FM Converter Version 5

Gord Rabjohn - February 2025 - Document version 1.0

This describes "Version 5" of my FM Converter project.

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1. Introduction

The AM band has become so devoid of interesting programing that it has become almost irrelevant. Unfortunately, most of our favorite radios receive only AM, and I am sure you have wondered if it is possible to convert an AM radio to FM. Although both AM and FM radios historically use the same superheterodyne architecture, it would be difficult to retune a traditional tube AM radio to receive FM. The frequency of the FM band is about 100X higher than AM. So, better active devices are required, and lead length becomes much more critical. The bandwidth of the FM signal is at least 10X wider, so the IF amplifier in an AM radio is far too narrow. Finally, a different detector is required for FM. Even if it was possible, permanently modifying a vintage radio seems wrong.

This FM converter circuit is intended to convert post-1932 tube AM radios to FM operation. A single band radio will operate just as it always did, only FM stations will be received. Although the tuning mechanism works as before, the tuning dial markings on the host radio become meaningless; it can be recalibrated for the FM band if desired. It will work on multiband radios, but the other bands will be disabled. The goal is to be able to convert a radio by just connecting to the tube sockets. The radio is not permanently modified in any way: no soldering, no permanent radio changes, no need to realign. The adaptor can be removed without affecting the antique value or the authenticity of the radio in any way. It will work with most tube superheterodyne radios, notably the very common "All American 5" (and variants).

This is version 5. All of my previous versions except version 2 (that used a conventional FM tuner) used the TDA7088 FM tuner integrated circuit. This is a very clever analog bipolar chip that uses unconventional tricks to receive FM. Its intended market is inexpensive toys and novelty radios that are tuned with 2 buttons: search and reset. I drove the varactor diode with the tuning voltage. These chips are not without their quirks. Tuning is tricky and sensitive and touchy. That makes them drift as they warm up. Fidelity is not fantastic. High frequency response is limited, and harmonic distortion (at low deviation) is specified at 1%. Some stations never tuned-in clearly. And it requires a large number of external capacitors. You were able to buy them in "Dollar Stores" and the like for a few dollars, but they are becoming less common. I built a tuner based on the original (Philips branded) TDA7000 using selected silvered mica capacitors, with pretty similar results to the dollar store versions. The TDA7088 chip is considered obsolete (though it is still widely available (Fall 2024)) so it was time to try something new. I found the Silicon Labs Si48xx series of mechanical (actually, potentiometer) tuned chips, which turned to be ideal for this application. They offer excellent audio quality, such that the radio, not the converter, will almost always be the factor limiting audio performance.

In addition, in this version I experimented with the 74HCT9046 (Philips) phase locked loop chip. This chip is an improvement on the standard 74HC4046 (they are almost pin-for-pin compatible), with improved stability, and an improved phase detector.

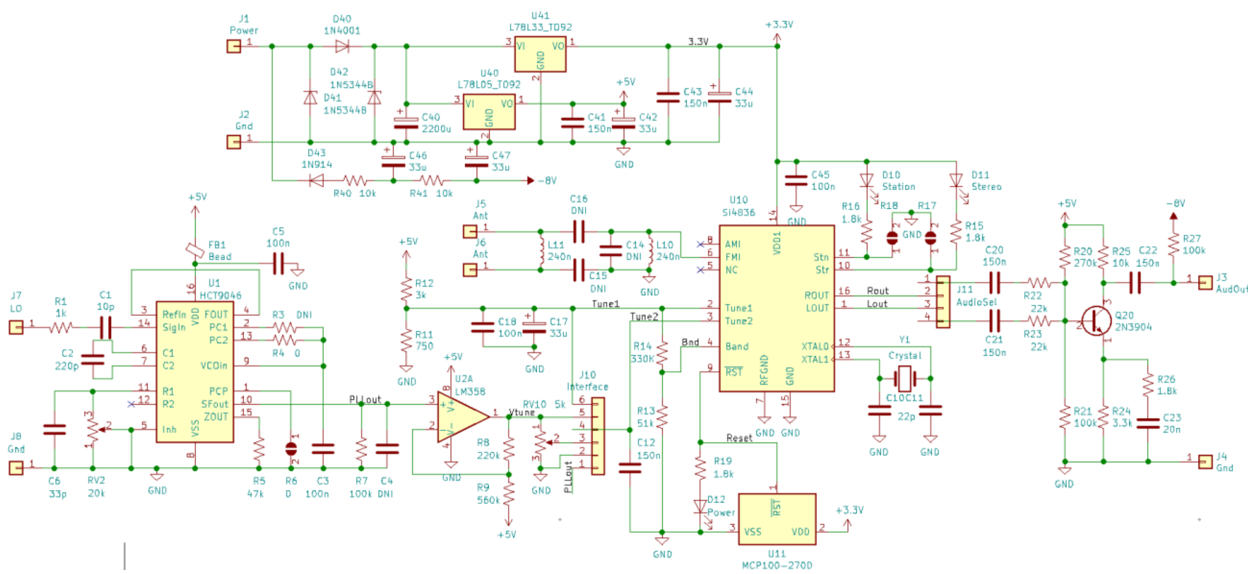
In addition to the other versions that I have made (see https://rabjohn.ca/gord/projects/fmconversion/ , I draw your attention to another ingenious approach out of France: https://radiofil.org/20-modules-et-kits . Their approach does require some modification of the radio.

If you are thinking of trying to convert a radio to FM, I recommend my “Version 5” described herein, because a) a circuit board makes assembly easier, b) the FM performance is better than earlier versions, and c) unlike the Radiofil approach, no permanent changes are required to the radio. For the sake of readability, I will refer to this circuit as the “FMC” (FM Converter) for the rest of this document.

2. FMC Circuit Description

In a typical superhetrodyne AM tube radio, a local oscillator (LO) that runs between about 1MHz and 2MHz is mixed with the signal from the antenna, producing an IF signal (the difference frequency: the LO frequency minus radio station frequency) at typically about 455kHz. This IF signal is amplified and detected and fed to an audio amplifier. As the LO frequency is adjusted, specific stations in the AM band are converted to the IF frequency and tuned in. When this FM converter is used, the same LO frequency is used to tune an FM radio in the converter. The audio output of the converter is fed directly to the radio's audio amplifier, skipping the IF amplifier and detector. This way, the radio appears to operate just as it had when it received AM, but FM stations are received instead.

U1 is a phase locked loop (PLL) operating as a frequency-to-voltage converter. It converts the host radio's variable LO frequency (about 1MHz to 2MHz) to a variable voltage. As you tune the host radio across the band, this voltage tracks. This voltage is level shifted by U2 to a level suitable for tuning U10. U10 is a single-chip FM tuner with "mechanical" (actually, voltage) tuning. It is designed for use with potentiometer tuning, but in this design will tune with the voltage generated by U2. Q1 provides about 10dB of amplification, and the whole circuit is supported with 2 power supply regulators.



Phase Locked Loop (PLL) Section

One way to translate a variable frequency to a variable voltage is with a Phase Locked Loop (PLL). My earlier FM converters used a 74HC4046 PLL chip for the frequency-to-voltage converter. This chip is not very stable (over temperature or voltage) and earlier designs of the FM converter circuit drifted as they warmed up. The 74HCT9046 PLL (similar but not identical pin-out and functionality to the standard HC4046) has superior VCO stability and a better phase detector. However, it is discontinued (while the HC4046 is not) (which is a shame) which makes it more difficult to find, so the circuit board has been designed to accommodate either a HCT9046 or a HC4046.

The 4046/9046 family of chips has a voltage-controlled oscillator (VCO) and two different phase detectors. The phase detector outputs are at pin 2 and 13, and either can be selected by populating R3 or R4. I have had good success with the phase detector at pin 13 so R3 is not used. C3 is the loop filter; a simple first order loop is used. Any of the 4046/9046 datasheets will describe the loop filter design. The 9046 uses an external resistor, R5, to set the charge pump current, so R4 is 0 ohms. If the HC4046 is used, R4 determines the charge pump current and R5 is not used. Pin 1 is ground on a HCT9046 and open-circuited when a HC4046 is used. The VCO frequency is set by C2 and RV2. The VCO operates without an offset (so 0V input would theoretically produce a 0Hz output) so a resistor is not required on pin 12. I found that the 9046 PLL was unstable (oscillated at just over 10kHz), and the easiest way I found to quiet it down was to install a 33pF capacitor across RV2. I cannot explain why this is necessary! The 4046 has its own stability problem at low drive (the 9046 does not exhibit this problem), but is stable with adequate LO drive.

