CWduino KT-004

Compact CW transmitter fully compatible with Arduino Uno board
500 mW of RF output power at 5 VDC, 2000 mW at 9VDC
Keyer input to build a semi-automatic key
Available in three band assemblies: 80 m, 40 m and 20 m

Features

- Highly integrated CW transmitter compatible with Arduino Uno board
- Class-E topology for high efficiency
- HF band coverage: 80, 40 and 20 m (depends on version)
- Built-in 2nd harmonic notch filter to meet CFR requirements (-43 dBc)
- 500 mW RF output power from 5 VDC Arduino's power supply rail
- 2000 mW RF output power at 9 VDC
- Keyer input connector (mini-jack)
- Transmitter keying available from pin PD4 (IOL group)
- Precise frequency adjustment via trimmer
- Equipped with SMA connector for size critical applications
- Equipped with ISP connector (2x3 pin header)
- Most components are THT for easy assembly

FIGURE 1. Assembled CWduino KT-004 board

Mechanical Characteristics

- Fully mechanical and electrical compliance with Arduino Uno™ board
- Double-layer PCB
- Compact design: 68 × 54 x 12 mm

Application

- Automatic keyer with integrated TX stage
- Part of Arduino's controlled beacon
- Board for experiments with class E amplifier
- Experimental CW transmitter controlled from Arduino
- Battery supplied experimental TX module
- Part of a portable CW transceiver

General description

The KT-004 CWduino is a fully integrated CW transmitter fully compatible with Arduino™ Uno platform. CWduino is built as a highly efficient class E transmitter. Installed key input (mini-jack) allows to build a semi-automatic key. In that case one of the microcontroller's output can key the transmitter.

Three MOSFETs connected in parallel help to achieve low Rdson at low voltage (5 VDC) operation. If the Arduino Uno module is supplied from an external voltage source it allows to increase the RF output power up to 2000 mW at 9 VDC.

To keep the circuit simplicity there are no additional safety circuits for overvoltage and overcurrent condition. There is a large power loss margin on three transistors which may dissipate possible power losses in mismatch condition.

Basic code examples for the Arduino environment can be downloaded:
http://www.krait-technologies.com/cwduino_examples.zip

► CWduino is only intended for use by licensed operators.

Circuit description

The Class-E amplifier (invented in 1964) is a highly efficient tuned switching power amplifier used at radio frequencies. [1] It uses a single-pole switching element and a tuned reactive network between the switch and the load. The circuit obtains high efficiency by only operating the switching element at points of zero current (on to off switching) or zero voltage (off to on switching) which minimizes power lost in the switch, even when the switching time of the devices is long compared to the frequency of operation. In Class-E, the output network values are chosen in such way that output capacitance is part of a total resonant circuit. [2]

Basic circuit topology is presented in the Fig. 2. It consists of three specific and one optional parts:

1) DC-feed choke (L1) connected to active switch (Q)

2) external capacitance (C1) connected parallel to MOSFET's drain-source junction

3) band-pass filter (L2-C2), which gives also impedance transformation

4) second harmonic notch filter (C3-C4-C5-L3) helps to strongly suppress harmonic content (not explicitly required, but desired to keep the second harmonic low according to CFR standard)

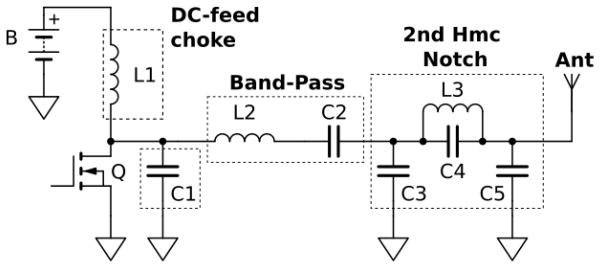


FIGURE 2. Class-E amplifier topology

Local oscillator is built using 74ACT00 logic gates. ACT series has 24 mA output current capability which efficiently control MOSFET's gates. BS170 transistors were chosen because of very low value of input capacitance Coss (17 pF) which can be easily driven using a logic gate. Special version of logic gate IC (ACT series) was chosen because of 24 mA output current capability which can be directly used to control MOSFET's gate circuits. Regulated bias circuit helps to set optimum operation point of transistors. Switches are driven with 50% duty cycle.

