HF PA kit with built-in standalone raised cosine controller

1. Introduction

The standard QRP Labs HF PA kit has an 8-bit shift register (74HC595) whose outputs control an 8-bit Digital-to-Analogue converter (DAC). This DAC controls a discrete-component power modulator with foldback current limiting. A microcontroller can load a sequence of values into the shift register in such a way that a raised cosine shape is applied to the RF envelope. **The assembly document for the PA kit is ESSENTIAL reading, prior to this application note!**

In your own homebrew applications you may wish to use the HF PA kit without having to worry about programming a microcontroller to generate the raised cosine sequence and load it into the DAC. For these applications, QRP Labs can supply a 14-pin ATtiny84 microcontroller which contains all of the logic and sequence of numbers, to generate a precise raised cosine keying envelope. The PA kit PCB was designed to be able to support this microcontroller plugged into the IC1 socket instead of the 74HC595 shift register.

This application note explains how to use the QRP Labs HF PA kit in this way, with an application circuit described for a single-band CW transmitter.

2. Modified PA circuit

The circuit diagram on the following page shows the effective new circuit diagram of the HF PA kit. The main change is that the 74HC595 IC has been replaced by the ATtiny84 microcontroller. The jumpers have been omitted from this diagram for clarity. The PCB of the HF PA kit was carefully designed such that when the jumpers are correctly configured, and an ATtiny84 microcontroller is inserted correctly in the IC1 socket, eight of its Input/Output (I/O) pins drive the 8-bit R-2R ladder network Digital to Analogue Converter (DAC).

The three shift register control inputs (SCK, RCK, D) are now re-purposed as follows:

- Key IN: An active-low keying signal
- Key OUT: An active-high output signal whose leading edge is synchronous with the keying IN signal, but whose trailing edge "over-hangs", or "lags" the keying signal, while the raised cosine shaping occurs
- Speed: an analogue input which allows the operator to configure the duration of the raised cosine shaping at key down and key up, from 2 to 113 milliseconds. Alternatively the signal may be simply connected to +5V which will fix the shaping at 5 milliseconds by default.

