EE 423: Communication Electronics
Prof. Mohammed Hawa

Project: FM Transmitter (Hardware)

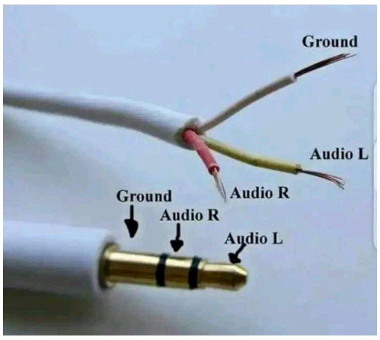
In this project, you are required to **understand, build and test** the FM transmitter circuit shown in the next page and **get it to work**. The first part of the circuit is a voltage-controlled oscillator (VCO) that generates an FM modulated signal with carrier frequency around 100 MHz. The output frequency of the VCO is controlled by an audio signal fed to the base of transistor Q1.

The input audio message (in the range of 200 mVpk-pk to 2 Vpk-pk) is required to be feed from the audio jack of your PC, cell phone, or music player. For example, you can play an audio file stored on your phone, or you can download an Android App that generates audio signals (such as a specific-frequency tone) on your phone. Here is the link for one of such Apps, but you can find many others:

https://play.google.com/store/apps/details?id=de.heinz.tonegenerator

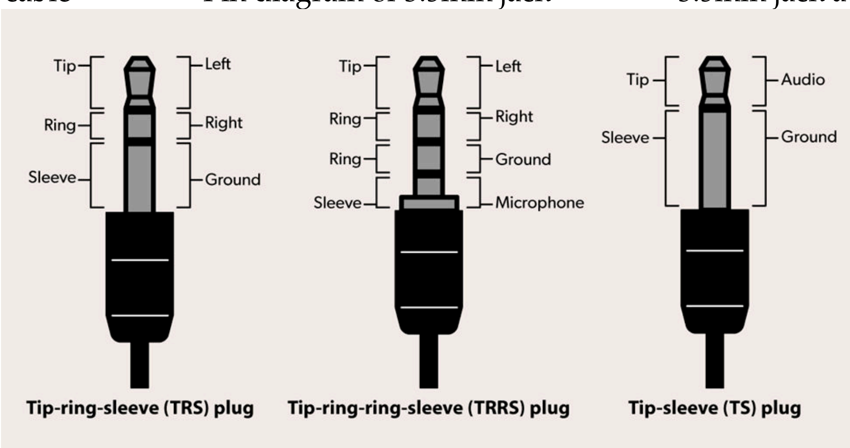
We want to test multiple audio files with different signal bandwidths. To connect your PC audio card, cell phone, or music player, you can either buy an audio cable with 3.5mm stereo jack or salvage one from an old headphone. The pin diagram for the 3.5mm jack is shown below. You can either solder the wires to your board, or you can buy an adaptor and attach it to your board if you do not want to cut the cable. Make sure you perform a short-circuit test, though, to make sure the cable you are using is in working order.