Local VCO is made using crystal oscillator connected to one of the NAND gate. The output frequency can be adjusted with a trimmer.

The board is equipped with an input for a telegraph key: straight or paddle. It supports single and paddle keys. Note that Arduino's pin 2 is INT0 and pin 3 is INT1. It allows to realize the reading of CW key state as external interrupts to simplify code. Similarly, the control output (CW_TX) is controlled via pin 4 which is linked to hardware Timer 0.

The JP1 connector allows programming the Arduino™ Uno device through 2x3 pin header.

The capacitors used in the resonant circuits are NP0 (C0G) components which are super stability and have no aging effects.

The number of pads on the board is more than necessary. This allows for easy parallel connection of multiple capacitors during experiments. Note that each capacitor in Fig.2 has four pads on the board.

► To keep simplicity the presented circuit has no additional OVP or OVC protection, because the power dissipated in the transistors will be safely dissipated on three transistors. Voltage margin is also provided. However, it is not recommended to run the amplifier with the disconnected load or in high mismatch condition. The optimal operation point of the amplifier is 50R RF load.

References:

[1] Ewing G.D., "High-Efficiency Radio-Frequency Power Amplifiers", Oregon State University, submitted in April, 1964.

[2] Sokal. N.O. "Class-E RF Power Amplifiers", QEX 2001, 204, 9-20.

Absolute Maximum Ratings

Maximum Input Voltage:	9V
Maximum Output Power @ 50R @ 5V:	500 mW (+ 27dBm)
Maximum Output Power @ 50R @ 9V:	2000 mW (+33 dBm)
Power Dissipation @ Pi_max @ 50R:	0.6 W
Operating Temperature Range:	-45°C to +65°C
Lead Temperature (Soldering 10 sec):	+300°C

► Operating CWduino from 12,0 V results in 60 V peak voltage on the MOSFETs transitors and Pi =4 W when running amplifier at 50R load. This voltage value is "Absolute Maximum Voltage" for BS170 transistor. Any load mismatch condition will cause their destruction!

Assembly procedure

It is highly recommended to start assembly from the smallest components (SMT IC and capacitors), then THT resistors and then install ferrite cores with windings. All types of connectors should be installed last.

Assembly variants

Note that CWduino kit can be assembled in a few variants depends on the ordered version.

If AVR microcontroller will be used to create key signal for transmitter stage do not assembly R3, C1.

If the CW paddle key plus semi-automatic code in Arduino board will be used assembly R1, R2 resistors and do not assembly R3, C1. Instead install R5.

If the CW straight key will be used install R2, R3, C1. Do not install R5.

Ferrite core winding procedure

If the next module (a shield board) will be stacked over CWduino it is required to assembly the ferrite cores in a horizontal position to meet the limit of height to the next board.

► It is a good practice to spread windings over a whole toroidal ferrite core.

►► If possible, measure the inductance of the coils to run amplifier at the optimal point. You can use VNA to measure coil's inductance at proper frequency.

Installing connectors

The CWduino layout has been designed in such a way that the two types connectors can be mounted interchangeably:
- SMA type (X3) or
- BNC type (X2) [optional]

Insulation consideration

► Pay attention for a required distance to the next stacked shield board (if exist). Put an additional insulator to avoid a short circuit.

Startup procedure

Connect two passive probes between points:

CH1 – D-S point to GND
CH2 – RF_OUT to GND

Use plastic trimmers during adjusting output frequency (CT1) and bias voltage (PR1). Optimum D-S voltage waveform is shown in the Fig. 3. Good starting point is middle of the potentiometer range. Measure the input current in comparison to output voltage(output power). Note that if output power is not increasing if you turn PR1 clockwise it means that you set proper BIAS voltage.

Final check

Connect dummy load (50R) to CWduino output. Connect a passive probe to points: RF_OUT and GND. Turn on the output power. Set FFT analysis on an oscilloscope. Check levels of non-fundamental harmonics.

47 CFR Part 97.307(d) specifies the limits. Below 30 MHz, all spurious emissions including harmonics must be suppressed 43 dB below the primary signal; from 30-225 MHz, it's 60 dB.