The input to the phase detector from the host radio is brought in through R1 and C1 which provide a DC block, and some protection from overdrive. Since U1 is fundamentally a digital chip (which could interfere with the operation of the FM tuner), provision has been made to block noise from the supply lines with extra decoupling and a ferrite bead, FB1 and C5. For the same reason, there is a provision for a shield around this section of the circuit. I experienced no interference, so FB1 and the shield were not used.

The HCT9046 VCO control voltage (and therefore the voltage output, proportional to the input frequency) is specified to operate from about 1V to about 4V (with a 5V supply). This must be scaled down to the 0V to 1V required by the FM tuner chip. This scaling is done with U2A, R8, R9 and RV10, using the 5V supply as a reference voltage. (R7 is the VCO buffer load as specified by the data sheet. C4 can be used if there is excess noise coming from the PLL, but I have not found that it is needed) With a 1MHz to 2MHz LO, this circuit is designed so the VCO voltage will be about 1.5V to 3V. At Pin 1 of U2, this voltage is 0 to 2.2V which is scaled down to 0 to 1V with RV10.

RV2 and RV10 are adjusted so that the host radio tunes the FM band. The host radio is set to the low end of the band (where the bottom end of the FM band should start, say 540kHz). RV2 is adjusted until the voltage at pin 5 of J10 is just above 0V (as RV2 is adjusted, the voltage at pin 5 will be 0V over part of the rotational range of RV2, and increasing over the other part of the range. It should be set at the inflection point). Then, the host radio is set to the upper end of the band (where the upper end of the FM band stops, say 1600kHz), and RV10 is adjusted until 1V is seen on pin 3 of J10. That should set the range correctly; as the host radio is tuned across the band, the voltage at pin 3 should vary from 0 to 1 volt. There should be enough tuning range so that IF frequencies of 175kHz to 500kHz can be accommodated. In operation, pin 3 and 4 of J10 are jumpered together.

Tuner Section

U10 is a single-chip FM tuner, which was developed at Silicon Labs. This product line was acquired by Skyworks (my former employer) in 2021. It is available at Digikey and Mouser among other suppliers. It employs a synthesized local oscillator (based on the 32kHz crystal) and digital signal processing to demodulate the FM. There is a family of these chips available in 2 package styles, some with AM and shortwave tuners, some with stereo demodulators. This board is compatible (with minor changes) with the monaural Si4825, or the stereo Si4836.

I still marvel at how compact FM tuners have become. "In the old days", a mono FM tuner required a chassis with at least 4 tubes, and often more. Stereo added at least 2 tubes. The alignment procedure required numerous adjustments and required a sweep generator and oscilloscope for a proper alignment. Transistors made everything smaller, but did little to simplify alignment. These tiny Silicon Lab integrated circuits require only a crystal (and crystal load capacitors), 2 resistors, decoupling capacitors, a tuning potentiometer, and a capacitor and inductor at the antenna input. They require no alignment, and the Si4836 provides a stereo output. Add a few more parts, and they receive AM and short wave! Remarkable.

The chips are designed to be tuned with a potentiometer supplied by an internally generated reference voltage on pin 2, with the tuning voltage (the "wiper" of the tuning pot) on pin 3. The actual value of the reference voltage is not critical; it can be varied by 0.2V without affecting the tuning. That is, this voltage is used both as a reference for internal ADCs and the tuning potentiometer. However, for this circuit to work predictably with the PLL, this reference voltage needs to be fixed. I do not know how the reference voltage varies over temperature or device-to-device, so I use R11 and R12 to fix it at 1.0V (based on the 5V regulator). These 2 resistors may not be necessary. The band is selected by the voltage (relative to the reference voltage on pin 2) on pin 4. The chip documentation shows 41 bands! The "bands" differ by the exact frequency extents, the threshold that activates the stereo and station tuning lights, AM vs. FM demodulation, and the FM deemphasis (North American FM standards require a deemphasis network with a time constant of 75us). This radio is set up for the North American standard:

Band3	FM1	87–108 MHz	75 μs	Separation = 6 dB, RSSI = 20

(meaning the stereo light comes on when there is a channel separation of over 6dB, and the station light comes on with a received signal strength of 20 (which seems to be an arbitrary number)) Note that the North America band edge is 88MHz rather than 87MHz. Other bands can be selected by changing the values of R13 and R14. 1% resistors are necessary to ensure that the correct band is selected.

The antenna input circuitry is designed for flexibility. The default, as suggested by the data sheet, is just L10, and C16 connecting to an antenna. However, better electrical isolation (very important for AC-DC sets) will be achieved if the antenna is coupled with a transformer, with L10 and L11 forming the transformer (in which case C14, C15, C16 are not used).

The Si4836 has a station tuning light that illuminates when a station is correctly tuned, and a stereo indicator. Si4825 does not have these indicators, and pins 10 and 11 must be grounded.

There is an internal Digital Signal Processing engine in these chips (strictly internal, software cannot be loaded onto these chips) that must be reset at power-up. A surveillance chip, U11, keeps the chip in a reset state until the power supply voltage has stabilized. The crystal supplies the clock for the digital circuitry and provides a reference for the internal synthesizer.

The Si4836 includes a stereo decoder, and there are 2 outputs which generally must be combined using two jumpers on J11. Alternatively, 2 converters and 2 host radios can be employed, one on the left and one on the right. The Si4825 does not have a stereo decoder, and only pin 16 is used for the audio output. In either case the audio output is lower than a typical AM radio, so a simple amplifier using Q20 boosts the audio by about 10dB. R26, C23 provide an optional treble boost, in case your vintage radio has weak treble. The amplifier may not always be necessary, and it may be possible to eliminate the circuitry surrounding Q20 if your radio has adequate gain.

The power supply is a simple half wave rectifier with three-terminal regulators. The PLL requires 5V for operation and the tuner chips require 3.3V. Since there are many different power supply scenarios depending on the host receiver, there are several options for the power supply implementation. There is a simple unregulated negative supply which is used to reduce the gain of the host receiver's IF amplifier (an artificial AVC voltage), and to reverse-bias the detector diode. Reverse biasing the detector diode reduces distortion. In installations where the converter runs off of DC voltage, this circuit (D43, C46, C47, R40, R41, R27) does nothing and can be skipped. In this case, disconnecting the detector diode is recommended.

Thermal Stability

We would like the tuner to stay correctly tuned as the radio heats up, and as ambient temperature changes. Temperature induced drift can occur in several places:
-The host radio LO could drift.
-The voltage-to-frequency characteristics of the VCO in the PLL could drift. This could be caused by the VCO itself or the PLL power supply.
-The VCO buffer offset voltage could drift.
-The op-amp level shifter could drift. Changes in the 5V supply will also cause drift.
-The FM tuner itself could drift.

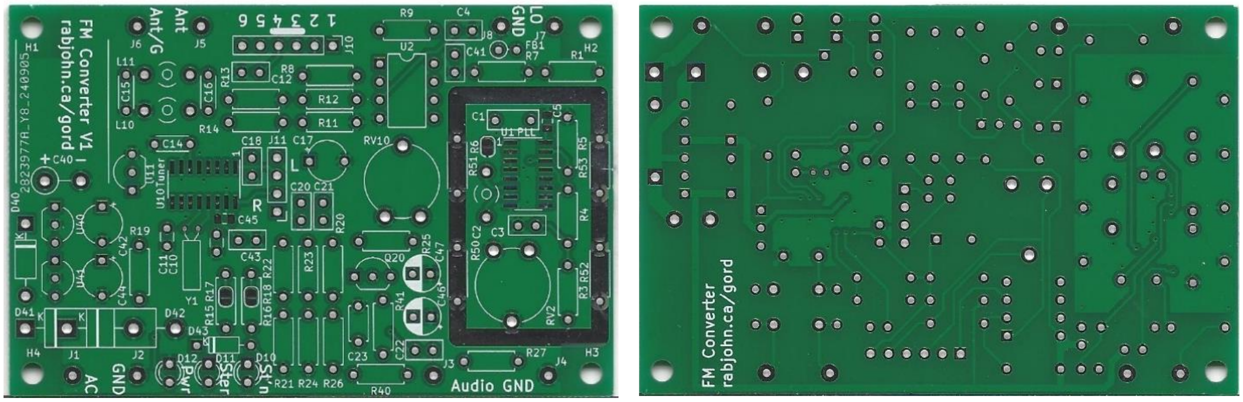
The AM band (in North America, at least) is divided into 10kHz channels, and there are a little over 100 channels in the band. The FM band is divided into 200kHz channels, and there are about 100 channels in the FM band. So, conveniently, one channel drift in the host AM radio is roughly equivalent to one channel drift in the FM radio. Note that the FM radio has powerful AFC which will track drift. This is very useful, but also causes some unexpected results. If there are 2 adjacent stations, the AFC will tend to grab onto the stronger of the two. You can tune in the weaker one, but drift (especially when the radio is turned on) may cause the AFC to switch to the stronger one. So, drift should be mininized.

