tinySA

HISTORY, DESIGN AND FUNCTIONALITY

Content

Some history

Spectrum Analyzer architecture options

tinySA design

tinySA Spectrum Analyzer functionality

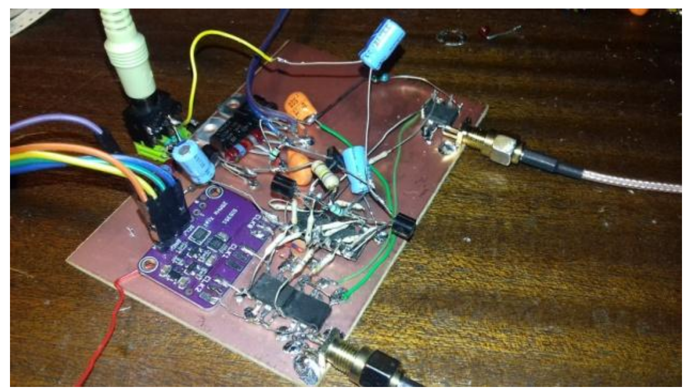
tinySA Signal generator functionality

User community and Web assets

How did this start?

- Retired two years ago
- Qualified for amateur radio license
- Restarted old electronics hobby by building measurement equipment, such as grid dipper, VNA and Spectrum Analyzers.

Grid dipper

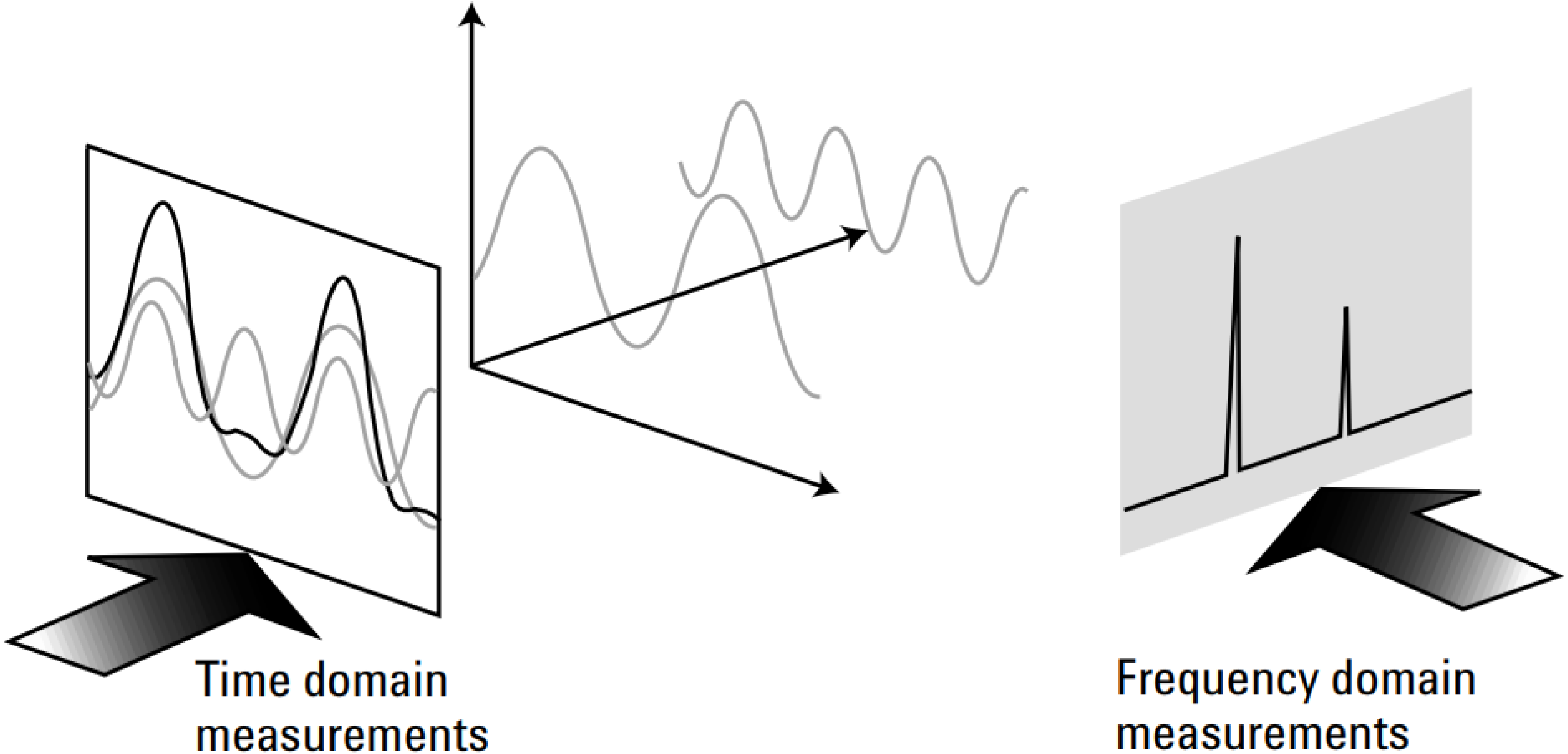


VNA (10kHz-900MHz)

- But what is a Spectrum Analyzer and how to build one?

Scope versus SA

- Scope displays signals in the time domain
- SA displays signals in the frequency domain



How to build an SA?

Variable frequency translator for conversion to fixed frequency resolution filters and power detector

Variable frequency input
Fast sweep, wide range!

Fixed center frequency filters
Many, steep!

Measures power at selected frequency
Large power range!

Important difference:

VNA: measure frequencies on grid (nanoVNA: 1-350MHz 101 steps)

SA: measure ALL frequencies in sweep (1-350MHz, RBW 500kHz, min 700 steps)

Frequency translation options(1)

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Zero Hz IF: Mixer with LO at input frequency (eBay 35-4400MHz SA)

- Pro: Low frequency low pass filters as resolution filters
- Con:
  - Gap at “zero” Hz
  - LO needs to go as low as lowest input frequency
  - Band pass filters needed before mixer to eliminate spurs from LO harmonics (visible as sub harmonics of the LO)

Mirror suppressing I/Q mixer with low IF: (RTL-SDR)

- Pro:
  - LO can be above or below RX frequency
  - Resolution filters at fixed low IF frequency in DSP
- Con:
  - Limited mirror suppression in I/Q combiner (max 50dB)
  - Band pass filters before mixer needed to eliminate spurs from LO harmonics

Frequency translation

Frequency translation options(2)

Dual conversion with High IF: First mixer converts to above the maximum input frequency for mirror suppression band pass filtering and second mixer down converts to frequency of resolution filters (Siglent, Rigol, HP,…)

- Pro:
  - Low pass filter before mixer and band pass filter after mixer eliminate mirrors.
  - Second mixer can be I/Q with low IF (no mirror) and DSP resolution filters
  - LO harmonics all above input range so no band filters needed before mixer
- Con:
  - LO range from max input freq to twice the max input freq
  - Complexity: Extra IF, extra mixer and extra filters

High IF key components options

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Mixer options

- Solid state Gilbert (SA602, SA612 like in nanoVNA):
  - Pro: Conversion gain
  - Con: Noisy and high current consumption for high IIP3
- Solid state switching (only used in HF receivers):
  - Pro: Excellent dynamic range and low noise
  - Con: Difficult to realize above 100MHz
- Double balanced diode mixer (Rigol, Siglent, HP,...)
  - Pro: Low noise and high IIP3
  - Con: Conversion loss (7 to 13dB) and LO drive power required

Frequency translation

High IF key components options

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1st IF filter: Must have narrow BW for one step down conversion to resolution filters

- LC filters: cheap but wide
- Helical filters: expensive
- Cavity filters: large and expensive
- Lumped elements filters: Too large for PCB when well below GHz
- SAW filters: cheap and sufficiently narrow, especially near 433MHz

Frequency translation

Resolution filter options

HW such as (passive/active) LC or crystal ladder filter

- Pro: Can design each filter to be optimal
- Con: Lot of work, large, expensive

DSP filters

- Pro: Much less effort to add more filters
- Con: Need fast/good enough ADC and DSP

Resolution filters

Power detector options

Standalone Log power detector + ADC

- Pro: High resolution, limited by ADC
- Con: Limited dynamic range or very expensive

Integrated RSSI in many IF components.