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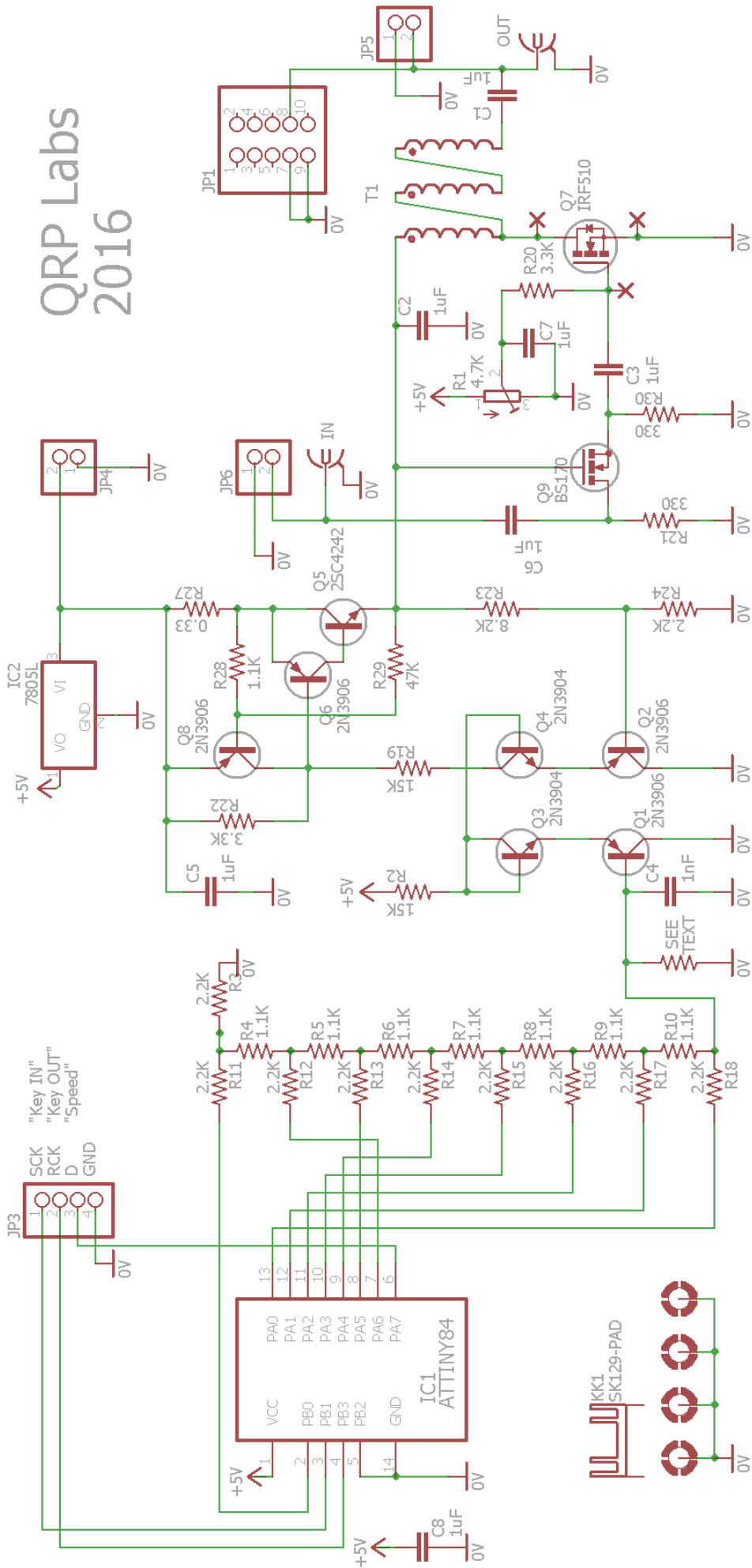
The following oscilloscope screenshots show the microcontroller keying input (active low) as the lower (BROWN) trace; the RF output is the upper (BLUE) trace. The PA kit is set up according to the CW Transmitter application circuit discussed in section 4 below. The screenshots all show a single 12wpm CW "dit", which has a duration of 100ms, and various speed settings for the rise/fall times of the RF envelope. 90ms will sound terrible. Practically, 5 to 10ms is most commonly used.
