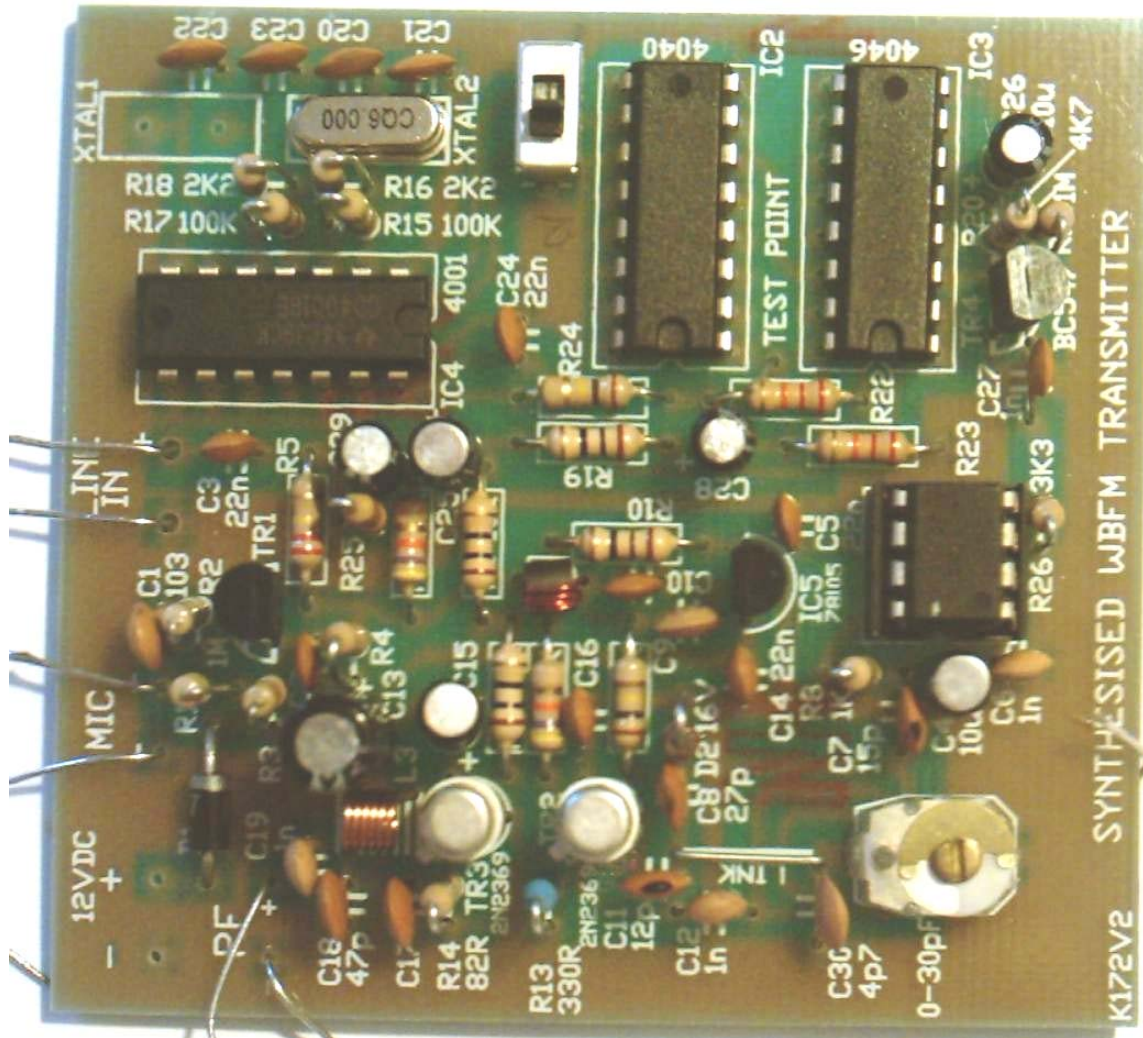


K172V21. Synthesised WBFM Transmitter

1 General

This project is a complete crystal-controlled Wide Band Frequency Modulated (WBFM) transmitter delivering a power output in the order of 10 milli-watts (+10dBm) using simple components. The transmitter is based upon the Phase-Locked Loop (PLL) principle, but due to the circuit's simplicity a true "phase lock" can never be achieved.