Audio cable

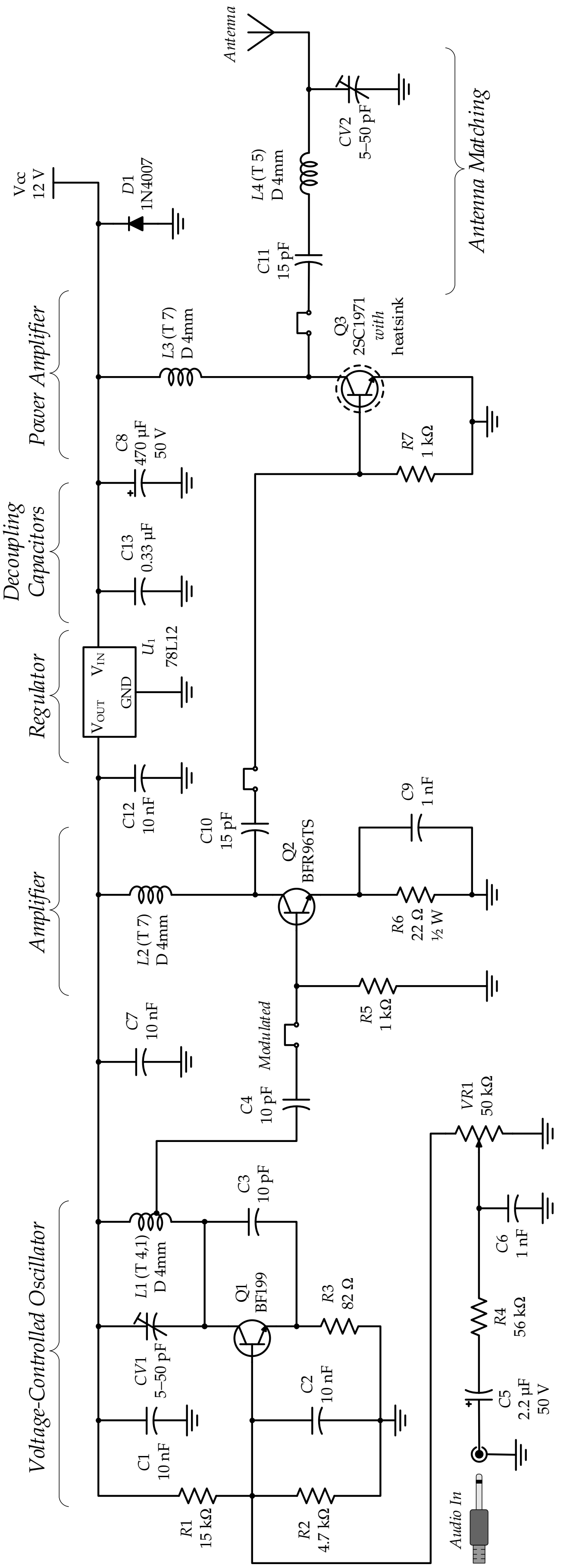


Pin diagram of 3.5mm jack

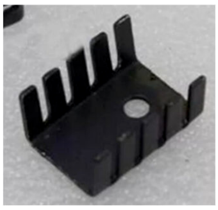
3.5mm jack adaptors



Different types of 3.5mm connectors

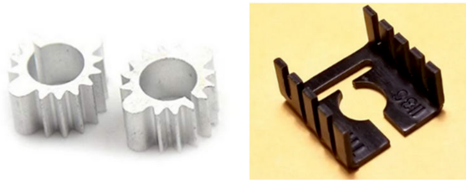

Antenna
Antenna Matching
CV2
5–50 pF
L4 (T 5)
D 4mm
C11
15 pF
Q3
2SC1971
with
heatsink
Vcc
12 V
D1
1N4007
Power Amplifier
L3 (T 7)
D 4mm
R7
1 kΩ
C8
470 µF
50 V
Decoupling
Capacitors
C13
0.33 µF
Regulator
VIN
GND
VOUT
U1
78L12
C12
10 nF
C10
15 pF
C9
1 nF
Q2
BFR96TS
Amplifier
L2 (T 7)
D 4mm
R6
22 Ω
½ W
R5
1 kΩ
C7
10 nF
Modulated
C4
10 pF
VR1
50 kΩ
C3
10 pF
C6
1 nF
Voltage-Controlled Oscillator
L1 (T 4,1)
D 4mm
Q1
BF199
R3
82 Ω
R4
56 kΩ
CV1
5–50 pF
C2
10 nF
C5
2.2 µF
50 V
C1
10 nF
R1
15 kΩ
R2
4.7 kΩ
Audio In

Your first task is to make sure that the three transistors in the above schematic are available locally and are reasonably priced. If not, please let me know as soon as possible, so we can find alternatives. The third transistor is supposed to carry moderate current, which means it will heat up during operation. Hence, it is important to attach it to a small heat sink to avoid the transistor burning during operation. You can buy a small heat sink (such as the ones shown below), which is more than enough, but if you want to salvage an old (small or big) heat sink from an old power supply, you can do that as well.



Small heatsink for TO-92 package

Slightly bigger heatsink for TO-92 package

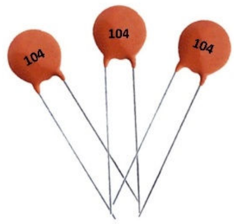


Different heatsinks for TO-39 package

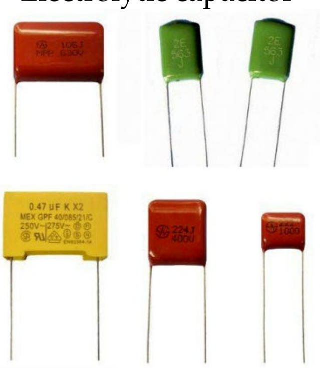
For the capacitors marked with a "+" sign, use electrolytic capacitors. For other capacitors, use *multi-layer* ceramic capacitors, which are slightly more expensive than ceramic capacitors, but have tolerances within 10%. Try to avoid the cheaper regular ceramic capacitors, since they have lousy tolerances of 20% or worse. You can also use other capacitor types, such as polyester, tantalum, or mica, but those tend to be much more expensive, and are not necessary for this design. Remember that electrolytic and tantalum capacitors are polarized, so pay attention to their terminal polarity when connecting them, otherwise you risk blowing up the capacitor. In addition, it is a good idea to measure the actual values of the capacitors, resistors, and other components before actually soldering them just in case there is a mistake in reading their color values.

