Building a modular transmitter: the Voltage Controlled Oscillator or VCO

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Abstract

I obtained my ham radio license more than twenty years ago and until recently, I had never build a radio transmitter. I will publish a series of articles about the design and build of a modular radio transmitter, using mostly discrete components. The fourth module I have designed is a Voltage Controlled Oscillator or VCO.

1 An overview

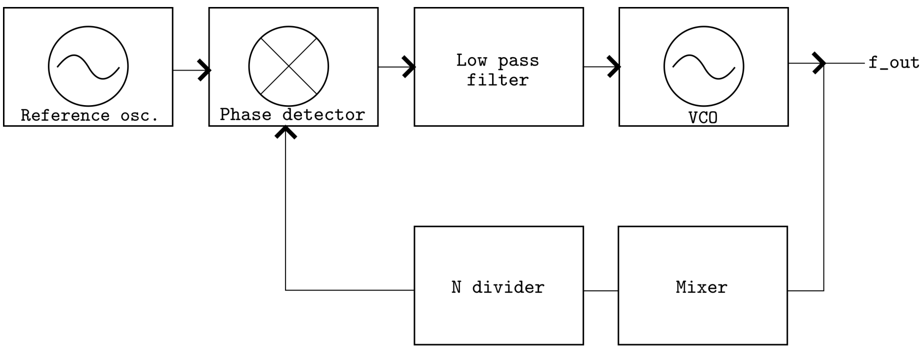

Figure 1: block diagram of the PLL

Figure 1 shows the block diagram of the PLL. Except for the VCO, all the separate parts are already designed and build. The VCO is the last part needed to close the PL-loop. It outputs a frequency between 3.5 MHz and 3.8 MHz which is proportional to the input voltage. This input voltage is the output voltage of the low pass filter (loop filter).

2 The VCO

2.1 Collpit oscillator

Figure 2 shows the actual oscillator. It is a classic Collpit oscillator, copied from a text book. D1 and D2 are varicaps. The capacitance of the varicaps changes when a changing DC voltage is applied. This voltage comes from the loop filter and is injected on connector J1.

The oscillation frequency can be calculated by this formula:

$$\frac{1}{2\pi\sqrt{L1(\frac{C7 \cdot C8}{C7+C8} + \frac{C5 \cdot C_{var}}{C5+C_{var}})}} \quad (1)$$

When entering the values of the design, the output frequency is:

$$\frac{1}{2\pi\sqrt{12 \cdot 10^{-6}(\frac{220\cdot10^{-12}\cdot100\cdot10^{-12}}{220\cdot10^{-12}+100\cdot10^{-12}} + \frac{220\cdot10^{-12}\cdot122\cdot10^{-12}}{220\cdot10^{-12}+122\cdot10^{-12}})}} = 3.8MHz \quad (2)$$

This is the lowest frequency the VCO can be tuned to. In the real world, parasitic capacitance will lower the calculated 3.8 MHz and with trimmer capacitor C28, this frequency can be lowered even more. To adjust the oscillator, you turn the trimmer until the minimum output frequency is slightly lower than 3.5 MHz, which is the lower side of the 80 meter amateur radio band. When the varicaps have lower capacitance, due to a different DC-voltage, the output frequency will be higher. The Collpit oscillator is designed so, that the maximum frequency is slightly higher than 3.8 MHz, the upper side of the 80 meter amateur radio band. This way, the PLL can be tuned to all the frequencies inside the 80 meter amateur radio band.