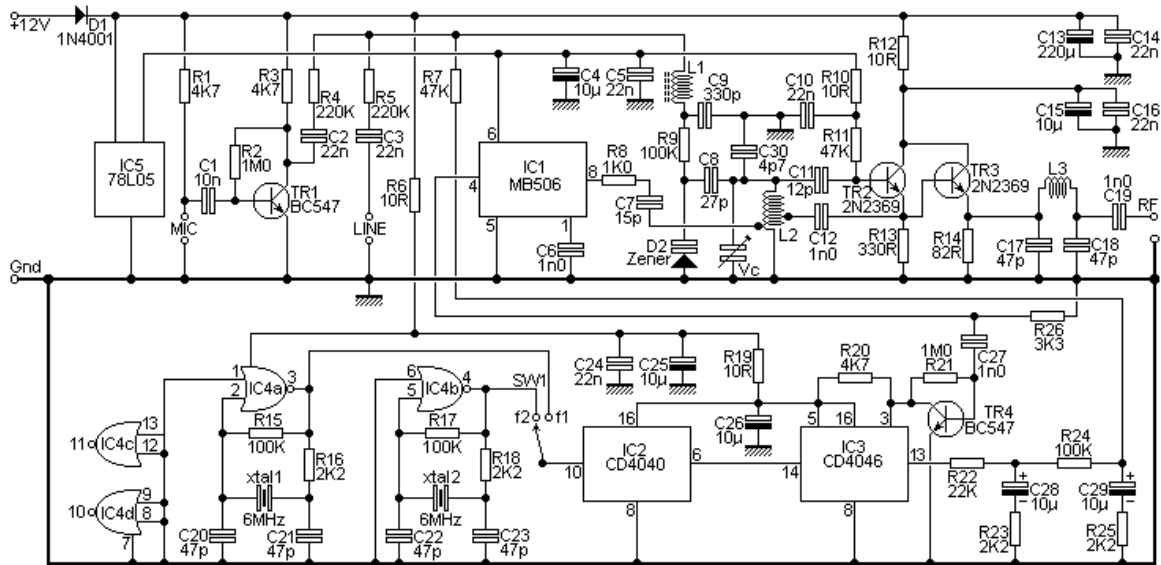
Picture of the completed FM transmitter

The transmitter has both 1v peak-to-peak 'LINE' input and 10mV 'MIC' audio inputs. These will accept audio input sources from external equipment, such as hi-fi, CD and computer equipment. The microphone input also has an in-built power source to energise an 'Electret' type condenser microphone.

The Radio Frequency (RF) output circuitry includes a three-pole filter for reduction of harmonics and other spurious signals. The spurious output signal level is better than -40dBc (0.0001 times the power of the wanted signal level), which makes the project suitable for driving an external power amplifier.

The transmitter is powered from a 12v supply, but it will operate from 9 Volts to 16 Volts. The DC power input is equipped with a diode (D1), which protects the transmitter in the event the supply voltage is inadvertently connected the wrong way round.

K172V21. Synthesised WBFM Transmitter



Circuit diagram of the completed transmitter.

2 Construction

Construction should begin with the wire link WLK, all horizontally mounted resistors, then the power diode D1. WLK is formed from one of the resistor lead off-cuts. All vertically mounted resistors and ceramic capacitors are next, followed by the electrolytic capacitors and the four transistors. Finally, fit the varicape diode, D2, and the integrated circuits.