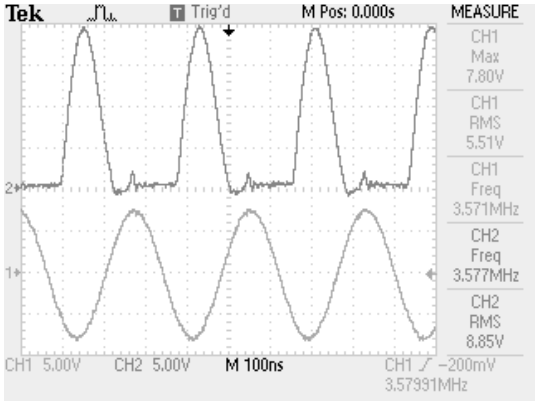


FIGURE 3. Class-E amplifier operated at 5VDC: CH1 – RF output voltage, CH2 – MOSFET's D-S voltage

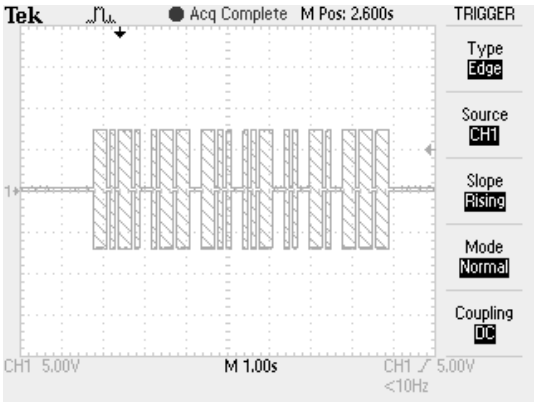


FIGURE 4. Example operation of CWduino in beacon mode: CH1 – RF output voltage

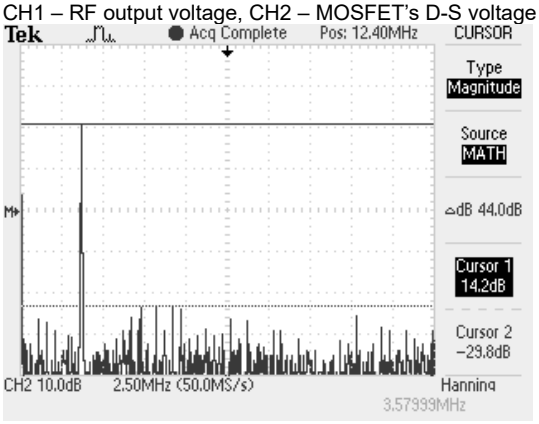


FIGURE 5. RF output signal spectrum measurement. Measured 44 dB margin between the carrier and the spurious content