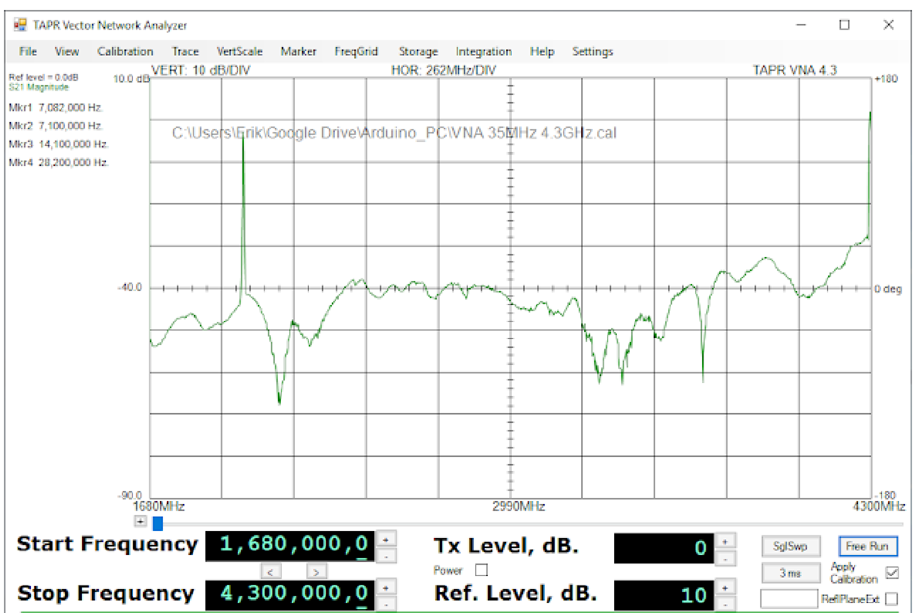
- Pro: Large dynamic range (often 120dB)
- Con: Limited resolution (0.5dB)

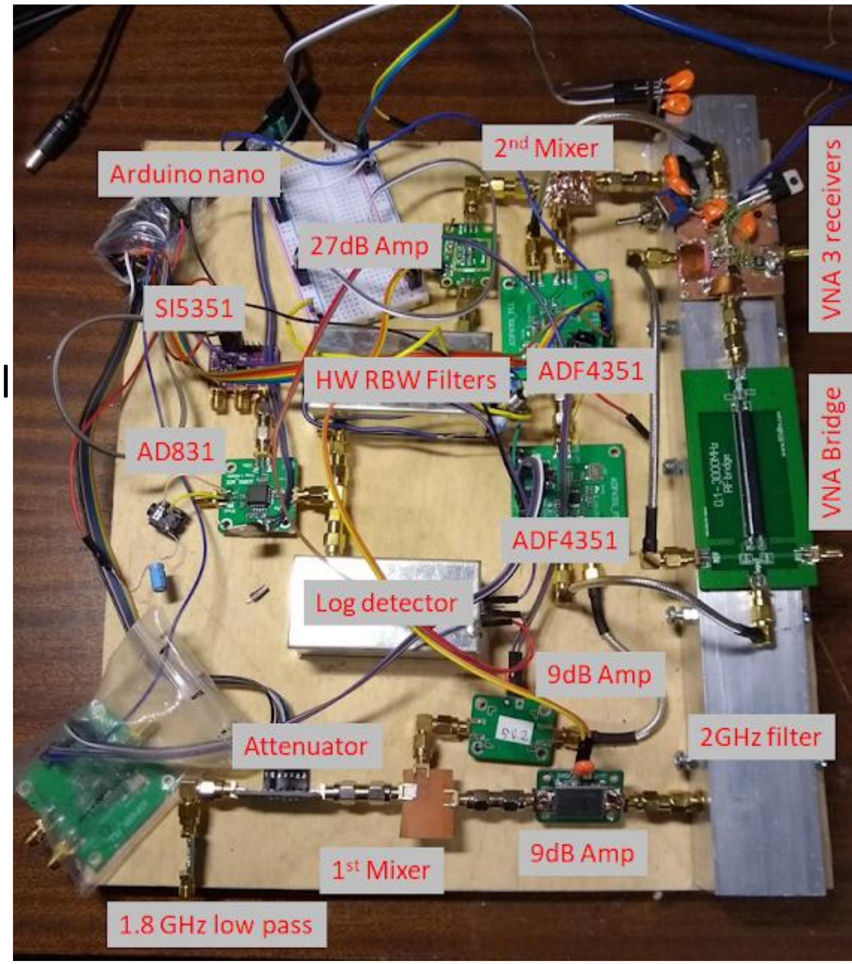
Enough theory, time to build!

Power detector

Combined 0-2GHz SA/VNA

- Triple conversion high IF: 1st IF at 2.1GHz
- HW + FFT resolution filters: 1Hz (FFT) to 300kHz
- Power detector log amp+VGA: 90dB range
- PC for UI and DSP, Arduino Nano for IC control
- Almost for free 35MHz-3Ghz VNA
- Good performance but too complex for practical use and impossible to replicate

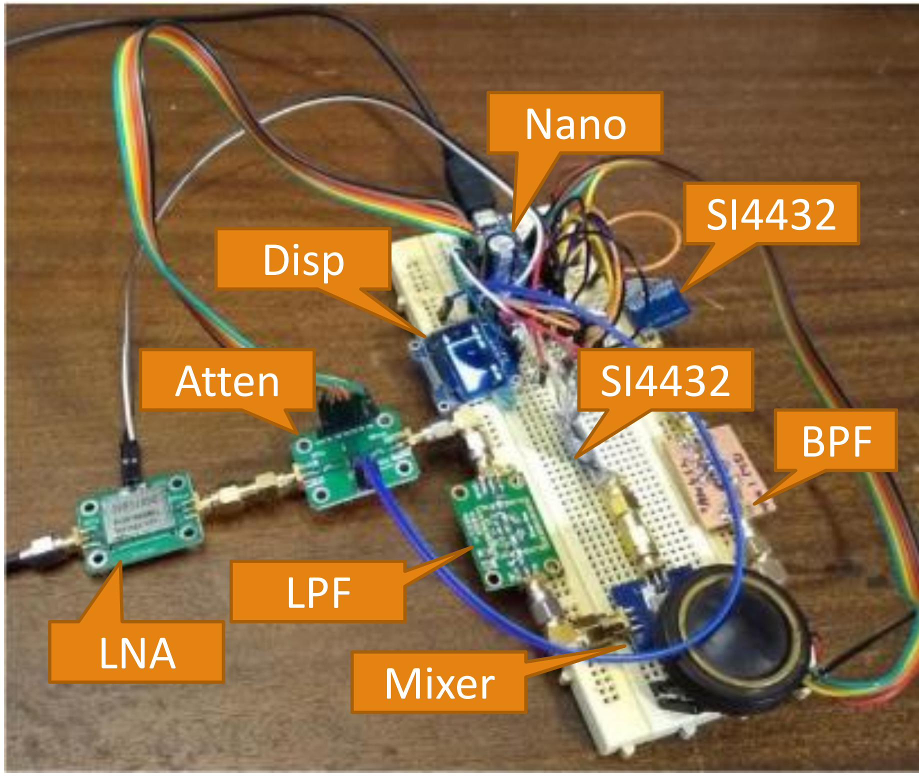




Can this be simplified?

In search for a simpler SA

- Standalone Arduino with own display
- Minimize components
- No cavity filter but SAW
- First prototype:
  - Arduino
  - Two SI4432 modules
  - Mixer
  - 1st IF at 433MHz using SAW
  - Low pass filter
  - Attenuator
  - Display
- Open source design
- Published on HBTE group
- Design available on GitHub
- Easy to build, simple to use
- But many people do not want to DIY
- How about a tinySA product?



Complete standalone SA

Design goals for tinySA product

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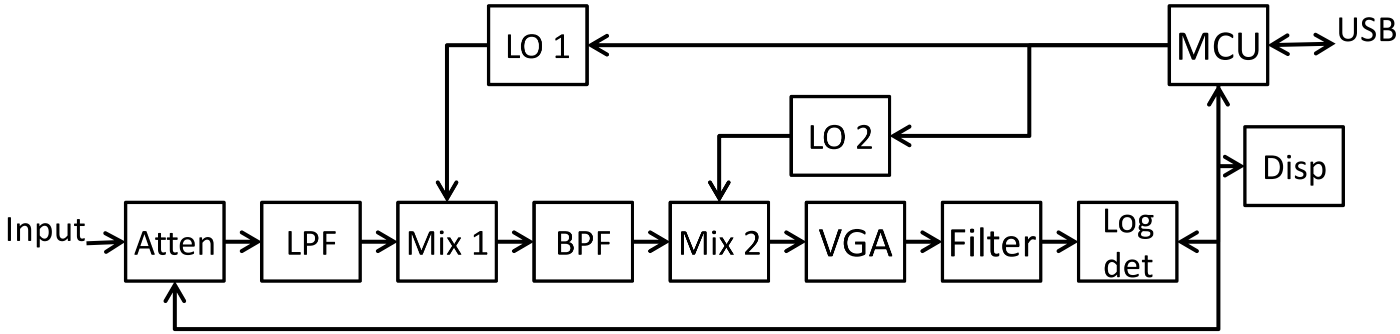
- Standalone portable SA
- Maximum retail price 50$
- Usable by novice SA user
- Reliable measurements
- Spur free
- All the functions of a big SA
- Frequency range from 100kHz to 350MHz
- No need for very narrow RBW (use your favorite SDR)

Key function selection(1)



Atten: Integrated 6 bit step attenuator 0-31.5dB

- Must have well defined attenuation over entire frequency to avoid calibration need.
- Required for mixer protection and assessment of harmonics/spur free dynamic range

LPF: 9th order Elliptic low pass filter with 350MHz corner frequency

- Commercial available filters not steep enough and high corner frequency supports higher max input frequency

Mixer 1: ADE-25MH. Double balanced level 13 diode mixer

- Better noise/IIP3 performance versus power compared to active mixers.