2.1 General

Although internally protected, the ICs should be fitted on a static protected workbench. In the absence of a suitable workbench, then aluminium foil can be taped to a work board and connected to the soldering iron Earth (Ground) via a 1M0 resistor. The ICs should be left in the packaging supplied until required. Before handling them, the worker should also be electrically connected to the workbench anti-static mat (foil) via a 1M0 resistor.

Note that C25 and C29 must be miniature capacitor types, due to space restrictions on the PCB. These two components should ideally be fitted after all the resistors and other components have been fitted, and the component bodies positioned about 3mm away from the PCB. These two capacitors should be mounted vertically, as shown to the right. Long component leads will have no effect on the operation of the project.



The distance between TR2 / TR3 can and the PCB must be at least 4mm minimum and no greater than 6mm. 4mm is required for clearance between TR3 and L3.

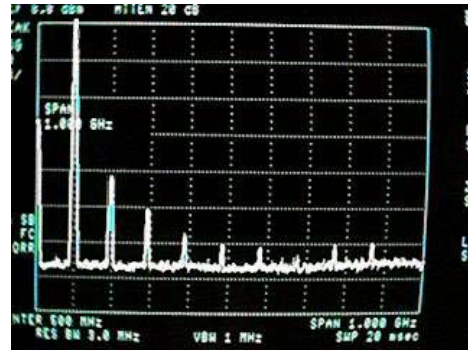
Failure to observe this may cause the collector of TR3 could touch L3 causing a collector-emitter short circuit. A good tip is to fit TR2 and TR3 after L3 has been fitted. L3 should be fitted touching the PCB.

K172V21. Synthesised WBFM Transmitter

C30 has been added to the circuit to restrict the upper operating frequency of the transmitter. 4p7 restricts this to approximately 125MHz. Without C30 fitted the transmitter is capable of operation over 150MHz. It is possible that certain manufacturers of IC1 produce a slightly less sensitive version. If this is used then C7 may be increased in value to 120pf.

3 Oscillator

The oscillator section generates the RF signal at the final frequency without multipliers or mixers. The frequency is controlled by a variable capacitance (varicap) diode (D2). The oscillator is buffered and filtered to reduce the level of harmonics. To the right you see the spectrum from DC to 1GHz with the carrier at 96MHz. The output from the transmitter is about +8dBm (9mW) and the worst harmonic is the 2nd, being some 45dB below the carrier. For a low-power transmitter this is good and improves further with a higher operating frequency.



The oscillator circuit is almost a textbook 'Inverted Hartley' configuration using TR2 as the oscillator. The tuned circuit L2/Vc initially determines the frequency of the transmitter. The tuned circuit is excited by TR2 via C12. Energy from the tuned circuit is fed back to TR2 via C11 to complete the feedback loop. TR2 provides current gain and L2 provides voltage gain. The oscillator signal is buffered by TR3. Since the RF voltage level at the emitter of TR2 is relatively high, TR3 is an 'emitter follower' that provides only current and power amplification. The main use of TR3 is to isolate the oscillator from the antenna, which would otherwise disturb the transmitter frequency. The oscillator transistor received a DC bias from the regulated -5v DC supply, via R10 and R11. Changes to the -12 volt supply therefore have little influence on the transmitter frequency.

4 Modulation

The tuning capacitor VC adjusts the oscillator frequency over a wide band of frequencies and covers the whole of the domestic FM broadcast band.

4.1 "Varicap" Diode

The 'Varicap' (or 'Varactor') diode, D2, is reverse-biased by having a positive voltage applied to the cathode. When reverse biased, all diodes exhibit capacitance, some more than others. This capacitance changes in sympathy with the bias voltage. This capacitance is coupled to the oscillator via C8. D2 therefore influences the transmitter frequency. It can change the frequency by typically 5MHz and frequency change voltage is coupled to the diode through R9. For VHF circuits, simple Zener (voltage regulator) diodes work just as well as a Varicap diode, as long as the Zener diodes avalanche point is never reached.