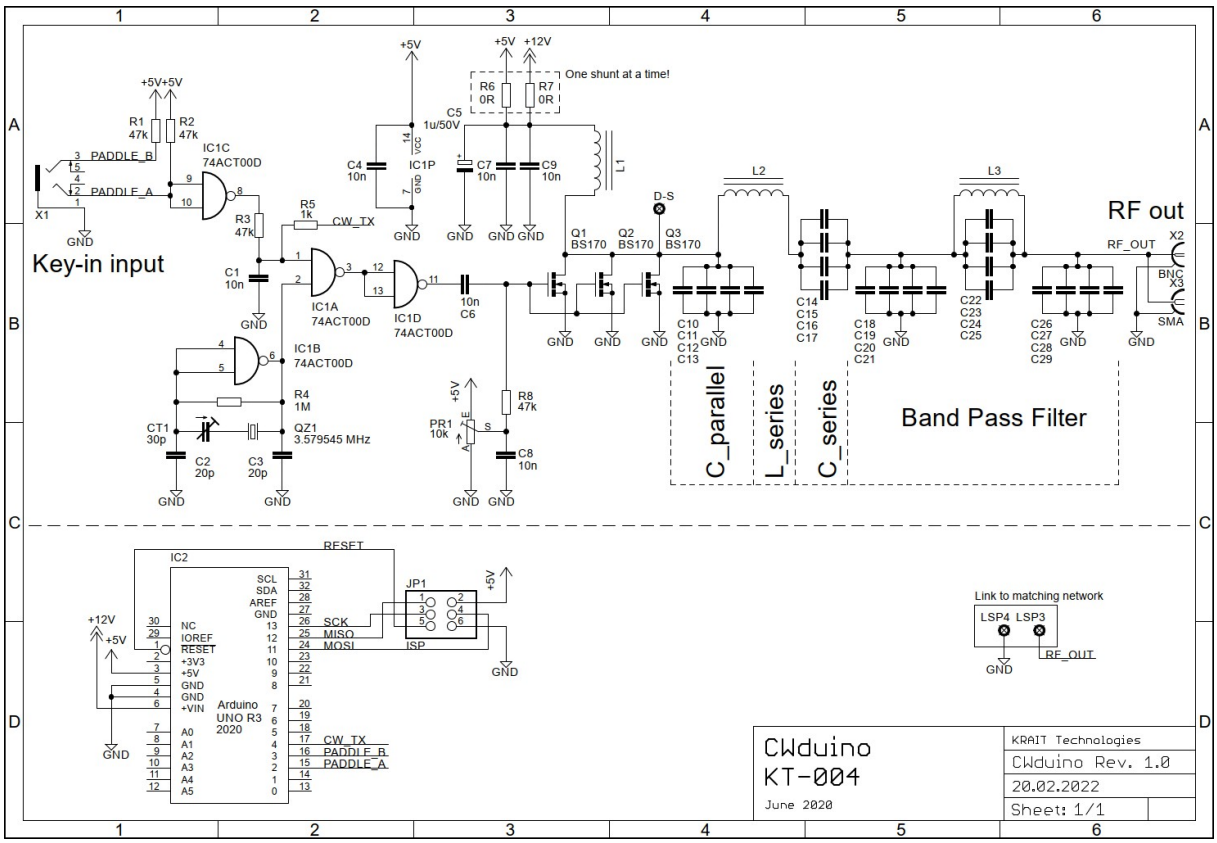


FIGURE 6. Schematic diagram of CWduino (KT-004)

Components List

Table 1. Components list (frequency independent)

No.	DESIGNATOR	DESCRIPTION	QTY	PART NUMBER	VALUE
1	X1	Mini-jack THT angle connector	1		
2	X2 X3	SMA THT angle female connector BNC THT angle female connector (optional; not included)	1 0	–	–
3	R1, R2, R3, R5	THT, 0,125 W, 47k	4		
4	R4	THT, 0,125 W, 1M	1		
5	R6	THT, shunt 0R	1		
6	C2, C3	THT, 20pF	2		
7	C1, C4, C6, C7, C8, C9	THT, 10nF, 35V, ceramic	6		
8	C5	1uF, 35V, THT electrolytic capacitor	1		
9	Q1, Q2, Q3	THT, MOSFET transistor	3	BS170	
10	CT1	5-30pF THT, trimmer	1		
11	IC1	4 x NAND gates, SO-14 package	1	74ACT00D	
12	PR1	THT, 10k, potentiometer	1		
13		Arduino connectors: 1x6 pins, 2x8 pins, 1x10 pins	4		
14		1x4 goldpin	1		
15	Enamel wire	AWG #28	0,6 m		

80 m version:

► For experiments and future kit variants, there are several pads of capacitors connected in parallel to make easier to precisely combine the required capacities.

Table 2. Components list (only for 80 m variant)

No.	DESIGNATOR	DESCRIPTION	QTY	PART NUMBER	VALUE
8	QZ1	Crystal quartz THT, low profile, 3.579545 MHz	1		
11	L1	35,49 uH (11 turns)	1	FT37-43	
12	L2	2.37 uH (21 turns)	1	T37-2 core	
13	L3	0.88 uH (11 turns)	1	T37-2 core	
14	C10, C11, C12, C13	1 x 560 pF (one components mounted in one of the four pads)	1	560pF 0805 NP0	
15	C14, C15, C16, C17	3 x 560 pF (three components mounted in three of the four pads)	3	560pF 0805 NP0	
16	C18, C19, C20, C21	3 x 560 pF (three components mounted in three of the four pads)	3	560pF 0805 NP0	
17	C22, C23, C24, C25	1 x 560 pF (one components mounted in one of the four pads)	1	560pF 0805 NP0	
18	C26, C27, C28, C29	3 x 560 pF (three components mounted in three of the four pads)	3	560pF 0805 NP0	

40 m version: TBD
20 m version: TBD

CW Key

When connecting a straight key use tip and sleeve.
When connecting a paddle use tip, ring and sleeve.