I measured several tube AM radios, and found in every case that the LO was very stable at the low end of the band, but tended to drift down in frequency (typically 8kHz in a half hour. Interestingly, my old Philco 71 was the best at 3kHz, possibly all the metal gives it a longer time constant). The temperature rise depends on the radio, and where in the radio the temperature is being measured, but I was seeing about 10C rise.

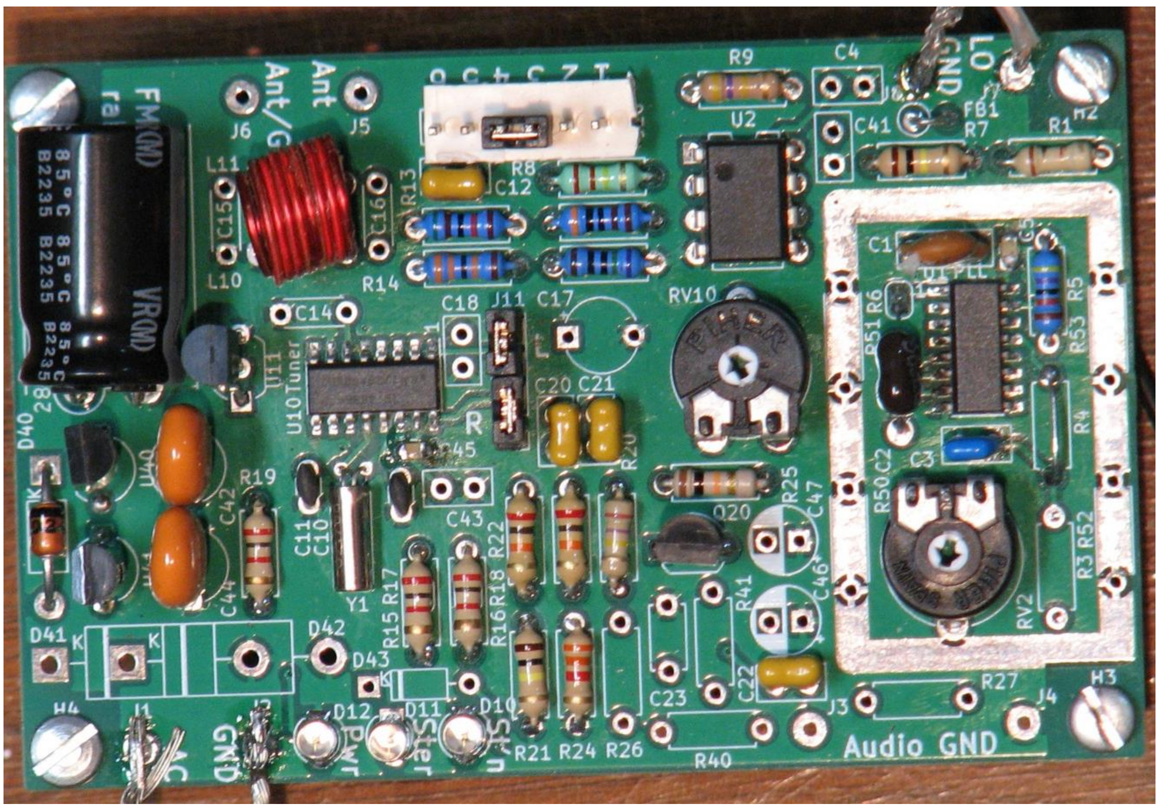
The PLL VCO in the 4046 is quite different than the improved 9046. The 9046 is quite good, exhibiting a increase in voltage at a given VCO frequency of about 1 channel width at the high end of the band (15C increase in temperature), and almost none at the low end. It is serendipitous that this compliments the radio characteristics, making the 9046 a really good choice. The 4096 does not fare as well. It drifts down (adding to the drift in the host radio) by over 2 channel widths (a little less at the low end of the band). If the 4096 must be used, then some form of temperature compensation should be considered. My RCA "Little Master" (5-tube AC-DC set with a back that tends to keep the heat in) using a FMC (situated inside the radio) built with a 4046 requires a couple of re-tunes over 1 hour of operation when tuned to a station at the high end of the FM band. The same radio using an FMC with a 9046 does not need retuning. If FMC's using the 4046 are exposed to heat, further work will be required to apply thermal compensation to the 4046.

3. Construction

A double-sided board has been designed and fabricated for the FMC, and I have a few bare boards available for sale.



Unpopulated board



Board populated with the Si4836 and 74HCT9046, without the negative voltage supply.

Most parts use through-hole technology, but the two main ICs are available only in surface-mount packages, and should be soldered down first. First mount U1, U10, C5, and C45; the surface-mount parts. I used a hot place, but an oven or a hot air gun can work too. The leads are at a 0.05” pitch, so definitely use solder paste.

After assembling the surface mount parts, install the power supply parts and verify that the power supply generates the correct voltages. Then, install the parts surrounding the tuner chip, U10, and make sure the tuner works (I connect a potentiometer (anything over 10K) to pins 2, 4, and 6 of J10 (wiper on pin 4) to allow me to tune it manually. Check for audio on J11). Then, install the parts around the PLL (U1), set RV2 mid-way, and make sure the output voltage (pin 1 of J10) tracks when a variable frequency RF signal generator is connected to the LO input. There are provisions for a shield around the PLL, but I have found it unnecessary.

There is one capacitor, C6, used with the 9046, that does not have a proper place on the board. It connects in parallel with RV2 on the back of the board.

Note that not all parts are needed; there will be some empty footprints on the board.

Bill Of Materials for area around PLL. BOM depends on which PLL chip is used. DNI=Do Not Install

Ref	Value		Tolerance	Note	Purpose
	4046	**9046**			
C1	10pF		Not critical	Use >200V cap.	LO input DC blocking capacitor
C2	220pF		10%	Use a good, very stable cap. Mica preferred.	VCO timing cap.
C3	100nF		Not critical	Use a good cap.	PLL loop filter
C4	DNI		Not needed		PLL output smoothing
C5	100n		Not critical	SMT : 0805 size	Local 5V decoupling
C6	DNI	33pF	Not critical		Mysteriously makes the 9046 stable
FB1	Short		Not needed		PLL supply filtering
R1	1k		Not critical		LO input protection
R3	DNI		Not Used		PC1 loop filter
R4	100k	Short	10%		PC2 loop filter
R5	DNI	47K	10%		PC2 current
R6	DNI	Short			Second ground for 9046
R7	100K		Not critical		Demod load
RV2	20K or 22K			Piher PT-10-LV10 series	Sets VCO Frequency
U1	74HC4046 or 74HCT9046			SMT: 16 pin SOIC	9046 is the preferred part

BOM for area around tuner IC. BOM depends on which tuner chip is used.

Ref	Value		Tolerance	Note	Purpose
	4825	**4836**			
C10	22pF		Not critical		Crystal Load Cap
C11	22pF		Not critical		Crystal Load Cap
C12	150nF		Not critical		Tune 2 smoothing
C14	DNI				RF input shunt tuning
C15	DNI				RF input grounding
C16	DNI				RF input blocking
C17	DNI		Not needed		Tune1 decoupling as per DS

C18	DNI		Not needed		Tune1 decoupling as per DS
C20	150nF		Not critical		Audio DC block
C21	DNI	150nF	Not critical		Audio DC block
C45	100nF		Not critical	SMT: 0805	3.3V decoupling at tuner
D10	DNI	LED	Vf <2.5V	Optional	Station indicator
D11	DNI	LED	Vf <2.5V	Optional	Stereo indicator
J11	DNI	4-pin		Short pin 1 to 2 4 pin header, 0.1” spacing	Not needed with 4825. Short pin 1 to 2 Selects right or left or both
L1	240n			See text	RF tuning
L2	240n			See Text	Antenna tuning
R11	750ohm		1%		Reference voltage setting
R12	3K		1%		Reference voltage setting
R13	51k		1%		Channel selection
R14	330K		1%		Channel selection
R15	DNI	1.8K	10%	Optional	LED current setting
R16	DNI	1.8K	10%	Optional	LED current setting
R17	short	DNI			Jump for 4825
R18	short	DNI			Jump for 4825
R22	short	22K	10%		Audio input mix
R23	DNI	22K	10%		Audio input mix
U10	Si4825	Si4836		SMT: 16 pin SOIC package	See text for selection
U11	MCP100-270D			TO92	Power-on reset circuit
Y1	32768 Hz crystal		12.5pF load	8.3 X 3.2mm package	Main Clock. Any common 32768 Hz xtal should work

