osmo-fl2k: Using cheap USB 3.0 VGA adapters as SDR transmitter

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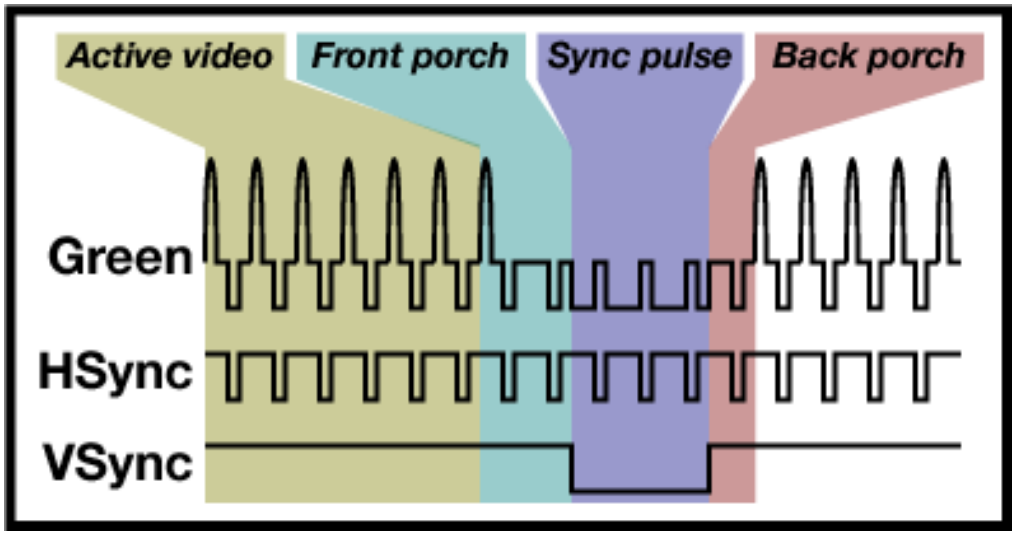
Devices with FL2000 chip

Transmitting signals with VGA

- Use the harmonics of VGA DAC to transmit RF
- Has a rather long history
  - 2001: Erik Thiele "Tempest for Eliza", AM Radio
  - 2005: Fabrice Bellard transmitted DVB-T and analog TV
  - 2009: Bartek Kania transmitted WBFM (VGASIG)
  - 2013: siro at "das Labor": I/Q modulator attached to VGA card
- Similar idea: RPitx, but VGA has a real DAC instead of PWM

VGA Synchronization



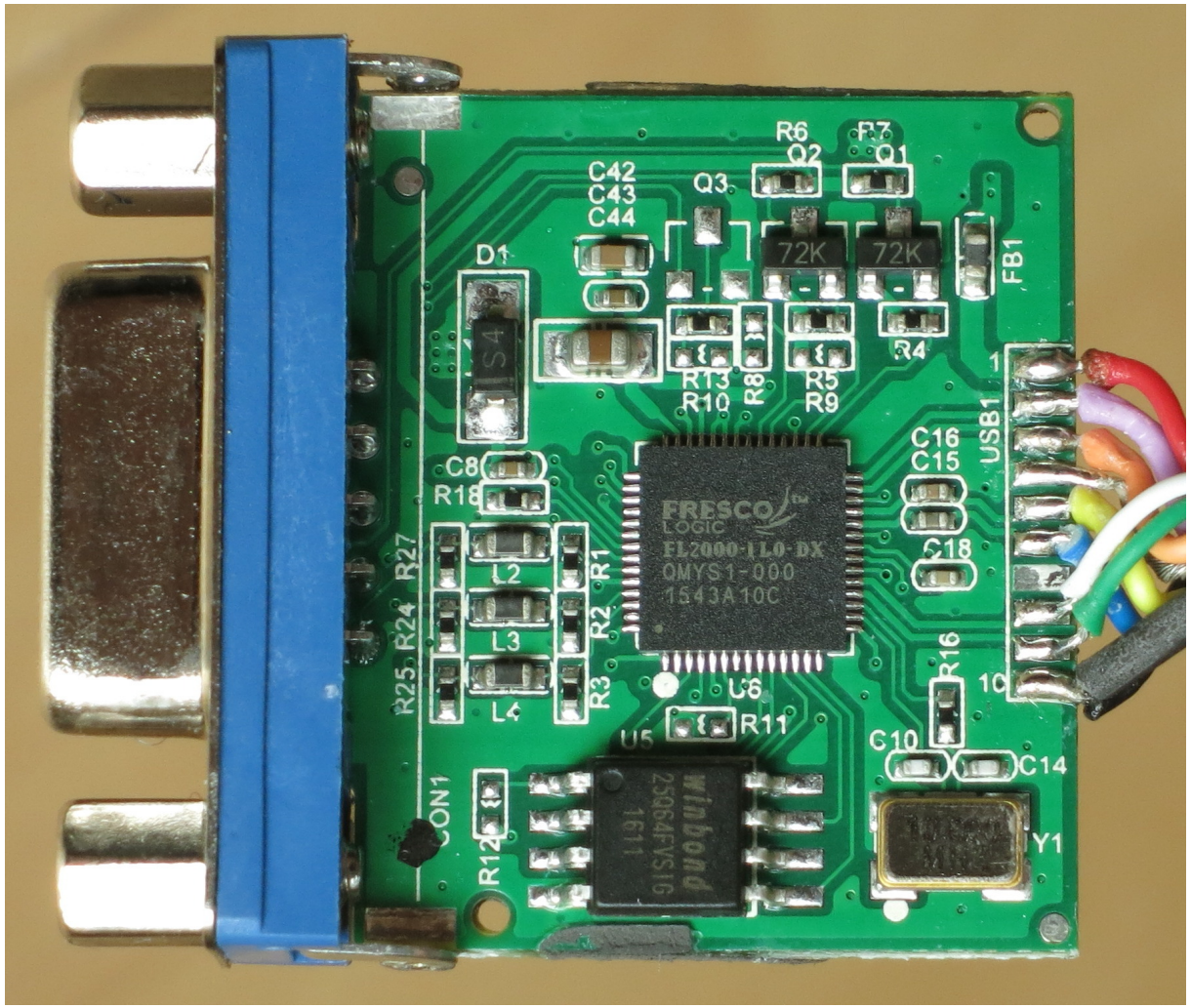
- Main issue with all VGA cards: HSYNC/VSYNC
- Basically "lost samples", not user controllable
- Very bad for analog modulation types
- Some OFDM-based systems can cope with it (like DVB-T)