LO 1: SI4432 TX 240-960MHz LO and +20dBm output power amplifier

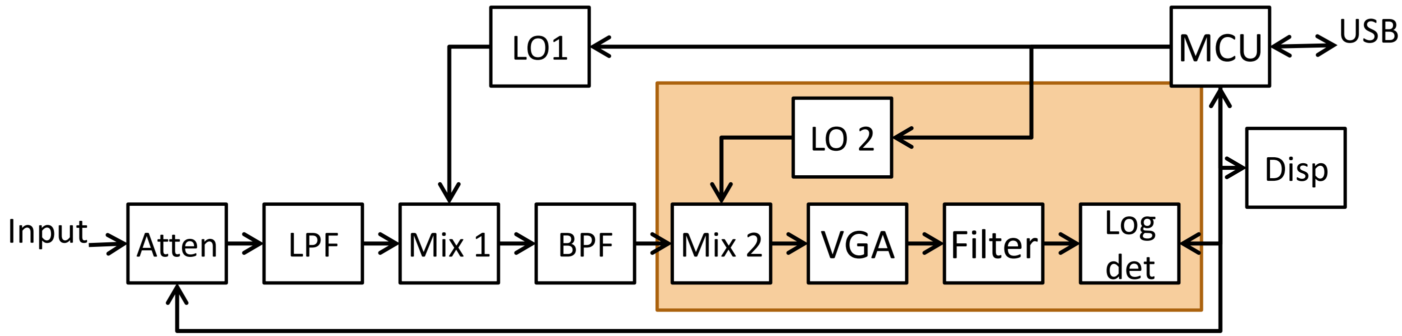
- Sufficient power to drive the AD-25MH at its required +13dBm and Frequency range sufficient for 0-350MHz Input range and 433MHz first IF
- Phase noise not very good

BPF: two 433MHz SAW filters with LC matching

- Sufficient narrow to avoid mirrors after mixer 2

What about Mixer 2, LO2, VGA, Filter and Log Detector?

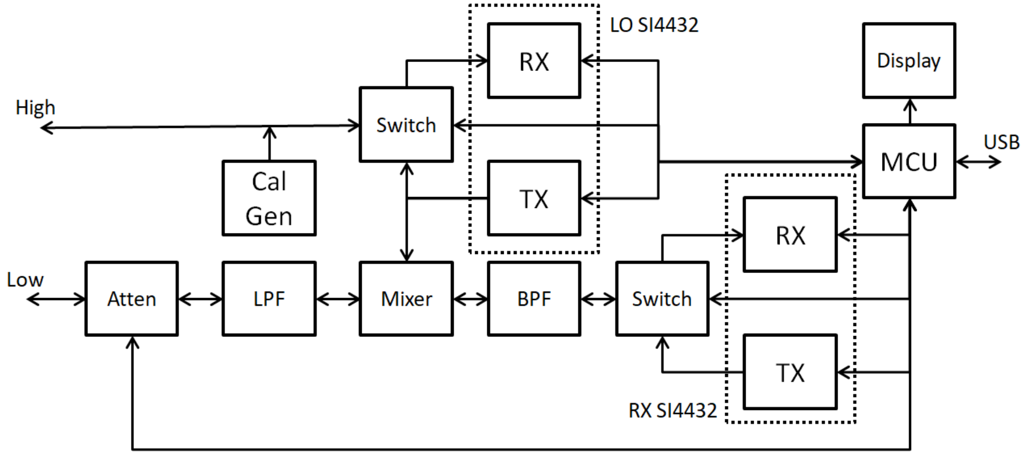
Key function selection(2)



Mixer 2, LO 2, filters and Log detector: all integrated in SI4432

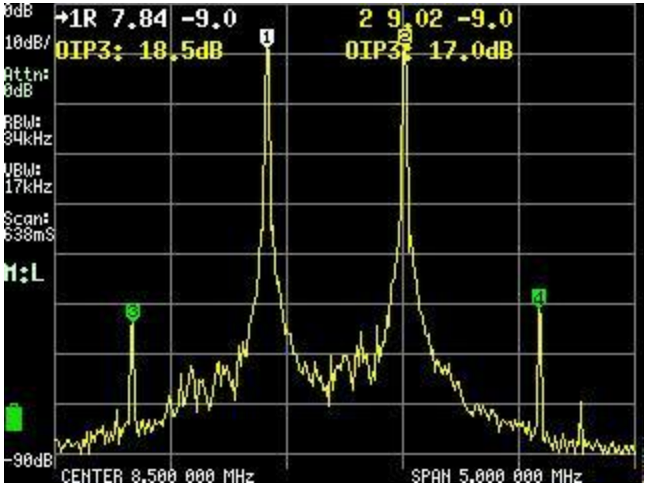
- Dual I/Q mixer to low IF at 937kHz
- I/Q IF digitized.
- 57 Resolution filters 3kHz – 600kHz in DSP
- Mirror suppression only 30dB.
  - No problem due to narrow BPF as mirror is two times IF away.
- Log power detector with 120dB range and 0.5dB resolution
- Uses large range internal AGC range to compensate for limited bits in ADC.
- AGC range matched with Phase Noise performance

Bonus functionality

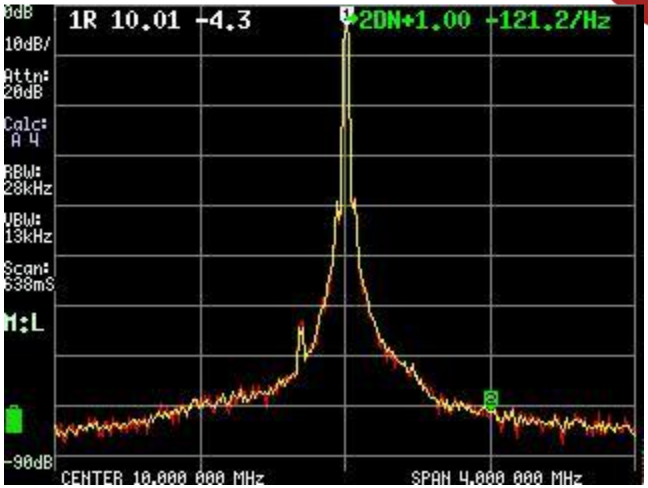


- SI4432 contains both TX and RX, only one can be active
- Whole signal path before Mixer 2 is bidirectional.
- TX in the RX SI4432 is used to create a 0-350MHz -76dBm to -6dBm signal generator with low harmonics (BPF+LPF)
- RX of LO SI4432 is used for “high input” (240-960MHz)
- LO SI4432 output used for “high output” (240-960MHz)
- Both “high” functions have limited performance.
- SI4432 fixed frequency output used for calibration generator at 30MHz

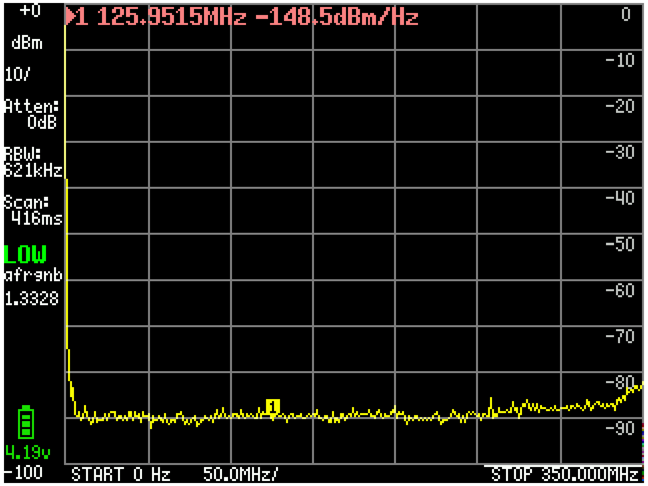
What about the performance?



IIP3 +17dBm: Excellent



Phase noise at 1MHz -121dB: Just acceptable



DANL -148dBm/Hz, NF = 27: On par

Performance figures for the 0-350MHz low input

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Performance overview

- Scan range: low input: 0-350MHz, high input: 240-960MHz
- Phase noise: Comparable to Rigol DSA815
- Dynamic range limited for close signals (within 1MHz) due to phase noise and ADC resolution, similar to Rigol DSA815
- DANL of -148dBm/Hz, comparable to Rigol DSA815 without LNA
- Low input amplitude accuracy 2dB, comparable to Rigol DSA815
- Lowest RBW 3kHz: not low enough to fully measure audio modulation performance. Biggest limitation for HAM's
- Power level resolution of 0.5dB.
- Measuring below 1MHz requires careful setup of attenuation and phase noise reduces dynamic range
- Lowest RBW leads to (substantially) increased sweep time as there is no FFT mode
- High input easily over steered

Protecting the tinySA

- Max +10dBm input level
- Max 10V DC at input (internal DC block)
- Build in ESD protection