BOM for power supply and op-amp circuit

Ref	Value	Tolerance	Note	Purpose
C40	2200uF	not critical	16V or more. Bigger is better	Filter cap
C41	100n	not critical		5V decoupling
C42	33u	not critical	6V or more	5V decoupling
C43	150n	not critical		3.3V decoupling
C44	33u	not critical	6V or more	3.3V decoupling
D12	LED	Vf <2.5V	Optional	Power Indicator
D40	Rectifier like 1N4001 or 1N5817 (which is Schottky)			Rectifier
D41	1N5344B		8.2V 5W zener	Protection, depends on application
D42	1N5357		20V 5W zener	Protection, depends on application
J10	6-pin 0.1" header. One jumper will be required.			Interface
R8	220k	10%		Op amp feedback
R9	560k	10%		Op amp feedback
RV10	5k			Range setting
R19	1.8k	10%	Optional	D12 LED current setting

U2	LM358		8-pin DIP	Level-shifting circuit
U40	L78L05_TO92		Or a LDO like LM2931AZ-5.0 or LP2950-50	5V regulator
U41	L78L33_TO92			3.3V regulator

BOM for audio amplifier

Ref	Value	Tolerance	Note	Purpose
C22	150n			Audio DC block
C23	20n		optional	Treble boost
Q20	2N3904 or any silicon NPN transistor			Amplifier
R20	270k	10%		Base bias
R21	100k	10%		Base bias
R24	3.3K	10%		Emitter bias
R25	10k	10%		Collector bias
R26	1.8K	10%	optional	Treble boost

BOM for negative supply. May not be required.

Ref	Value	Tolerance	Note	Purpose
C46	33uF	Not Critical	16V minimum	Filter
C47	33uF	Not Critical	16V minimum	Filter
D43	1N914 or any silicon diode			Rectifier
R27	100K	Not Critical		Current into radio
R40	10K	Not Critical		Filter
R41	10K	Not Critical		Filter

Connect the FMC to the host radio as described in section 5. I use shielded cable for the LO and audio signals.

3.1 Construction Options

U1: 74HC4046 vs. 74HCT9046

If you are using the 74HCT9046 (recommended), populate R5. R3 is not used. FB1, R4, and R6 are all shorts. Solder a 33pF cap, C6, in parallel with RV2 on the back of the board.

If you are using the 74HC4046B, populate R4. R3, R5, R6 are not used. FB1 is a short. Give thought to temperature compensation; perhaps using thermistors or a temperature compensating capacitor in place of C2.

There is a provision for a shield around the PLL, however this has been found to be unnecessary.

U10: Si4825 vs. Si4836

My preferred FM tuner chip is the Si4836. The Si4825 is mono, and does not have the outputs for the signal strength LED or the stereo LED, and is slightly less sensitive. Otherwise, they are similar. (You probably only need a mono chip, and the LEDs will probably be hidden, and the difference in sensitivity is tiny, so the Si4825 will do just fine. Use what you can get.)

For the Si4825, the J11 header is unnecessary, just jumper pin 1 and 2. Do not populate D10, D11, R15, R16. Blob solder on the pads under R15, R16.

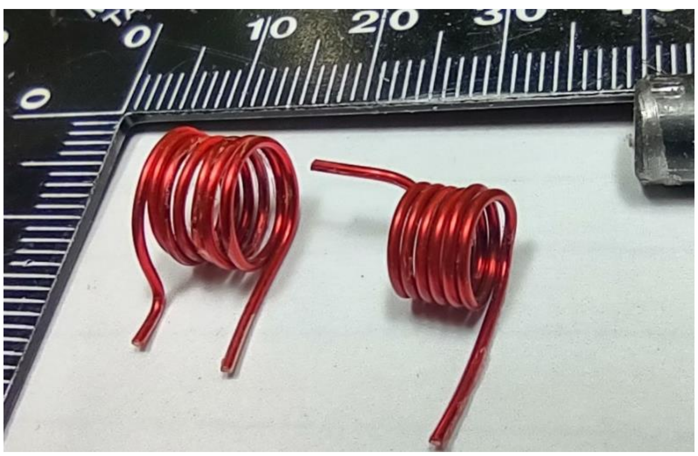
For the Si4836, populate J11 (and use slide-on shorts to bridge 1 to 2 and 3 to 4). D10, D11, R15, R16 are optional if you want the signal strength and stereo indicator. Do not blob the contacts under R15 and R16.

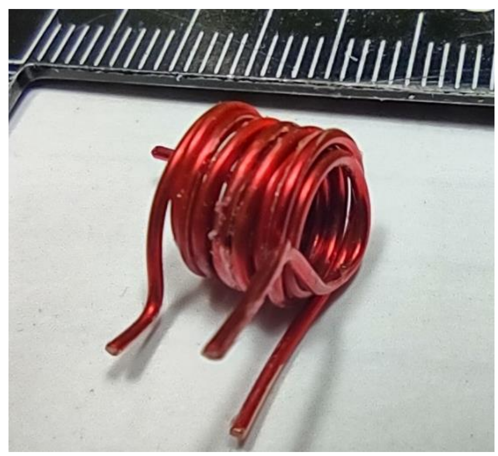
Antenna coupling options

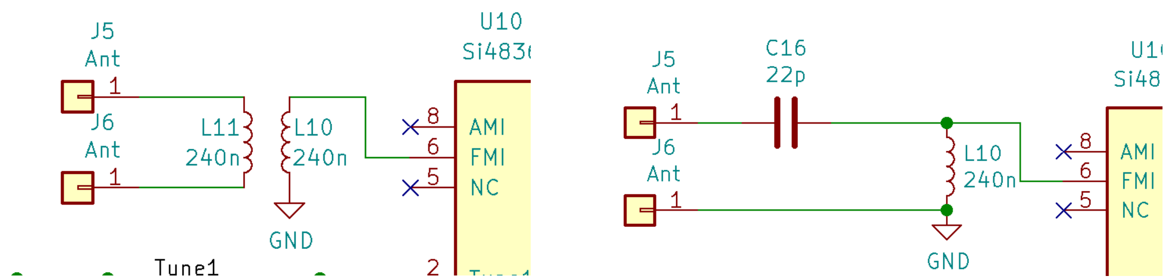
An inductor of about 0.25uH is required at L10. This can be 6 turns of #20 enameled wire, close wound (formed on a quarter inch drill bit), or a chip or thru-hole inductor.

Single ended capacitance coupling: The data sheets recommend coupling the antenna to pin 6 of the Si4836 through a capacitor of about 22pF (C16). In AC/DC sets, this should be a good quality high voltage capacitor.

Inductive coupling: I use a second inductor (L11) tightly coupled to L10. This allows a balanced antenna to be used, and the antenna is isolated from ground, making it suitable for AC/DC radios. I did not populate any capacitors. In this case, L10 is the larger: 6 turns on #20 wire on a 9/32” drill bit. L11 is the smaller, inside L10: 6 turns of #20 wire on a 7/32” drill bit.







Transformer coupling (left) and capacitive coupling (right).

Power Supply Options

C40, C46, C47 are specified with a 16V rating. If more than 16VDC or 10VAC is supplied to the board, then their voltage rating should be increased. If a DC supply is used (for example in a car radio), then D43, R40, R41, R42, R27, C46 and C47 are unnecessary.

A common 5V regulator, the 78L05, was specified by default. This needs a minimum input of about 6.5V for proper operation. However, if power supply voltage is limited (like in a 6V car radio), a “Low-Dropout” regulator, such as the LP2950-50 should be used instead.

The FMC has provisions for Zener diodes at the AC input. If the host radio has a parallel heater circuit, then there should be no need for a Zener diode in either position. Series heater circuits must use a Zener diode to limit the voltage seen by the circuit. If the FMC is in parallel with a heater in a series string set, then D42 protects the FMC in case the heater fails open. If the FMC is in series with the heaters in a series string set, D41 defines the voltage that the circuit receives. See section 5 on implementation.

4. Suitable Radios

In order to determine if a radio is suitable for the FMC, one needs to consider A) the radio architecture; generally, only superheterodyne radios are easy to accommodate; B) whether an appropriate voltage is available to run the converter, and this is generally pulled from the filament supply, so the filament circuitry matters; C) the IF frequency of the host radios; and D) whether there is room for the converter card. Also, it goes without saying that the radio should be in working condition. Also, do not expect miraculous sound from your radio. The sound quality will be limited by the host radio, not the FMC. Although you will be receiving an FM signal, on smaller cheaper radios, FM stations may sound a lot like AM stations. Better radios (with larger, better speakers and careful design of the audio circuit) will be able to take advantage of the superior fidelity of the FMC.