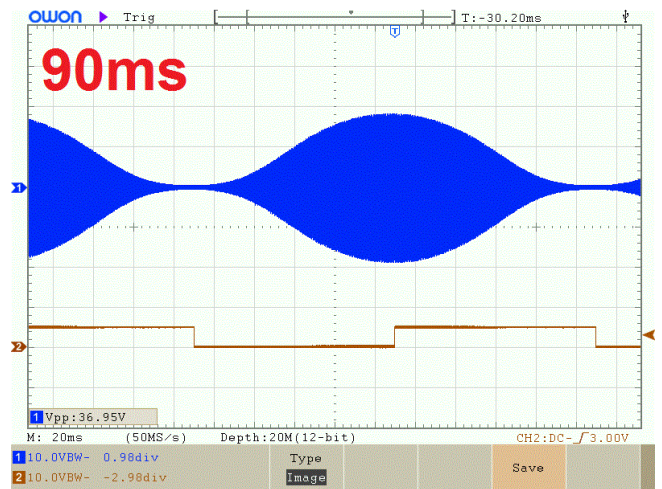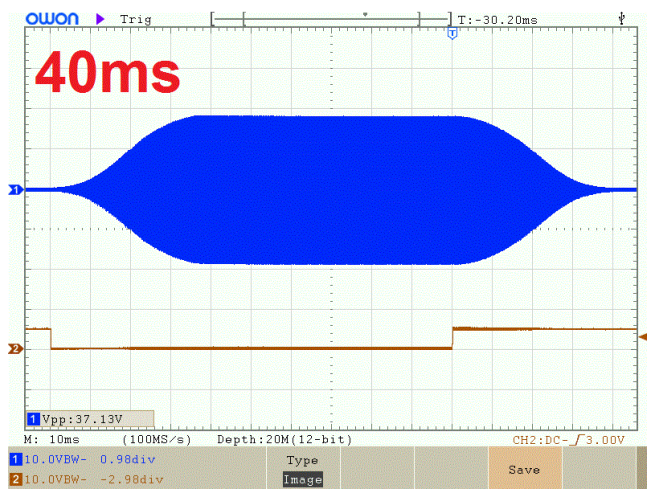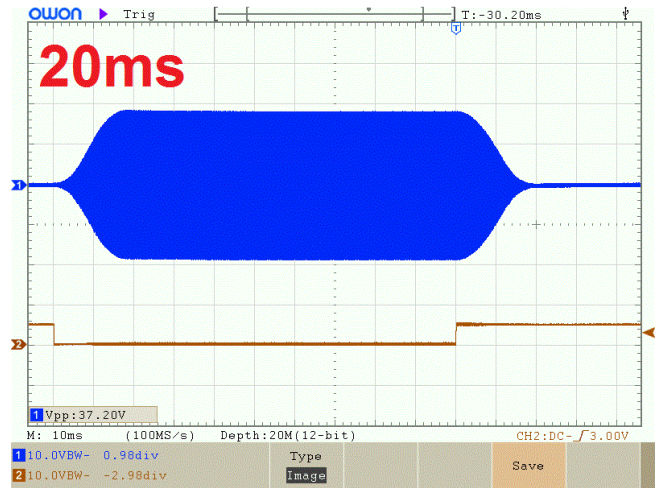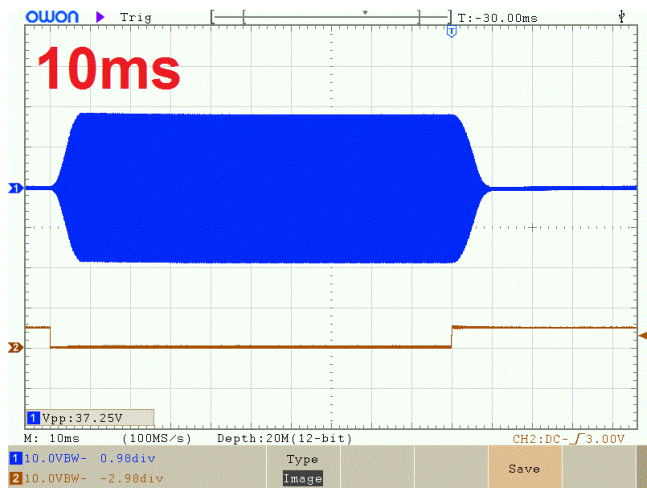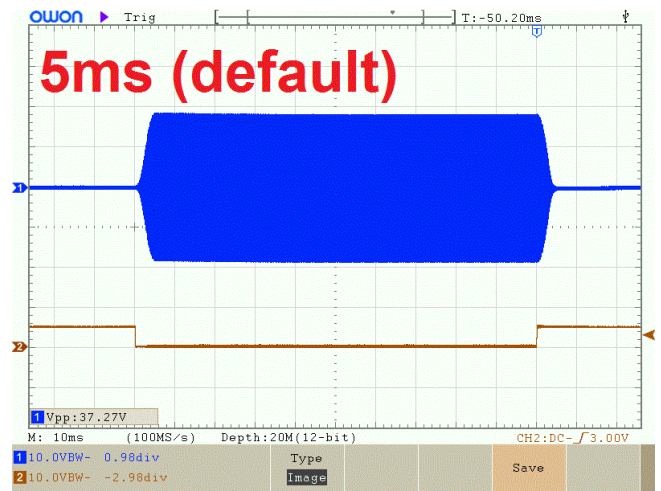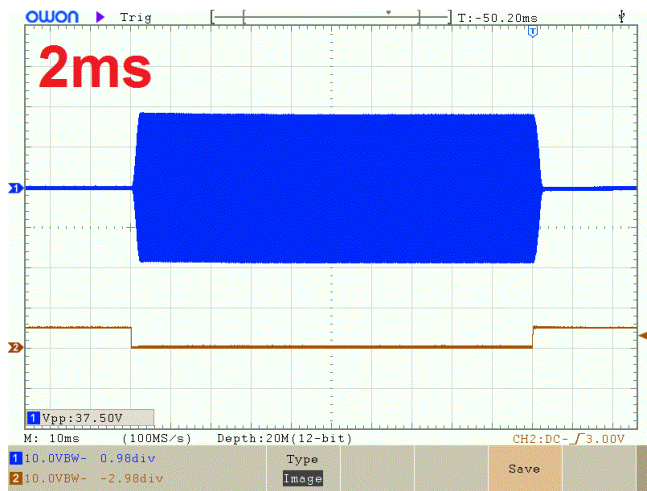
The rise/fall speed is determined by the voltage at the Speed input connection (the pad labelled "D" on the PCB silkscreen). If you simply connect this input to the +5V supply (specifically, any voltage higher than 4.375V) then the rise/fall speed is set to the default 5ms. For any voltage lower than 4.375V, the keying envelope rise/fall speed is proportional to the input voltage. An input voltage of 0..4.375V varies the rise/fall speed from 2..113ms.