Electrolytic capacitor

Multi-layer ceramic



Ceramic capacitors



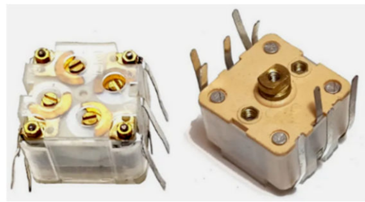
Polyester film capacitors

Tantalum capacitors

Mica capacitors

For the variable capacitor, you can use a 5-50 pF (or any wider range) variable capacitor, or alternatively, you can salvage a ganged capacitor from an old AM/FM radio, which contains multiple capacitors, some of which cover the desired range (and beyond).

Variable capacitor (trimmer)



Ganged capacitor (AM/FM radio)

For the variable resistor, it is highly recommended that you use a rotary potentiometer (for easier manual control), and avoid trimmer or preset potentiometer. The latter should work if you use them; it is just a hassle when you need to change their values during testing.

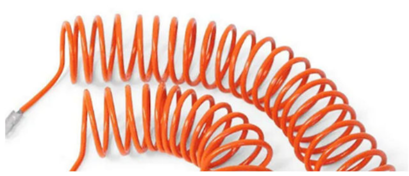
Rotary potentiometer

Trimmer potentiometer

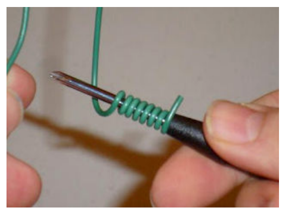
Preset potentiometer

For the coils, you can wind the coils using enameled wire, in which case please be careful to remove the insulation material by scratching the edges of the coil or burning such edges. Otherwise, you can just use a 0.8mm jumper wire to wind the coils since removing the plastic insulation at the edges is much easier. Do not remove all the insulation of either wire, though, as this will just create a short circuit between the windings. You can wind the coil around a pencil or a screwdriver with proper diameter as shown below.

Enameled wire coil



Jumper wire coil



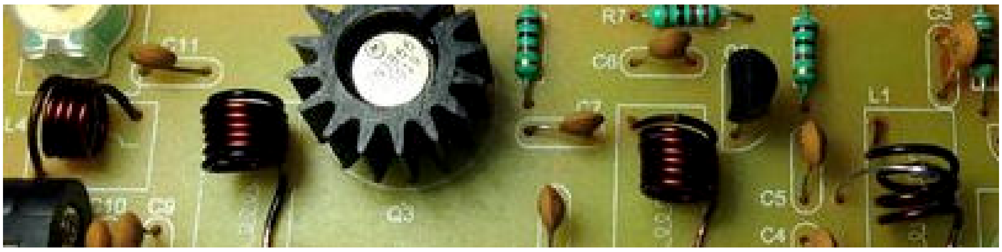
Winding the coil

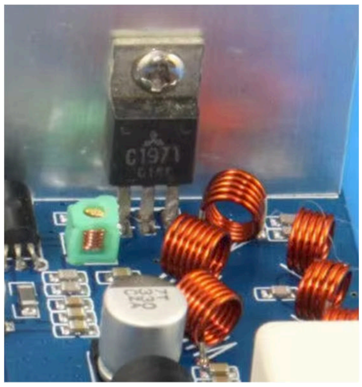
The coil specifications are as follows:
L1: Use 0.8mm diameter wire, wind **5 turns** with coil diameter of **4 mm**. Tap the coil at a ratio of 4 turns to 1 turn, with the 4 turns connected to the supply side.
L2: Use 0.8mm diameter wire, wind **7 turns** with coil diameter of **4 mm**.
L3: Use 0.8mm diameter wire, wind **7 turns** with coil diameter of **4 mm**.
L4: Use 0.8mm diameter wire, wind **5 turns** with coil diameter of **4 mm**.