Most post 1932 tube radios will work. Suitable home radios include:

> The classical post-1935 AC-only tube radio uses the following tubes:
> 6A8 or 6K8 or 6SA7, 6K7 or 6SK7, 6Q7 or 6SQ7, 6V6 or 6F6 or 6K6, and 80 or 5Y4 or 5Y3 or 5Z3 or 5W4 or maybe 6X5. Other tubes are possible too. These sets are AC-only and have a large transformer that supplies the heaters in parallel.
>
> A more modern version would use 6BE6, 6BA6, 6AT6 or 6AV6, 6AQ5, and 6X4.
>
> The classical All-American 5 (AA5) uses this tube line-up:
> 12SA7, 12SK7, 12SQ7, 35L6 or 50L6, 35Z5.
> These sets are “AC-DC” sets and run the heaters in series.
>
> The more modern version of the AA5 uses these tubes:
> 12BE6, 12BA6, 12AV6 or 12AT6, 50C5 or 50B5, 35W4
>
> There are numerous variations on these themes, some with fewer or more tubes, some using other tubes such as the “Loktal” tubes, or some mixture between tubes. Some do not use a 6Q7/6SQ7 but rather use a dedicated diode such as the 6H6. Some use an older style of tubes with the larger bases. Some more expensive radios may use many more tubes with high power push-pull outputs, tuning eyes, fancy IF strips, and all of these are quite suitable.

12V tube car radios with negative chassis work well with the converter. (Positive chassis is not impossible to work with, but adds complications) Space tends to be at a premium in these radios.

6V tube car radios with negative chassis work, but a low-drop 5V regulator must be used. (Positive chassis is not impossible to work with, but adds complications)

European radios can be converted, and should offer no special challenges, but I have less experience with them.

Radios that present challenges:

Portable (Battery-only or battery/AC sets) tube radios are a challenge. The circuitry to feed the filaments from the AC mains, typically 7.5V, relies on the filaments consuming 50mA. The converter draws about 35mA, so the radio circuitry would need to be modified to accommodate the extra current. Portable radios that operate on 7.5V or 9V filament batteries can be converted. Portable radios that use 1.5V or 3V filament battery simply do not have enough voltage.

Radios that use 2.5V filament tubes (like 2A7, etc…), do not have enough voltage unless you use a voltage tripler to generate enough DC voltage to feed the regulators (about 6V with the LDO).

TRF (unless you make one of the amplifiers oscillate) or regenerative radios cannot be converted.

Farm radios usually use a 1.5V filament supply. However, if you are using your farm radio, it has an external power supply that may be capable of supplying 6V needed for the converter.

5. Making connections to your radio:

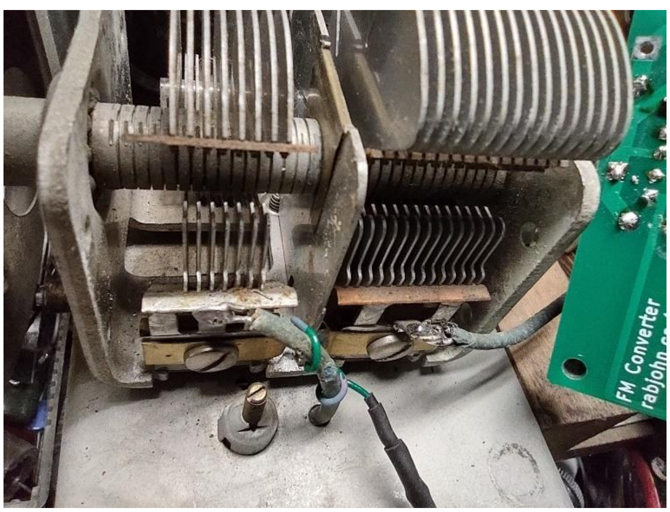
Three connections (local oscillator signal, audio output, power) plus ground must be made to the radio, generally made at the tube sockets. It is very easy to make these connections without any disassembly, modification, or soldering to the host radio by making the connections at the tube sockets with socket adaptors.

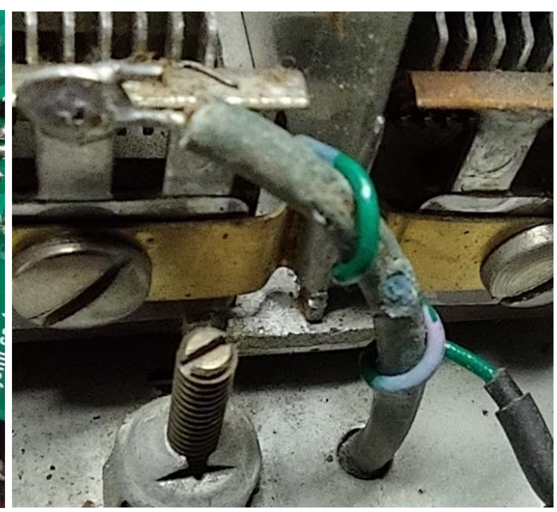
5.1 The local oscillator

There are 2 ways to do get this signal: either use a capacitive link to the "LO" variable capacitor, or connect to a pin on the "Converter" tube.

The FMC is very sensitive, so only a small LO signal is required, and this can be extracted with a capacitive link. An insulated wire wrapped around a wire provides enough capacitance to extract the LO signal. The link can be made by wrapping insulated copper wire from the FMC LO port to the LO tuning capacitor in the host radio. Suitable radios have dual (or more) tuning capacitors, and you must pick the right one. If they are of unequal size, then the smaller one is the one you want to couple to. If they are equal size, try this: Turn on the radio and tune to a station at the upper end of the AM band. Touch each variable capacitor terminal, one at a time, with an insulated screwdriver. Touching the LO side will make it sound like the radio is being tuned away. Touching the other (antenna) side will have a less dramatic effect, may even increase volume.

Shielded wire should be used to get close to the tuning capacitor. A solid insulated copper wire should be soldered to the center conductor of the shielded cable, and the outer shield is left unterminated. Insulate well with heat-shrink tubing. The insulted wire is wrapped around (3 turns should be enough) the wire connecting to the LO variable capacitor that was identified above. No "DC" electrical connection is required.