Note that the rise/fall speed must never be more than the symbol rate! Otherwise the keying will miss key-down events because it will still be processing the falling edge of the raised cosine envelope shape!

The 'scope screenshot (right) shows the active-low "Key IN" signal (BROWN, bottom trace), and the corresponding "Key OUT" signal (BLUE, top trace). The horizontal timebase is 10ms/division. The rise/fall time here is set to 20ms. It can be seen that the "Key OUT" signal rising edge occurs on the key-down event, but the falling edge of "Key OUT" is delayed from the key-up event. This delay is for the duration of the rasied-cosine envelope shape decay that the microcontroller manages. The intention is to use this "Key OUT" signal perhaps to key a driver stage, so that the oscillator may be kept running and there is no issue with leakage during key-up.
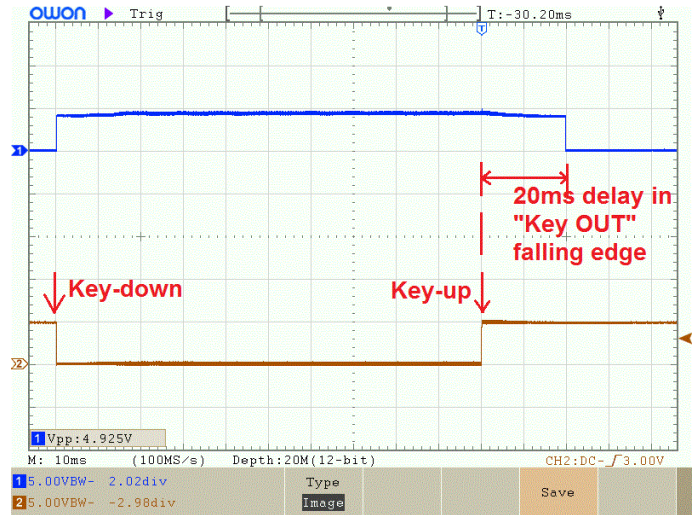
3. Step by step changes to the HF PA kit assembly

In the following sections please refer to this layout diagram.
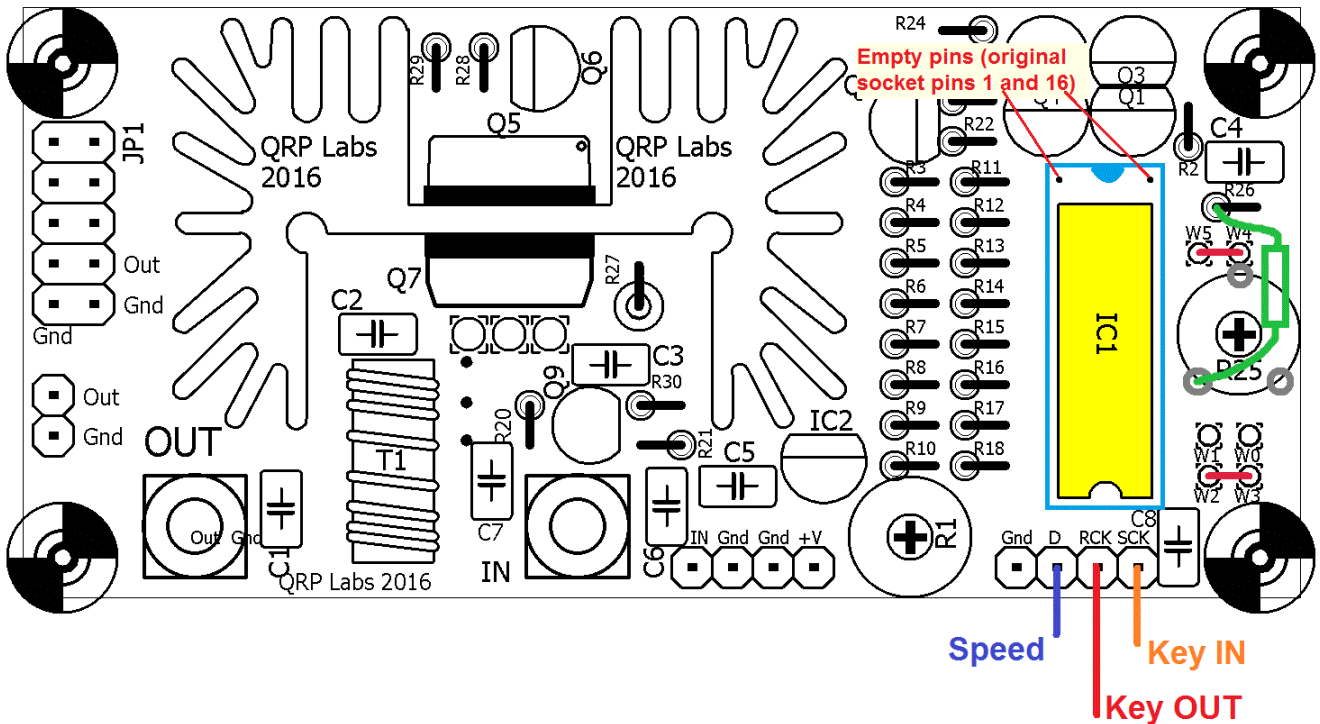
3.1   Jumper configuration

Two jumpers are required. Install a jumper wire to connect W2-W3 as shown, and install a second jumper wire to connect W4 and W5 as shown. If you have previously constructed the PA by the default PA assembly instructions document, remove or cut the jumper between W0-W1.