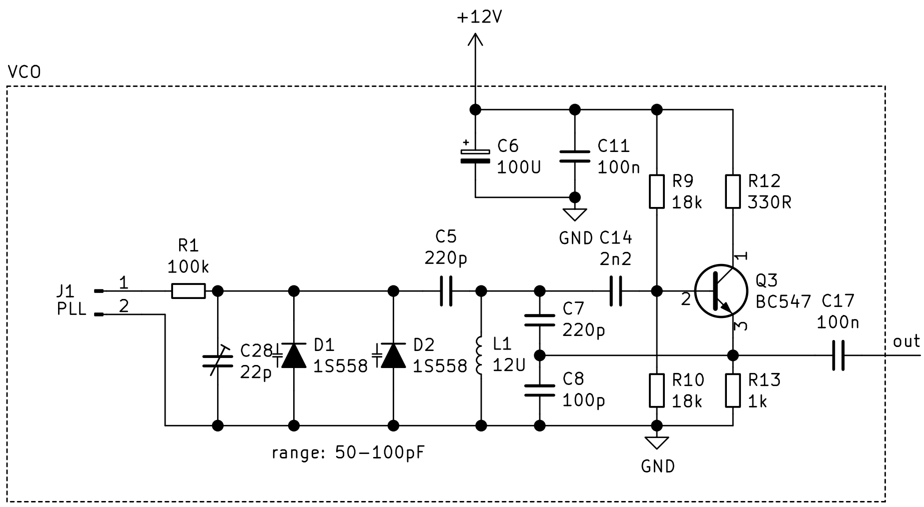

Figure 2: Collpit oscillator

2.2 Outputs

Figure 3 shows the schematic of the two outputs of the VCO. Class A amplifier Q4 buffers the Collpit oscillator. The output of this amplifier goes to Q5, another class A amplifier. The output of this amplifier is present on connector J6 and is the signal that goes back to the mixer, so the loop can be closed. The signal from Q4 also goes through a low pass filter. This signal is present on connector J5 and is the actual synthesized output from the PLL.