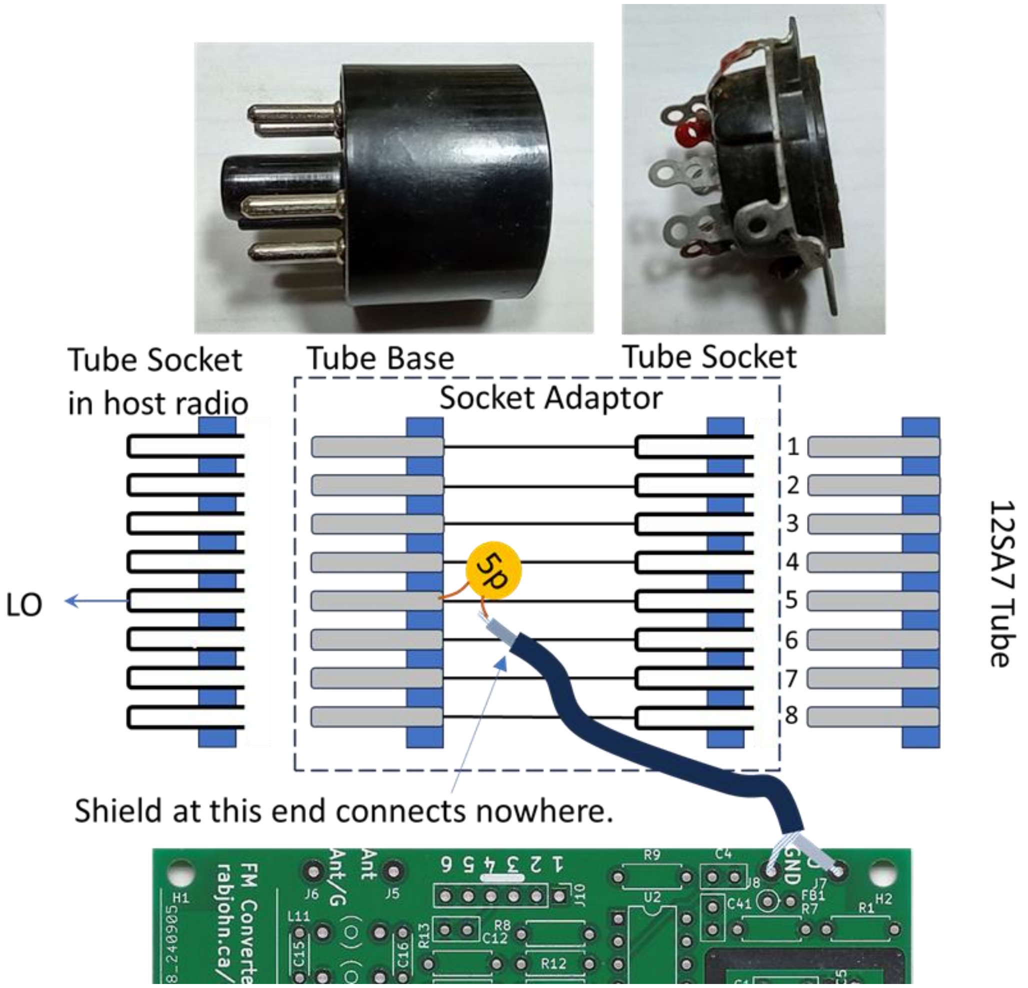


The LO signal may also be pulled from the "converter" tube, or the LO tube if it is a separate tube. (This may be the easier technique if the tuning capacitor is difficult to access) In principle, you could pull the signal from either the grid or the plate of the oscillator, but I have found that the grid (which is connected to the oscillator coil and tuning capacitor) is more sinusoidal; the plate can have significant harmonics that can fool the phase locked loop.

Tube type	LO grid pin number
6SA7, 6SB7, 12SA7	5 (octal)
6A8, 6J8, 6K8, 12A8	5 (octal)
2A7, 6A7	5 (7-pin standard)
6BE6/12BE6	1 (7-pin miniature)
6L7	Better to find the local oscillator
12AD6	1 (7-pin miniature)
7A8, 7B8, 7J7, 7Q7, 7S7, 14B8, 14J7, 14Q7	4 (8 pin loktal)
1R5	4 (7-pin miniature)
1A6, 1C6	4 (6-pin standard)
1A7, 1B7, 1C7, 1D7	5 (8-pin octal)
1LA6, 1LC6	4 (8-pin loktal)

The best way to make this connection is through a tiny capacitor (say 5pF, not critical) mounted very close to the pin. This way, minimal capacitance will be added to the oscillator circuit. The capacitor is connected to the circuit board LO port with shielded cable. A "socket adaptor" is recommended so no soldering is required on the host radio. For octal and "Standard" tubes, this is easily made with the male end taken from an old tube, and a matching tube socket on the female end. The pins are wired up 1 to 1. This gives you access to the nodes required. Miniature tube socket adaptors may take a little more creativity, but soldering rigid wires to a miniature socket may work.

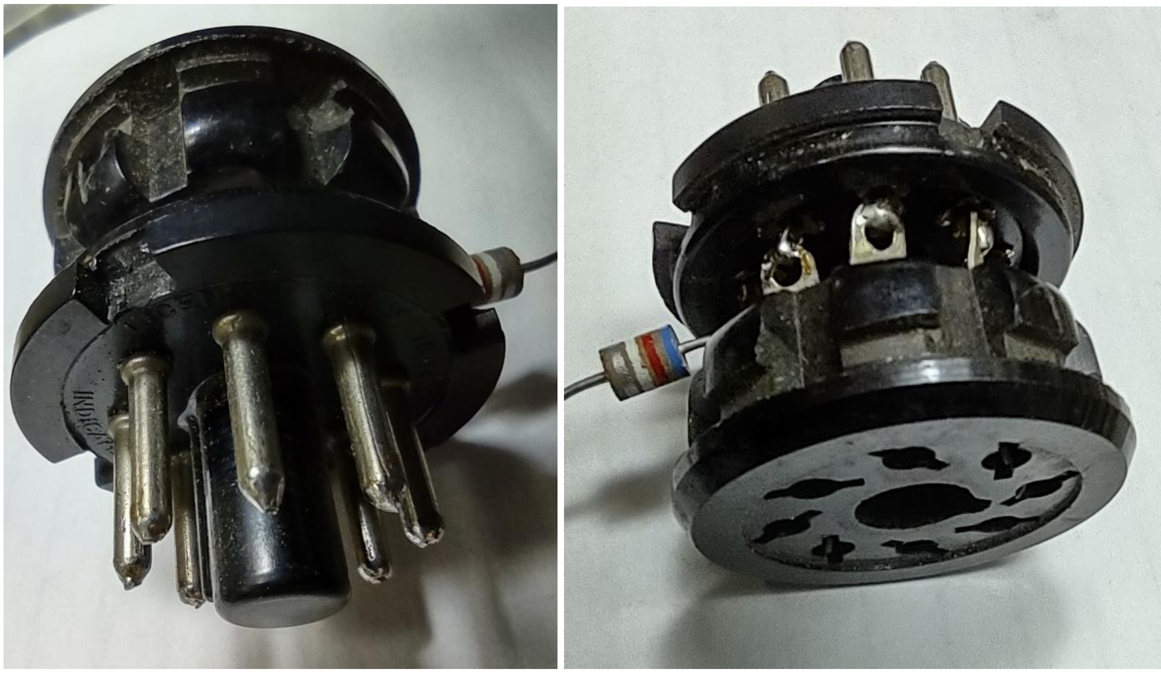
Another option is just to wrap a piece of solid wire around the tube pin.



Socket Adaptor

In radios that have a separate oscillator tube and mixer tube (radios that use a 6L7 mixer, or early radios that use some other tube (perhaps a 24)), it is best to find the associated local oscillator (which can be many different tube types) and tap the signal from its grid.

I do not include European tubes in this list, because I don't have much experience with them, however it should work just as well with them. European radios often used a separate triode oscillator in the same envelope as the mixer, and the LO can be pulled from the grid of the triode. Pin 3 or a UCH42/ECH42, for example.



Above: a socket adaptor. It plugs into the radio, and the tube plugs into it.

5.2 The Audio

In general, the audio is injected at the detector, though if the radio has a phono input, that may be another option. Detector diodes in tubes tend to come in pairs, and either or both diodes could be used as the detector, and the other diode could be open or shorted or used elsewhere. You will need to determine which diode to use, either by consulting the schematic, or looking under the chassis, or simple trial and error.

Tube type	Pin number : Audio	Pin Number : Ground
6SR7, 6SQ7, 12SQ7, 12SR7	3 or 4 (octal)	3
6Q7, 12Q7	4 or 5 (octal)	8
75, 85, 2A6	3 or 4 (6-pin standard)	5
6AT6, 6AV6, 12AT6, 12AV6	5 or 6 (7-pin miniature)	2
6H6	3 or 5 (octal)	4 or 8 or 1 *
12AE6, 12BF6	5 or 6 (7-pin miniature)	
7B6, 7C6, 7E6, 14B6, 14E6	5 or 6 (8 pin loktal)	7
1U5	4 (7-pin miniature)	1*
1S5	3 (7-pin miniature)	1*
1B5	3 or 4 (6-pin standard)	1 or 6*
1H5	5 (8-pin octal)	2 or 7*
1H6	4 or 5 (octal)	2 or 7*
1LH4	4 (8-pin loktal)	1 or 8*

* Best to just use the chassis ground

This connection should be made with grounded shielded cable to avoid hum pick-up. The shield of the shielded cable can connect to ground at the socket as well. Note that the chassis of an AC-DC receiver may not be at ground! The cathode of the audio triode is almost always at ground. A socket adaptor is a good way to do this (and to extract the power, too).

European tubes are not included because I have little experience with them, however they should work just fine. Often, the diode is included in with the IF amplifier which should cause no difficulty.

If the negative voltage generator is not available (e.g. in installations where the converter board is supplied with DC, such as car radios), the tube detector diode should be disconnected. Failure to do so will slightly increase the amount of audio distortion, and very strong AM stations may break through.

Radios with a switched “Phono Input” can receive audio through that connection. But, beware, radios like this sometimes remove power from the RF section and might disconnect the coils when the radio is switched to “phono” mode, so tuning could be impossible. If the connections are maintained, then you may be able to turn your radio into a true AM-FM radio.

If you do not have enough head room for a tube adaptor, you can try connecting directly to the socket pins or using a solid-state tube replacement.

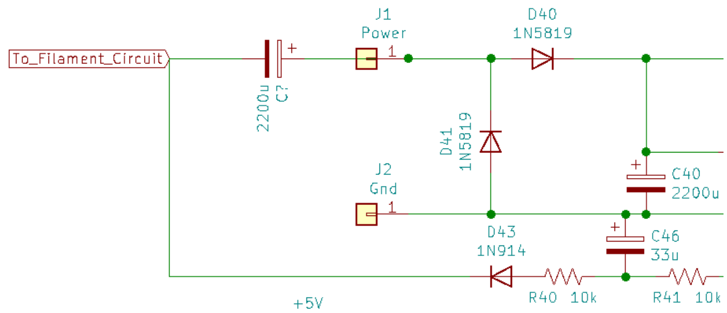
5.3 Power

Extracting the power can be done several different ways, depending on the voltages available and whether the tube heaters are in series or in parallel.

