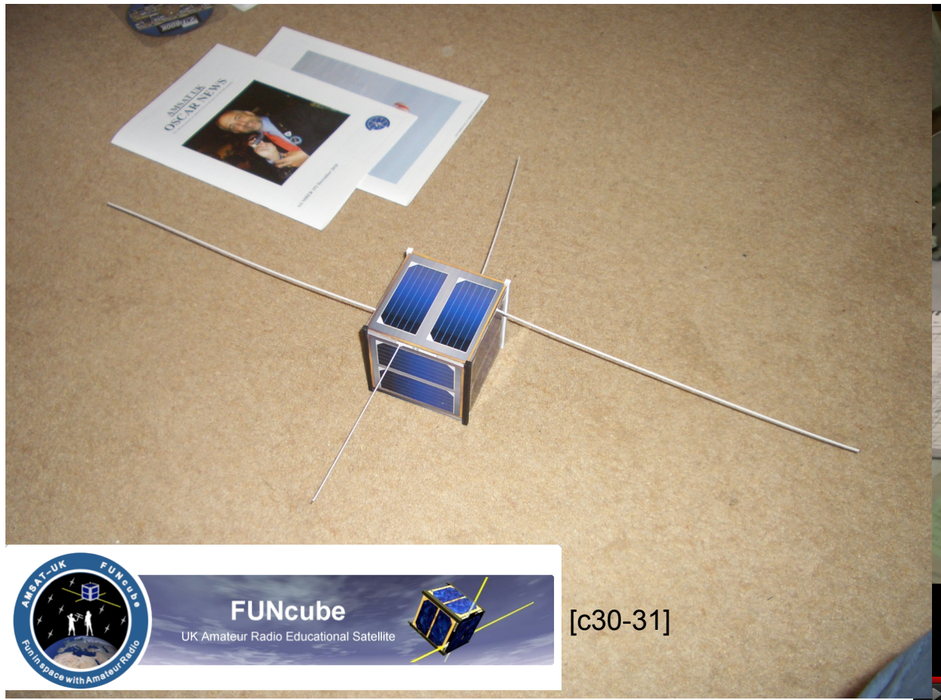
Aerospace-Lab.de Stuttgart-Herrenberg
Highschool students will help building [c29]

Beacon should be as simple as possible to fit future needs.

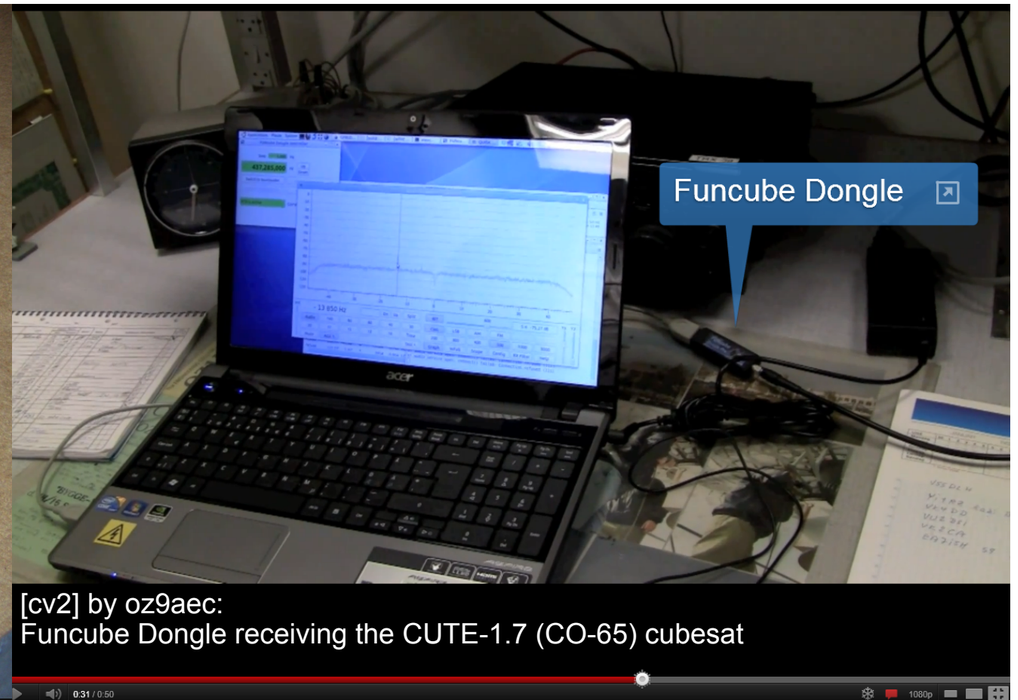
Do we get contact

Small Satellite: FunCube
Small Receiver: FunCubeDongle (USB)