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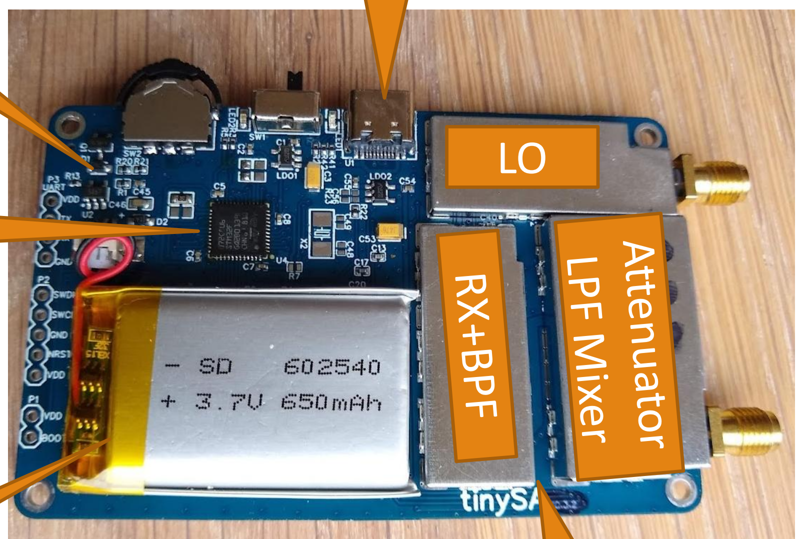
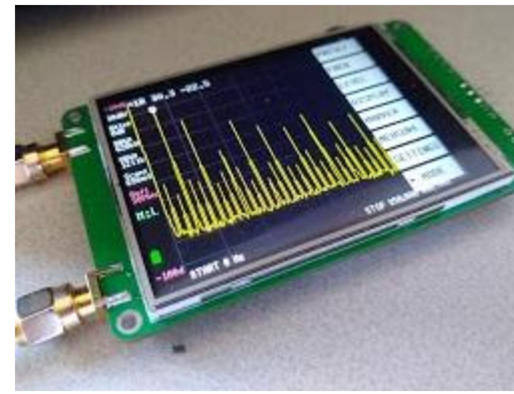
Putting it in a box



Everything on one PCB



Same housing as nanoVNA

Break

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Demo!

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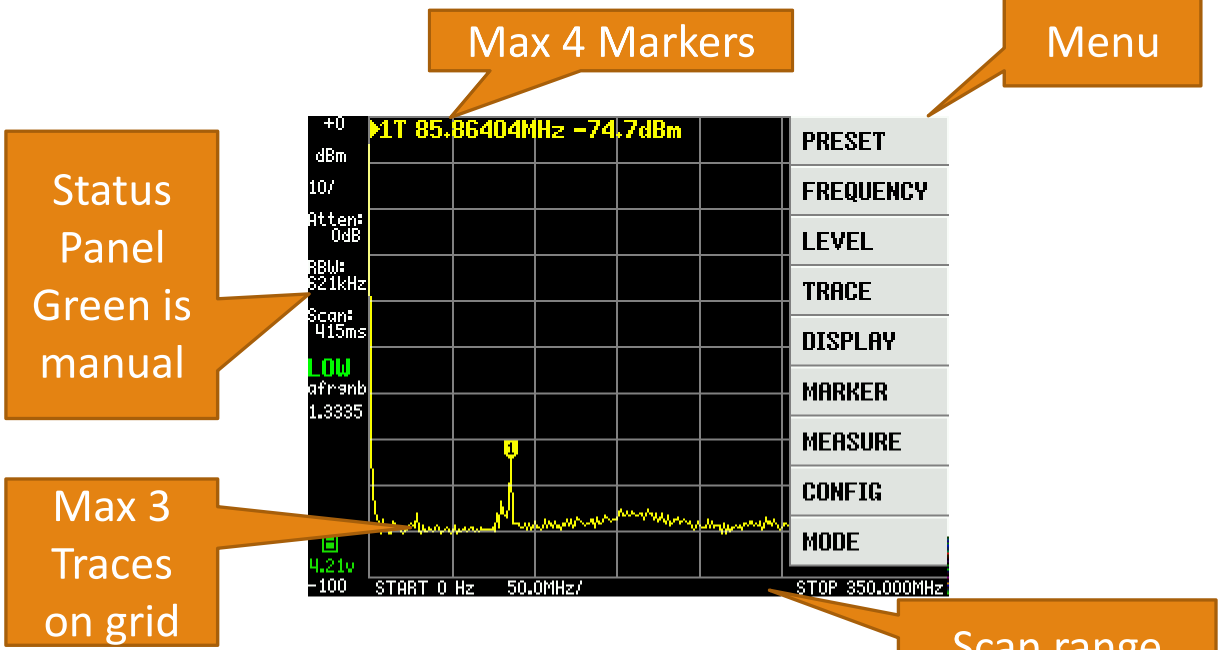
tinySA functionality

- LCD + resistive touch, Jog button
- Control by PC over USB
- Remote display/touch from PC
- UI approach similar to nanoVNA
- Main UI elements



Calibration and Self test

- Calibration:
  - Some manufacturing variation in loss in LPF and BPF made level calibration necessary.
  - Uses internally generated 30MHz signal of well known level
- Self test:
  - Validates whole low input path
  - Gives confidence on performance

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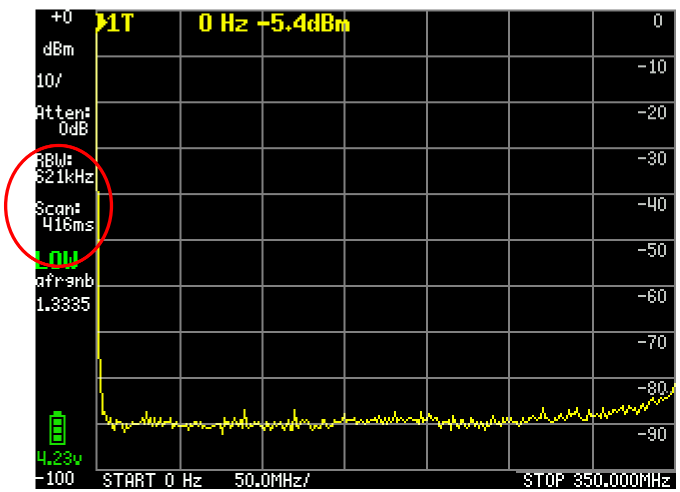
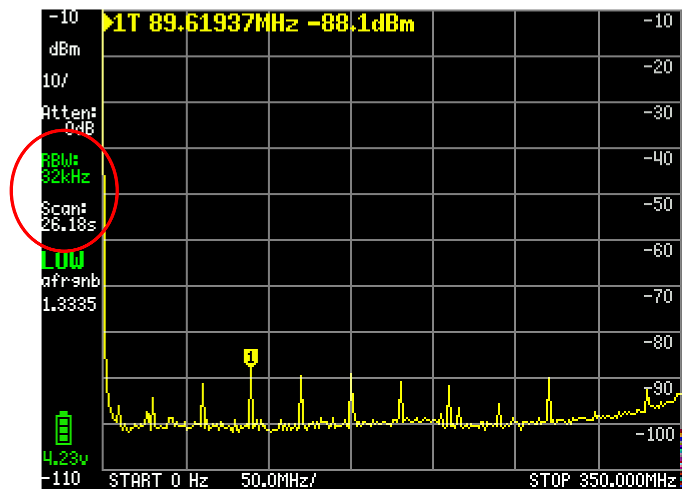
Measuring in the frequency domain

- Scanning speed dependent on many parameters
- Lower RBW increases scan time but reduces noise floor
- Narrower scan takes less time unless RBW is also reduced
- Less scan point reduces scan time unless RBW was already at maximum



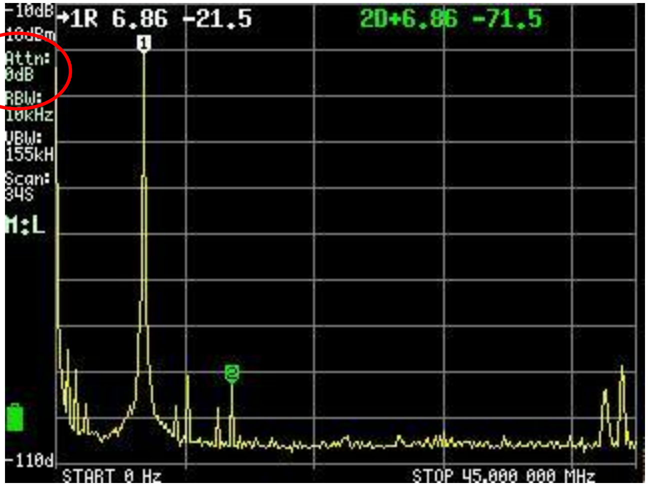
Full scan at default settings takes 416ms



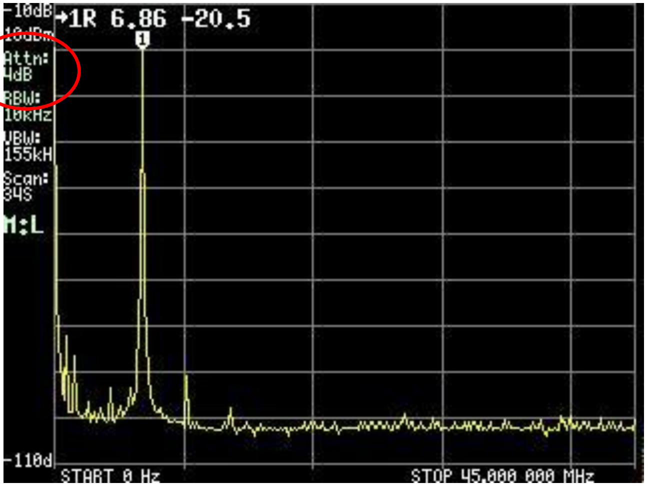
Full scan with RBW of 32kHz takes 26s but reduces noise floor by 10dB

Assessing harmonics

- Signal level and internal attenuation determines level of internally generated spurs
- Spur Free Dynamic Range (SFDR) is maximum level difference that can be observed without internally generating spurs.
- Use internal attenuator to assess harmonics



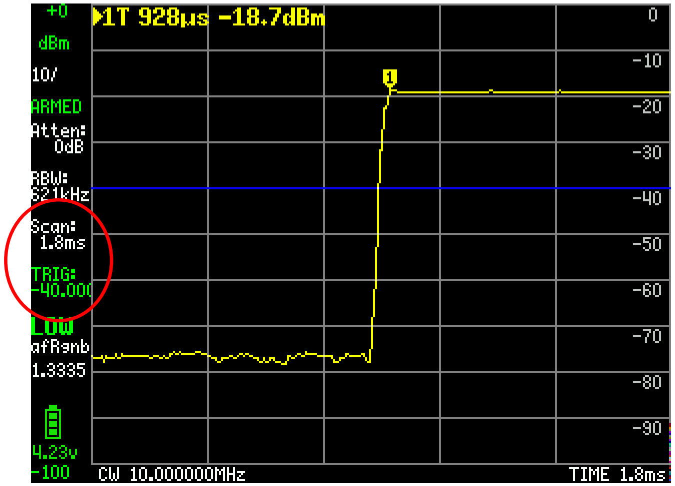
Is the second harmonic under marker 2 internally generated?