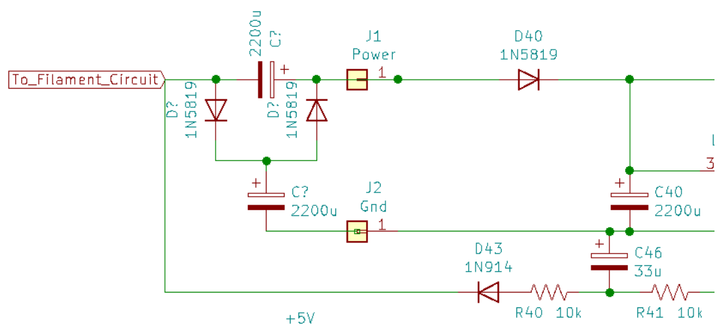
5.3.1 AC parallel heater sets

If the radio has a large power transformer (with a 5Y3, 5Y4, 5W4, 5U4, 80, 6X4, 6X5, or similar rectifier), the filaments of all tubes (other than the rectifier) will be in parallel. The power for the converter board may be extracted from any of the filament pins (other than the rectifier! Please not the rectifier!). Note that one filament pin will be grounded and the other will have power on it, and this must be determined by looking under the chassis. Connect the powered filament pin to the power pad on the FMC board, and a ground pin to the ground pad on the circuit board. D41 and D42 are not required. In the rare cases where 12V tubes with paralled filaments are used with AC on the filaments, please make sure capacitor C40, C46 and C47 (if used) are rated at 20V or more.

Some radios use a center-tapped winding for the filaments, which means that only 3.15VAC (half of the 6.3VAC) is available, and this voltage is not sufficient with a simple half wave rectifier. In cases like this, a voltage doubler configuration using Schottky barrier diodes (such as 1N5817, 1N5819) must be used. Not too difficult, requires an additional diode (at D41, on the board), and an external electrolytic. If the negative bias circuit is used, D43 must be connected back to the filament.



Radios that use tubes with 2.5V filaments actually require a tripler to generate enough voltage. This required 2 additional capacitors and 2 additional diodes.



If you have a radio with 2.5V filaments and a center-tapped filament transformer, you have only 1.25V AC to work with, so even a quadrupler is not enough. Good luck with that!

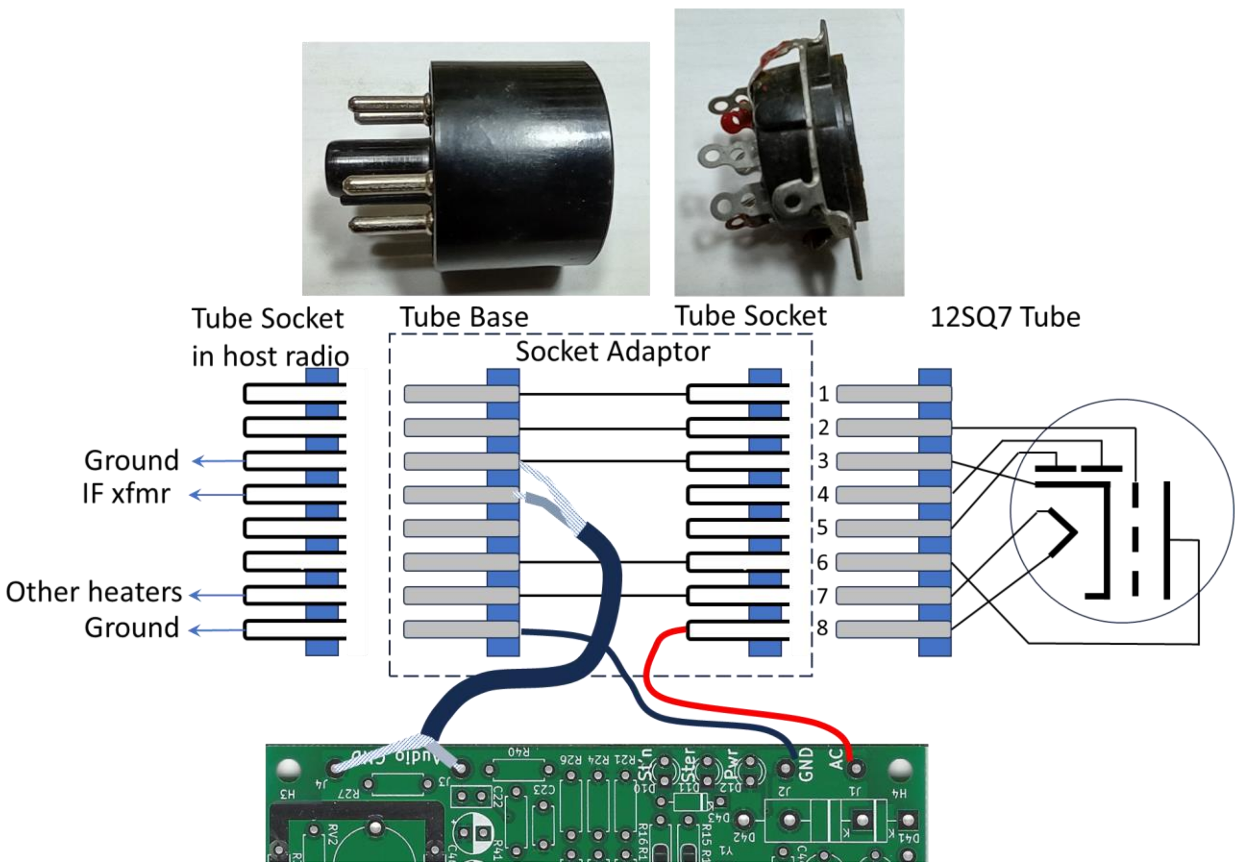
Tube type	Heater pin numbers
6SR7, 6SQ7, 12SQ7, 12SR7	7 and 8
Pretty much any other octal tube	2 and 7
6-pin standard tubes	1 and 6
7-pin standard tubes	1 and 7
7-pin miniature (except battery tubes)	3 and 4
7-pin miniature battery tubes (start with 1 or 3)	1 and 7
8-pin loktal tubes (start with 7 or 14)	1 and 8
9-pin miniature tubes	4 and 5

The IF amplifier and RF amplifier (if present) tubes can be removed in a set with filaments wired in parallel. This will allow the set to run a little cooler, and may give more room to manoeuvre in compact sets.

5.3.2 AC-DC series-heater “All American 5” sets.

Earlier versions of my FM converter required less current and could be connected to a series-string radio in a similar way to a parallel string radio, however, this version of the converter takes more current, about 35mA (and, with half-wave rectification, this 70mA half the time). If this current is extracted by connecting it in parallel with a 150mA heater, then the tube heater is starved, and insufficient voltage is generated for the converter. So, the power must be extracted in series with the heaters. It is essential that a 8.2V, 5W Zener diode be populated at D41 on the board. (Failure to do this will destroy the board!)

You must locate the tube that is at the “ground end” of the heater string. This will almost always be the detector + first audio tube. One end of the filament will go to ground (generally not the chassis ground, rather will be connected to the cathode of the triode). This ground-end of the filament is opened (with the socket adaptor), and connected to the power port of the board. On radios that use a 12SQ7, you would usually open the circuit at pin 8, but check. 12Q7 will usually be pin 2, but check. The illustration shows what might be done with a 12SQ7. It shows the series heater string being interrupted at pin 8 (because you discovered that pin 8 is the ground side of the heater). It also shows that detector diodes disconnected at pin 4 and 5, and the audio is fed into pin 4, because you discovered that pin 4 connected to the IF transformer. The shield of the audio cable is connected to the ground on both ends.



AC/DC radios all offer another challenge: safety. Even without the FMC, they can present a shock hazard because much of the radio circuitry is connected directly to the line cord. When connected properly, the FMC is tied to one side of the AC power line. To be safe, this board should be situated (possibly enclosed) within the radio so that it cannot be accidentally touched.

Some very old AC/DC sets use tubes with 300mA series connected heaters and line-cord dropping resistors. These can be some of the most frightening radios (from a safety perspective), but indeed this circuit will work when connected with the power connected in parallel with the filament at ground. In this case, D42 should be populated; this will protect the FMC in case the filament of the tube (that it receives power from) goes open.

5.3.3 12V car radios

The challenge with car radios is finding a place for the circuit board inside the radio; it may be impossible, so mounting the radio outside may be the only option. 12V negative ground car radios that use 12V (filament) tubes are quite easy to connect to. Follow instructions in section 3.1 . If the radio uses a vibrator to generate high voltage, there may be some interference from the vibrator. Additional shielding or decoupling may be necessary. If the radio uses 12V low plate voltage tubes (quite common in the late 1950's and early 1960's), no difficulty should be encountered. Note that these radios often use permeability tuning, but that should cause no difficulty. 12V positive ground radios will be more challenging, and I will not go into the difficulties likely to be encountered.

5.3.4 6V car radios

6V negative ground car radios can be used, but the board must be modified. Diode D40 is shorted (D41 and D42 are not used). And the 5V regulator must be replaced with a Low Dropout Regulator.

6V positive ground car radios present a problem, because the audio signal is referenced to the noisy negative supply. Attempt this only if you are an expert!

5.3.5 Portable (battery) radios and farm radios

Portable radios are challenging because they operate at such low voltages.

Portable radios that can also run from AC often use 7.5V batteries for the filament, and this voltage will supply the FMC nicely when operating from a battery. (But, who has 7.5V batteries these days?) However, when running from AC, the filament voltage is generated by a (hot) series resistor. The FMC takes too much current to simply connect it, so the resistor would need to be reduced, and possibly the rectifier would need to be enlarged. Probably easier to use a battery (a 9V battery is suitable) to power the FMC.

Portable radios that cannot run from AC (this includes farm radios) usually employ low voltage (1.5 or 2V) batteries for the filament. The only option here is to use a separate battery (9V does nicely) for the FM converter. Farm radios are usually used with external power supplies these days, and the FMC may be able to get power from this.

The FMC can be used with a transistor radio, as long as 6V or more is available, however finding the LO tap-off points is best left to an expert.

5.4 Examples

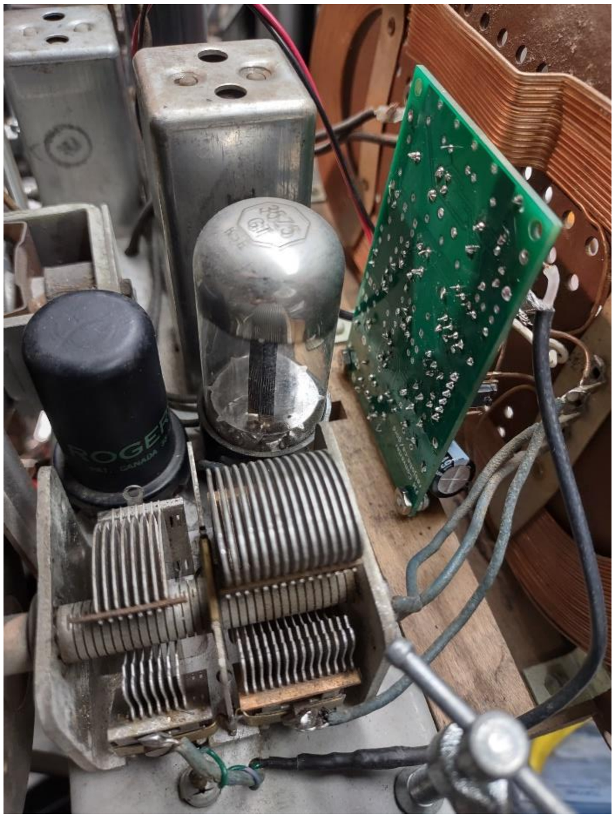
A Viking (Electrohome) 5-tube AC set

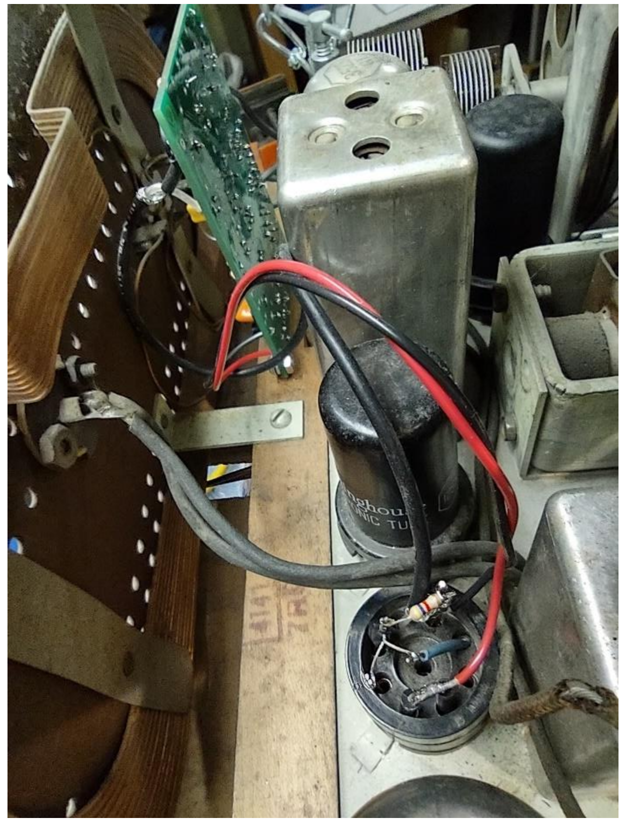
This is a very standard AC-only 2-band radio from about 1946. It uses these tubes: 6SA7, 6SK7, 6SQ7, 6F6GT, and 5Y4G. It has a phonograph input, but switching to phono also kills the bias to the 6SA7. The FMC is held in place by screwing it to the antenna/ground terminals of the host radio. The LO is extracted by wrapping an insulated wire to the LO input on the board to a terminal on the oscillator variable capacitor. In this case socket adaptors were not used, the power and audio were connected to the radio by wrapping a wire around the appropriate tube socket pin. This particular FMC uses the Si4836 tuner and the 74HCT9046 PLL. Diodes D41 and D42 were not needed. It does use the negative bias generator (D43 etc) to kill the IF gain and shut down the detector diode.

The RCA “Little Master” AC-DC set

The little master is a very typical AC-DC set using a 12SA7, 12SK7, 12SQ7, 50L6GT, and a 35Z5GT. It has a phono input on the back, but there is no switch for it, so it is not terribly useful. LO was extracted by wrapping the insulated LO input to the variable capacitor terminal. DC was extracted with a 7.5V Zener diode in series with heater chain. I did this one a little differently: I replaced the 12SQ7 with a solid-state equivalent. Back-to-back Zener diodes replaced the 12SQ7 filament, with the common connection between diodes connecting to D40. D42 was used. The detector diodes of the 12SQ7 were not needed, of course. The 12SQ7 triode was replaced with a D-mode FET, the Supertex/Microchip LND150 high voltage d-mode FET. Please contact me if this implementation is of interest and I can provide more details.

The board is mounted on the wood support at the back of the radio with 2 eye hooks.





6. Specifications

I/O

Antenna (2 wire balanced or 1 wire single-ended)
LO (Local Oscillator) input from host radio
Audio output to host radio
Power from host radio
Common ground

Power Supply

Current draw ~36mA DC
Minimum voltage required:
- 7.5VDC (negative ground) or 5.5VAC (50/60Hz). Use a voltage doubler or tripler for lower voltages.
- OR 5.6VDC (with low-drop regulator and D40 removed).
- Maximum voltage 30VDC or 20VAC. Increase voltage rating of C40, C46, C47 above 15VDC/10VAC.

FM

Covers FM band: 87-108MHz (75us deemphasis). Other bands possible by modifying R13/R14 (eg: 86.5-109MHz or 76-90MHz or 64-87MHz).
Sensitivity: ~4uV (Si4825) or ~2.2uV (Si4836)
Antenna Input: Balanced or single-ended, isolated from the rest of the radio.
Audio Output: ~1V p-p with a standard FM station into a high impedance load. Output impedance 10k.
Frequency Response: 30Hz – 15kHz
Distortion: 0.1% typical (from data sheet, I cannot confirm)
Either mono output or (with Si4836) R or L channel of a stereo output

Local Oscillator (LO) Interface

LO frequency: ~1MHz-2MHz. Suitable for a “Broadcast Band” or “MW” receiver with an IF of 175-500kHz. It will lock up to well over 5MHz with a modification to C2.
Minimum swing: ~50mV RMS (and most oscillators have 20X that, so only very light coupling is needed)

Size:

5.5cm X 8.5cm X 1.5cm. Mounting holes (for 4-40 screws) on 4.85cm X 7.85cm centres
2-layer 0.062” thick board with plated-through holes.