When they can do it, we too!



[c30-31]



[cv2] by oz9aec:
Funcube Dongle receiving the CUTE-1.7 (CO-65) cubesat

Future perspective

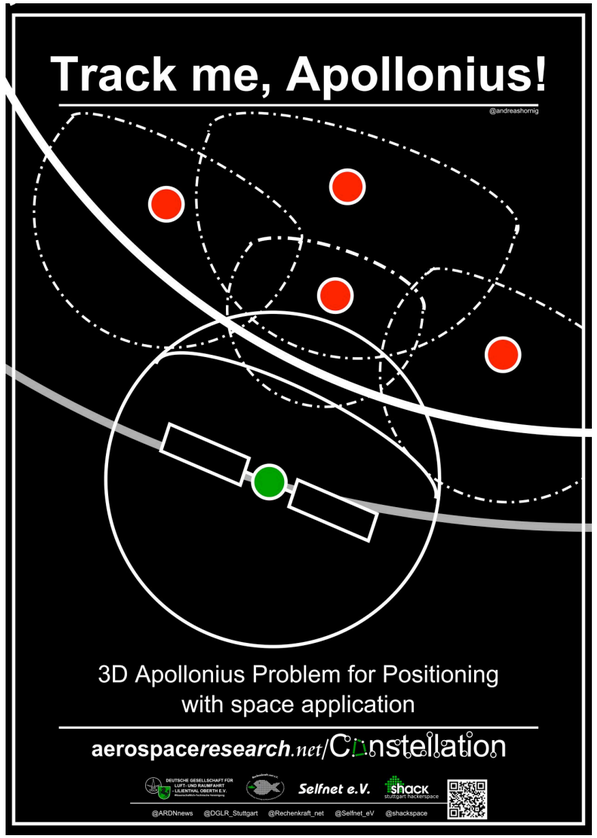
for system itself

<u>Time Synching:</u>

- Measurements

<u>Tracking:</u>

- Satellites



[c5]