4.2 Frequency Deviation



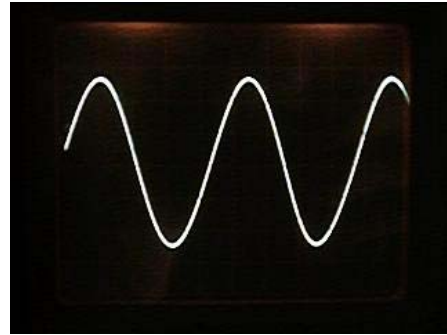
The application of frequency modulation to an oscillator causes a wide range of side-bands to be generated. Each side-band is composed of many carriers, each displaced from the carrier frequency by a multiple of the modulating frequency.

The waveform to the left shows the output of the transmitter with a 1KHz tone at 500mV Pk-to-Pk applied to the LINE input. The microphone was also live, so a little background noise can also be detected.

K172V21. Synthesised WBFM Transmitter

4.3 Modulation Linearity

One of the most important properties of a transmitter is to transmit a clean signal without any objectionable noise being added. This particular design has a lot of supply decoupling added to help prevent interaction between stages. The recovered audio from a receiver is shown to the right.



4.4 Modulation Input Circuit

Transistor TR1, with resistors R2 and R3 form a textbook common emitter amplifier. It is used as a microphone amplifier. R1 provides a DC source to power a condenser type microphone having an internal amplifier. C1 couple the microphone signal into the amplifier and it is this component that limits the lower frequency response and provides a degree of pre-emphasis. C2 couples the amplified audio to the modulator mixer. The line input signal from a hi-fi audio system, or computer 'LINE OUT', requires no amplification. The line signal is therefore coupled directly to the modulator mixer. R4, R5 and R7 form a resistive mixer for combining the microphone, line and control signals to the frequency modulator, via L1.

5 Frequency control

The frequency control of this transmitter is the real heart of the unit. The frequency control action is quite simple, once understood. In effect, the loop form a frequency multiplier, which multiplies the reference frequency by a value equal to a digital divider/counter (frequency sensing element).

5.1 Frequency Reference

IC4 is an array of four CMOS gates and is used as a frequency reference oscillator. Two gates have each been used as crystal oscillators, one of which is selected by the switch SW1. The 6MHz signal from the selected oscillator is divided by 8 by IC2, to around 800KHz, at pin 6.

5.2 Frequency Sensor

The oscillator tuned circuit is very loosely coupled by C7 and R8 to IC1, which is an 'Emitter Coupled Logic' (ECL) frequency divider. IC1 divides the oscillator signal by 128 so the output frequency is somewhere around 800KHz with 100MHz input. IC1, however, requires a regulated 5-Volt supply. This is provided by IC5, which is a simple 78L05 low power series regulator. The 800KHz signal from IC1 pin 4 can now be processed using simple CMOS components. It is coupled, via C27, to TR4, which is another simple common-emitter amplifier. It converts the ECL logic levels from IC1 to a level that is compatible with the CMOS logic family. The output of TR4 is coupled directly to pin 3 of IC3.

5.3 Control Decision

IC3 is a Phase Locked Loop (PLL), but in this application, the internal voltage controlled oscillator is not used. The IC compares the two 800KHz signals presented to pins 3 and 14, then makes a decision as to which is the greatest frequency. The result is available at pin 13, which switches between 12 volts and ground (0v).

5.4 Loop Filter

IC3 pin 13 is coupled to a long time-constant formed by R22 and C28. C28 charges to the average DC voltage and so provides a control voltage to the transmitters oscillator frequency control circuit, D2, via R24 and R7. R24 and C29 form a second filter, but both filters have 'damping resistors', R23 and R25, to reduce the gain of the control loop. Without these resistors the control circuit would over-correct a frequency error, causing a larger and opposite frequency error. The loop operates in such a manner that the transmitter oscillator (TR2) and its frequency monitor (IC1) is compared with a reference frequency (IC4, IC2 and IC3). An error signal from IC3 pin 13 is filtered and coupled back to D2 to correct the frequency error of the oscillator.