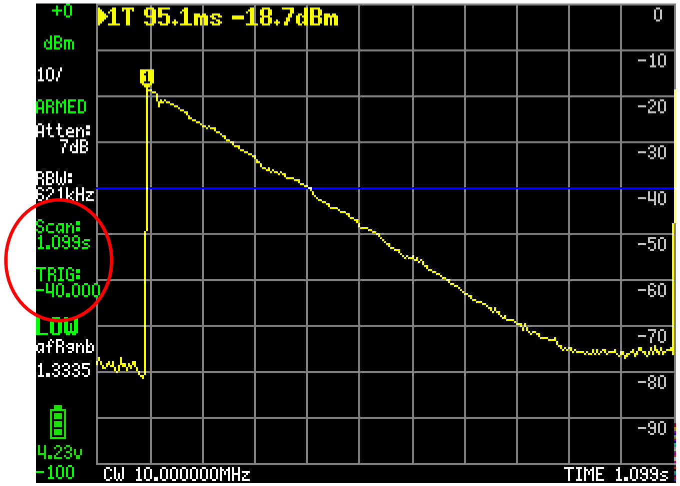
Increasing the internal attenuation to 4dB removed the second harmonic so It was internally generated

Measuring in the time domain

- A selective power meter
- Scan time between 2ms and 600s
- Pre/mid/post up/down level trigger
- Much larger dynamic range than a scope
- Useful for studying dynamic behavior of amplifiers



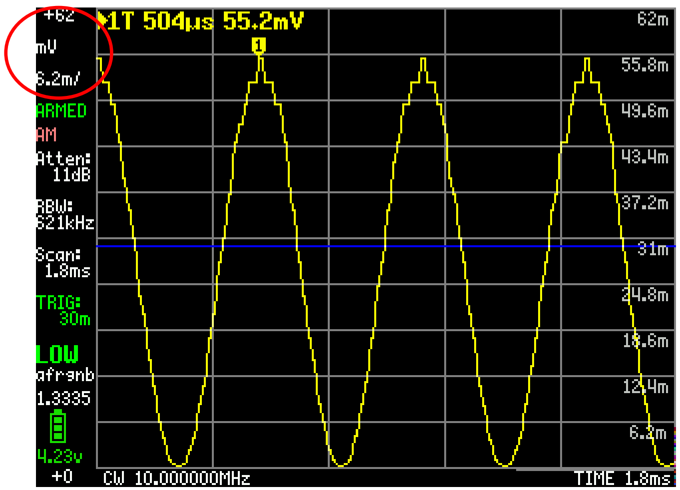
1.8ms scan with -40dBm trigger



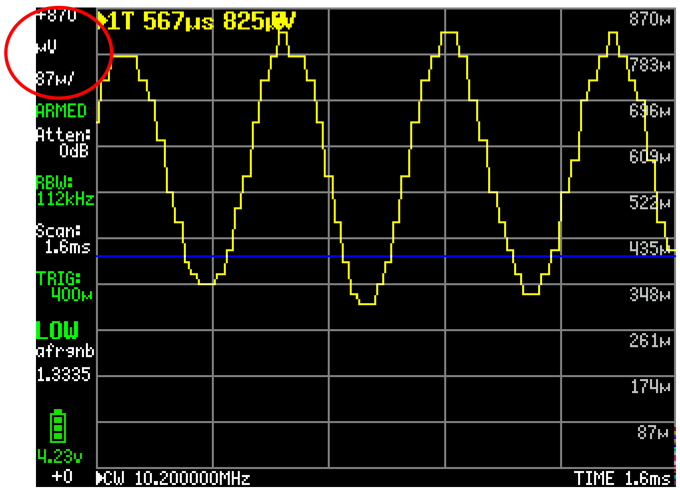
1.1s scan with post trigger to show full event

Changing the level unit

- Level can be displayed in dBm, dBmV, dBuV, Volt and Watt
- Scan time between 2ms and 600s
- Single, auto and normal scan
- Can be used to assess AM and FM modulation
- Linear unit shows 0.5dB power resolution as steps in signal level



Measuring level in mV of 2kHz 100% modulated AM signal



Slope detection in uV of 2kHz FM Modulated signal with 2kHz deviation

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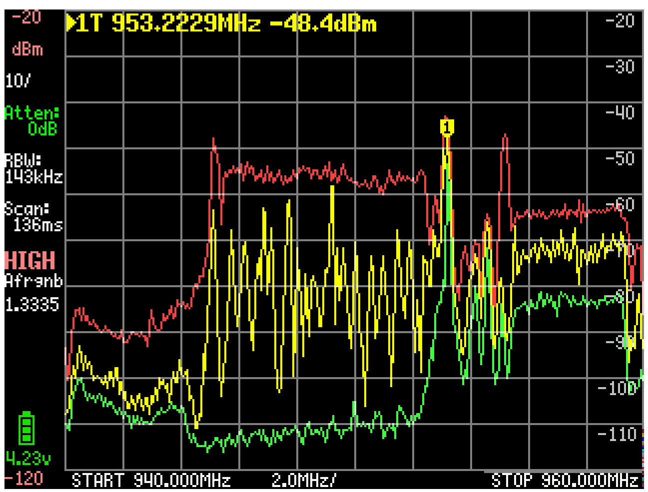
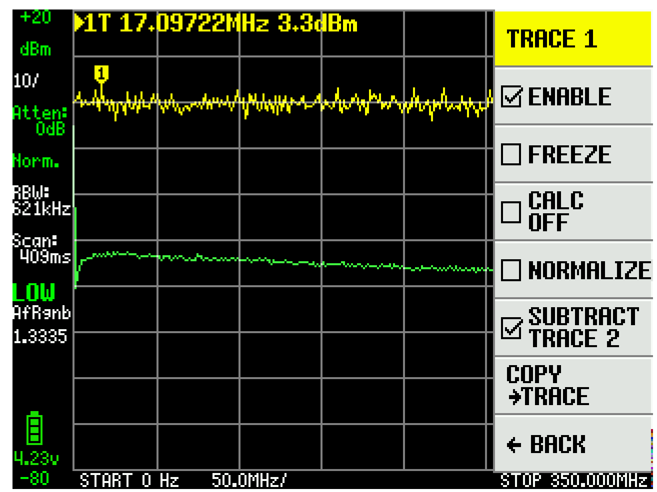
Multiple trace and calculations

- 3 independent traces available
- Each trace can be enabled/disabled or frozen
- Traces can be subtracted from each other
- Each trace can have calculation over multiple scans: Min Hold, Max Hold, Average



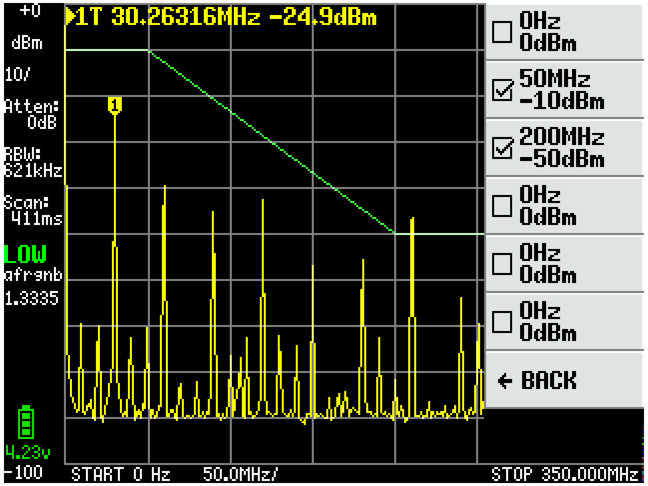
Mobile phone base station with max hold(red), min hold(green) and current(yellow) signal