Future perspective

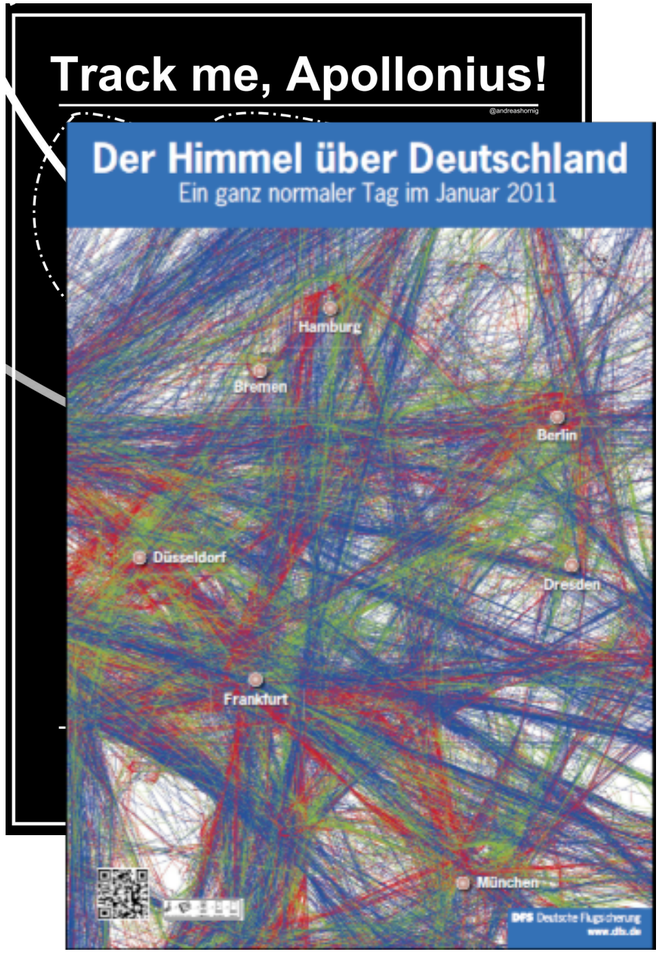
for system itself

<u>Time Synching:</u>

- Measurements

<u>Tracking:</u>

- Satellites
- Aircrafts (Deutsche Flugsicherung)



[c32]

Future perspective

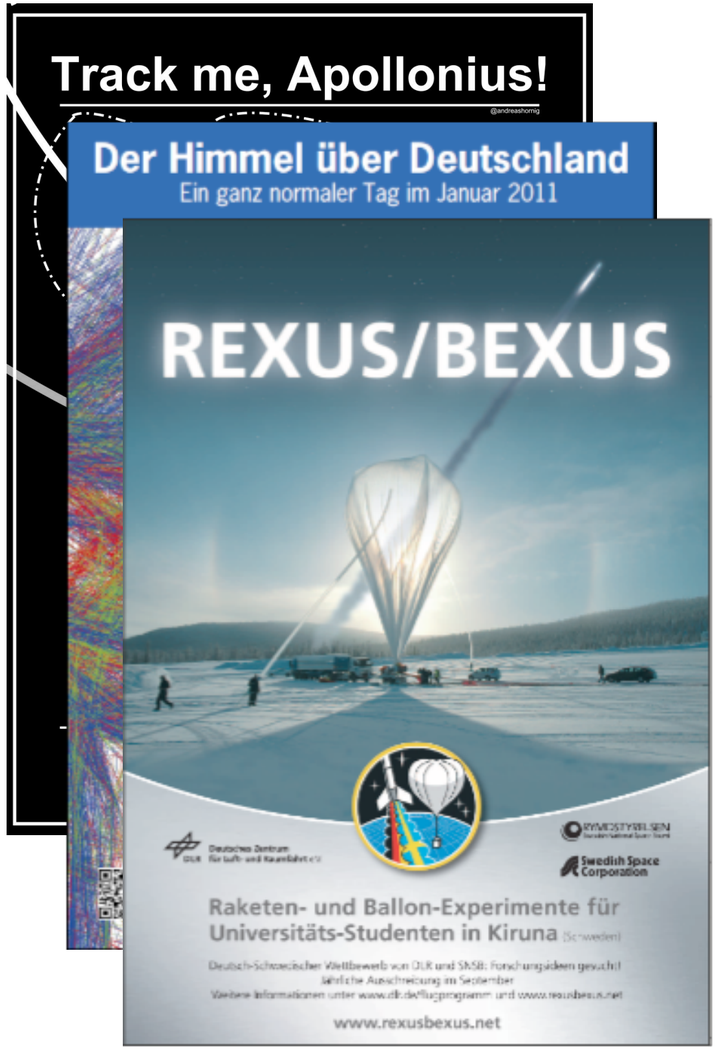
for system itself

<u>Time Synching:</u>

- Measurements

<u>Tracking:</u>

- Satellites
- Aircrafts (Deutsche Flugsicherung)
- Science Experiments
  (DLR REXUSBEXUS)
- Weather Balloons



[c33]

Future perspective

for system itself

<u>Time Synching:</u>

- Measurements

<u>Tracking:</u>

- Satellites
- Aircrafts (Deutsche Flugsicherung)
- Science Experiments
  (DLR REXUSBEXUS)
- Weather Balloons
- UAVs
  (UAVP-NG, Stuttgarter Adler)

[c34]
[c35]