[Image source: http://martin.hinner.info/vga/vga.html]

USB VGA adapters

- Two manufacturers:
- Displaylink
  - classical graphics card with framebuffer and USB interface
- Fresco Logic
  - Software defined approach
  - Framebuffer in host memory
  - Image constantly being streamed via USB 3.0
  - Makes adapters very cheap (5-10$)
- Sounds very interesting… ;)

FL2000 Hardware

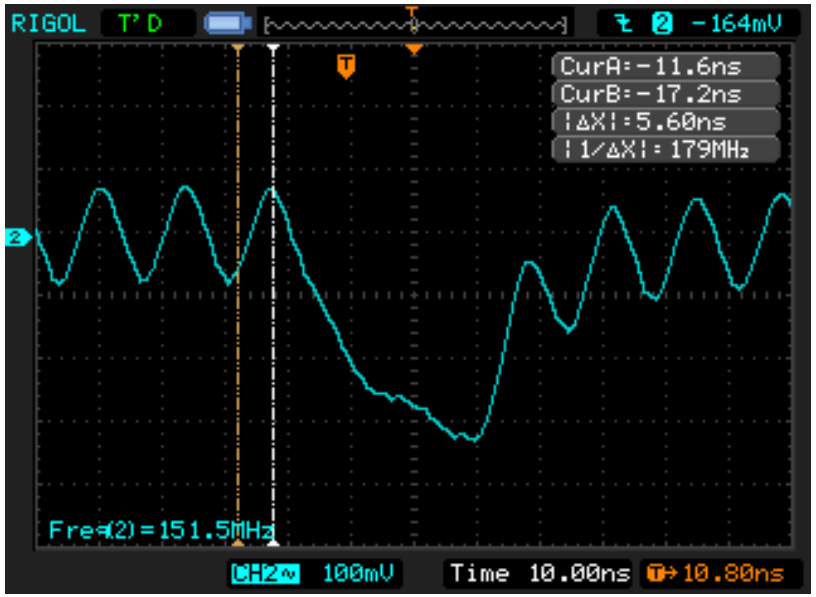


Reverse Engineering

- Same approach as with rtl-sdr
- VirtualBox VM with Windows and original driver
- USB 3.0 device forwarded to VM
- Sniffing USB traffic with Wireshark on Linux
- Replaying commands in libusb-based application
- Remove stuff until it doesn’t work anymore
- Play with register contents to figure out what does what

Reverse Engineering cont.