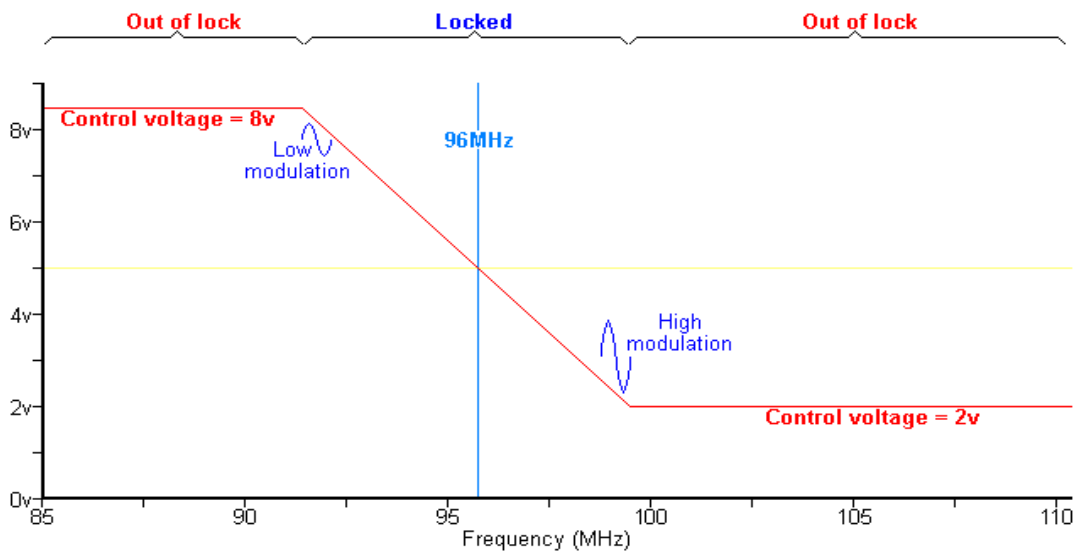
K172V21. Synthesised WBFM Transmitter

5.5 Control Summary

In effect, the transmitter oscillator is stabilised and referenced to a crystal, giving crystal stability. The oscillator, however, can still be modulated to +/-75KHz with an audio signal. This would have been impossible if a crystal directly controlled the oscillator. It must be remembered that audio modulation is NOT limited in this simple synthesiser. The amplitude of the line input signal must be regulated so as not to cause the transmitter to over-modulate. R4/R5 and C9 only restrict the audio bandwidth. This will allow modulating signals to have a wide frequency response. Microphones are physically bandwidth limited and usually have a maximum frequency response of typically 8 to 16KHz. This transmitter will accept up to 60KHz modulating frequency at the LINE input. The transmitter is therefore suitable for use with an external stereo encoder.

6 Setting Up (Alignment)

Audio frequency modulation itself causes a frequency error. The loop filter (R22, C28, R24 & C29) filters out the error voltage control that would otherwise correct this error. The filter must therefore take a short while to operate, whilst capacitors charge. This has an effect on tuning. Using an ordinary analogue voltmeter, having a sensitivity of at least 20K Ohms/Volt, measure the DC voltage at the TEST POINT (TEST POINT is connected to the junction of R22 and R24). Be careful not to touch R19 with the meter probe. This will do no damage to the transmitter, but it will disturb the loop for several seconds. The negative lead of the meter is connected to the ground (-VE supply voltage). A digital voltmeter may be used, but the reading will tend jump around a little. Use an analogue meter if at all possible.



Adjust the tuning capacitor VC until the meter reads, ideally about 5 Volts, but anywhere between 3 Volts and 7 Volts is fine. Each time VC is adjusted the voltage will jump. Allow the transmitter to settle for a few seconds before re-adjusting. The transmitter will lock anywhere between 2 volts and about 8 volts, but the modulation sensitivity will be affected and may drop out of lock in the event of a large change of supply voltage. The actual figure of 5 volts is not at all critical, as long as the same voltage is used every time the transmitter is re-aligned. In this way the modulation characteristic will be repeatable.