Future perspective

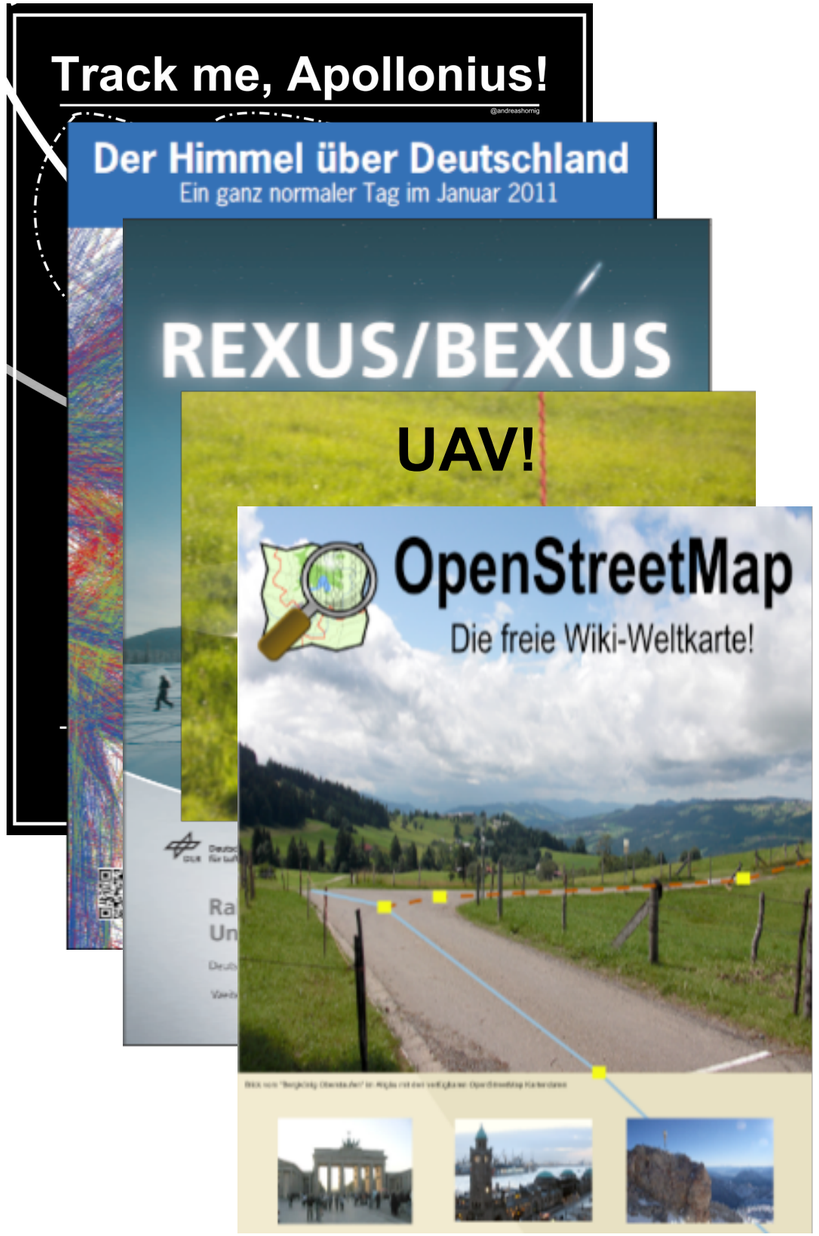
for system itself

<u>Time Synching:</u>

- Measurements

<u>Tracking:</u>

- Satellites
- Aircrafts (Deutsche Flugsicherung)
- Science Experiments
  (DLR REXUSBEXUS)
- Weather Balloons
- UAVs
  (UAVP-NG, Stuttgarter Adler)
- OpenStreetMap
- Differential GPS



[c36]

Future perspective

for system itself

<u>Time Synching:</u>

- Measurements

<u>Tracking:</u>

- Satellites
- Aircrafts (Deutsche Flugsicherung)
- Science Experiments
  (DLR REXUSBEXUS)
- Weather Balloons
- UAVs
  (UAVP-NG, Stuttgarter Adler)
- OpenStreetMap
- Differential GPS
- Animal Tracking

Future perspective and chances

beyond system

- Constellation could be the first big application for the DGSN
- DGSN and modules are not exclusive
- spin-offs and derivates for everybody
  - „Wurfantenne“ / „Fast deployable antenna“

Midterm Goal for Constellation & HGG

- Telemetry and Tracking
- Receiving and Broadcasting of data
- Alternative infrastructure for and driven by community
- Collaboration with active community

With you,
By you,
For you and everyone

Lessons learned

- interdisciplinary collaboration works!
  (hackers, science, volunteers, ...)
- almost everything is already available
- just bringing everything together
- keep on working
- best ever communities!
- *space rocks!*

Space is big, really big...

