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## A 200-Watt Push-Pull Class-E AM Transmitter for 1710 kHz

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Max Carter

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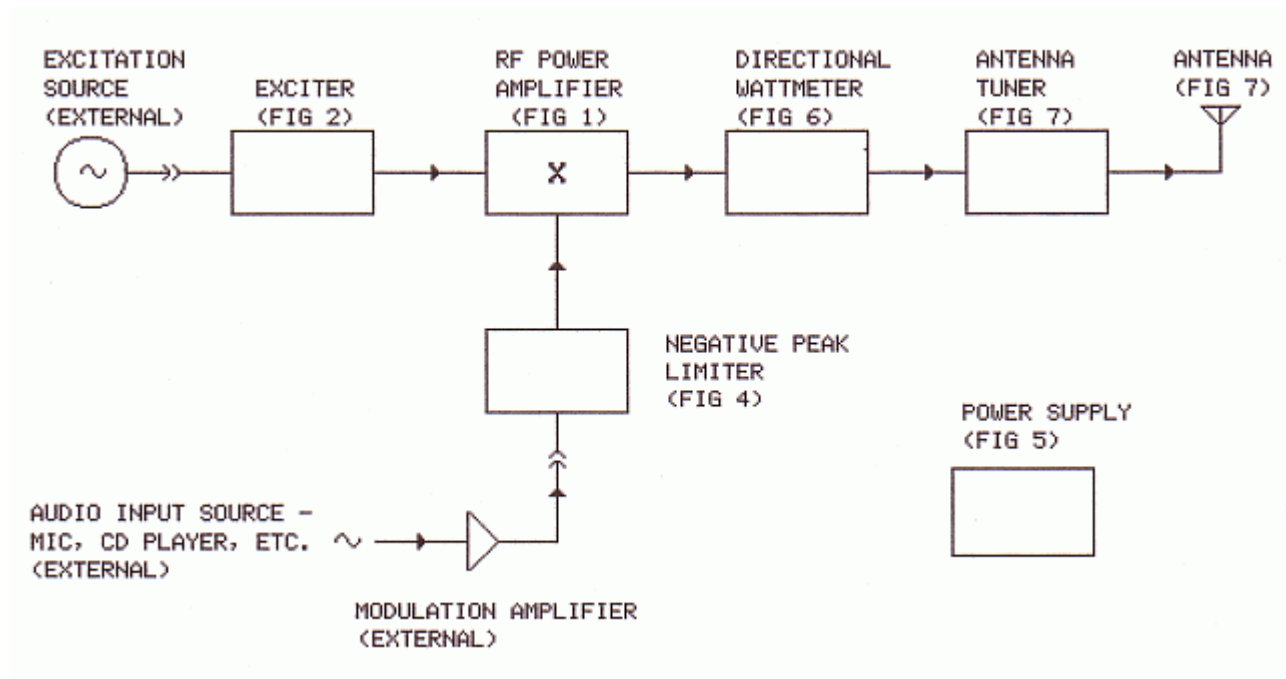
**Input power (DC volts x DC amps): 220 watts**  
**Output power (AM rating; into 50-ohm resistive load):**  
**about 205 watts**  
**Peak envelope power (PEP; at 100% modulation): 820 watts**  
**Operating frequency: 1.71 MHz**

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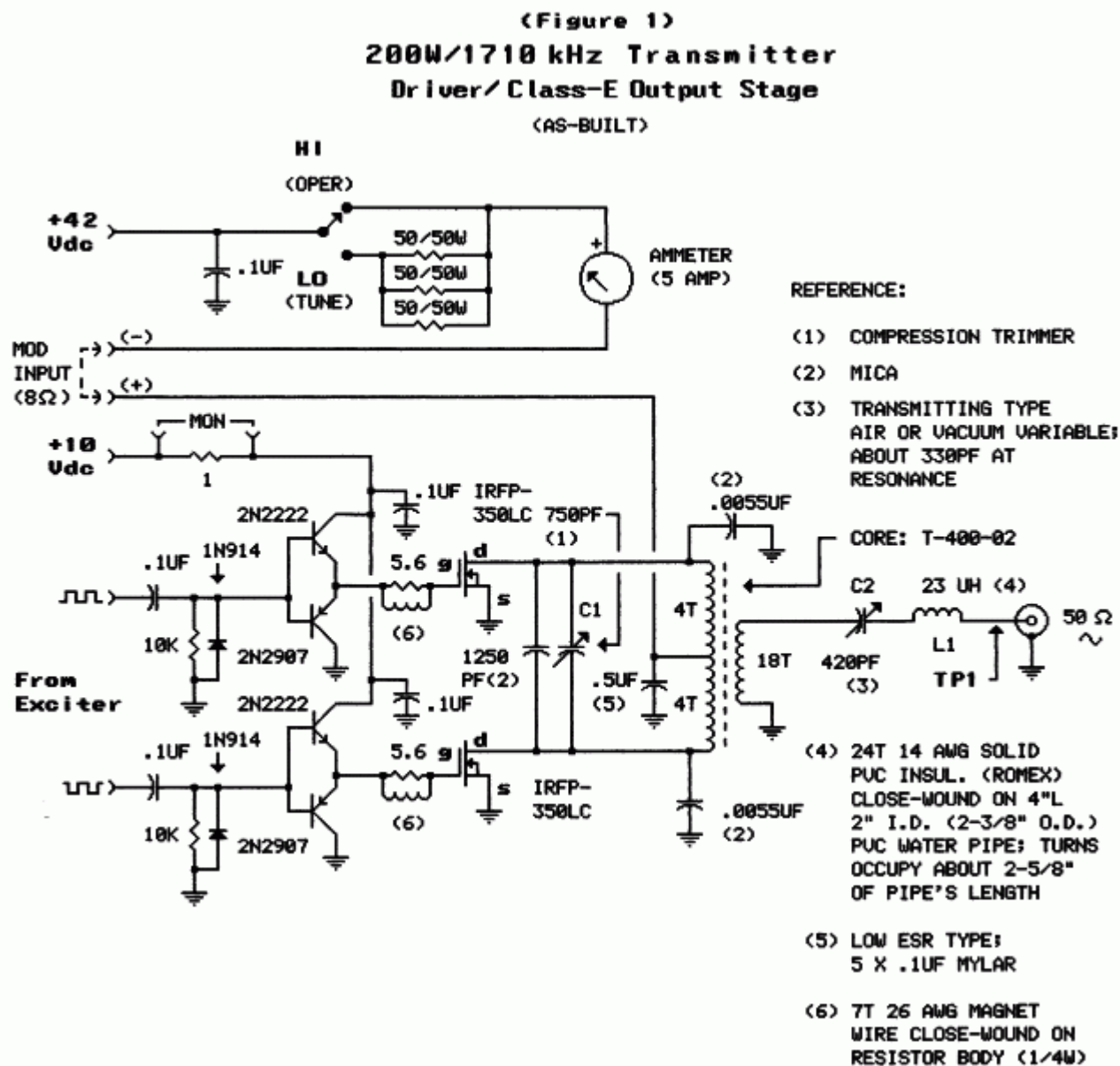
This transmitter is based, more or less, on equations presented in a 1988 Mark Mallory [article](#) detailing a single-ended class-E output stage for a 1-watt transmitter operating in the 160-190 kHz LowFER band. The present circuit is a push-pull design and achieves about 93% efficiency at 1710 kHz. The circuit should be adaptable to transmitting in the 160-meter ham band with slight component value changes, or to any frequency within the medium or longwave bands (0-2 MHz) by following the design steps given below. The 'as-built' transmitter can be tuned about 100 kHz either side of 1710 kHz (1600-1800 kHz) without modification.

The transmitter has the same basic layout as any AM transmitter, though it may differ in specifics. A block diagram of the as-built unit appears below. Refer back to this diagram as the parts are explained in the article below. Items marked "external" are not described (except in a general way) in the article.

### AM Transmitter Block Diagram



The transmitter's output amplifier circuit is shown in Figure 1:



The amplifier circuit consists of two of the Mallory circuits connected in a push-pull configuration with a coupling transformer acting as both the finals' tank inductance and output matching device. The push-pull configuration allows current sharing between two transistors while the transformer provides great flexibility in matching the amplifier to a load. The push-pull configuration also greatly reduces the second harmonic content of the output signal, lowering the demands on the output filtering.

The .0055 uF value for the capacitors tied to ground at the ends of the output transformer primary was determined from Mallory's equations, as was the inductance of the transformer

primary. The number of turns specified for the transformer primary winding was determined from the winding chart for the specified core.

The output power of Mallory's 1988 prototype was adjusted by selecting an appropriate tap on the final tank inductor. In a similar manner, the output power of the present unit (at the specified power supply voltage) is determined by the primary/secondary turns ratio of the output transformer. The 8-to-18 turns ratio shown on the schematic was selected to take full advantage of the current available from the power supply. To state it another way, the ratio shown adapts the final-stage 10-ohm output impedance to the unit's 50-ohm output feedline (load) impedance.

The output filter consists of the output coupling capacitor C2 and series inductor L1. This type filter satisfies the basic requirement for class-E operation: The final 'sees' the output load at the fundamental frequency only. Higher order harmonics are blocked and the filter presents a high impedance back to the amplifier stage at those frequencies. The output filter has a Q of 5.