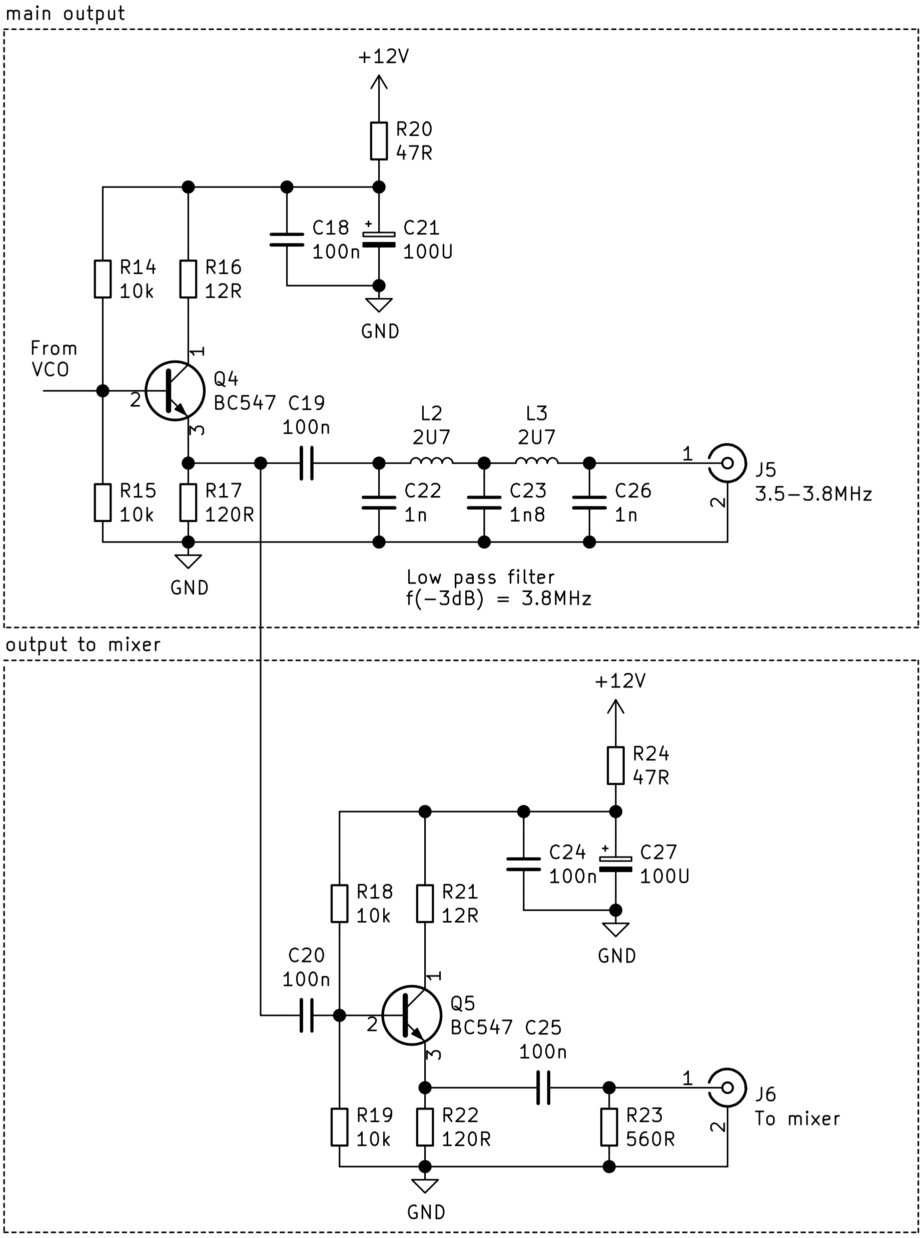

Figure 3: outputs of the VCO

3 Ripple filter

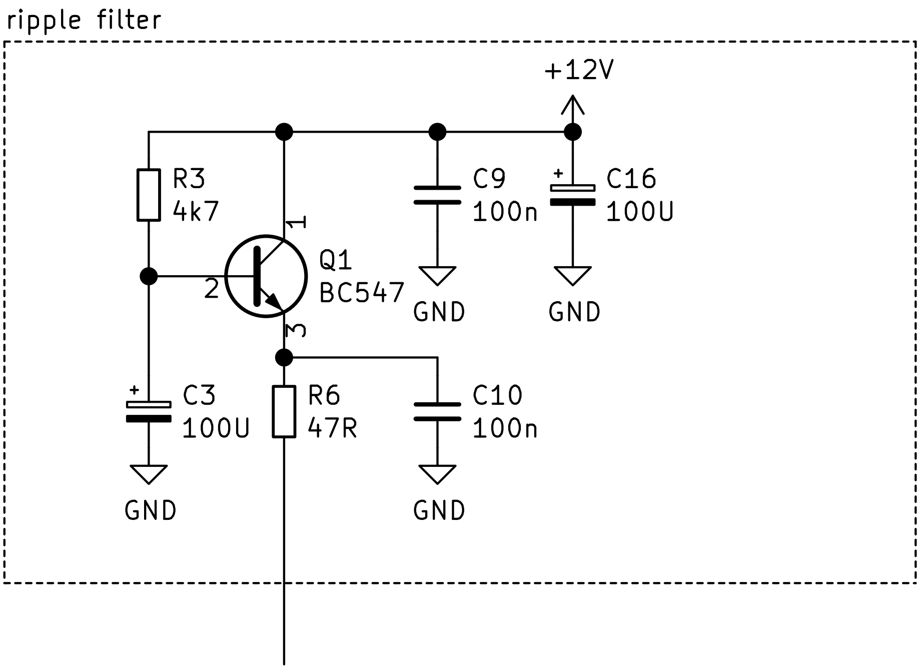

Figure 4: ripple filter

Figure 4 shows the ripple filter. It filters the power supply for the Collpit oscillator. This increases the power supply rejection ratio of the VCO and prevents feedback from the oscillator to the power supply rails. The open end of R6 is connected to the positive terminal of C6 of the oscillator.

4 A fix for a design oversight

When testing the complete PLL, I stumbled across a design flaw: the output of the mixer cannot drive the input of the programmable divider. In order to correct this problem I designed a simple buffer, which can be placed between the output of the mixer and the input of the programmable divider. Figure 5 shows this buffer. Because there is ample space on the PCB of the VCO, I placed the buffer on this PCB.