<questions>anyone?</questions>

</end>

So Long, and Thanks for All the Fish

Meta

- @rel0c8
- @hdznrrd (hadez@shackspace.de)
- @andreashornig (horn@aerospaceresearch.net)
- hgg.shackspace.de
- aerospaceresearch.net/constellation
- constellation@lists.shackspace.de

A problem has been detected and windows has been shut down to prevent damage
to your computer.

If this is the first time you've seen this Stop error screen,
restart your computer. If this screen appears again, follow
these steps:

Check to be sure you have adequate disk space. If a driver is
identified in the Stop message, disable the driver or check
with the manufacturer for driver updates. Try changing video
adapters.

Check with your hardware vendor for any BIOS updates. Disable
BIOS memory options such as caching or shadowing. If you need
to use Safe Mode to remove or disable components, restart your
computer, press F8 to select Advanced Startup Options, and then
select Safe Mode.

Technical information:

*** STOP: 0x0000007E (0xC0000005,0xF88FF190,0x0xF8975BA0,0xF89758A0)

*** EPUSBDSK.sys - Address F88FF190 base at FF88FE000, datestamp 3b9f3248

Beginning dump of physical memory

Links

h0 hackerspace global grid / project hgg shackspace.de/wiki/doku.php?id=project:hgg
h1 Allan et al - The Science of Timekeeping allanstime.com/Publications/DWA/Science_Timekeeping/
h2 Jeff Wofford - A programmer's greates enemy jeffwofford.com/?p=835
h3 miniADSB Receiver miniadsb.web99.de
h4 Arduino Microcontroller Platform arduino.cc
h5 Adafruit GPS Logger Shield ladyada.net/make/gpsshield/
h6 M0UKD - Slim Jim Antenna Calculator m0ukd.com/Calculators/Slim_Jim/
h7 Space program of the Hacker Scene events.ccc.de/camp/2011/wiki...
.../Space_program_of_the_Hacker_Scene:_For_our_future
h8 First Galileo navigation satellite begins broadcasting spaceflightnow.com/news/n1112/18galileo/
h9 Wikipedia: J-Pole & Slim-Jim en.wikipedia.org/wiki/J-pole
h10 Weekend Graffiti Workshop Timelapse vimeo.com/32865163

Sources

Common:

c1 University of Stuttgart - www.uni-stuttgart.de
c2 Institute for Space Systems (IRS) - www.irs.uni-stuttgart.de
c3 Small Satellite Project - www.kleinsatelliten.de
c4 Apollonius of Perga (ca. 262 BC – ca. 190 BC), en.wikipedia.org/wiki/Apollonius_of_perga
c5 Constellation Platform - www.aerospaceresearch.net/constellation
c6 DGLR e.V.: Stuttgart - http://stuttgart.dglr.de/
c7 Rechenkraft.net e.V. - www.Rechenkraft.net
c8 Selfnet e.V. - www.selfnet.de
c9 shackspace - www.shackspace.de
c10 hlrs - www.hlrs.de
c11 top500.org - http://top500.org/lists/2011/11
c12 http://download.intel.com/support/processors/coreduo/sb/core_T2000.pdf
c13 BOINC - www.boinc.berkeley.edu
c14 HyEnD - www.hybrid-triebwerk.de
c15 Quake Catcher Network - http://qcn.stanford.edu
c16 Radioactive@home - www.radioactiveathome.org
c17 Oliver Montenbruck; Eberhard Gill, "Satellite orbits : models, methods and applications", ISBN:354067280X
c18 Dr. Yuji SAKAMOTO, Assistant Professor, Dept. of Mechanical and Aerospace Engineering, Tohoku University, Japan, http://www.astro.mech.tohoku.ac.jp/e/index.html
paper: Yuji Sakamoto and Akari Yoneyama, "Orbit Determination System with Reasonable Performance Using Low-Cost Ground Station for Nanosatellite Projects," The 28th International Symposium on Space Technology and Science (ISTS), Naha, Japan, June 2011, No.2011-f-37.