3.2   ATtiny84 microcontroller installation

The 14-pin ATtiny84 microcontroller chip is inserted in the IC1 socket, instead of the 16-pin 74HC595 supplied in the kit. However, it must be inserted with the dimple at the WRONG end! Please refer to the diagram above and follow it carefully! The "dimple" and (marking pin 1) of the ATtiny84 microcontroller must be at the OPPOSITE end to the dimple marked on the silkscreen and the 16-pin socket. The original pins 1 and 16 of the socket must be empty. So make sure that IC1 is positioned all the way slid down towards the key connections (in the diagram).

3.3   Scaling resistor

The ATtiny84 microcontroller outputs an 8-bit binary code to the 8-bit DAC, and uses the full 8-bit range (0..255) to generate the raised cosine envelope from the cosine coefficients programmed in the ATtiny84.

Please refer to the explanation in section 5.3 of the PA kit assembly manual to understand why a full DAC output range 0..255 will saturate the power modulator, ruining the raised cosine key shape. For this reason it is necessary to scale the DAC to suit the power supply voltage, so that the DAC never drives the power modulation into saturation.

In this standalone application of the PA kit, the scaling is achieved in hardware via a single resistor, marked in green on the above layout diagram. The output impedance of an R-2R DAC Ladder network is R – which in this case is 1.1K. The scaling resistor is connected from the DAC output to ground. Effectively then, this scaling resistor and the impedance of the DAC output created a potential divider at the output of the DAC. For example, if the scaling resistor is also 1.1K, then the output voltage will be halved, so that the range is then 0..2.5V instead of 0..5V.

The potential divider resistors in the feedback of the power modulator, R23 and R24, scale the output voltage by a factor of 0.21. So for example, if the supply voltage is 12V, and allowing for some voltage drop across the power modulator transistor Q5, suppose we wish to supply a maximum of 11V to the final PA transistor. 0.21 x 11 = 2.31V. So we need to choose a scaling resistor such that the DAC output range is 0..2.31V. Some calculation shows that a value of 945 ohms is needed.

There are a number of unknowns which may make an experimental method of determining the resistance preferable. For any fixed supply voltage, the RF envelope can be observed using a Digital Storage Oscilloscope. The oscilloscope traces below show a 100ms "dit" (12 WPM CW, for example) with a raised cosine rise/fall time of 40ms. In these traces the upper (blue) trace shows the RF. The lower (brown) trace shows a positive-going keying signal.

If the resistor value is too large (LEFT picture), the voltage range at the DAC output will be too large, and the RF envelope will show a clipping effect. There will be a sharp corner at the maximum amplitude instead of a smooth cosine shape. Furthermore there is a delay between key-up and when the envelope amplitude starts to decrease.

If the resistor value is too small (RIGHT picture), the voltage range at the DAC output will be too small. The RF envelope has a nice raised cosine shape but due to the attenuated DAC output voltage, the amplitude is reduced, i.e. the power output of the amplifier is reduced.
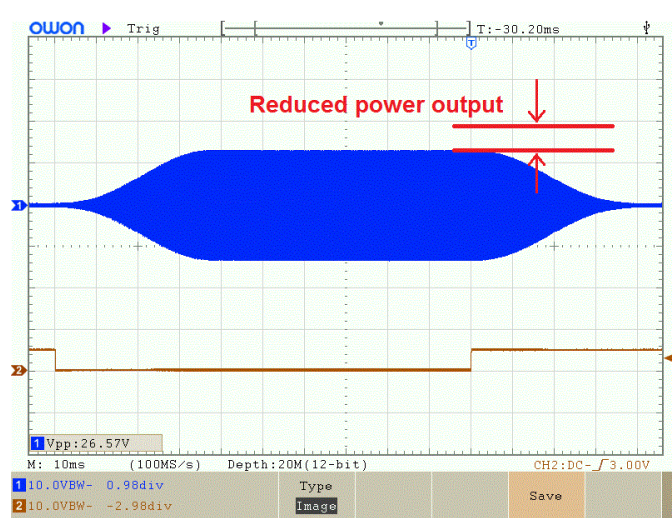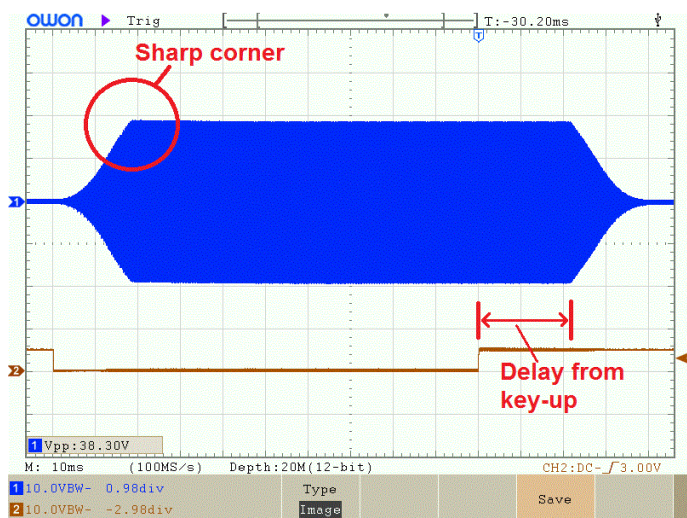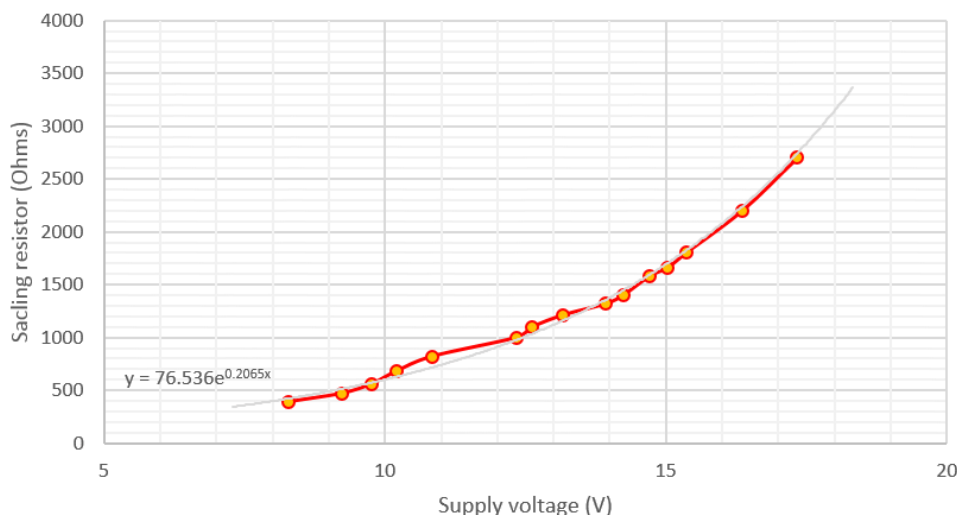