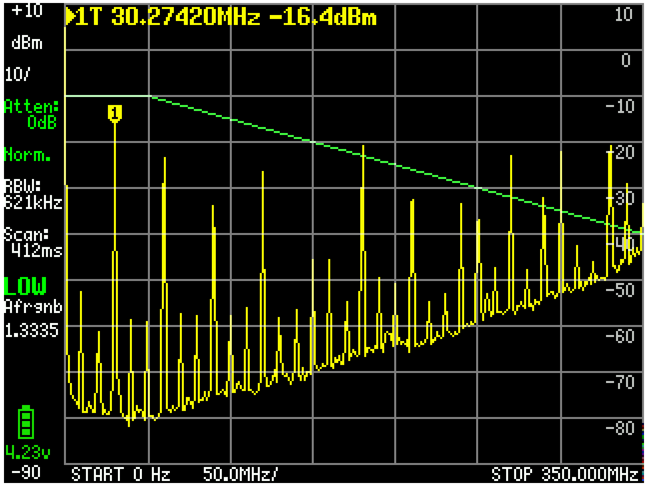
Wide band noise source averaged and stored (green) and subtracted from live trace (yellow)

Create static trace with trace table

- A static trace be defined by 6 points and optionally shown on the display
- Static traces can be used to display limits or to compensate for known frequency dependencies as specified in datasheet



Static trace table used to quickly assess if any signal goes above measurement limit



Static trace table used to compensate measurement for frequency dependent sensitivity of antenna

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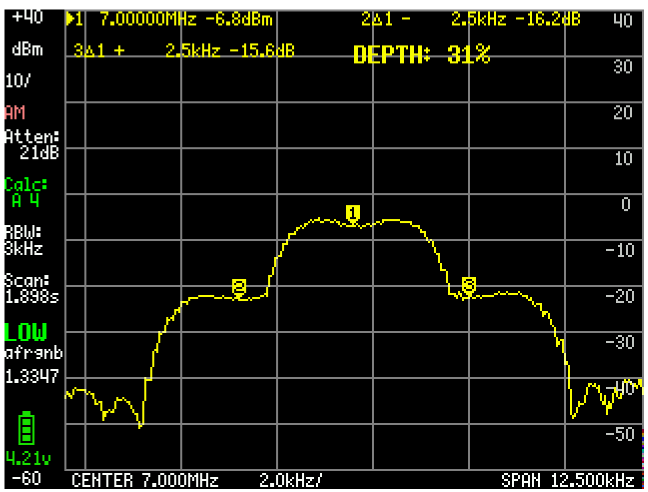
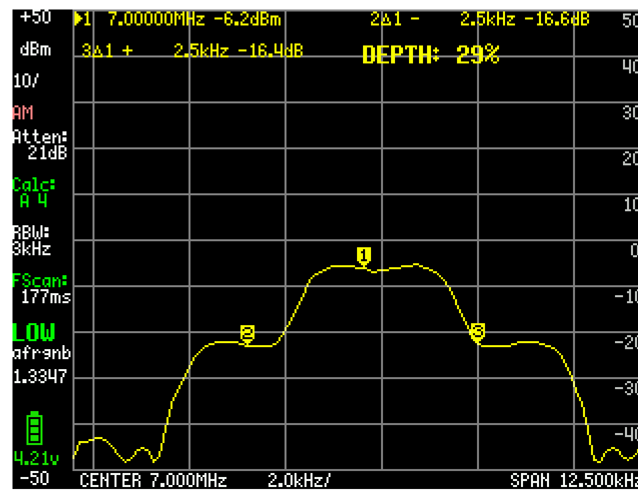
Tweaking the display(1)

- Scan points can be 51,101, 145 or 290
- Scan speed can be increased with some reduction in accuracy
- Allows balancing between speed and detail of information shown
- Speedup is useful for fast feedback when tuning HW



30% AM modulated signal with default settings. 1.9s scan time



Reducing scan points to 101 and enabling FAST scanning results in 0.177s scan time

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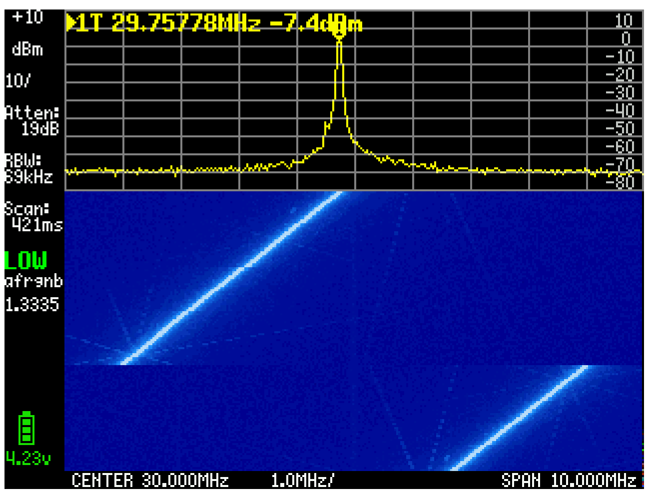
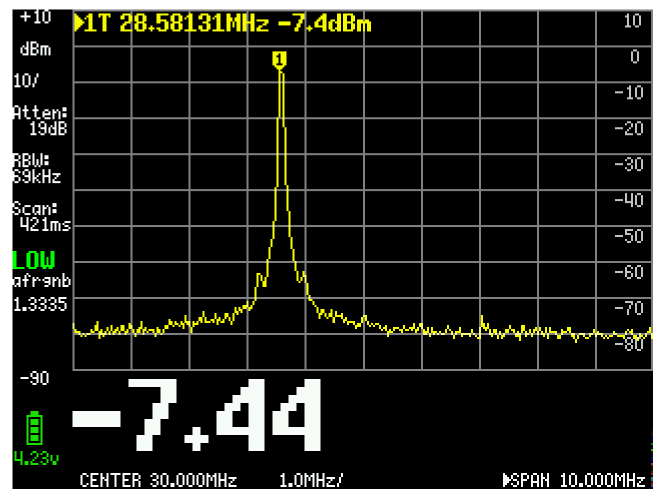
Tweaking the display(2)

- Waterfall (small and large) for monitoring a spectrum over time
- Big number display



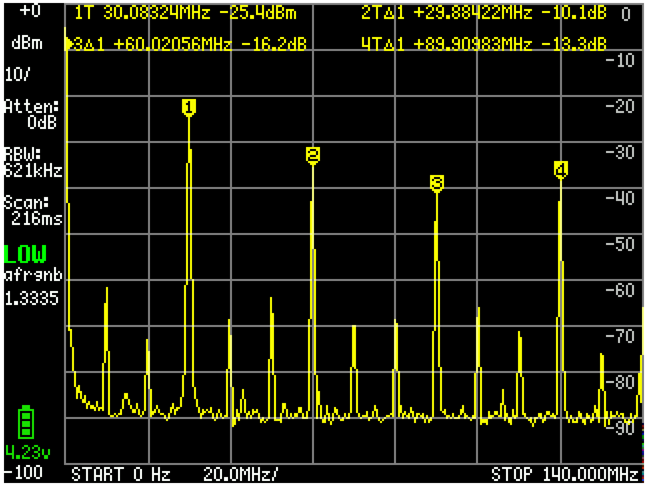
Monitoring frequency shift over time



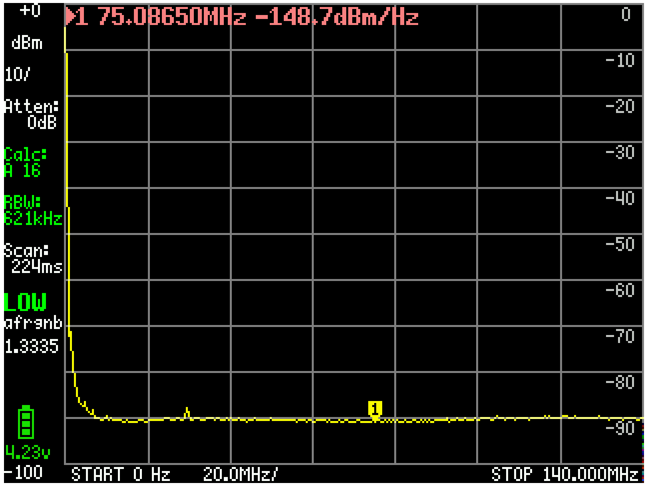
Displaying the value under the marker as big number

Measuring with markers

- Maximum 4 markers active
- Manual positioning or tracking for auto peak search
- Display signal level at marker in selected unit
- Or used as delta marker referring to any other marker
- Markers can be put on any trace
- Noise markers remove impact of selected RBW
- Doing the setup for a specific measurement can take some time!