Sources

Common (ctd):

c19 USDOD - www.defense.gov
c20 ROSCOSMOS - www.roscosmos.ru/main.php?lang=en
c21 NORAD - www.norad.mil
c22 USSTRATCOM - www.stratcom.mil
c23 ESTRACK - www.esa.int/SPECIALS/Operations/SEM8YCSMTWE_0.html
c24 DORIS - http://smsc.cnes.fr/DORIS
c25 Thomas Feuerle, "GPS- und Ionosphärenmonitoring mit Low-Cost GPS-Empfängern", ISBN:9783928628549
c26 Hagit Messer; Artem Zinevich; Pinhas Alpert3, "Environmental Monitoring by Wireless Communication Networks", www.sciencemag.org/content/312/5774/713.abstract
c27 Blitzortung.org - www.blitzortung.org
c28 Daniel N. Baker, "The Earth's Secrets, Hidden in the Skies", www.nytimes.com/2010/05/28/opinion/28baker.html
c29 Aerospace Lab - Jugendforschungszentrum Herrenberg-Gäu - www.aerospace-lab.de
c30 FunCube - www.funcube.org.uk
c31 FunCubeDongle - www.funcubedongle.com
c32 Deutsche Flugsicherung (www.DFS.de) http://www.dfs.de/dfs/internet_2008/module/presse/poster_mobilitaet_03.pdf
c33 REXUS/BEXUS - Rocket and Balloon Experiments for University Students - www.rexusbexus.net
c34 Next Generation OS Quadcopter Project, Project Home: http://ng.uavp.ch events.ccc.de/congress/2008/wiki/UAVP-NG/index.html
c35 Stuttgarter Adler - www.irs.uni-stuttgart.de/uav
c36 OpenStreetMap - www.openstreetmap.org

Sources

Picture/Images:

cp1 Small Satellite Project - www.kleinsatelliten.de
cp2 Keplerian Elements - commons.wikimedia.org/wiki/File:Bahnelemente.svg
cp3 Student Research Project by Bastian Mayer, RA3AQ Feed with 2,5m Parabolic Antenna
cp4 data-dump mode by A. Hornig - www.aerospaceresearch.net
cp5 en.wikipedia.org/wiki/File:2005-05-15-raisting_900x460.jpg
cp6 de.wikipedia.org/w/index.php?title=Datei:Berlin-neukoelln_satellite-dishes_20050314_p1010596.jpg
cp7 http://commons.wikimedia.org/wiki/File:World_map_blank_with_blue_sea.svg
cp8 http://de.wikipedia.org/wiki/Datei:Pseudorange3,2.png
cp9 apollonius solutions 2d http://en.wikipedia.org/wiki/File:Apollonius8ColorMultiplyV2.svg
cp10 apollonius solutions 3d http://www.diku.dk/hjemmesider/ansatte/rfonseca/implementations/apollonius3d.pdf
cp11 http://inside.hlrs.de/images/autumn02_09/hlrs_room1.png
cp12 http://commons.wikimedia.org/wiki/File:Kondensstreifen_Abendrot.jpg
cp13 "Rainbow dash vs F15" by CIRILIKO http://ciriliko.deviantart.com/art/Rainbow-dash-vs-F15-260794311
cp14 http://en.wikipedia.org/wiki/File:Internet_as_cloud.svg

Videos:

cv1 "HyEnD Micro Hybrid Engine Test-14" by rocketman0815 - www.youtube.com/watch?v=XnvQM9MlCdU
cv2 "Funcube Dongle receiving the CUTE-1.7 (CO-65) cubesat" by oz9aec - www.youtube.com/watch?v=TqFCHR2vQtI
cv3 "Котенка запустили в космос!" (SpaceCat) by gosloto1 - www.youtube.com/watch?v=UB8NofPUbaU