The above graph shows the effect on the loop voltage of tuning VC. In this graph we have assumed a test frequency of 96MHz. If VC is tuned to within about 5MHz of 96 MHz, then the loop will bring the oscillator back to the correct frequency. If VC is tuned outside this range then the error will become too great for the loop to correct, and the synthesiser will become “out of lock”. The 8 volt lock limit will vary with the supply voltage. When the transmitter is initially switch ON, allow a couple of seconds for the frequency to settle. This property of the circuit is a little annoying, but it is this self-same property that allows the transmitter modulating frequency to be as low as 10 Hz.

K172V21. Synthesised WBFM Transmitter

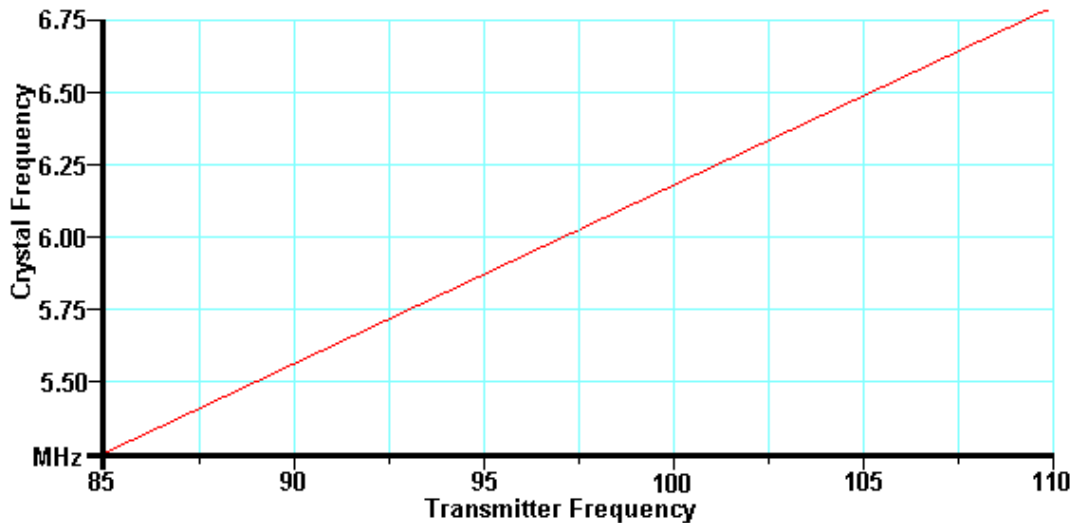
7 Frequency & Crystals

A suitable crystal, 'Xtal-1' or 'Xtal-2', determines the transmitter frequency. The formula for deciding the correct crystal to use is:

$$F_x = F_o / 16$$

Where: F_x is the crystal frequency and F_o is the transmitter output frequency.

For example, if the transmitter final frequency of 96MHz was required, then $F_x = 96\text{MHz} / 16 = 6.000\text{MHz}$. The crystals must be in the range of 5.500MHz to 6.75MHz. If two crystals are fitted and you do NOT wish to re-tune when changing frequency (SW1), then the two final frequencies must be within about 2MHz of each other. A quick reference chart is given here. It can save a lot of time when searching for crystals.



7.1 Antenna Length

Transmitting antennas are available, but for low power operation a normal receiving antenna is also a good transmitting antenna. The main difference between the two is the ability to tolerate large voltages and electrical stresses. A simple "ground-plane" antenna can be constructed using a metal rod or wire. The length is calculated to be $\frac{1}{4}$ -wavelength. The formula for calculating the antenna length is:

$$\text{Length (meters)} = 750 / \text{MHz}$$

A quick reference chart simplifies this calculation:

