The MPX 2000

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The *MPX 2000* is a multi-feature FM stereo transmitter that offers full coverage of the 88–108 MHz band in 100-kHz steps. This unit is intended for use by hobbyists, experimenters, and others needing a low-power short-range FM stereo transmitter. The left and right audio channels may be used independently to transmit two separate audio channels. The MPX 2000 is also suitable for hobby Part 15 operation where a transmitter with digital frequency readout and keypad entry of frequency is desirable.

This low-powered unit is fully crystal controlled. The pilot and subcarrier signals are both generated from a quartz crystal. A *phase-locked loop* (PLL) system assures frequency accuracy and crystal stability; while the use of a keypad and microprocessor permit ease of frequency entry without having to set jumpers or switches, ensuring that the programmed frequency will be correctly produced.

Stereo Transmission. When FM stereo transmission was introduced back in the 1960s, there were millions of monophonic FM receivers in use. Whenever anything new is introduced into a mass market, it is desirable to maintain compatibility with existing equipment and not make it obsolete. The new stereo system had to be backwards compatible with mono FM. The new stereo transmissions had to be received by existing mono receivers as monophonic audio, much like color TV transmissions were received as black and white on the millions of black-and-white TV sets still in use. What this meant was a stereo audio format was necessary, whereby the main audio channel was transmitted as the sum of left and right (L+R) audio channels. In addition, a signal is also transmitted that is the difference of the channels (L-R). By adding the signals, the right channel cancels, and the left channel alone appears. By subtracting the (L+R) and (L-R) signals, the left channel cancels; and the right channel similarly is now obtained. A mono receiver would reject the (L-R) component and reproduce only the (L+R) component as a mono signal.

The trouble is that the sum and difference channels (L+R) and (L-R) both are audio that occupies the baseband of 20 to 15000 Hz. Using analog methods, in those pre-digital days, there was no way to separate the channels as is. What was done was to superimpose the difference (L-R) component on a subcarrier in the ultrasonic range, where it would be inaudible. A pilot carrier must also be transmitted to assist in demodulating this subcarrier back to audio. The stereo receiver has to extract this subcarrier and pilot signal, process them to recover the (L-R) difference signal as audio, and then perform the adding and subtracting (called matrixing) to obtain the separate L and R channels. Then two audio channels (L and R) and two speakers can be used to obtain true stereo reproduction.

Command the FM band with this do-it-yourself transmitter.

A stereo-generator system must be used to process the incoming audio channels into a form suitable for transmission by a standard FM transmitter on a standard FM channel 200 kHz wide, with 75-kHz peak deviation. The usual pre-emphasis and deviation limiting must be provided for, and the frequency response of the audio should not be degraded from standard mono transmissions. Since available deviation is limited by FCC regulations to 75 kHz, the L and R channel total audio must not ex-ceed that for an equivalent mono channel. In addition to the pilot signal, some provision must be made for the use of auxiliary subcarriers, such as SCA transmissions on 67 or 92 kHz.

The circuitry needed for all this processing, while using quite a few components, is quite simple and straightforward. It involves only low frequencies and is easily implemented with just a few ICs and transistors. Indeed, there once existed an IC that did the whole job (BA1404 or BA1405), but this IC has suffered the fate common to many ICs—discontinuance. Thousands of hobbyist stereo FM transmitters both in kits and individual projects were constructed around the BA1404/BA1405 ICs. While they may be available in surplus for a few years, they have no future, as there is little mass-market demand for these chips. While they were OK for low-end uses, real FM stereo

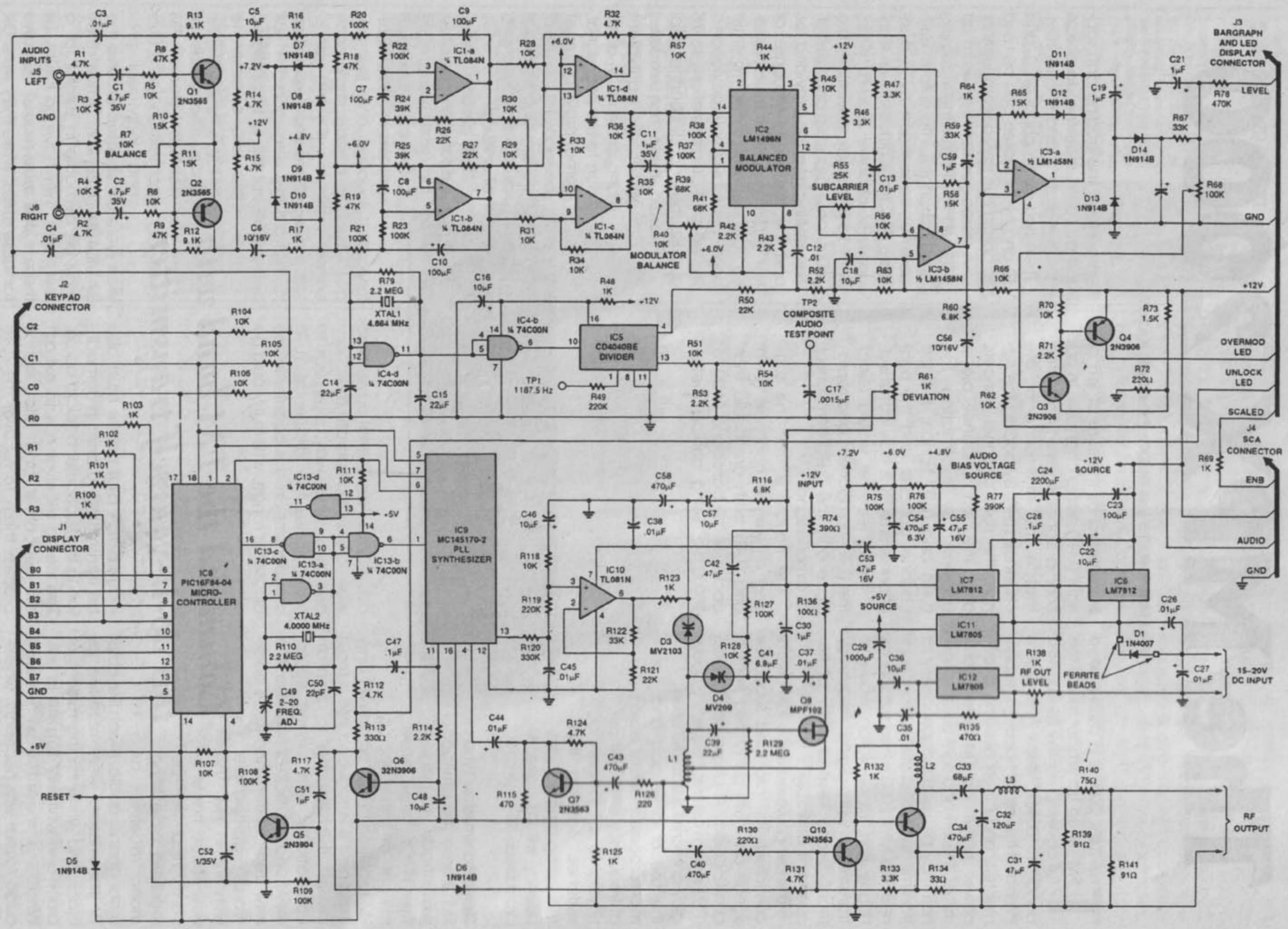


Fig. 1. This is the schematic diagram outlining the circuitry for the MPX 2000.

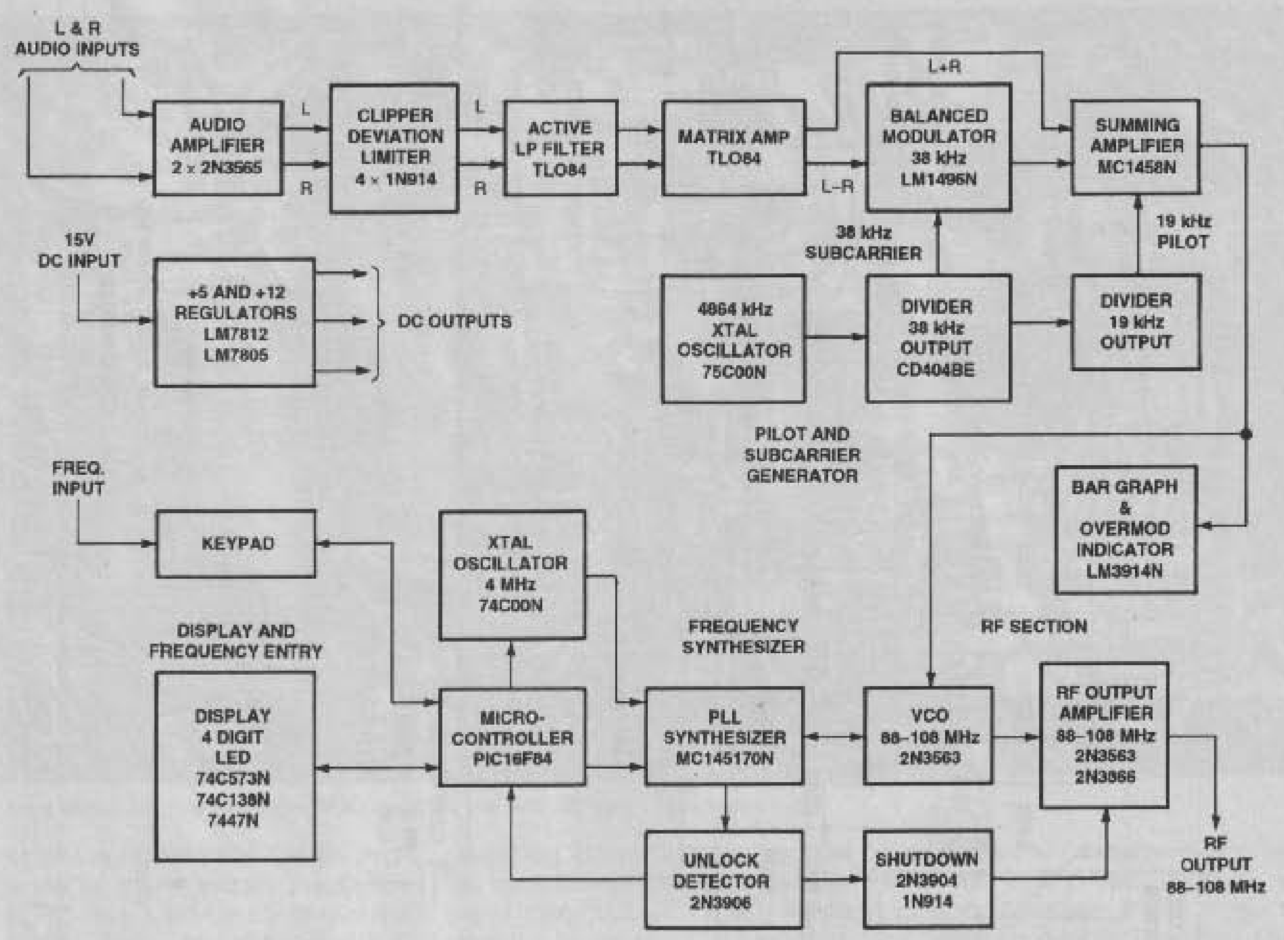


Fig. 2. A detailed block diagram—like this one depicting the signal flow within the MPX 2000—is a vital tool in designing and troubleshooting complex circuits.

demands performance and signal-to-noise ratios beyond the capabilities of these chips. Today, it is not difficult to build a stereo generator using discrete transistors and a few "classic" IC devices widely available from several manufacturers, together with a handful of resistors and capacitors that will give "broadcast quality" stereo sound to a LP hobby transmitter. In addition, all waveforms are accessible for study and for learning how the stereo system works.

Stereo Generation. The stereo generation process is as follows: The two input channels L and R (left and right) are first fed to a preamplifier where the audio is amplified and pre-emphasized. This means that higher frequencies are boosted relative to lower frequencies by a controlled amount. This improves the signal-to-noise ratio (s/n) of the received audio. In the receiver, exactly the opposite is done (de-emphasis), which reduces high-frequency receiver noise and produces an overall improved s/n and, therefore, "cleaner" high frequencies. In US FM practice, a high-pass filter with a corner frequency of 2.1 kHz, corresponding to an R-C circuit time constant of 75 microseconds, is used. Therefore, below about 1000 Hz no alteration is made to the audio. At 1 kHz a boost of around 1 dB occurs, at 2.1 kHz a boost of 3 dB, and at 4.2 kHz a boost of 7 dB, and so on, at 6 dB per octave, until 15 kHz.

The audio then is limited in amplitude by a limiter, generally a diode peak clipper, to protect against overmodulating the transmitter. This is done for both L and R channels. Program input should be limited in frequency to 15 kHz to avoid artifacts and aliasing effects and to make the job of the lowpass filter easier. The stereo-generation process assumes that no input frequencies above 15 kHz will be present. Next, a low-pass filter is used to reduce audio components above 15 kHz, both input and those resulting from any clipping. In European systems, a pre-emphasis time constant of 50 microseconds, corresponding to a zero at 3.15 kHz, is used instead of 2.1 kHz.

Next, the processed audio channels are added and subtracted algebraically in a matrix amplifier circuit. The L+R and L-R signals are now generated. The L+R signal is the main component of the "baseband" signal and is fed to a summing amplifier where it is combined with other components to be discussed later. The output of this summing amplifier is fed to the transmitter audio input.

The difference L-R signal must be separated in frequency from the L+R signal in order to keep them separated while being transmitted on the same channel. This is done by transforming the L-R signal into a double-sideband suppressed-carri-

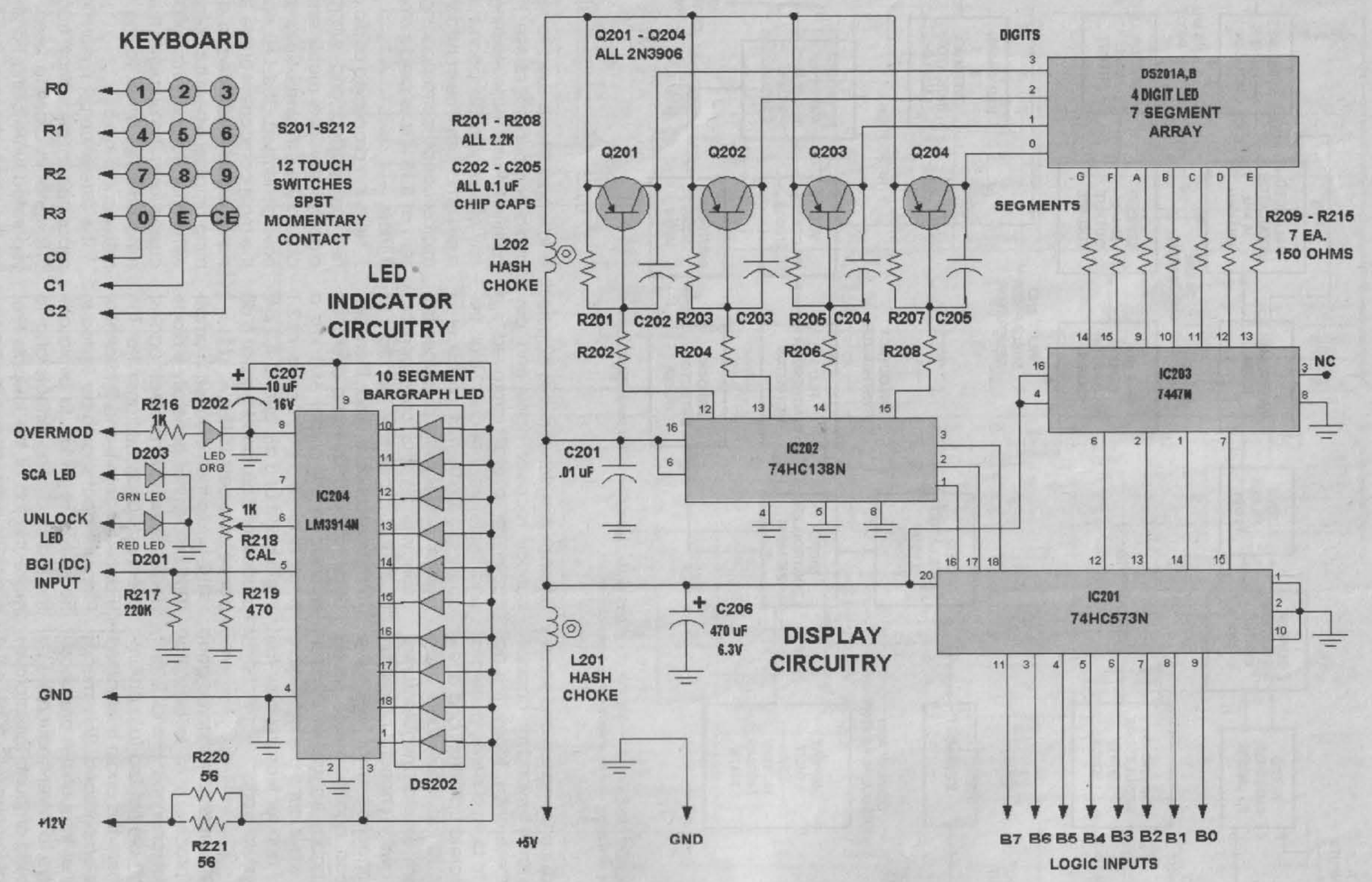


Fig. 3. This is the schematic for the display-board circuitry

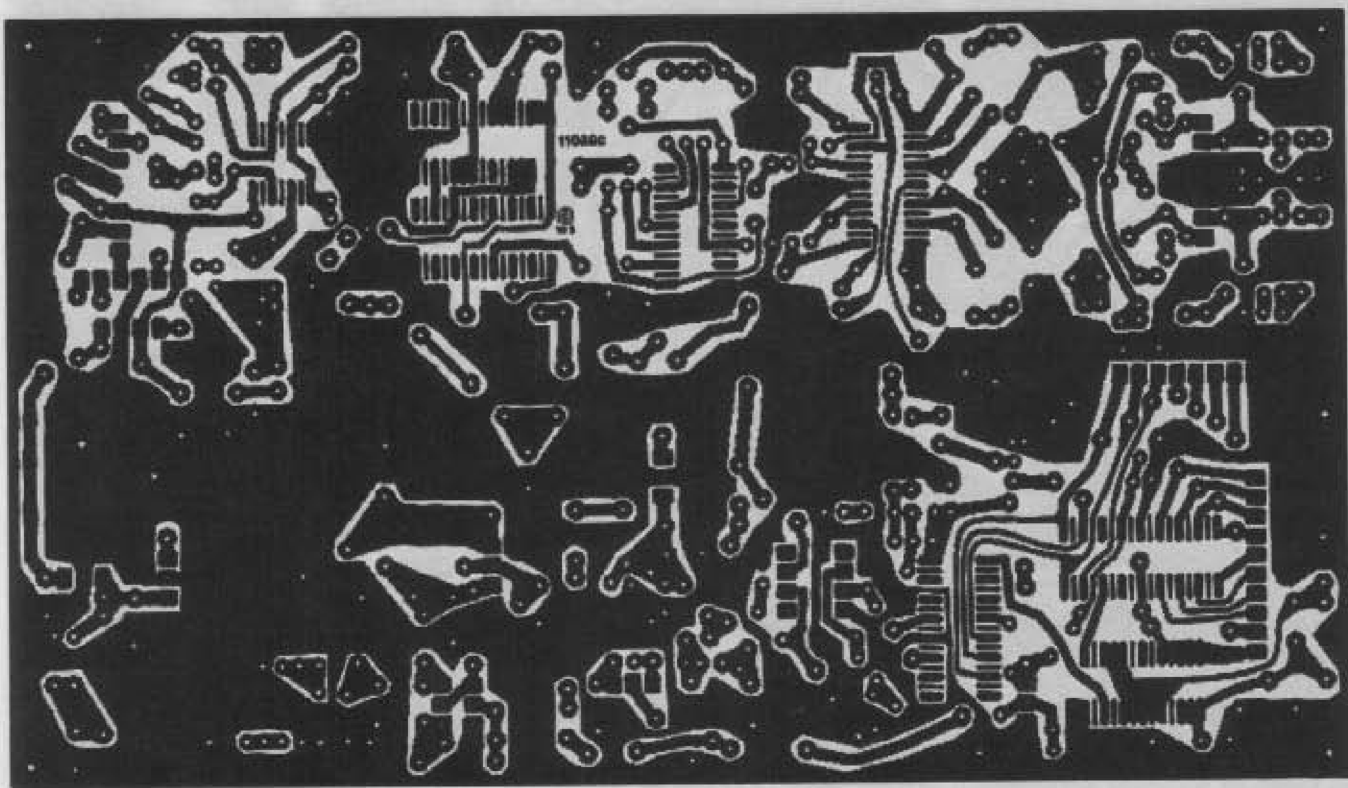


Fig. 4. Here is one of the foil patterns for the mainboard. The MPX 2000 uses a double-etched board.

er AM signal at a frequency high enough so its lowest frequency components will be far above the highest frequency components in the main L+R signal. A balanced modulator circuit is used for doing this operation. A carrier frequency of 38 kHz has been standardized for this purpose, and a pilot signal of half this frequency at 19 kHz is also generated.

The pilot signal can be doubled at the receiver and used to generate a local 38-kHz signal for demodulation of the subcarrier into L-R audio, and it can also be used to signify the presence of stereo audio. Also, the pilot carrier is used by some receivers as a signal to switch from mono to stereo and back to mono if the pilot at 19 kHz falls below a minimum level, indicating insufficient signal for good stereo reception. For TV stereo audio, 31.468 kHz and 15.734 kHz—2X and 1X the horizontal scan frequencies—can be used if the audio response is limited to about 12 kHz or so. A double-sideband suppressed-carrier signal is used because if a standard AM signal were used, the carrier at 38 kHz would "hog" a large part of the allowable deviation of 75 kHz total permitted. This result would reduce the available deviation for the sideband components, which really carry the desired audio information the FM. In addition it would reduce the signal-to-noise ratio and contribute a filtering problem by getting rid of the carrier component at 38 kHz, while keeping the higher frequency audio components at 10–15 kHz relatively "clean."

The audio out of the balanced modulator has components from 23 to 53 kHz. This corresponds to the sum and difference of the audio components at 0 to 15 kHz with the 38-kHz subcarrier (which is suppressed). This signal, together with the 19-kHz pilot signal, is fed to the summing amplifier. The pilot carrier and the subcarrier frequencies must be held to within one hertz or so. This is not as bad as it sounds, about 52 parts per million for the pilot carrier and 26 parts per million for the subcarrier. Since the subcarrier is referenced to the pilot, the 52-PPM tolerance at 19 kHz can easily be held with a crystal-controlled oscillator. The 38-kHz signal can be generated and then divided by two to get the 19-kHz pilot.

Although crystals for 38 kHz are available, they can be delicate and sometimes expensive. A crystal in the 2- to 6-MHz range is, by contrast, cheaper, more rugged, and easily available. Therefore, the best approach is probably to use a crystal in the MHz range and use a CMOS divider chip to divide the higher frequency by some power of two to get 38- and 19-kHz signals. This approach is used in our MPX 2000. A 4.864 MHz crystal is used in an oscillator. Its frequency is divided by 128 to get 38 kHz and then again by two to get 19 kHz. The outputs from the divider are square waves, but the balanced modulator used to generate the subcarrier needs a square wave, anyhow. The pilot is inherently filtered by the bandwidth of the audio system. Only two common digital CMOS ICs are used in this circuit, and cost is very low.

The output from the summing amplifier has the following spectral components:

The sum of the L and R channels (L+R) consisting of audio program components up to 15 kHz. This is the part received and used by mono FM receivers.

A pilot signal at 19 kHz of sufficient

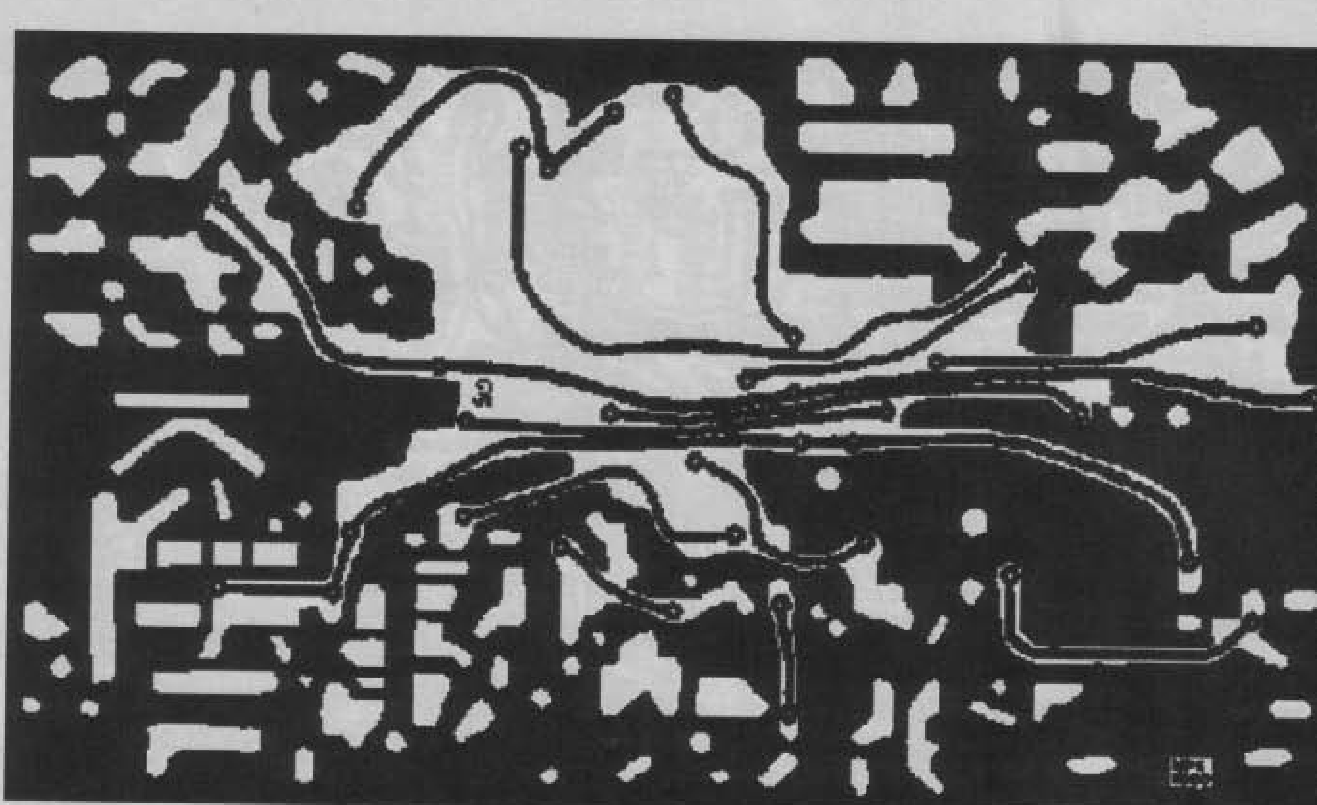


Fig. 5. This is the foil pattern for the other side of the main PC board. The double-sided design makes it easier to distribute the DC voltages needed to run the transmitter.

amplitude as to produce around 10 percent of the total deviation permitted for the transmitter. This signal is used for stereo detection and for regeneration of the 38-kHz subcarrier at the receiver

A double-sideband suppressed-carrier signal having frequency components from 23 to 53 kHz, which carry the L-R signal needed by the stereo receiver

Optionally, subcarriers at 57, 67, or 92 kHz used for data transmission or for SCA programming for use by private organizations. The MPX 2000 is ready to support this mode with an external SCA generator.

Therefore, an FM stereo transmitter must have modulation capability up to as high as 100 kHz, with reasonable flatness of frequency response. Ideally, frequency response should be flat with constant time delay vs. frequency, which implies a linear phase response vs. frequency. Distortion, both harmonic and intermodulation, should be kept low to avoid crosstalk and unwanted spurious mixing products, which interfere with audio programming. These components may show up as noise, whistles, audio artifacts, or loss of separation. Additionally, distortion on the transmission path between transmitter and receiver must be avoided as much as possible for best stereo reception. Multi-path transmission effects that occur at VHF frequencies can cause severe distortion and ruin stereo reception. Antennas used with FM stereo transmitters and receivers must have adequate bandwidth (rarely a problem) and enough gain to ensure adequate received signal.

Circuit Signal Flow. The MPX 2000 circuitry will now be discussed. Refer to the schematic shown in Fig. 1 and the block diagram shown in Fig. 2 for this discussion. Audio input at line level (1 volt peak-to-peak at a 500- to 10,000-ohm impedance) is fed into jacks, J5 and J6, which are left- and right-audio input channels, respectively. Resistors R1 through R4, with R7, make up an input network, and R7 is used to obtain an equal audio gain for both L (left) and R (right) channels. Q1 and C1, along with resistors R5, R8, R10 and R14, all make up the L audio preamp, which has a gain of about 5 at 1000 Hz. Gain is shaped to produce a 75-microsecond pre-emphasis standard on FM receivers used in North America. The R channel is identical (Q2 and associated components). Capacitor C5 and resistor R16 feed amplified audio into a clipper consisting of diodes D7 and D8. These are biased by voltages from the network formed by R74, R75, R76, and R77. Audio is limited to 3 volts peak-to-peak by these diodes. The R channel uses the same circuitry. The purpose of the clipping is to prevent exceeding the maximum deviation (75 kHz) with excessive audio input. The clipper acts as an audio limiter. Next, both channels are fed into a 2-pole active filter consisting of a quad op-amp, IC1, a TL084N; resistors R20, R22, R24, and R26; and capacitors C7 and C9 (left channel). The right channel has identical circuitry. The active filters cut off at 15,000 Hz and serve to reduce aliasing distortion.

The audio signals are fed to a matrixing network using the other two sections of IC1. In one amplifier, the L and R channels are summed to produce the signal

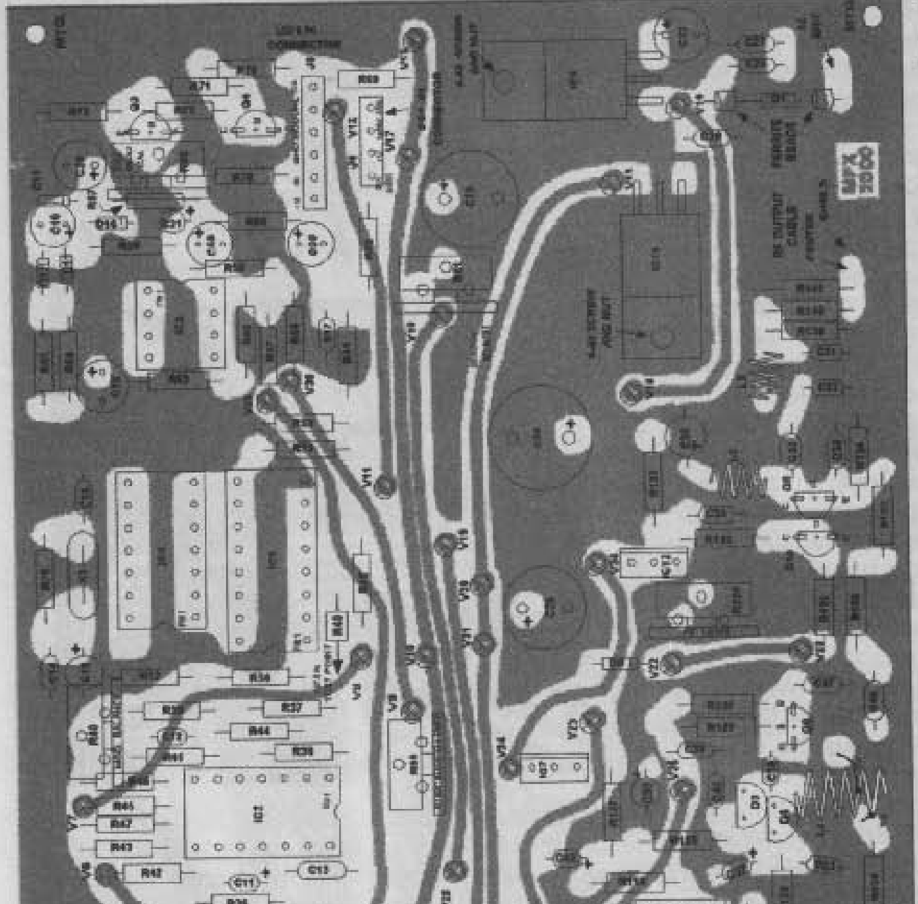


Fig. 6. When you are ready to solder components to the main board use the parts layout shown here as a guide. Pay attention to what side of the board you solder the components on.

(L+R) and the signal (L-R). Both signals are necessary for stereo generation. The signal (L+R) is the main monophonic channel that occupies the band 20 to 15,000 Hz, and it is the signal received in a monophonic FM receiver. This allows stereo to be received as mono on an FM receiver without a stereo decoder, ensuring compatibility.

The signal (L+R) is fed to summing amplifier IC3 via R57 where it will be combined with two other signals, the subcarrier signal (L-R) and the 19 kHz pilot. The signal (L-R) is the difference between the channels. This audio signal has the same frequency components as the main signal (L+R) and cannot be transmitted in the same channel as the (L+R).

To solve this problem, the signal (L-R) is then modulated on a subcarrier at 38 kHz. The result is a double-sideband AM suppressed-carrier signal occupying a band from 23 to 53 kHz (38 kHz plus and minus up to 15 kHz). It is produced with a balanced modulator circuit, IC2, and its associated components. Audio (L-R) is fed into IC2 via R35, R36, and C11. Pins 1 and 4 of IC2 are fed DC bias via R37, R38, R39, and R41. Resistor R40 is used to balance the voltages at pins 1 and 4. Balance occurs when they are identical. Resistor R44 sets the circuit gain; and R42, R43, R45, R46, and R47 are biasing resistors for the input and output of IC2.

The 38-kHz subcarrier is inputted at pin 8, and output appears at pin 12. In the absence of input, the audio output is zero; and, in practice, R40 is adjusted to null the 38-kHz output with no L-R input. The 38-kHz signal is obtained from frequency divider, IC5, a CD4040BE. This IC is driven by a crystal oscillator/buffer at 4864 kHz, made up from two sections of a 74C00N NAND gate. Capacitors C14 and C15 and IC1 make up the oscillator circuit. In addition, a 19-kHz signal for the pilot carrier and an 1187.5-Hz signal useful for testing are obtained from the CD4040BE at pins 13 and 1, respectively. The 1187.5-Hz signal is taken off through a series resistor, R49, and can be used to test the audio section, but is otherwise not used in the system. The subcarrier output is taken off through C13 and level control R55 and is fed to summing amplifier, IC3.

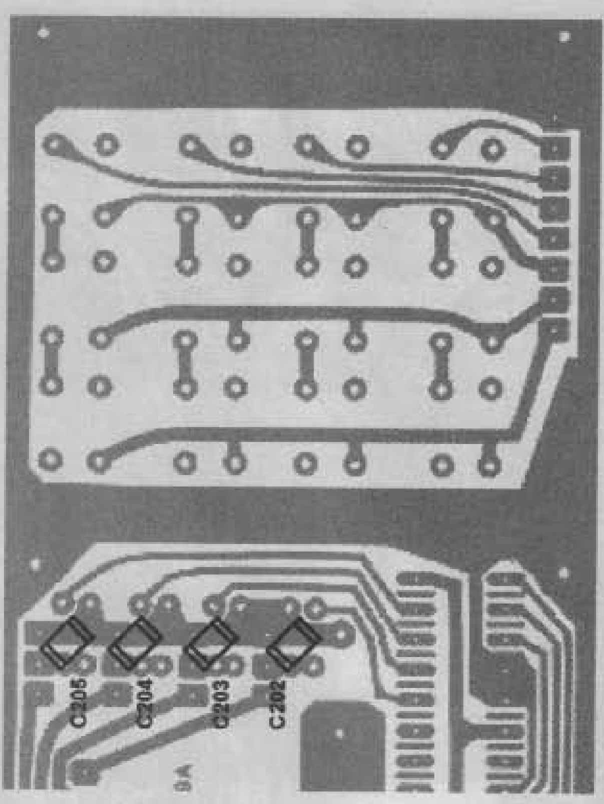
The output of IC3 is the sum of (L+R) and the (L-R) signal. It is fed to network C17-R61 via R60. In addition, the 19-kHz pilot signal from IC5's pin 13 is fed to this point via attenuator R51, R53, and R54, where it is reduced to 7 to 10 percent of the peak audio level. This 19-kHz signal is used by the receiver to generate a 38-kHz subcarrier for recovery of the audio (L-R) component from the 38-kHz subcarrier signal received along with the main (L+R) signal. Adding and subtracting (L+R) and (L-R) will result in 2L and 2R, which are the individual L and R audio channels.

The signal appearing across network R17–C61 is called the baseband or composite stereo multiplex signal. This signal is fed to the transmitter modulator. In order to ensure good audio quality on the transmitted signal, some audio-level monitoring is needed. The MPX 2000 uses a 10-segment bar-graph level indicator, which consists of ten LEDs mounted side by side to simulate a solid-state meter movement. In addition, another LED is provided which lights when the peak audio level that would result in overmodulation is reached. Audio from the summing amplifier is taken via R59, fed to an op-amp, a section of IC3, and then rectified to produce a DC level corresponding to the peak audio signal. Resistor R65 sets the gain of this stage to unity; and C19, D13, D14, and C20 make up a half-wave voltage-doubler detector. Diodes D11 and D12, and resistor R64 are used to improve the linearity of the circuit at lower signal levels. They increase the gain of IC3 to permit low-level signals to overcome the 0.6 volt drop normally encountered in silicon diodes.

The audio components are removed by R67 and C21 and applied across potentiometer R68. The DC voltage is fed to the bar-graph level display via R78. A part of this voltage appearing from the wiper of R68 to ground is fed to the base of Q3. The emitter of Q3 is biased at 1.5 volt via R72 and R73. Potentiometer R68 is adjusted so that when the audio signal lights all ten segments of the bar-graph display plus 10 percent more, there will be sufficient voltage (2.2V) available at the base of Q3 to cause it to conduct. This signal turns on Q4 via R70 and R71, causing voltage to appear from the collector of Q4 to ground. This voltage is fed to an LED on the display, lighting it, and indicating overmodulation. The display panel will be described separately in another part of this discussion.

Frequency Modulation. An RF carrier that can be frequency modulated is required. It should be variable from 88 to 108 MHz to cover the entire FM broadcast band, and it must be stable within 10 kHz or better. The MPX 2000 uses a *phase-locked loop* (PLL) frequency synthesizer to generate all 200 channels at 100-kHz spacing, between 88.1 and 107.9 MHz—the standard FM broadcast band. The synthesizer is frequency modulated by applying audio to its voltage-controlled oscillator (VCO). Contradictory as it seems, we want the VCO to be rock stable and to vary the frequency. With proper design, this can be accomplished without any serious compromises in transmitted audio quality or synthesizer performance. The VCO is the heart of the transmitter, and the synthesizer circuitry serves to keep it exactly on the desired transmit frequency.

Free-running oscillators were used in the past for this



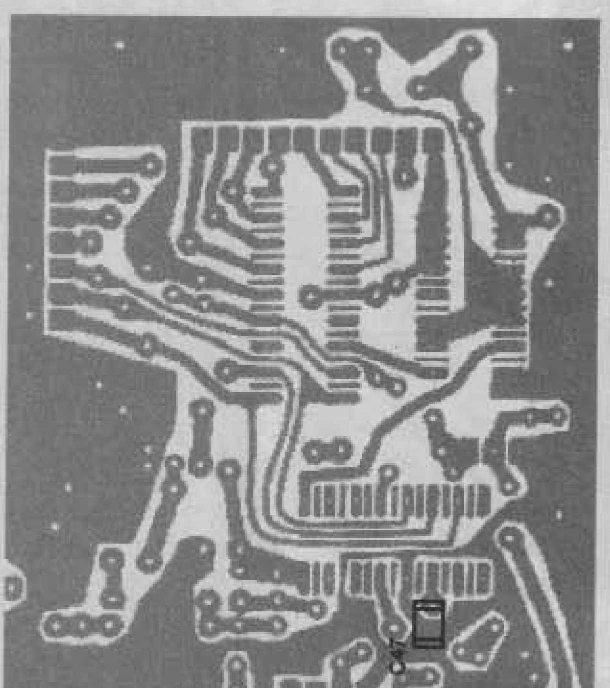


Fig. 7. These two guides show the soldering points for required chip capacitors.

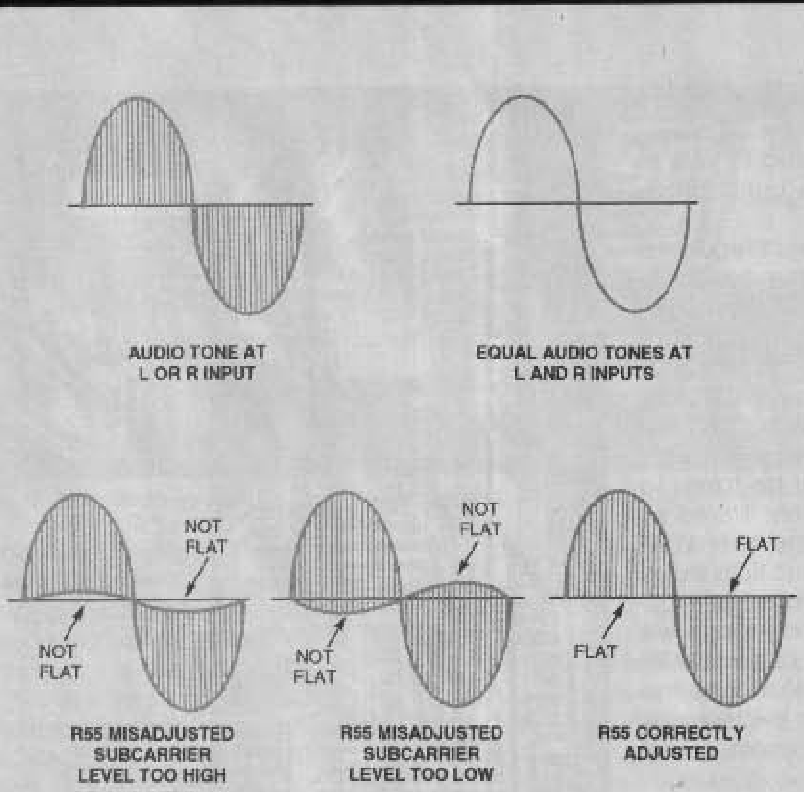


Fig. 8. These waveforms can serve as a guide for signal chasing. An oscilloscope can be used to compare the composite audio-signal to the nominal waveform shown above.

application. This approach is still used in low-end, low-cost FM transmitters. It is difficult to keep these transmitters on frequency, and, therefore, they can be hard to use, especially with digitally tuned receivers. Stability of better than 100 kHz is difficult to come by with this approach. The use of frequency synthesis eliminates this problem. The VCO output must be buffered to eliminate frequency pulling caused by varying antenna loads, proximity effects, etc.

In the MPX 2000, JFET Q8 is the VCO. Inductor L1 and the combined capacitances of tuning varactor D4 and modulator varactor D3 together make up the L-C tuned circuit that determines the transmitter frequency. JFET Q8 is biased by R129 and R136. The drain of Q8 obtains DC from R136. Feedback is from a tap on L1, which is fed to the source of Q3 via C42. Capacitor C40 and resistor R130 couple some output from the VCO to buffer amplifier circuit Q9–Q10, made up of R132, R133, R134, and C34 and C35. Inductors L2 and L3 and capacitors C33, C32, and C31 make up an RF output network and harmonic filter for the buffer amplifier. Resistors R139, R140, and R141 ensure proper termination of this network and feed RF to the antenna. Resistors R135 and R138 make up a regulator circuit to feed regulated 5.6 volts to the buffer amplifier. In case of synthesizer malfunction, a DC level from the synthesizer IC is fed to R131 and cuts off the buffer, killing the RF output and reducing the possibility of transmitting outside the FM band.

Frequency Control. Voltage from the PLL chip phase/frequency detector tunes the VCO. The PLL chip (IC9) is a Motorola MC145170-2. Inside this chip, a sample of the VCO signal is compared with a reference frequency. If they are not in phase and frequency agreement, an error voltage is generated. This is used to change the tuning voltage on the VCO to achieve frequency and phase agreement (lock). Resistor R126 and capacitor C43 feed a sample of the VCO signal to amplifier Q7. Collector resistor R115 biases Q7, and the signal to drive IC9 appears across it. Capacitor C44 couples this signal to chip IC9. Integrated circuit IC13 generates a clock signal at 4.000 MHz via XTAL1, trimmer C49, and C50. Capacitor C49 is used to adjust the frequency to exactly 4.000 MHz, which is used both as a reference signal for the PLL synthesizer and for microcontroller IC8. Two sections of IC13 are used as buffers to provide this signal to IC8 and IC9.

The synthesizer frequency depends on several data words programmed into IC9. The needed data words are provided by IC8, a PIC16F84 microcontroller. This microcontroller has built-in software to program IC9 and to manage other tasks, such as the control of the frequency display and scanning the keypad for frequency entry. Other functions necessary are system shutdown in case of malfunction, rejection of out-of-band frequency entries, and automatically setting to the last transmitted frequency upon power-up.

When a valid frequency is entered, a voltage appears at the phase-detector output pin (13) of IC9. This voltage is fed to network R118, R119, R120, and C46. This network determines some of the loop characteristics of the synthesizer. The output of this network is fed to op-amp IC10 and then to tuning varactor D4. At lockup, this will be a steady DC voltage, varying from 3–4 volts at the low end to as much as 10 volts at the high end of the FM band.

In case of loss of lock, IC9 produces pulses at pin 11. These pulses are integrated by R114 and C48. The DC voltage turns on Q6, placing 5 volts across R113 and R112 and D6. This sequence sends a voltage to the unlock indicator LED, D201, and cuts off the RF buffer via D6 and R131. In addition, the rising voltage is coupled to the base of Q5 via R142 and C51, turning on Q5 momentarily. This action causes Q5 to conduct, resetting the microcontroller via R108 and resetting network D5–R107. Capacitive coupling is used to couple the signal to Q5 so as not to permanently reset the microcontroller; otherwise, a lockup condition will occur. Normally, resetting will be a sufficient cure if the problem is incorrect frequency entry or a "glitch," as resetting the microcontroller will reprogram IC9 with the correct data. During this process, the RF output is disabled.

Modulation is achieved by applying baseband audio from R61–C17 to varactors D3 and D4. This allows better modulation and fewer compromises than if audio were applied to the tuning varactor D3 alone. Integrated circuit IC7 provides a regulated 12 volts to the PLL and helps filter out any noise disturbances appearing on the power supply.

The audio section is supplied with 12 volts regulated from IC6, and IC11 supplies 5 volts to the microcontroller, display logic, and PLL synthesizer IC. The use of separate regulators for audio and digital functions helps to reduce circuit noise. DC input to the MPX 2000 should be between 15 and 20 volts to allow sufficient headroom for the regulators, keeping dissipation within reasonable limits. (This can be reduced a few volts with low dropout regulators). Care must be taken to use a wall transformer that is adequately filtered so that the input voltage waveform to the MPX 2000 never gets below 15 volts. With less than 15 volts input, there will not be sufficient DC voltage to allow full VCO swing; and some of the 88–108-MHz tuning range will be lost at the high-frequency end. Also, adequate RF decoupling of the DC supply is needed to reduce the possibility of RF-induced ground hum on the transmitted signal. RF chokes may be needed in both power leads in certain situations.

Display-Board Design. Let's discuss the display-board circuitry (refer to Fig. 3 for schematics). This board contains a 4 × 3 matrix of touch switches arranged in 4 rows and 3 columns, a 4-digit LED multiplexed display, and the bar-graph LED and its associated driver, an LM3914 (IC204). In addition, three other LEDs that serve as overmodulation (D202), PLL unlock (D201), and SCA subcarrier ON (D203) are also on this board. The keyboard is polled periodically by the microcontroller for switch closure by applying a logic level to a row and looking to see if this level appears on one of the three columns. Each switch has a unique row and column location; and the switches are scanned sequentially, 1 through 10 (10 is represented by zero). There are two other keys, E (enter) and CE (clear entry). The desired frequency is entered, most significant digit first. Since we have four digits, the most significant digit is zero for frequencies below 100.0 MHz. This zero does not have to be entered, but it is recommended. This eliminates possible "glitches" or entry errors and fully clears the keyboard memory. When the first entry is made, two zeros appear on the display to the left of the entered digit. The leftmost is blanked on leading zeros. For example, 99.5 MHz will be displayed as 995 instead of 0995.

No changes are made in the PLL programming or the transmit frequency until the enter key is pressed. The digits appear on the display as they are entered and shift right to left. If more than four digits are entered, the leftmost will be shifted out. After the display shows the desired frequency, the E key is pressed. If it is a valid (legal FM channel) entry, the display retains it, the PLL shifts the transmitter frequency to it, and it is also stored in memory. It will come up when the MPX 2000 is powered up the next time. If an illegal entry (<88.1 or >107.9) is made, the microcontroller rejects it and simply reverts to and displays the current

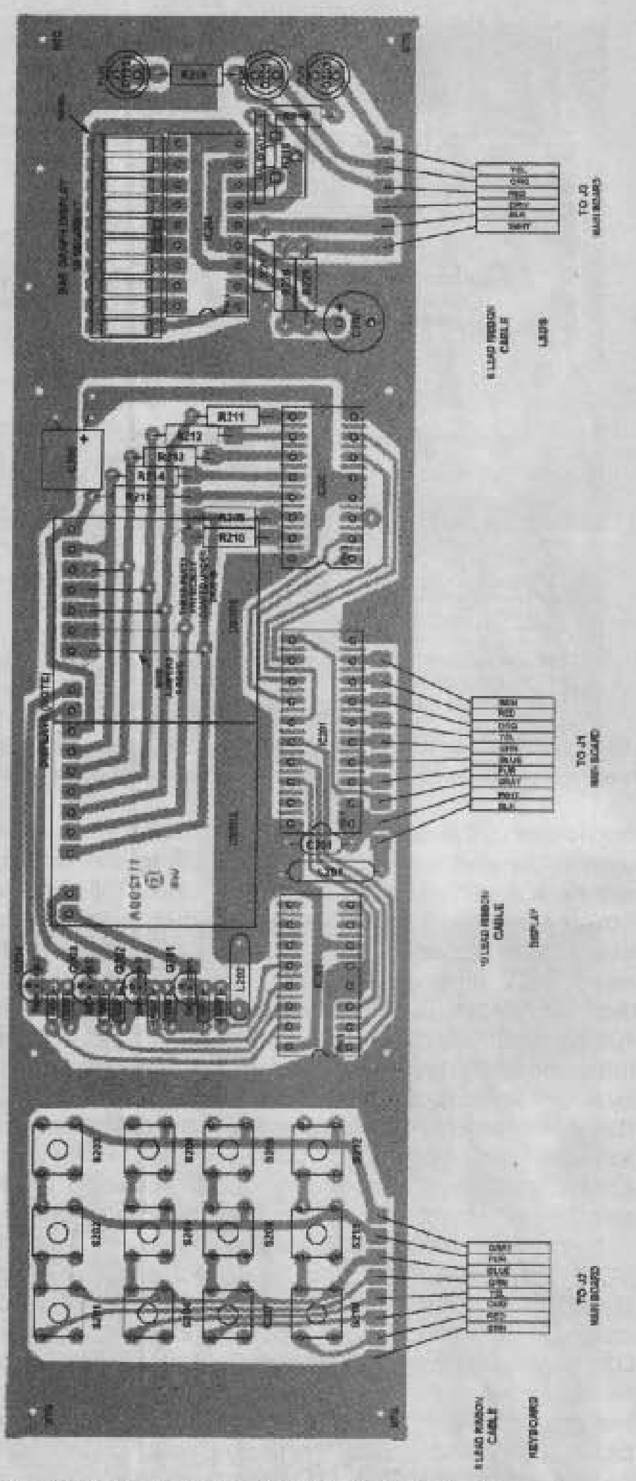


Fig. 9 This parts-placement diagram shows the display-board components' location. Pay careful attention not to apply too much stress on the cable ribbons.

frequency. If an error is made during entry, press the CE key and the current frequency once again appears. When the MPX 2000 is powered down, the current frequency is retained in memory and reappears on the next power up. No memory backup battery is needed for the microcontroller.

The display section is a conventional 4-digit multiplexed display using four seven-segment common

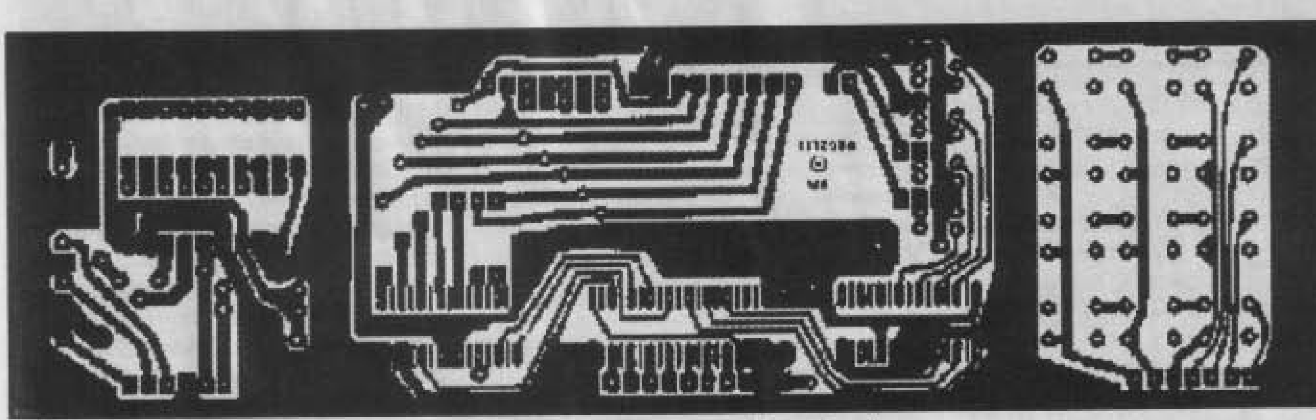


Fig. 10. Here is the display-board foil pattern. The display board is exactly half the size of the main board.

anode LED digits, driven by a 7447N TTL driver IC. Resistors R209 to R215 are current-limiting resistors for the individual segments. No decimal point is used in this display. There are eight logic inputs from the microcontroller, and those feed a 74HC573N 8-bit latch IC201. The digit data is latched into the 74HC573N by a strobe pulse from the microcontroller at the appropriate time, and this data contains the binary value of the particular digit and its position on the display. A 74HC138N decoder decodes the digit-select information, and its output turns on one of four 2N3906 switching transistors Q201–Q204, via bias resistors R201–R208. Inductors L201 and L202, along with capacitor C206, are noise-suppression chokes to reduce switching noise. The display segments are operated at 20 mA each and if an 8 is shown, 140 mA must be switched by the 2N3906 associated with that digit. Chip capacitors C202–C205 slow down switching speeds to further reduce noise spikes .

While an LED display can be noisy and can consume a lot of current, it is much brighter, has more eye appeal, and is easier to read than an LCD. LED readouts need no illumination. The display is shut down by the microcontroller about 15 seconds after the last keypad press, cutting off the display multiplexing and leaving a few segments lit on the least significant digit to serve as a power on indicator. This approach eliminates residual switching noise generation and conserves current. The display can be awakened by pressing the zero key to check the current frequency setting. It will stay on for 15 seconds and go back to sleep.

The display and multiplexing could have been handled directly by the microcontroller without the three ICs. However, the software overhead would be larger, and the current for the LED display would be too much to be directly handled. This approach was tried, but there were problems—the display was too dim, performance of the microcontroller was a little slow, and some additional "glue" circuitry was needed because of the limited number of pins available on the PIC16F84. In cases like this, a "hardware versus software" tradeoff has to be made. The hardware multiplexing approach was used here as it gave the best results. A larger microcontroller could also have been employed, but this was not investigated.

The bar-graph display is conventional and uses a LM3914 linear bargraph driver (IC204). DC input from the main board is applied to pin 5 of IC204, and the sensitivity is determined by the setting of R218. Approximately 0.8 volts DC is needed to light all ten segments of LED display DS202. Resistor R218 is set so that ten segments light when the main board audio system is producing full audio level just short of limiting. This represents 100 percent modulation. Resistors R220 and R221 limit power dissipation in IC204, and C207 bypasses the V_{CC} line to the display. LED D201 is fed from the unlock detector on the main board. When it is illuminated, it indicates that the PLL is unlocked. LED D202 is powered from the main board and is illuminated when audio clipping occurs, indicating over modulation. LED D203 is used to indicate that the optional SCA audio-subcarrier system is activated.

The MPX 2000, once programmed to a desired frequency, will operate without the display board, since its functions are mainly supervisory. The board may be disconnected during operation with no effect on the transmitted FM signal. However, it is needed for reprogramming of frequency.

Overall power requirements of the MPX 2000 are 15 to 20 volts DC at 350 mA. The display consumes much of this current. If the display is asleep, the current is about 160 mA. When the display is disconnected from the main board, current consumption drops to 125 mA. Operation below 15 volts is not recommended unless low-dropout regulators (LM2930, etc.) are substituted for the LM7812s used here. Operation above 20 volts may cause overheating of the 5-volt and 12-volt regulator ICs. Heatsinks should be fitted to these ICs if operation over 20 volts is expected. The DC input is polarity protected by D1 and accidental polarity reversal will do no harm; the MPX 2000 simply won't operate and won't draw any current until the supply polarity is corrected.

Construction. Although the MPX 2000 PC boards aren't difficult to assemble for someone with a little experience, it is important to follow a certain assembly sequence to avoid mistakes that could lead to hard-to-find problems. In particular, a number of through-hole connections (vias) are required to connect traces on both sides of the board.

Plated-through boards are great

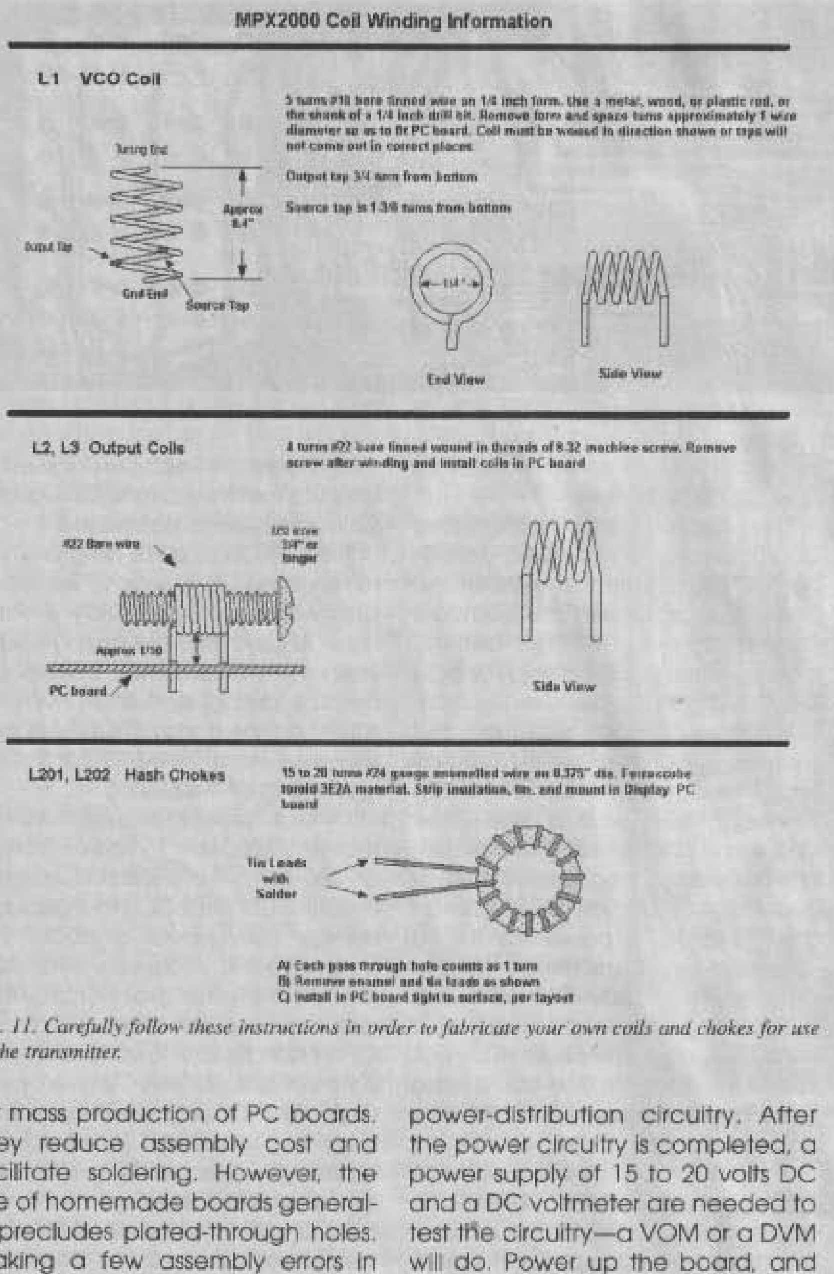


Fig. 11. Carefully follow these instructions in order to fabricate your own coils and chokes for use in the transmitter.

for mass production of PC boards. They reduce assembly cost and facilitate soldering. However, the use of homemade boards generally precludes plated-through holes. Making a few assembly errors in constructing any new project is expected. If you must remove a component from a plated-through board, you will find it very difficult and will probably ruin the component and the PC board, as well. That is why we do not recommend the use of plated-through PC boards in this project.

The boards are best assembled and tested circuit by circuit. First, the main board can be prepared, using Figs. 4 and 5 as references for the PC-board foil patterns. Figure 6 and Fig. 7 can be used as guides for component placement on the main board. Build one section at a time, starting with the installation of jumper vias and the parts for the power-distribution circuitry. After the power circuitry is completed, a power supply of 15 to 20 volts DC and a DC voltmeter are needed to test the circuitry—a VOM or a DVM will do. Power up the board, and using the meter check the continuity of the power-distribution circuitry. Next, the audio (MPX) circuitry can be assembled and tested. If these test results are OK, the display board should then be assembled. At this point, the main board will have the microcontroller section installed; and this can then be tested together with the display board if desired. After this is done, the RF circuitry can be assembled. Now, the entire MPX 2000 can be checked out. At this time, the project will be operational. There are no critical adjustments to be made, and it should work the first time with the default settings given in the assembly procedure that follows, assuming that there are no mistakes.

While it is possible to simply "stuff" the PC boards and wait until after completion of assembly for testing, this is not recommended unless you are *very* experienced.

After completing the power-distribution circuitry, install all vias and any parts that connect to them—the regulators and DC power supply filtering and bypassing components. Check your work and make sure all connections are soldered. Connect +15 to +20 volts DC to D1 (positive lead) and the negative lead to ground on the PCB. Check for the following voltages. All voltages assume that the regulator ICs supply an exact 5 or 12 volts. Since they have a 5 percent tolerance that is acceptable for this application, remember to allow for this if the voltages are a little low or high, as they will be dependent on exact regulator voltage. Consult the parts-placement diagram for the physical location of the test points as needed. Table 1 is a list of voltages to check.

Next, inspect all V points (see parts-placement diagram) to make

TABLE 1

• Junction C26, C27, D1 (Input)	+15 to +20 V_{DC}
• Junction C28, IC6, IC11, IC12, IC7	+14.4 to +19.4 V_{DC}
• V31	+5.0 V_{DC} ±5%
• V1	+12.0 V_{DC} ±5%
• V6	+6.0 V_{DC}
• Wiper, R40	+6.0 V_{DC}
• Junction R74, R75, C53	+7.25 V_{DC}
• Junction R76, R77, C55	+4.75 V_{DC}
• Junction IC7, C30	+12.0 V_{DC}
• Junction IC12, C36	+5 to > +12.0 V_{DC} (Should vary with R138. Set for +5.6)

sure they are soldered and a clean contact exists between the traces on both sides of the board. The purpose of these tests is to make sure that all sections of the PC board will get DC power and that all signal traces are intact. Then, install the audio and MPX generator circuit components.

Audio And MPX Generator Benchcheck. Apply +15 to +20 volts as before to the DC input and check for the following voltages (Table 2). It is assumed that all voltages that you obtained were as specified in the first checkout of the PC board, before the audio components were installed. Ten percent tolerance is OK. Preset all potentiometers—except R138—to the center of rotation.

TABLE 2

• Q1 and Q2 Collector	+3.6 V_{DC}
• IC1 Pin 4	+12.0 V_{DC}
• IC1 Pins 1, 7, 8, 14	+6.0 V_{DC}
• IC2 Pins 1, 4	+3.1 V_{DC} (varying with R40)
• IC2 Pins 2, 3	+2.4 V_{DC}
• IC2 Pins 8, 10	+5.9 V_{DC}
• IC2 Pins 6, 12	+8.5 V_{DC}
• IC2 Pin 5	+1.2 V_{DC}
• IC3 Pins 1, 7, 8, 14	+6.0 V_{DC}
• Q4 Collector	0 V_{DC}
• Q3 Collector	+12.0 V_{DC}
• Q3 Emitter	+1.5 V_{DC}
• Junction R67, R68, R78, C21	0 to +0.2 V_{DC}
• IC5 Pin 16	+7.5 to +9.0 V_{DC}

Next, set R40 so that the voltage between pins 1 and 4 of IC2 is zero. Make this adjustment with the most sensitive scale on your meter to as low as 1 mV, if possible. Using a scope and audio generator, you can apply a 1-volt peak-to- peak audio signal to the L and R inputs and trace the signals through the circuitry. This is excellent for uncovering any errors—so far. Using a source of stereo audio—such as a CD player, cassette player, or a stereo receiver—you can trace the signals through the circuitry with an audio amplifier and speaker. You will not be able to hear the pilot and the subcarrier signals (unless you are a cat or a dog), as they are above the audible range of frequencies. Refer to the waveform diagram (Fig. 8) for audio waveforms. Adjust R7, R40, and R55 as needed to get these waveforms. If you don't have the test equipment for this procedure, then leave all potentiometer adjustments where they are. If the DC voltages were all correct and your assembly is error free, all should be OK so far.

Construction Of The Display Board. The display board consists of three separate circuits: the keypad, LED display circuitry, and the bar-graph metering and status LEDs (see Fig. 9 and Fig. 7). These should be tested in conjunction with the microprocessor section, but some initial tests can be made on this board without it. This board is single sided and the foil pattern is shown in Fig. 10.

Insert the 12 touch switches that make up the keypad. If you like, you can check out the keypad with an ohmmeter to see if continuity exists between a row and column when the corresponding switch is pressed.

Next, assemble the display section (center of display board). Make sure that you first install the jumpers below the site for the LED displays. You can use low profile DIP sockets here if you wish to avoid soldering the ICs directly onto the PC board. Now, install LED assembly DS201. This consists of two identical 2-digit subassemblies. Next, fabricate and install hash chokes L201 and L202. These are not critical as to inductance, and 15 to 20 turns will be OK.

Install a 20-pin socket where DS202 is to be located. This socket MUST be used so the top of DS202 will be at the same height as DS201. Then plug DS202 in the socket making sure the rounded corner or pin 1 indicator faces the corner of the PC board. No harm will be done if DS202 is inserted backwards, except that DS202 will fail to light.

Next, install IC204, the LM3914N BG driver chip. You can use a DIP socket if you wish, as before. Install LEDs D201, D202, and D203, making sure to observe polarity. Also make sure the tops of these LEDs are the same height as DS201 and DS202. This completes the display-board assembly.

Microcontroller And Logic. First, install ten-pin header (J1) and eight-pin header (J2) as shown in the display-board parts-placement drawing. Make sure V32 and V33 are well soldered, as you will not be able to get at them after this step. Next, apply DC power to the board as before and check for +5 volts on the J1 pin shown. Remove DC power and allow a minute for the capacitors to discharge. Then, install the programmed PIC16F84 microcontroller and all related parts. The microcontroller must be programmed with the appropriate software in order to operate properly. If you are building this project from scratch, you will have to do this for the project to work. Refer to the books and data sheets published by Microchip Corporation to see how this is done. You can write your own software or, if you prefer, a preprogrammed microcontroller can be purchased from the source mentioned at the end of this article.

Make sure to install an 18-pin socket at IC8. This is required to allow easy removal of IC8 so that future changes can be made to the internal operating software if needed. You may also install a DIP socket for IC13, but this is optional. The display board can be connected to the main board using ribbon-lead cable of the kind used in PC internal cabling, and this is recommended. You can use Molex or similar connectors with 0.100-inch spacing to plug directly into the headers on the main board. However, installing these connectors generally requires a special crimp tool. Alternatively, you can use solder-type connectors or "press on" types. Check out a computer parts catalog for suitable connectors.

Connectors are not absolutely needed, although it does make testing easier. However, it takes time to install these connectors and may not be worth the time and effort to do it. Once the MPX 2000 is assembled and packaged in a case, these leads will not usually have to be disconnected again. You can check out the microcontroller section now, but it requires wiring it to the display board and disconnecting it again. If the wiring is correct, there is little to go wrong here.

PLL And RF Section. This section is the last to be assembled and when completed, the MPX 2000 PC boards will be ready for final testing and installation in a case of your choosing. Once again, refer to Fig. 6 for parts-placement information. First, install all the resistors and then the capacitors, followed by transistors Q5 through Q10 and all the diodes. Next, install remaining ICs—IC9 and IC10. Again, you can use low-profile DIP sockets for IC9 and IC10, if you wish. Make sure to observe correct IC orientation. The final step is the fabrication of L1, L2, and L3. Inductor L1 is five turns of #18 tinned wire wound around a ¼-inch mandrel. The coil (L1) is installed in the PC board with the turns spaced evenly so it fits the PC board. A tap consisting of a short wire lead soldered to the appropriate point on the PC board is then connected to the first turn of the coil as shown in Fig 11. Inductors L2 and L3 are made from four turns of #22 bare tinned wire, wound using the threads of an 8-32 screw as a mandrel. They will look like small springs when completed—the screw controls the dimensions, so you cannot go wrong. Shape the leads as shown in Fig 11. Remove the screw and install the coils in the PC board. Make sure no adjacent turns short together on L1, L2, or L3. Next, check over all work done so far for any errors. You are then ready to do final testing. The display board must be connected to the main board first.

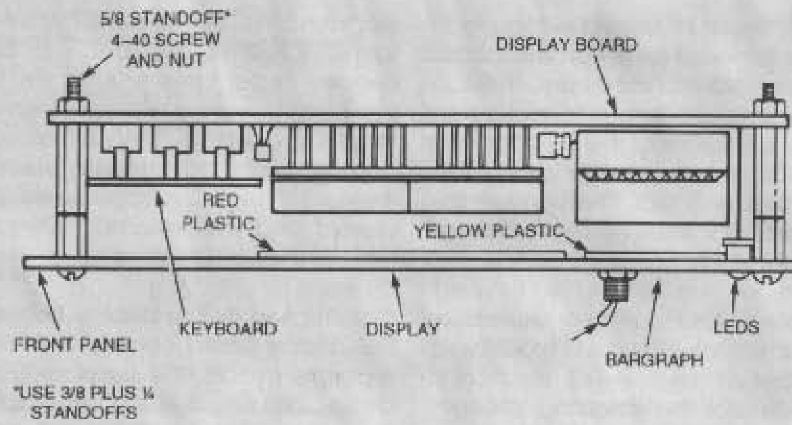


Fig. 12. Here is the front-panel design used by the authors. The container should provide adequate space for the boards to fit snugly, yet without crimping the various cables connecting the display to the main board.

After installing all components, make sure that the ICs, diodes, and capacitors are correctly oriented. Power up the board as before and note the following:

Bar-graph display DS202 should momentarily flicker and then go out; this is normal and a good sign that things are working. The frequency display should light and either show a valid FM station frequency or three zeros. The left-most (MSB) digit is zero blanked and will not display a zero. Next, examine the keyboard layout in the display-board parts-placement diagram. It is pretty standard. Now, enter an eight, which should display as the right digit. Enter another eight, and now the two right digits should show "88." Enter a one. The display should show "881." Press the E (enter) key. The display should still show "881." Next, remove DC power, and after about ten seconds reconnect power. The display should light up "881." Try entering each digit—1-9—in sequence. The newly entered digit should appear on the right and move left as new digits are entered; the fourth digit will disappear off the left side as new digits are entered. Press the E key, and unless the display is showing a frequency between 881 and 1079, the display will revert to 881 or whatever valid frequency it previously showed. To reject an entry, press the CE (clear entry) key; and the display will show the previous valid frequency.

Try entering a few valid FM frequencies, each time pressing the E key after frequency entry. Removing power and re-powering should result in retention of the frequency in memory. If the frequency displayed differs, try re-entering all four digits (i.e. 0995 for 99.5 MHz instead of 995). The leading zero is needed and does not show.

It sometimes happens that a 1 is retained in memory when a frequency of 100 MHz or more was previously entered. Entering a new frequency less than 100 MHz may not erase the fourth digit and the 1 will be retained, confusing the microcontroller. This is not a fault, but a result of suppressing the leading zero for purely aesthetic reasons, making the operator forget that it is still really there. It is best to enter 0883 rather than 883, for example, especially if the previous frequency was 100 MHz or higher. When you are done, enter "0981" as this will be needed for later testing. If all works as specified, you can assume that the microcontroller and display circuit are OK.

Next, apply an audio signal of about 1-volt p-p to the L input. The bar-graph indicator should show several lit segments. Adjust R218 on the display board so all ten segments light. Then increase the signal about ten percent and adjust the potentiometer R68 on the main board, so that D202 on the display board (to the right of DS202) just lights. Reduce audio drive and D202 should extinguish, with DS202 showing fewer segments lit as the audio input is decreased. This checks out the metering circuit.

PARTS LIST FOR THE MPX 2000

SEMICONDUCTORS

IC1—TL084N quad op-amp
IC2—MC1496N balanced modulator/demodulator
IC3—MC1458N dual high-performance op-amp
IC4, IC13—74C00N quad 2-input NAND gate
IC5—CD4040BE 12-stage binary/ripple counter
IC6, IC7—LM7812 12V voltage regulator
IC8—PIC16F84-04 programmable microcontroller
IC9—MC145170-2 PLL synthesizer
IC10—TL081N JFET op-amp
IC11, IC12—LM7805N voltage regulator
IC201—74HC573N
IC202—74HC138N
IC203—7447N BCD-to-7-segment decoder/driver
IC204—LM3914N voltage-level indicator
Q1-Q3, Q5—2N3904 NPN RF-AMP DRIVER
Q4, Q6, Q201-Q204—2N3906 PNP RF-preamp
Q7, Q10—2N3563 IF-amp
Q8—MPF102 JFET N-channel amp
Q9—MPS3866 or 2N3866 oscillator, amp driver
D1—1N4007
D2—Not used
D3—MV2103 or equiv.
D4—MV209 or equiv
D5-D14—1N914B or 1N4148
D201—T1 ¾ red LED
D202—T1 ¾ yellow or orange LED
D203—T1 ¾ green LED
DS201—Seven-segment 2-digit display
DS202—Ten-segment bar-graph

RESISTORS

(All resistors are ¼-watt, 5% units unless otherwise noted.)
R1, R2, R14, R15, R32, R112, R117, R124, R131—4700-ohm
R3-R6, R28, R29-R31, R33-R36, R45, R51, R54-R57, R62-R64, R66, R67, R70, R104-R107, R111, R118, R128—10,000-ohm
R7, R40—10,000-ohm potentiometer
R8, R9, R18, R19—47,000-ohm
R10, R11, R58, R65—15,000-ohm
R12, R13—9100-ohm
R16, R17, R44, R48, R69, R100, R101, R102, R103, R123, R125, R132, R216—1000-ohm
R20-R23, R37, R38, R109, R127—100,000-ohm
R24, R25—39,000-ohm
R26, R27, R50, R121—22,000-ohm
R39, R41—68,000-ohm
R42, R43, R52, R53, R71, R114—2200-ohm
R46, R47, R133—3300-ohm
R49, R119, R217—220,000-ohm
R55—25,000-ohm potentiometer
R59, R122—33,000-ohm
R60, R116—6800-ohm
R61, R138, R218—1000-ohm potentiometer
R68—100,000-ohm potentiometer
R72, R126, R130—220-ohm
R73—1500-ohm
R74, R77—390-ohm
R75, R76, R108, R136—100-ohm
R78—470,000-ohm
R79, R110, R129—2.2-megohm
R113—330-ohm
R115, R135, R219—470-ohm
R120—330,000-ohm
R134—33-ohm
R139, R141—91-ohm
R140—75-ohm
R201-R208—2200-ohm, ¼ Watt
R209, R210-R215—150-ohm
R220, R221—56-ohm
R80-89, R137, R142-200—Not used