Tracking markers automatically
Find the strongest signals



Noise marker shows DANL/Hz
Using this number you can calculate the tinySA NF: 25dB

Measurement functions(1)

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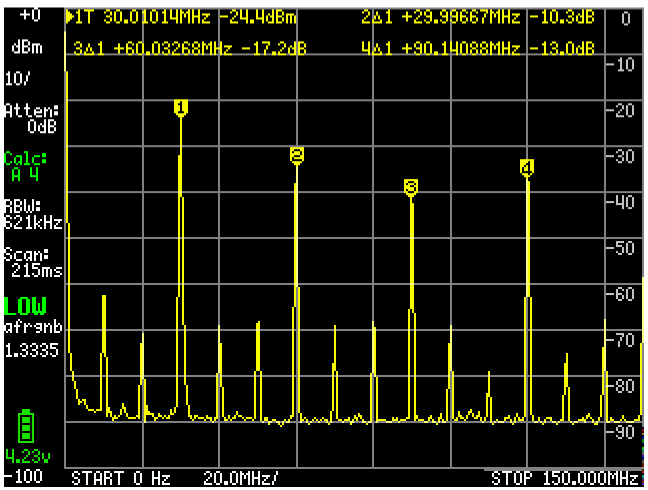
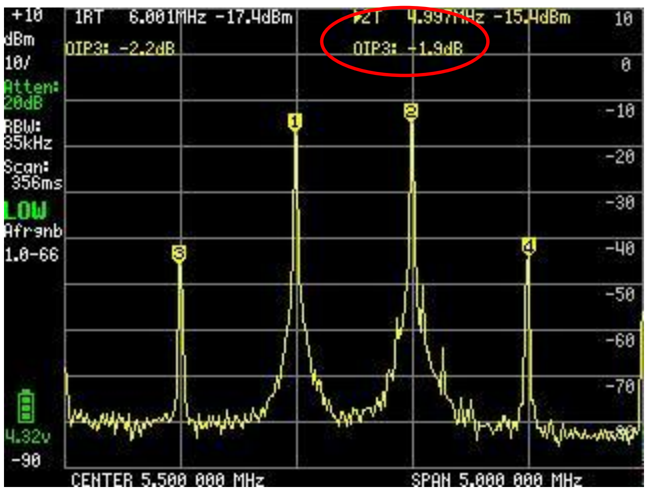
- Perform quick setup of range and markers
- Optimize internal settings for specific measurement if needed
- Calculate additional information



Harmonic measurement function quickly sets up to measure fundamental and 3 harmonics



Measuring OIP3 of amplifier

Measurement functions(2)

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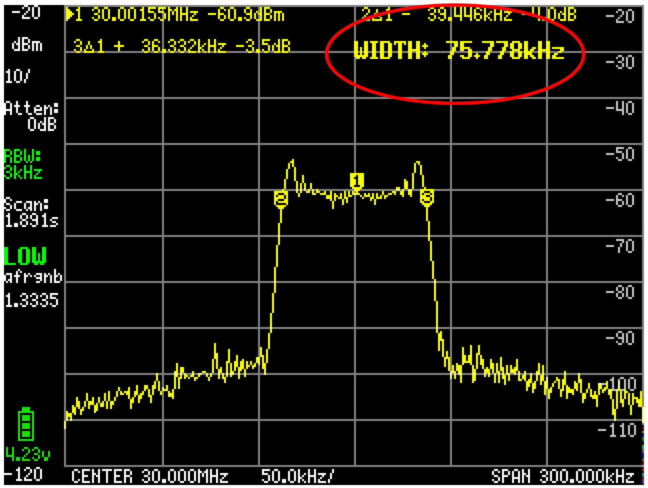
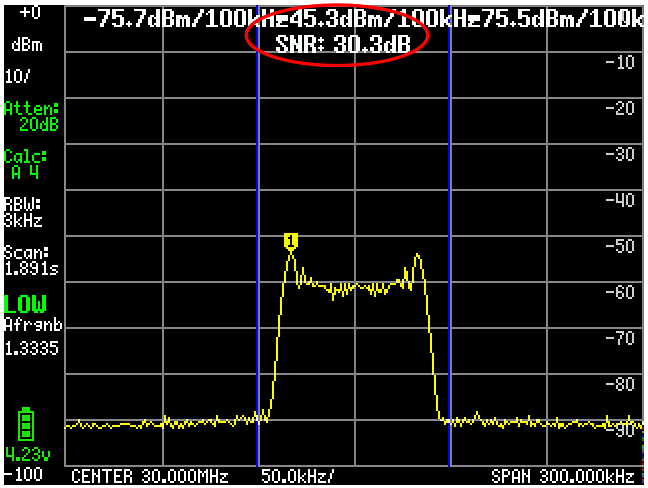
- Perform quick setup of range and markers
- Optimize internal settings for specific measurement if needed
- Calculate additional information



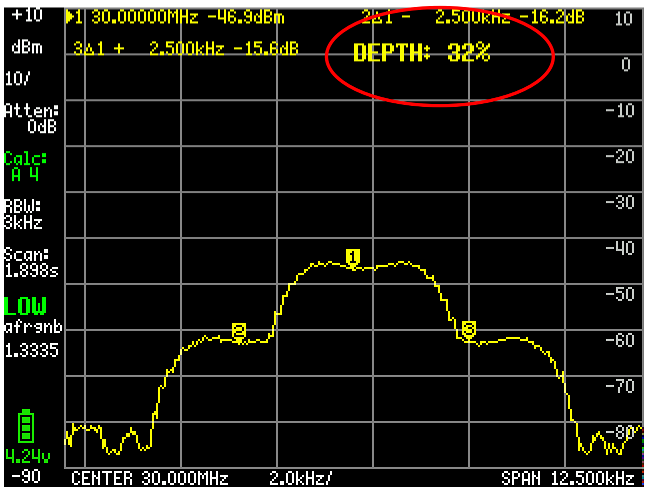
Measuring the width of an FM signal



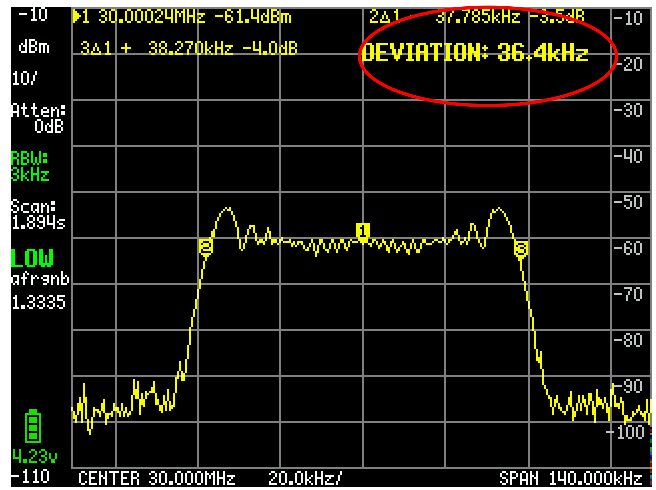
SNR measurement using channel power to integrate noise power

Measurement functions(3)

- Perform quick setup of range and markers
- Optimize internal settings for specific measurement if needed
- Calculate additional information



Measuring AM signal with 2.5kHz modulation at 30% depth



Measuring FM signal with 1kHz modulation and 35kHz deviation

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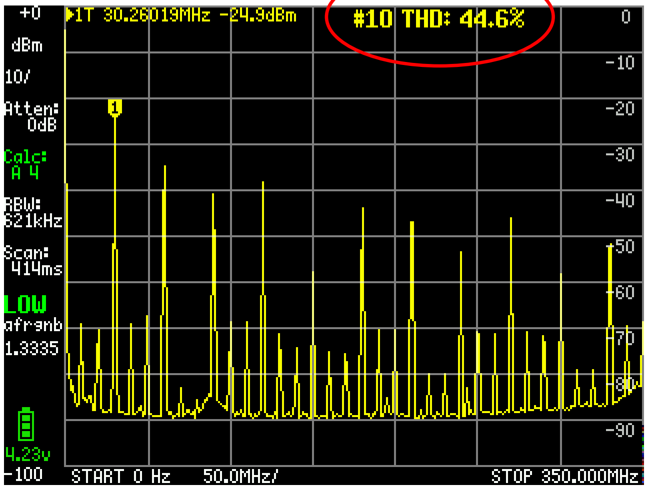
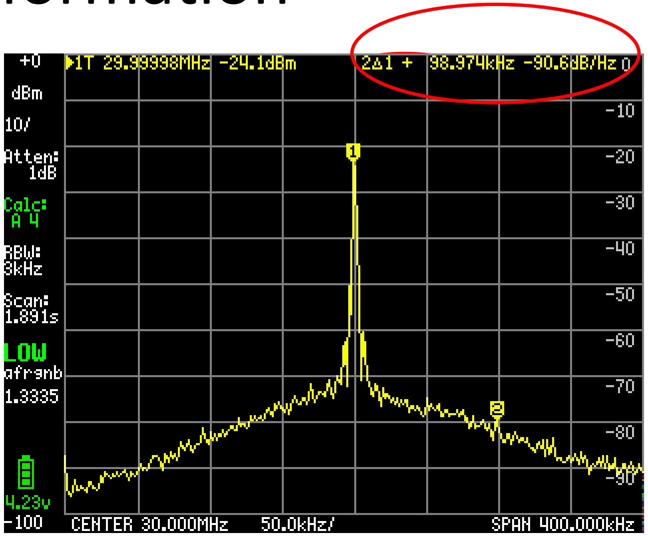
Measurement functions(4)

- Perform quick setup of range and markers
- Optimize internal settings for specific measurement if needed
- Calculate additional information