You can calculate the inductance of the above coils using an online calculator, such as these:
https://www.66pacific.com/calculators/coil-inductance-calculator.aspx
https://coil32.net/online-calculators/one-layer-coil-calculator.html

Later on, you can stretch or compress the turns on L1 coil to control the carrier frequency. In addition, the CV1 trimmer allows you to fine tune the desired carrier frequency to avoid interfering with an existing FM radio station.

Here is an example image to show you what the coils might look like after you have built them.





And to the right you see a different implementation. Notice how the inductors are placed on the board in such a way as to make them as perpendicular to each other as possible. This is useful in minimizing mutual coupling (i.e., electromagnetic interference) between the different inductors.

The remaining part of the circuit is an amplifier/buffer followed by a power amplifier. This is followed an antenna matching network which connects to the antenna.

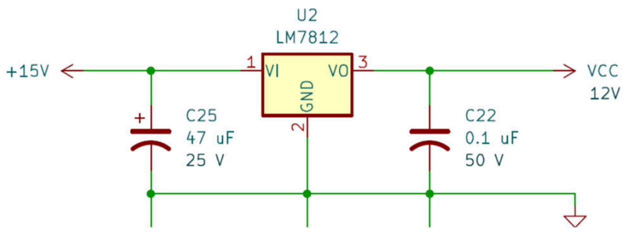
Make sure that Q3 terminals are as short as possible, but do **not** bend it as you might break the pins internally. The heatsink should **not** be tied to the ground.

Adjust the trimmer capacitor CV2 to obtain maximum output power at the antenna (i.e., to obtain impedance match). If you adjust the carrier frequency later or change the antenna length, make sure to re-adjust CV2 for maximum power.

At 100 MHz, the half wavelength of the modulated signal is $\lambda/2 \approx 1.5$ m, which means a monopole antenna would be around 75 cm long. You can use a piece of wire 75 cm long, or salvage an FM telescopic aerial antenna from an old radio (see image to the right).

The circuit requires a well-regulated +12V DC source (V_{CC}). The easiest way to obtain such voltage is to use a switching power supply unit from an old PC, which provides you with +12V, -12V, +5V, and 3.3V. If you do not have an old PC, you can find nowadays very cheap PC power supplies (their cost is about that of two 9V batteries). There are more expensive options, of course, but those are more efficient supplies that deliver high power suitable for gaming PCs. The circuit in this project requires small power, and the cheapest power supply you can find should suffice. If you want to use a battery, you can do that as well, but finding a small 12 V battery might be more difficult. In addition, the power amplifier might drain the battery quickly. If you want to use a 12V power adaptor that you already own, then make sure you add the regulator circuit below (with the LM7812 voltage regulator), since typical power adopters are not well regulated. Most PC power supplies, on the other hand, might work without the need for the extra regulator, but we added it to the circuit just to be extra careful.

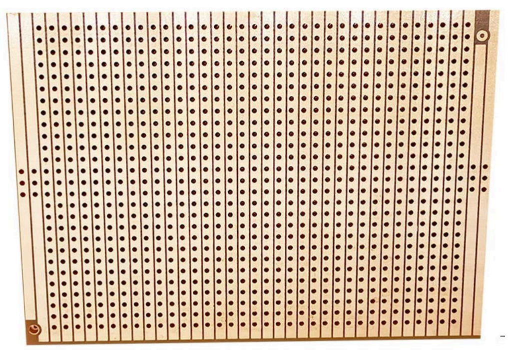
PC power supply unit



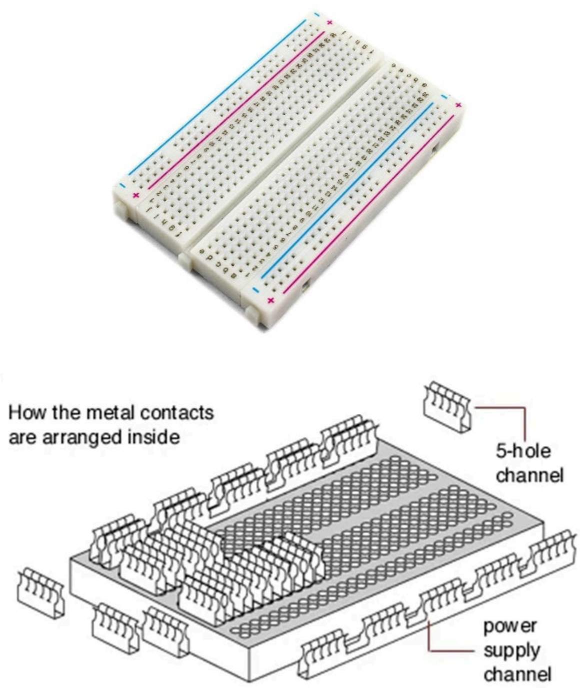
Voltage regulator circuit

For this project, the modulated signal should be transmitted at an appropriate FM frequency so that we can hear it on a regular FM radio device within a range of 50 meters.