The IRFP350LC MOSFETs in the final are low gate charge types (the 'LC' in the part number). This type has a reduced gate drive power requirement compared to 'standard' types. Additionally, class-E operation substantially cancels the 'Miller effect', a dynamic interaction between the FETs' drains and gates caused by inter-electrode capacitances, further reducing the drive power requirement. Adjustment of the 750 pF variable capacitor (C1) across the primary (between the drains of the output transistors), along with SYM and BAL adjustments in the exciter, serve to fine tune the transformer primary to achieve optimal class-E operation. After adjustment, two watts of drive power easily drives the final stage to its full 200-watt output.

The output transistors are mounted on a 5.5"x5"x1" aluminum heatsink. A small fan circulates air across the heatsink. The driver transistors are mounted on a small board mounted directly on the output transistor leads.

The push-pull drive signal for the power amplifier is developed by the exciter circuitry shown in Figure 2. This circuit's adjustability is the key to obtaining optimal efficiency of the class-E output stage:



## Construction

If you'd like to reproduce this transmitter, the components and values shown should work as advertised at 1710 kHz using a 42-volt power supply.

Fixed capacitors should be mica dielectric or low ESR type where indicated; the values shown can be made up with smaller-value units in parallel. C2 should be a transmitting type air or vacuum variable. The output transformer primary windings should be made with AWG 16 or heavier wire. The secondary should be of AWG 18 or heavier. Cores other than the one shown (the biggest one I could find) can be used with the number of primary turns recalculated (see below). The core material should be type-2 powdered iron.

The output transistors should be mounted to the heatsink with insulating hardware. The heatsink should be grounded.

A 160m version of the 200-watt transmitter can be built by following the schematic in all respects except for the following change: substitute .0044 uF capacitors for the .0055 uF units shown at the ends of the output transformer primary winding.

If you'd like to try the circuit at other frequencies or power levels first carefully read the Mallory [article](#), then decide at what frequency you'd like the transmitter to operate (usually in the range from 10 kHz to 2 MHz; see [frequency](#) below), at what power level (taking into account the available power supply voltage and current), and the required output load impedance (typically 50 ohms), then:

1. Calculate the inductor and capacitor values and load resistance per the [equations](#) given in the article. (Here's a [calculator](#).) The calculated inductance value will be for **both** sides (all windings counted) of the center-tapped primary. **Two** of the calculated capacitors will be installed.

### About the Calculations

The class-e equations assume a 50% duty cycle drive signal. Their application to this (or any) real-world transmitter circuit is a function of the switching characteristics of the transistors used in the circuit. Generally, as frequency is increased, gate charge times become an increasingly larger fraction of the *on* portion of the duty cycle. The result is a shortening of on-time as frequency is increased. (See also the [frequency](#) paragraph below.) The adjustable exciter (Fig 2) provides for duty-cycle adjustment during tune-up, compensating for this effect. The adjustable exciter also allows the designer to take some liberties with calculated component values.

*The calculated L value for the as-built transmitter is 1.07 uH. The calculated C value is 4829 pF. The installed value is 5500 pF.*

2. Consult the  $A_L$  [table](#) for the core selected and calculate the number of turns needed for the calculated inductance. (Calculate [here](#).) Round up to the nearest even whole number.

*The  $A_L$  value for the T-400-2 core in the as-built transmitter (from the table) is 185. The number of turns calculates to 7.6. That number was rounded up to 8.*

3. Calculate the primary/secondary turns ratio needed to transform the amplifier impedance (the load resistance determined in step 1) to the load impedance (50 ohms). The turns ratio is the square root of the impedance ratio, i.e.,

$$Z_p/Z_s = (T_p/T_s)^2. \text{ (calculator)}$$

All of the primary windings (both sides of the center tap - the number determined in step 2) should be counted when calculating the primary/secondary turns ratio. Multiply the primary turns by the turns ratio to determine the required number of secondary turns.

4. Wind the secondary, spacing the turns evenly around the

- core. Cover the secondary with electrical tape.
5. Wind the primary in 'bifilar' style over the secondary, spacing the turns evenly ([photo](#)). The total number of turns on the primary should equal the value determined in step 2. Divide that number by 2 and wind an equal number of turns on each side of the center tap.
  6. Calculate the values for L1 and C2. The reactances of these components should be at least 5 times the load impedance (i.e.,  $Q \geq 5$ ) at the operating frequency. ([LC calculator](#) | [coil calculator](#))