- Figure out data format used in USB buffer
- Experiment with PLL register to figure out how clocking works
- At some point after lots of experimentation end up with this:



- VSYNC and HSYNC completely disabled, but still some lost samples

Goal: Continuous stream of samples

- Look again at Wireshark traces
- Last URB of USB transfer was smaller than other URBs
- Choose a new resolution that is a multiple of URB size (61440)
- 1280 * 1024 * 3 colors = 61440 * 64
- ⇒ Result: 150 MHz, 3 channel 8-Bit DAC with USB 3.0 interface

libosmo-fl2k

- Initializes the device, sets the sample rate
- Can be fed with 8 bit signed or unsigned samples
- Performs conversion of buffer format
- Can use zero-copy buffers to reduce CPU load

Applications

- fl2k_file
  - Streams a file with samples to device, repeats
- fl2k_tcp
  - Streams samples from TCP to device, e.g. GNU Radio
- fl2k_fm
  - FM Modulator with stereo and RDS support
  - Can be used together with SoX to transmit WBFM
  - based on VGASIG code for FM modulation and PiFmRds
- fl2k_test
  - Determines PPM offset to system clock
  - Useful for calibration of device
- Still needed: fl2k_upsample
  - Upsample I/Q baseband samples in real time
  - Hoernchen started with it, more work needed

VGA SDR transmitter

- Transmission of several signals was tested successfully:
- WBFM
- DAB
- DVB-T
- GSM
- UMTS
- LTE
- GPS (11th harmonic!)

Example: GSM transmission

- Upsample using GNU Radio
- Synthesized carrier frequency: 40.6 MHz
- DAC sample rate: 138 MHz ± 40.6 MHz
  - 3rd harmonic: 414 MHz ± 40.6 MHz
  - 5th harmonic: 690 MHz ± 40.6 MHz
  - 7th harmonic: 966 MHz ± 40.6 MHz
  - ⇒ Images: 925.4 MHz (ARFCN 976), 1006.6 MHz

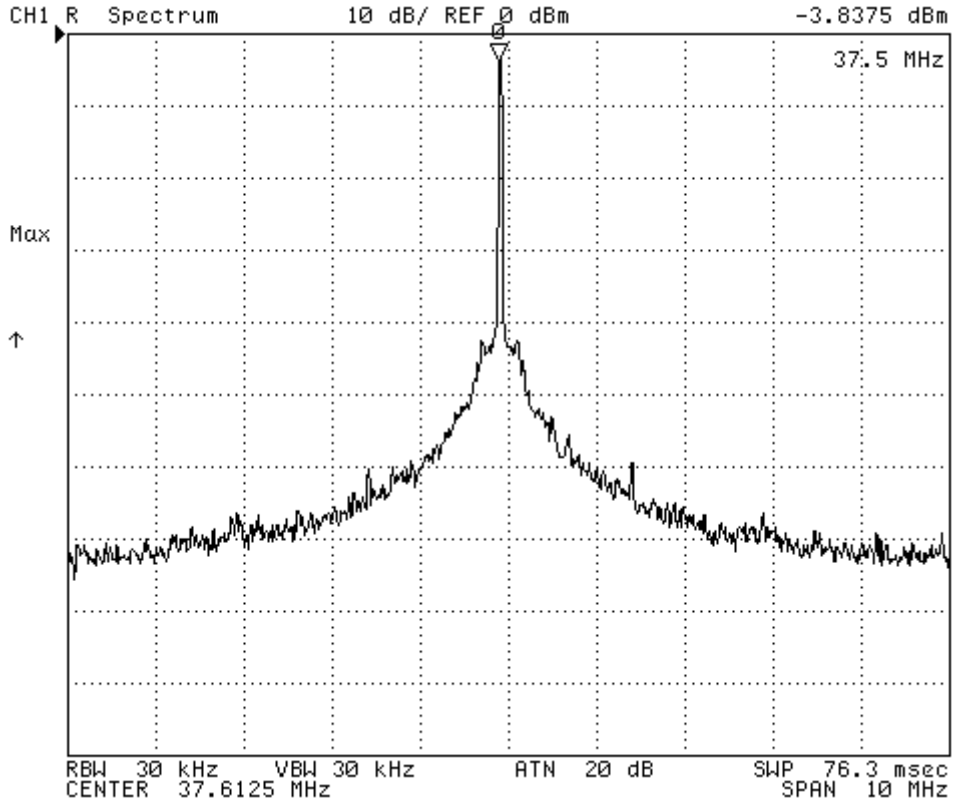
Example: GSM transmission

Further ideas

- Connect I/Q modulator to do "proper" transmission
- Add reconstruction filter and use as lab signal generator (0-75 MHz)
- Synchronize clock with rtl-sdr to use both as very cheap transceiver