► Make sure the voltage retained by the keyer is less than 0.4 V when the key is ON.

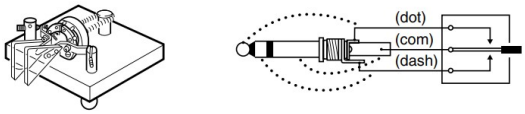
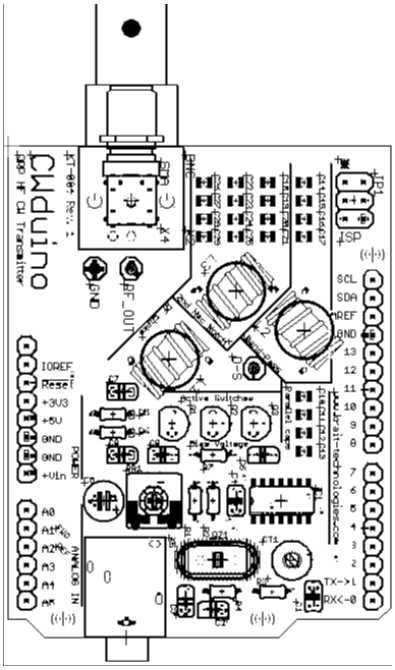


FIGURE 7. Connecting CW key

Pin Configurations

Table 3. Pin configurations

PIN CONNECTIONS	
ARDUINO standard	**Function on CWduino**
–	–
–	–
–	–
–	–
N.C.	N.C.
IOREF	N.C.
/RESET	**Reset (ISP)**
+3V3	N.C.
+5V	**+5V (ISP)**
GND	**GND (ISP)**
GND	**GND (ISP)**
+Vin	**+Vin**
A0	N.C.
A1	N.C.
A2	N.C.
A3	N.C.
A4	N.C.
A5	N.C.



PIN CONNECTIONS	
ARDUINO standard	**Function on CWRduino**
SCL	N.C.
SDA	N.C.
AREF	N.C.
GND	**GND (ISP)**
13	**SCK (ISP)**
12	**MISO (ISP)**
11	**MOSI (ISP)**
10	N.C.
9	N.C.
8	N.C.
7	N.C.
6	N.C.
5	N.C.
4	**CW_TX**
3	**PADDLE DASH**
2	**PADDLE DOT**
1 (TX)	N.C.
0 (RX)	N.C.

FIGURE 8. Descriptive layer of CWduino (KT-004 board)

Electrical characteristics

Table 4. Input voltage vs. output voltage and output power

Input DC voltage [V]	Output RF voltage @ 50R load [Vrms]	Output power @ 50R load [W]
5.0	5,00	0.50
6.0	6,65	0.88
7.0	7,83	1.23
8.0	9,00	1.62
9.0	9,96	1.98
10.0*	*11,8*	*2,42*
11.0*	*12,9*	*2,88*
12.0*	*14,2*	*3,92*

*) Operating CWduino at input voltage > 9,0 VDC in mismatch condition will destroy transistors. Given for reference only.

CW band plan on HF bands

Table 5. CW bandplan

Base band	Frequency range for CW mode	Center frequency for CW QRP operation
80m	3500 – 3580 kHz	3555 kHz
40m	7000 – 7040 kHz	7030 kHz
20m	14000 – 14070 kHz	14060 kHz

Mechanical Details

CWduino shield is fully compatible with the Arduino Uno™ footprint.
If ferrite cores are assembled flat it is possible to install a next shield above, according to Arduino Uno™ standard.

Board dimensions: 68 x 54 x 12 mm (measured without pins length below the board)
PCB specification: FR 4, double sided, 35 um layers, HAL

Ordering Information

Table 6. Ordering information

Description	Version	Ordering Code	QTY
Printed circuit board only	PCB	KT-004B	1
Kit for self assembly (components for 80m, SMA output connector, crystal 3.579545 MHz)	Kit	KT-004K/80	1
Kit for self assembly (components for 40m, SMA output connector, crystal 7.023 MHz)	Kit	KT-004K/40	1
Kit for self assembly (components for 20m, SMA output connector, crystal 14.060 MHz)	Kit	KT-004K/20	1

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