You are required to build your circuit on top of a stripboard, not a breadboard. The metal strips inside breadboards can cause undesirable parasitic capacitance at higher frequencies. Breadboard rarely work above 1 MHz, so it is safer to just use a stripboard. You are not required, nor allowed, to build a PCB for this project in case we need to tweak the design later.



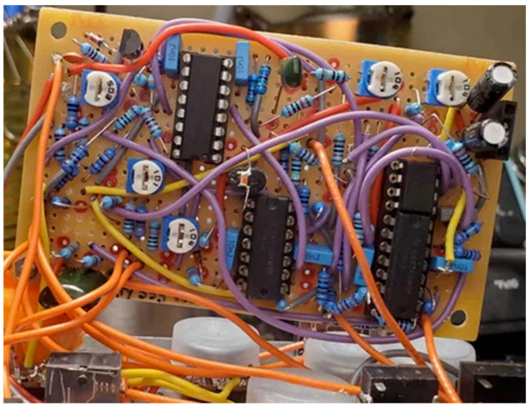
Stripboard



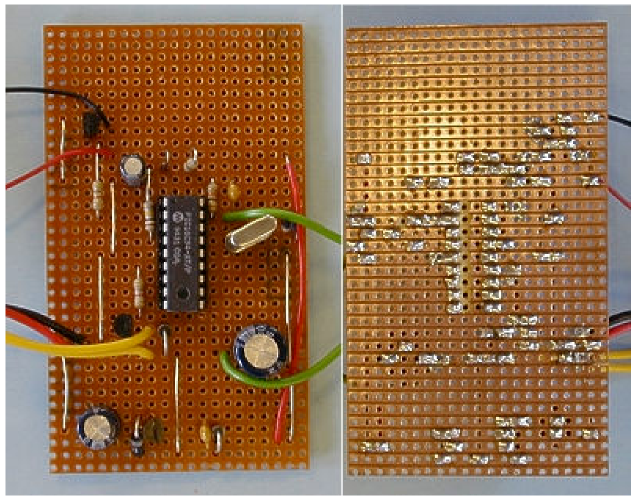
Breadboard

The design of the circuit is modular, so you can build different parts of the circuit on different regions of the stripboard (and also test each part individually), then connect the different parts of the circuit using 0.8mm jumper wires. Each module can be built by one team member. However, all team members should understand the whole design and be able to answer questions about the details of every part of the circuit.

When building your circuit, please use soldering to connect components and avoid too many wires, especially tangled ones. Also avoid haphazardly placing your components, as this will make testing the circuit and finding issues much more difficult for you.



Avoid too many tangled wires

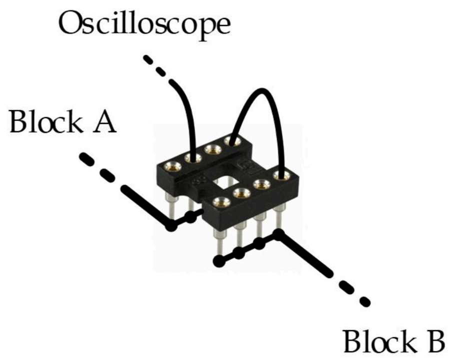


Reasonable connections and soldering

It is highly recommended that you place some jumpers between the different parts of the circuit (in the places indicated by the schematic), which will aid in testing each part individually. You can use DIP socket adaptors as jumpers if you want, since they do not break easily. In addition, you can use such sockets to place transistors and ICs on the board. This also allows you to replace the transistor and/or IC when it fails without having to do too much re-soldering.

Manually built jumper wire

Avoid these pin headers as they can easily break with multiple use



Using DIP 8 socket adaptor as a jumper with extra wires to different testing equipment

At the time of **project submission** please:

- Make sure that you understand how the different parts of the circuit work.
- Test multiple audio files and hear them over FM radio.
- Be prepared to answer questions about FM hardware in general and this transmitter circuit in particular.