The graph below was obtained experimentally. Various resistor values from 470 ohms to 2.7K were used, and the oscilloscope used to observe the corresponding supply voltage at which envelope clipping occurs. It is a little difficult to precisely determine the supply voltage. The graph below also shows an exponential best fit line.

Using the equation of the exponential best fit line, we find that the resistor value for a 12V supply is 912 ohms. It is not far from the above theoretical predicted value of 945 ohms.

In practice, you will need to select a resistor from the series of common values (unless you wish to make more precise values from parallel or series combinations of resistors). Due to component tolerances it would be prudent to select a slightly lower resistor – even if the power output is slightly reduced, it will at least ensure a beautiful raised cosine envelope shape.

Even better will be to observe your RF keying envelope on an oscilloscope and adjust the resistor value accordingly!

$$y = 76.536e^{0.2065x}$$

3.4 Connections

3 possible RF output connections

2 possible RF input connections

0 **+** Supply voltage, typically 12 or 13.8V

Speed

Key IN

Key OUT

JP1 — Out / Gnd / Gnd

OUT — Out / Gnd

IN

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T1

C1 C2 C3 C5 C6 C7 C8

R1 R2 R3 R4 R5 R6 R7 R8 R9 R10 R11 R12 R13 R14 R15 R16 R17 R18 R19 R20 R21 R22 R23 R24 R25 R26 R27 R28 R29 R30

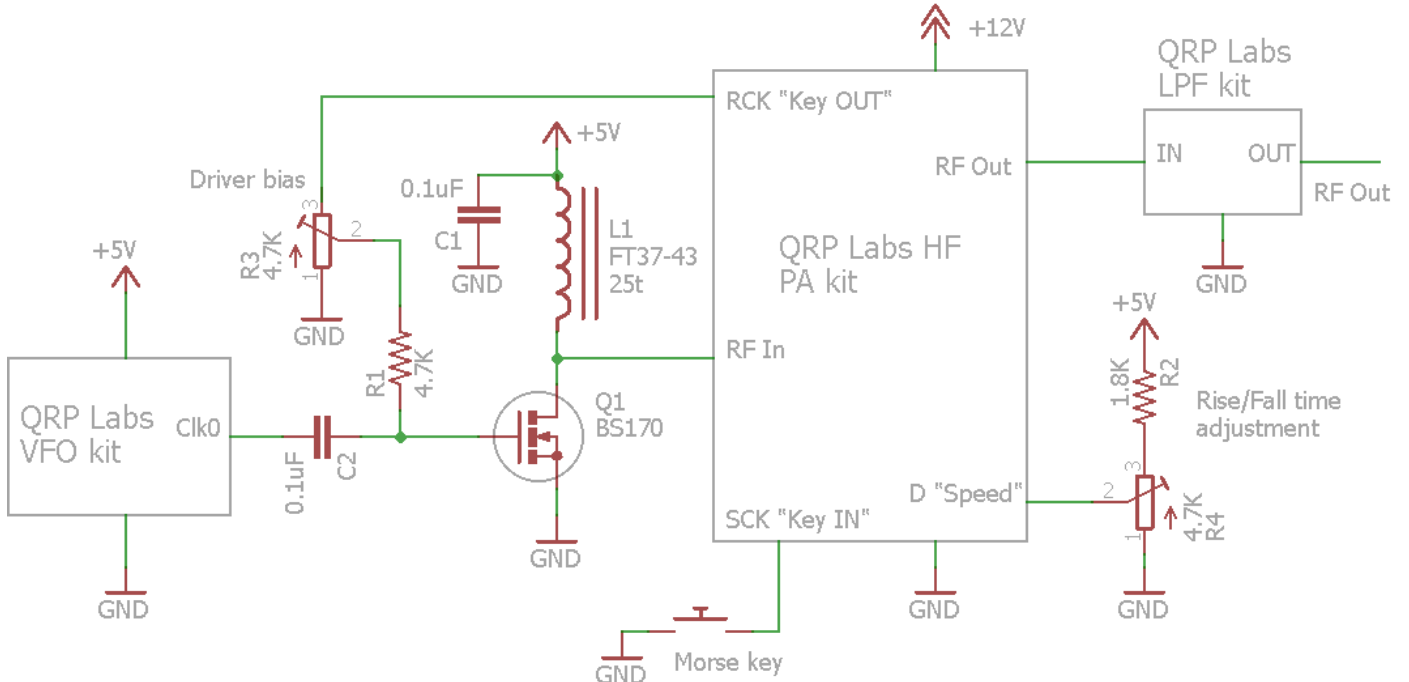Q1 Q2 Q3 Q4 Q5 Q6 Q7 Q8 Q9

IC1 IC2

W0 W1 W2 W3 W4 W5

Gnd D RCK SCK

IN Gnd Gnd +V
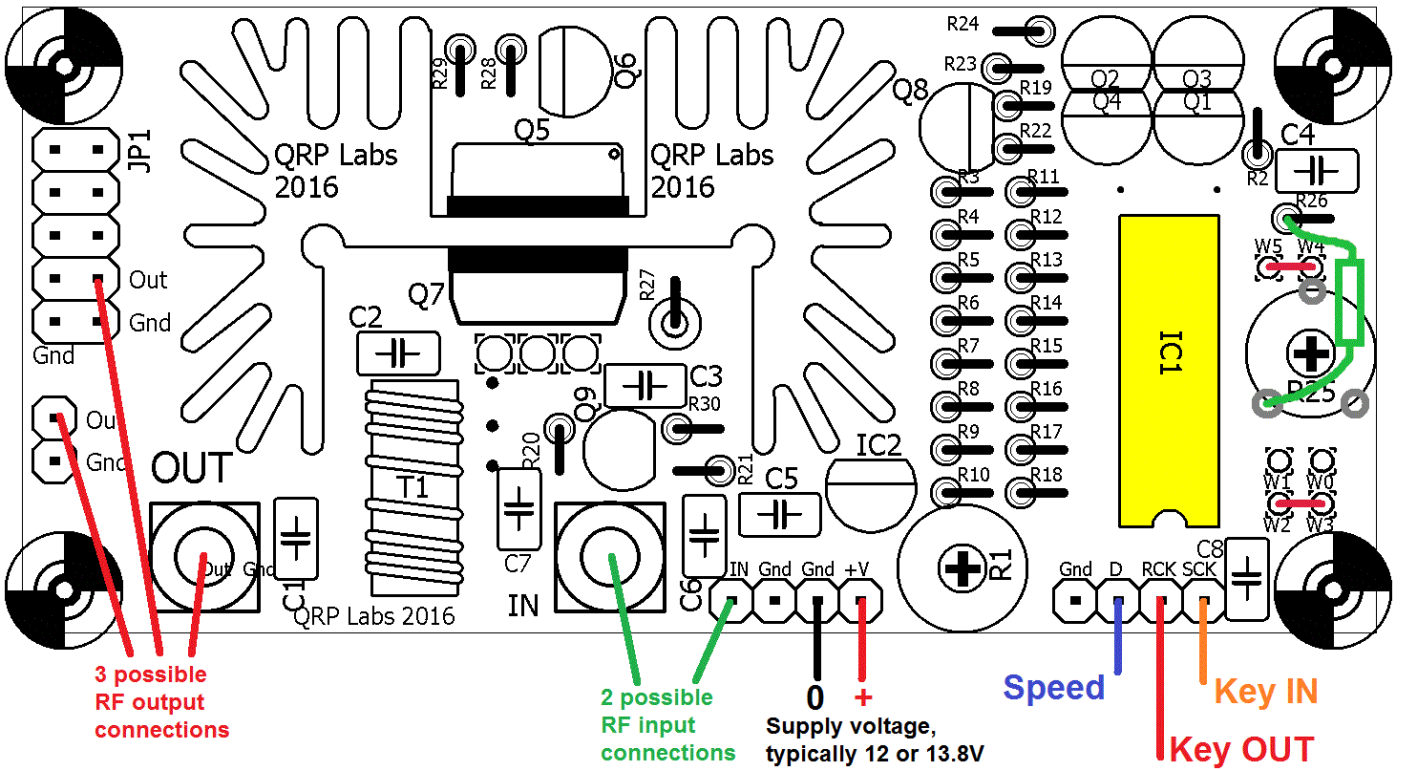
4. Application circuit: a CW Transmitter using QRP Labs VFO kit