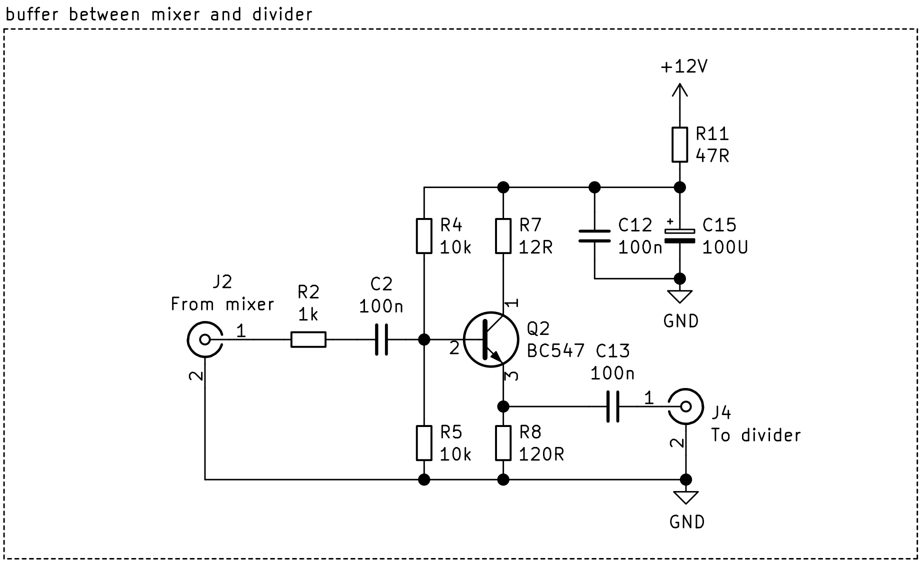

Figure 5: buffer

5 Practical notes

5.1 Build the pcb

Building the printed circuit board is straight forward. The design files are made with KiCad 5.1.8 and scaled PDF files of the printed circuit board are available. The pcb has two layers and I etched it myself. Therefore, there are no plated through vias. All ground connections, as well as some other connections, should be soldered on both sides of the pcb.