Measuring THD, 10 harmonics found



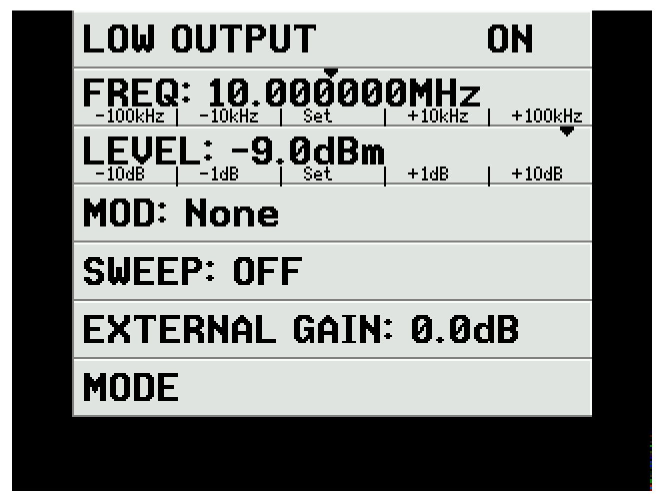
Measuring internal phase noise at 100kHz offset. This is the lowest limit that can be measured

High input performance

- 240-960MHz scan range
- No attenuator
- Various spurs
- Same resolution filters

Signal Generator(1)

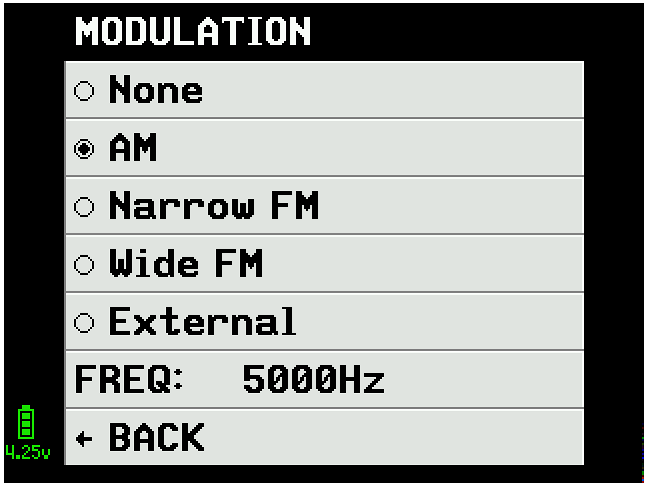
- Sinus output, harmonics < -40dBc
- Frequency 10kHz-350MHz
- Output level -76dBm to -6dBm in 1dB steps
- Frequency/Level control:
  - Button works as slider when touch and hold
  - Direct entry with keypad
  - Up/down buttons



- High output:
  - 240-960MHz
  - Limited power levels
  - Square wave

Signal Generator(2)

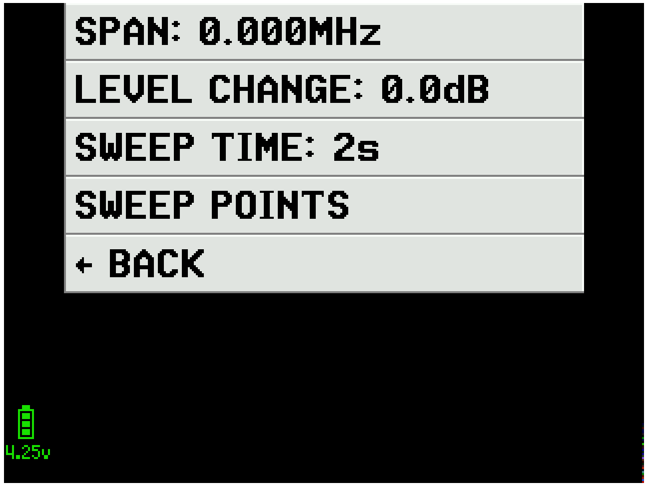
- Modulation none, AM, NFM or WFM
- AM depth fixed 33%
- FM variation width 3kHz or 35kHz
- Modulation frequency 50-6000Hz



- High output
  - Only FM modulation

Signal Generator(3)

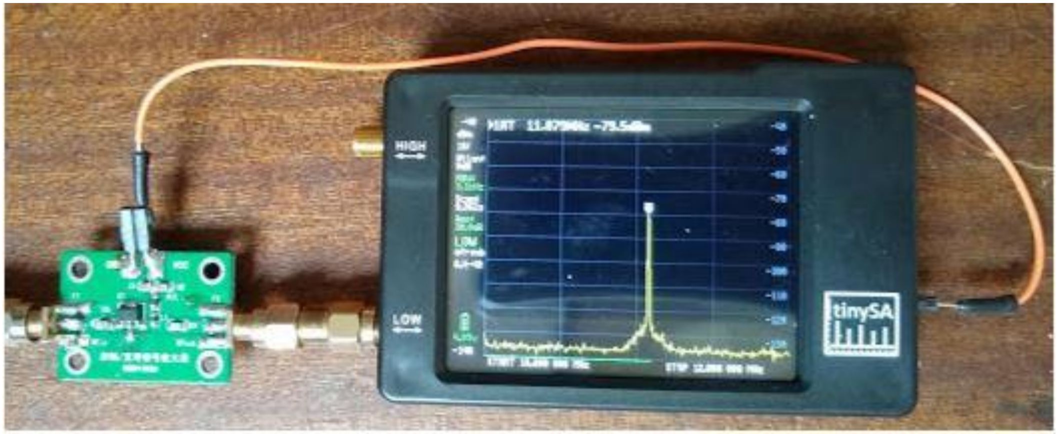
- Sweep frequency span 0-full range
- Sweep level change +/-70dBm
- Sweep time 0.1s – 600s
- Sweep points 51,101,145 or 290
- Sweep exclusive with modulation



- High output
  - Only frequency sweep

Extending functionality(1)

- LNA can be added supplied from internal +3Volt made available with small modification



- In low mode the LO can be output through the high port to create a tracking generator

Extending functionality(2)

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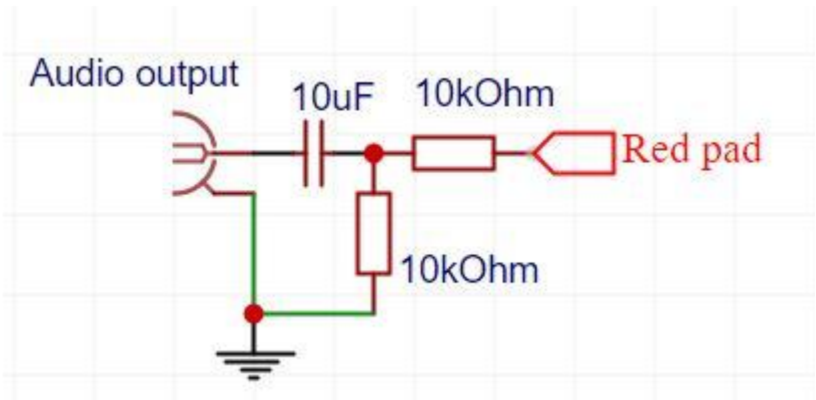
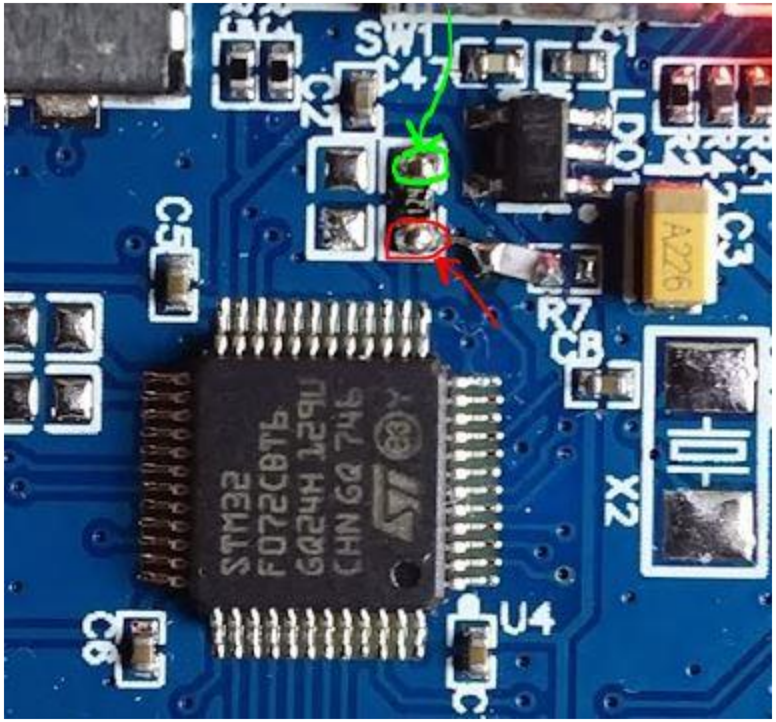
- The high port can output a pulse at the start of each low input or output sweep for synchronization with other equipment
- A simple HW modification enables you to listen to the demodulated signal using a regular headset





How to buy (see wiki)

- Zeenko store on AliExpress and Alibaba
- R&L electronics in the USA
- Eleshop in Europe
- Switch Sience in Japan
- Mirfield Electronics in the UK

Many sellers on Ebay and other web shops are selling clones

Bangood only sells clones

User community and web assets

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Large (+1500 members) and friendly user community providing user support at http://groups.io/g/tinysa

Continuously growing WiKi containing everything from first use guide to expert examples at http://tinysa.org/wiki

Many (+40) video showing all aspects of the tinySA at https://www.youtube.com/channel/UCh140tYlt5ZvDMVy0B1eTSg

Source code on GitHub at https://github.com/erikkaashoek/tinySA

Ask all you support questions at: http://groups.io/g/tinysa

Question time!

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