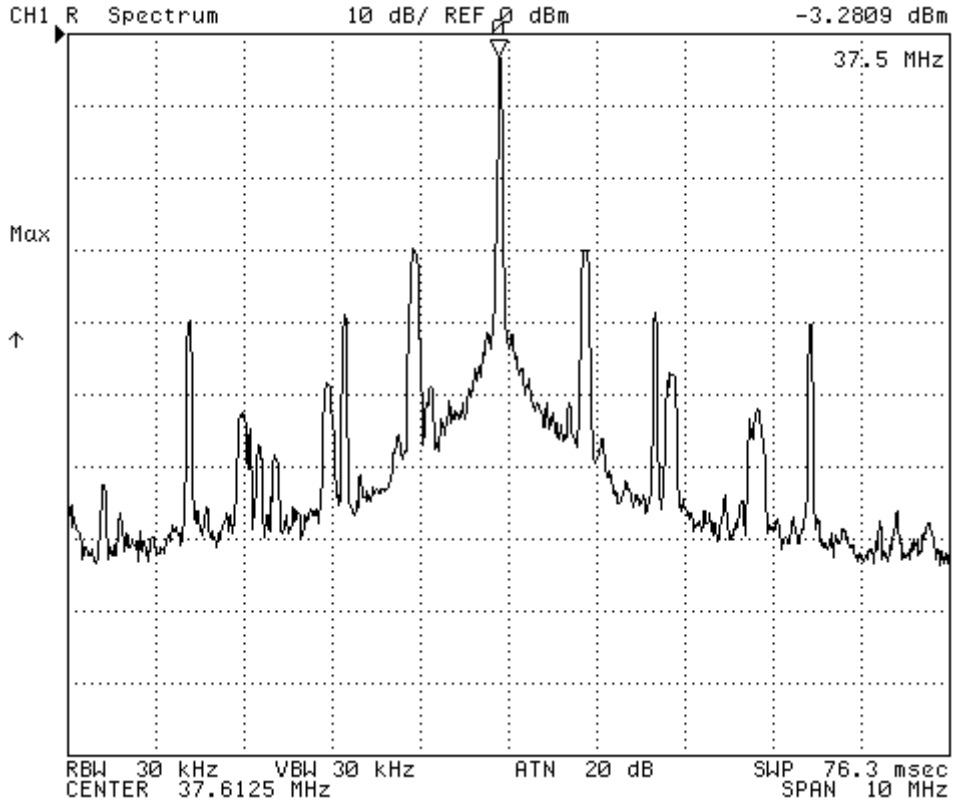
Quality differences

- Device with two LDOs for DAC reference and digital supply

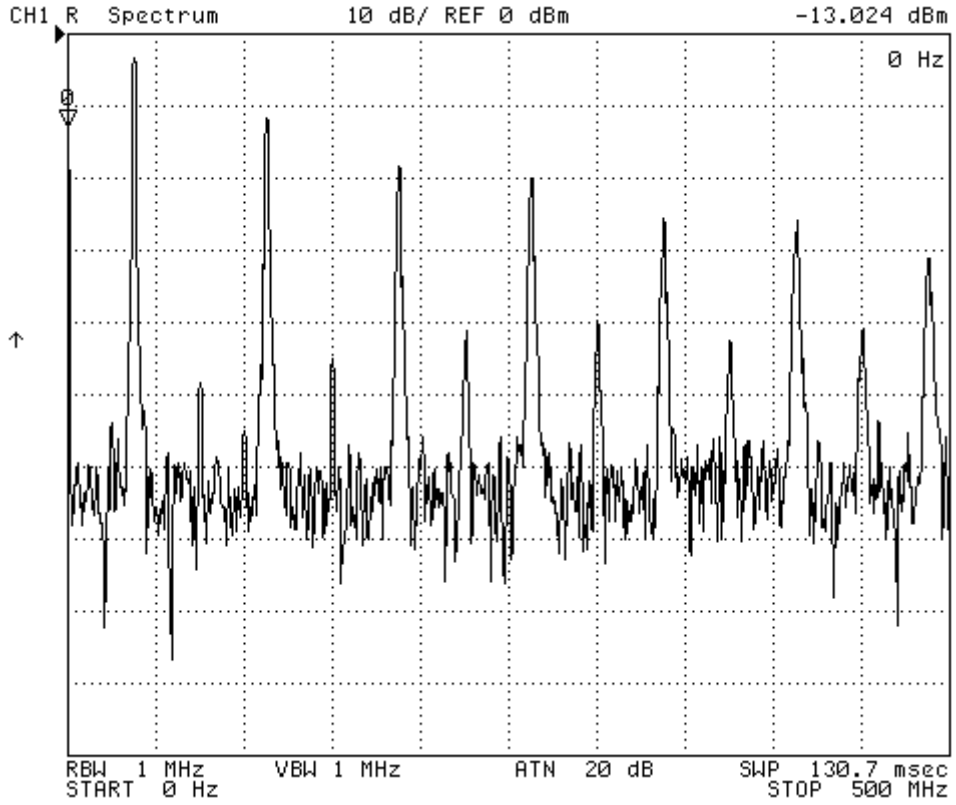


Quality differences

- Device with two switching regulators



Output spectrum



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- More information:
- https://osmocom.org/projects/osmo-fl2k/wiki
- Questions?