CAPACITORS

C1, C2—4.7-µF, 35-WVDC, electrolytic
C3, C4, C26, C27, C43-C45—.01-µF, 10%, 50V, Mylar
C5, C6, C16, C18, C22, C36—10-µF, 16V, electrolytic
C11, C19, C20, C21, C30, C51, C52, C59—1-µF, 50V, electrolytic
C12, C13, C35, C37, C38—.01-µF, 50V, GMV, ceramic-disc
C17—.0015-µF, 10%, 50V, Mylar
C23, C29—1000-µF, 16V, electrolytic
C24—2200-µF, 25V, electrolytic
C28—0.1-µF, 50-WVDC, Mylar
C31—47-pF, 5%, NPO, ceramic-disc
C32—120-pF, 5%, NPO, ceramic-disc
C33—68-pF, 5%, NPO, ceramic-disc
C34, C40, C43, C58—470-pF, GMV, ceramic-disc
C41—6.8-pF, NPO, ceramic-disc
C42—0.47- or 1.0-µF, 35V, tantalum electrolytic
C44, C201, C14, C15, C39, C50—22-pF, 5% , ceramic-disc
C46—10-µF, 6V, tantalum electrolytic
C47, C202, C203, C204, C205—0.1-µF, 60X120, 50V, chip
C48, C56, C57, C207, C7-C10—100-pF, 5%, NPO, ceramic-disc
C49—2-20-pF, trimmer, 7.5 mm
C53, C55—47-µF, 16V, electrolytic
C54, C206—470-µF, 6.3V, electrolytic

ADDITIONAL PARTS AND MATERIALS

S201-S212—Touch switches, momentary contact
L1, L2, L3—See text and figures
L201, L202—Ferrite toroid 3E27 Material
XTAL1—Crystal, 4.864 MHz
XTAL2—Crystal, 4.000 MHz
Connector, 0.1-inch, 10 pins
Connector, 0.1-inch, 8 pins
IC socket, 18 pin
IC socket, 20 pin
Label, Keyboard
3-feet #24 enamel wire
2-feet #22 tinned wire
1-feet #18 tinned wire
Ribbon cable, 8 inches, 24 conductor
PC board, main
PC board, display
Ferrite beads, 43 Material
4-40 × ½-inch BHMS
4-40 Hex Nut
4-40 Lockwasher

NOTE: The following items are available from North Country Radio, PO Box 53, Wykagyl Station NY 10804-0053; *www.northcountryradio.com*: A complete kit of parts, consisting of all items listed on the parts list. That includes drilled and etched main and display PC boards, preprogrammed microcontroller, all resistors, capacitors, diodes and LEDs, displays, transistors, integrated circuits and all miscellaneous parts as well as a detailed theory, assembly and test manual: $154.95 plus $5.00 for p/h in the US.

A complete case package that includes the plastic case (NC225) shown in the photo in this article, drilled and lettered front and rear panels, all connectors, and wire and cables as needed to finish the kit, as well as all necessary instructions, $39.95 plus $1.00 for postage and handling if ordered with the above parts kit or $39.95 plus $5.00 for postage and handling if ordered separately.

Collapsible 8-section whip antenna with BNC connector and right angle adaptor $14.00 plus $1.00 for postage and handling if ordered with the parts kit or $14.00 plus $5.00 for postage and handling if ordered separately.

PLEASE NOTE:
For shipment outside the US, please add $10.50 for the first item, plus $3.50 for each additional item ordered. NY residents must add 8.25% sales tax to the price of any of the above items.

Now repeat with audio connected to the R input. No difference should be noted, and no readjustment should be needed.

Final Test and Setup. You will need a VOM or DVM, an FM stereo receiver of some kind, and a source of line-level stereo audio. The MPX 2000 is designed so that 1-volt peak to peak (0.316 volts RMS sine wave) at the input will produce the required deviation, and the audio-input level should not exceed this figure. The input impedance is approximately 10k ohms. Power up the board and check the voltages in Table 3.

TABLE 3

• IC9 Pin 16	+5 V_{DC}
• IC10 Pin 7	+12 V_{DC}
• IC10 Pin 6	+3 to +12 V_{DC}
• Q5 Collector	+5 V_{DC}
• Q7 Collector	+1.5 to +3.8 V_{DC}
• D4 Center pin	+3 to +12 V_{DC}
• Junction D2, D3, R128	+12 V_{DC}
• Q8 Collector	+12 V_{DC}
• Q8 Base	+5 to +7 V_{DC}
• Q8 Emitter	+4.5 to + 6.5 V_{DC}
• Q10 Collector	+1.4 V_{DC}
• Q9 Emitter	+0.7 V_{DC}
• Q9 Collector	+5.6 V_{DC} (adjust R138 as required)

After this test, remove power from the MPX 2000. If any of the voltages were incorrect, you need to find the problem before proceeding further. If these voltages check out, you may proceed. Now, you can power up the MPX 2000. The numbers 981 should appear in the display and, if not, enter this frequency, as described before. On power up, the bar-graph display (DS202) and the unlock LED (D201) should both flicker and go out. Measure the voltage at TP1, pin 6 of IC10. It should be >3 and <11 volts. Now, enter a frequency of 107.9 MHz. When the E button is pressed, D201 should flicker and go out, indicating lockup of the PLL. The UNLOCK LED may take several seconds to extinguish. This is normal due to the long loop-time constants used. If D201 stays lit, check voltage at TP1. It may be 11 volts or higher. Spread the turns of L1 until this voltage drops below 10 volts and D201 goes out. Next, program in a frequency of 88.1 MHz. Check to see if D201 flickers and goes out. Measure the voltage at TP1. It will be around 3 to 3.5 volts. If D201 is still lit, compress the turns of L1 slightly until the voltage rises slightly and D201 goes out. Recheck at 107.9 MHz and 88.1 MHz until lock is obtained at both frequencies, indicated by D201 extinguishing. It is normal for D201 to flicker slightly when changing frequency. Should you be unable to get both 88.1 and 107.9 to lock up with one setting of L1, check to make sure you have at least 12 volts at the output of regulator IC7. If not, you can replace it or add a diode in the common leg of IC7 to raise the voltage slightly.

Once the PLL is adjusted, set up an FM receiver on 98.1 MHz or somewhere near this if 98.1 MHz is busy in your area. Enter this frequency into the MPX 2000. Then, D201 should extinguish after a few seconds, and you should hear a carrier in the receiver, as evidenced by the quieting of the receiver. Momentarily power down the MPX 2000—this is to confirm that the carrier is indeed coming from it and not from some other source. Restore power and the carrier should reappear in a few seconds when D201 extinguishes.

Next, connect audio to the L and R inputs. The bar-graph display should indicate something, and you should hear the audio in the FM receiver. The receiver's stereo indicator should be on, and the audio should sound like any other FM station. Make sure you do not apply excess audio, as this will cause distortion and degrade stereo separation. Adjust R55 for best separation. If you have access to an audio generator and scope, you can get an exact alignment by adjusting for the waveforms shown in the waveform diagram. Adjust audio-input level for best sound in the receiver without distortion and clipping. With this audio-input level, set R218 on the display board so that the LED bar graph shows all ten segments lit on the loudest audio peaks. Slightly increase input audio and adjust R68 so that the overmodulation LED D202 just flashes. Then back off the audio-input level so that it barely flashes on the loudest audio peaks. This sets the proper audio drive level.

Packaging. The MPX 2000 may be packaged in any suitable metal or plastic case. Remember that this is an audio device, and it also generates RF signals. For that reason, the use of shielded cables for audio input and RF output is recommended. Keep the display board as far as possible from audio lines and the main board, as it does generate some switching noise. Such noise could appear as buzz or hum on the transmitted signal until the display goes to sleep. Once programmed, the MPX 2000 will operate without the keyboard and LED frequency display as long as the frequency is not changed. We recommend that accessibility to the keyboard be limited to keep curious individuals from playing with the MPX 2000 and inadvertently changing frequency. This can be done with a removable panel or cover over the display. The LEDs indicating lock and modulation should be kept visible at all times to signal improper operation. Figure 12 can be used as a guide for front-panel design.

A good RF-ground and antenna system is essential in reducing RF-ground-induced hum, a problem with low-power FM transmitters. Simply using a wall transformer and a whip antenna plugged into the RF output jack might not provide adequate RF grounding. To check if hum is RF-induced, power the MPX 2000 from a battery. If this

(Continued on page 56)

lems with solder joints, but not to the extent of these.

Wrapup

That's all for now. Intermittent faults have been present since the days of the cat's whisker radio and will be with us until something replaces electronics in the high-tech world. Until then, we will have to deal with bad soldering and other similar problems. However, in most cases, they will yield to a systematic approach of inspection and testing. I welcome comments and suggestions in regard to this and previous Service Clinics (via e-mail to sam@repairfaq.org, please—I am not able to reply to snail mail, sorry).

DIGITAL DOMAIN

(continued from page 20)

legitimate products. Even so, MLM participants, called "distributors," typically make money less by selling products than by enticing other people to sell products. Distributors earn commissions of the sales of their recruits, and their recruits' recruits, and so on, with everybody scrambling to work their way up the pyramid where the big money supposedly is.

MLM has a bad reputation for good reason. The hype surrounding MLM is in direct proportion to its penchant for taking people for a ride. Most people wind up losing money on the cost of inventory, "educational" products, and travel, says Edwards. On the other hand, you can indeed use your personal computer and the Internet to help you make money from home, either full time or on the side, and many people do. Various statistics indicate that about one-third of Americans have a home office and that about one-quarter of these offices are used to support home-business activities.

Some do succeed at MLM, and if you want to explore it as a moneymaking opportunity, recommendations from friends or colleagues are best, says Edwards. Find a company selling products you find useful. Check out the company with the Federal Trade Commission and the Better Business Bureau. Your best bets for making money with the help of your PC are more mainstream pursuits, such as Web site creation, computer consulting, computer repair, and technical writing, says Edwards. He provides more tips at his Web site, at *www.homeworks.com*. Another good site, which offers particularly good advice about technology for those working in either home or small offices, is Smalloffice.com, at *www.smalloffice.com*. You may not get rich quick doing it the right way, but you won't lose your shirt either.

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COMPUTERS AND THE ECONOMY

Perhaps the days of a cashless society are still beyond our grasp, but over the past five years, more people are participating in trade over the Internet. Although society-at-large may not yet be cash-free, the Web has proven that money does not have to physically change hands in order to make profits. The so-called Information Revolution has produced new profit-yielding opportunities and careers for folks the world over. Cyberspace may be a cashless society bustling with trade, but it is still a far cry from utopia.

THE MPX 2000

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cures the hum, the problem is either a poorly filtered DC supply or RF induced hum. There is filtering built into the MPX 2000 so a pretty poor DC supply will be tolerated, but this is still not recommended. If improving the power-supply filtering does not help, the hum is most likely RF induced. In this case, you may have to experiment with antenna placement, grounding, and RF chokes in the power leads. A metal case is helpful sometimes, as it provides some shielding and grounding via its self-capacitance.

Final Words On FM Transmission. It is important to remember that the FM band is strictly governed by federal regulations in the US. Likewise, the use of transmitters also must follow certain guidelines. In keeping with Part 15 FCC requirements, the radiated field must be kept below 250 mV per meter at 3 meters (about ten feet) from the transmitter. The use of a six-inch whip antenna is recommended. If the receiver is close to the MPX 2000, no antenna at all will be needed. Sufficient signal will radiate from the PC board itself to be detectable, if a plastic case is used for packaging. In practice, this 250 µV per meter at 3-meter limit will permit good reception at 50 to 500 feet from the transmitter, depending on the receiver sensitivity and its antenna system. DO NOT connect any more length of antenna than you need, or you may invite an FCC citation.