+12V

RCK "Key OUT"

QRP Labs LPF kit — IN / OUT — RF Out

RF Out

Driver bias

+5V

R3 4.7K

C1 0.1uF

GND

L1 FT37-43 25t

QRP Labs HF PA kit

RF In

GND

+5V

R2 1.8K

Rise/Fall time adjustment

QRP Labs VFO kit — Clk0

R1 4.7K

GND

C2 0.1uF

Q1 BS170

GND

SCK "Key IN"

D "Speed"

R4 4.7K

GND

Morse key

GND

This simple circuit shows how to create a 5W CW transmitter using the QRP Labs VFO kit as the oscillator, and QRP Labs Low Pass Filter module at the output. The R3 bias potentiometer should be set in a similar way to the main PA kit bias – please refer to the PA kit assembly manual.

Q1, L1 are the driver circuit. They amplify the 3.3V squarewave from the Si5351A. The power output of the Si5351A may be considered to be roughly 10mW (10dBm). The power output of the

driver will be approximately 200mW (23dBm). The PA kit output will be around 5W (37dBm). The driver stage therefore has a gain of about 13dB and the final PA kit has a gain of about 14db.

This circuit diagram illustrates how to use the Key IN, Key Out and Speed connections.

Key IN has an internal pull-up resistor in the microcontroller. It is active low, so that it is compatible with connecting a straight morse key to ground.

Key Out is used here to provide 5V to the driver bias preset potentiometer. Therefore while the RF output is active, Key Out is at 5V and the potentiometer provides bias to the BS170 driver MOSFET. When Key Out goes low at the end of the raised cosine envelope of the trailing edge of the transmitted symbol, the bias to the BS170 is removed, which will drastically cut its amplification gain.

The speed control input is shown here connected to a preset potentiometer R4. Resistor R2 is provided to limit the control range of R4 to 0..3.62V which will give a rise/fall time control range of 2..93ms approximately. Alternatively the speed control input can just be connected to +5V which will cause the speed to default to 5ms.

In implementing this circuit, note that all of the driver components (BS170 etc) are already present (and supplied) in the VFO kit. This is because the Ultimate3S kit and the VFO kit share the same common PCB and pack of components. The only exception is the FT37-43 toroid, which is not supplied in the VFO kit; this can be purchased separately from the QRP Labs shop "spare parts" section. There are even sockets on the VFO board for the Low Pass Filter kit. The BS170 output would need to be routed to the PA kit input, and the PA kit output back to the Low Pass Filter input. This requires a few short lengths of coax, and is further described in App Note AN004.

It would be perfectly acceptable to default the rise/fall time "speed" setting to 5ms by connecting it to +5V instead of making it adjustable; many commercial radios do not provide adjustable rise/fall times. So practically this application circuit may be assembled using the following items, all from the QRP Labs shop:

- VFO/SigGen kit
- FT37-43 toroid
- 5W HF PA kit
- Low Pass Filter kit for the band of your choice
- 25mm spacers for bolting the PA Kit behind the VFO kit

The system could be further extended by adding the 6-band relay-switched filter kit, and five further Low Pass Filters, making it into a 6-band CW transmitter.

5. References

- App Note AN004 explains how to use this PA kit in conjunction with an Ultimate3S QRSS/WSPR kit to increase the output power to around 5W, and apply raised cosine RF envelope shaping for a beautiful clean click-free signal. Refer to http://qrp-labs.com/appnotes
- For updates relating to the PA kit please visit the QRP Labs PA Kit page http://qrp-labs.com/pa
- For any questions regarding the assembly and operation of this kit please join the QRP Labs group, see http://qrp-labs.com/group for details

6. Document Revision history

1.0   First version, 30-Dec-2016