A Full schematic

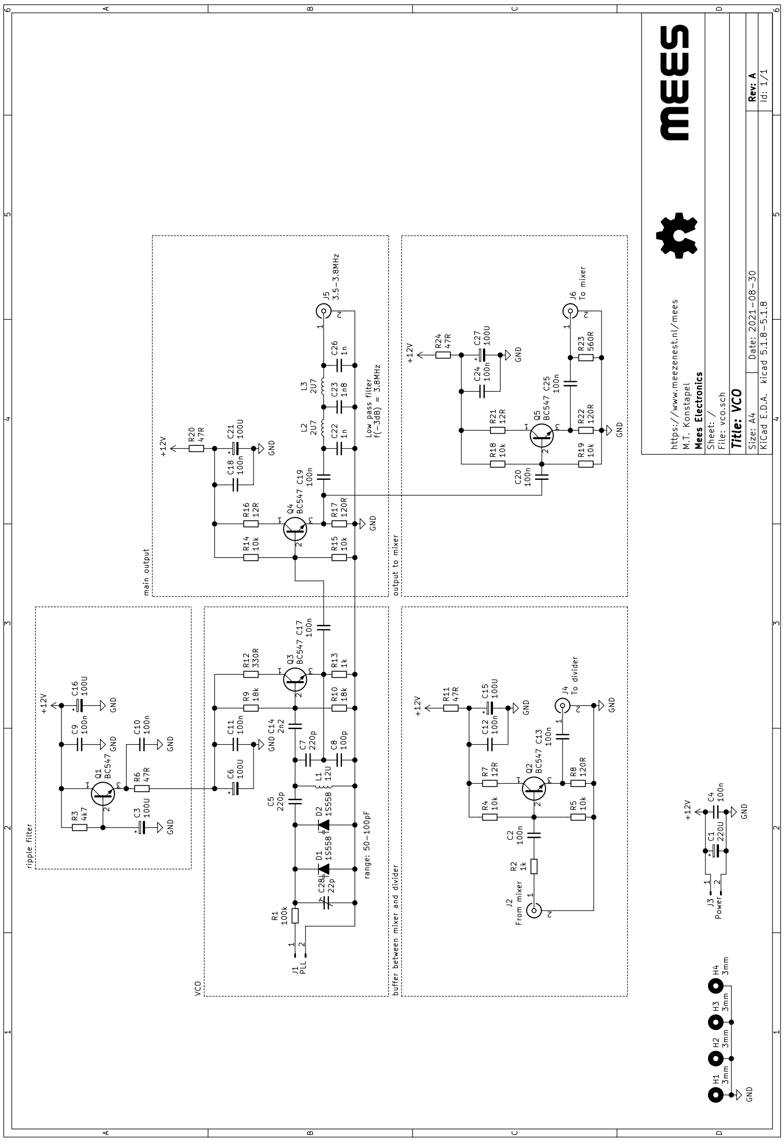

Figure 6: full schematic of the VCO

B Component placement

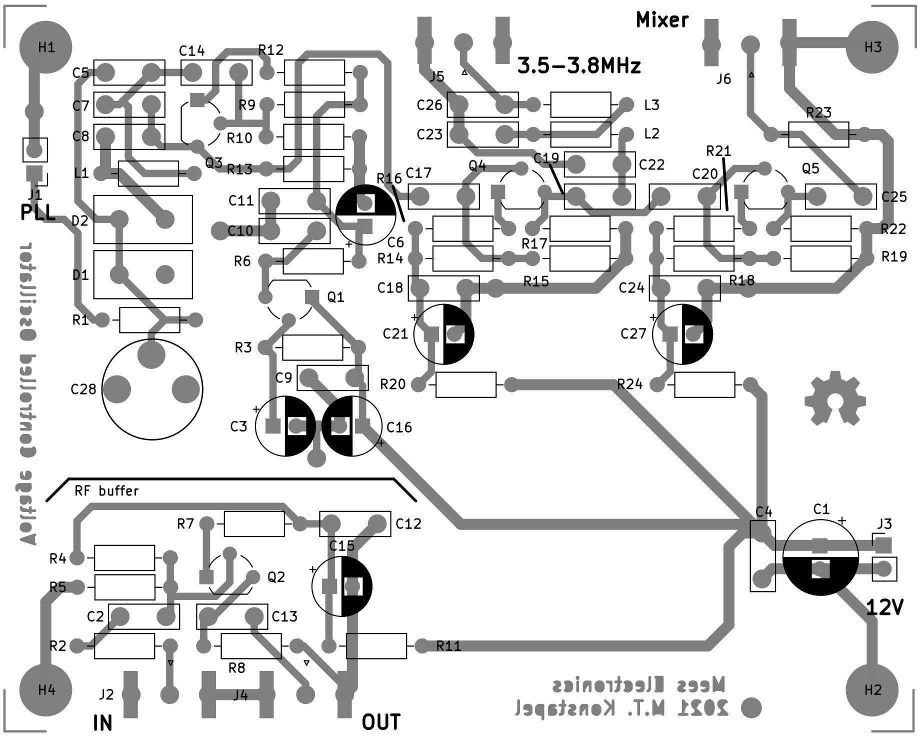

Figure 7: component placement

C Bill of material

#	Reference	Description	Value	Ordering #
1	C1	Electrolitic capacitor	220U	220U/25V
1	C14	Capacitor	2n2	2.2n/50V
13	C2 C4 C9 C10 C11 C12 C13 C17 C18 C19 C20 C24 C25	Capacitor	100n	100n/50V
2	C22 C26	Capacitor	1n	1n/50V
1	C23	Capacitor	1n8	1.8n/50V
1	C28	Variable capacitor	22p	22p trimmer
6	C3 C6 C15 C16 C21 C27	Electrolitic capacitor	100U	100U/25V
2	C5 C7	Capacitor	220p	220p/50V
1	C8	Capacitor	100p	100p/50V
2	D1 D2	Varicap	1S558	1S558 or other 50pF varicap
4	H1 H2 H3 H4	Mounting hole	3mm	not a placable part
2	J1 J3	Single row connector	-	2 pin header 2.54mm pitch
4	J2 J4 J5 J6	SMA connector	-	SMA for PCB edge mount
1	L1	Inductor	12U	12UH
2	L2 L3	Inductor	2U7	2.7UH
5	Q1 Q2 Q3 Q4 Q5	Transistor	BC547	BC547
1	R1	Resistor	100k	100k 1% 0.25W
4	R6 R11 R20 R24	Resistor	47R	47R 1% 0.25W
1	R12	Resistor	330R	330R 1% 0.25W
2	R2 R13	Resistor	1k	1k 1% 0.25W
1	R23	Resistor	560R	560R 1% 0.25W
1	R3	Resistor	4k7	4k7 1% 0.25W
6	R4 R5 R14 R15 R18 R19	Resistor	10k	10k 1% 0.25W
3	R7 R16 R21	Resistor	12R	12R 1% 0.25W
3	R8 R17 R22	Resistor	120R	120R 1% 0.25W
2	R9 R10	Resistor	18k	18k 1% 0.25W

Figure 8: bill of material

D Open source hardware

All the design files are available on my website: https://www.meezenest.nl/mees