### Tune-up:

1. Establish a no-load condition on the transmitter by disconnecting any antenna or dummy load from the output connector.
2. Set the power level switch to 'low' and power the transmitter.
3. Monitor the DC voltage across the 1-ohm driver current monitor resistor; adjust C1 and the DELAY BAL and SYM controls on the exciter for MINimum driver current (<200 mA).
4. Connect an oscilloscope through 10x probes to the drains of the output transistors; verify dual 'class-E' [waveforms](#) at the drains. Peak amplitude (voltage) of the drain waveforms should be about 3 times the power supply voltage.
5. Shut off the transmitter and connect a resistive 50-ohm load (Bird Termaline or similar) to the output connector. Connect a 10x oscilloscope probe to TP 1.
6. Power the transmitter (still set to 'low') and adjust the output coupling capacitor (C2) for maximum amplitude of the output signal sinewave. Maximum purity of the output signal (prettiest sinewave) should occur at or near the point of maximum amplitude.
7. Set the power level switch to 'high' and readjust the output coupling capacitor as above. (Subsequent adjustments to C2 can be made with the unit's directional wattmeter - see below.)
8. All adjustments may be repeated at this time if you want, but little improvement will be obtained if the waveform requirement in step 4 was met. Strive for maximum output power, best signal purity, highest efficiency and lowest driver current. Minimum driver current is a secondary requirement. Driver current will be close to minimum in a correctly adjusted transmitter operating under load but not necessarily *at* minimum. Driver current should be around 175 mA at 1710 kHz and proportionately higher at higher frequencies. Note also

that, depending on the transmitter's physical layout, grounding and shielding, oscilloscope waveforms viewed at points *other* than TP 1 may be *unreliable* when the transmitter is operating under load.

The transmitter's final current ammeter and voltmeter should be used to check for proper loading on the output stage. The supply voltage divided by the current should equal about 80% of the load impedance calculated in design step 3 above (10 ohms for the as-built transmitter). Thus, for the unit's 42-volt power supply, the correct DC current is about 5.25 amps [ $42 / (.8 \times 10) = 5.25$ ]. Output power is calculated as follows:

$$P = (E_{pp} / 2.828)^2 / 50 \text{ (calc).}$$

The transmitter is tolerant of reactive (high VSWR) loads. Mismatches can be tuned out by adjusting the output coupling capacitor (C2). However, depending on the nature of the mismatch, the transmitter may not deliver the calculated output power in that situation. Remember that the transmitter's output power is limited only by the capability of the power supply. If the non-reactive (resistive) component of the load impedance is less than the amplifier's design load impedance, the amplifier will dutifully try to deliver the extra current, possibly overheating the power supply. If the load's non-reactive component is greater than the design impedance, the output power will be less than calculated. As mentioned, the amplifier can be designed to operate into almost any load impedance - refer back to construction step 3 above - but employing an external tuner, like the one shown in Figure 7 below, is usually a more practical approach to unusual or unknown impedance situations.

### **Pushing the Limits**

#### *Power:*

Input power of the presently built unit is limited by its power supply (42 volts@5.25 amps) to 220 watts in continuous (CW) mode, but the circuit components appear to be capable of at least twice that. The 16-amp continuous current, 64-amp pulsed current and 190-watt dissipation ratings of the IRFP350LC FETs used in the as-built unit suggest the design is capable of CW operation in the 500- to 1000-watt range when used with a suitably hefty power supply, heatsink and cooling fan. For AM service, 250 watts is about the limit. (Remember that a 250-watt AM transmitter must deliver 1000 watts, four times its rated power, on modulation peaks.) Limit the power supply voltage

to about 50 volts for AM service using an external modulation amplifier, or 100 volts for CW (or AM using a series-type modulator). If you want more power, increase the *current* rating of your power supply and calculate the output transformer primary turns and primary/secondary turns ratio to match. A possible substitution for the IRFP350LC is the IRFP360LC with twice the current handling capacity (and twice the drive power requirement) of the '350LC. Other transistors capable of higher voltages probably can be substituted in the circuit but I can't vouch for any in particular.

The T-400-2 core shown should be capable of power levels up to a couple of kilowatts, but if your design calls for more power, stack multiple cores for higher current capability. Stacking of cores will require recalculating primary turns per the cores' winding chart. Add the  $A_L$  values when stacking cores. For example, stacking 2 cores, each with an  $A_L$  value of 185, will result in a total  $A_L$  value of 370.

The output transformer should be wound with wire heavy enough to carry the expected current with minimal heating loss, as should inductor L1. Output coupling capacitor C2 likewise should be sized to handle the expected current and voltage. Consider using a vacuum variable for C2.

### Transmitting Capacitors

Capacitors in transmitter service are subject to much higher voltages than those encountered in typical consumer electronic equipment. To generate 200 watts in a 50 ohm load, for example, requires about 280 peak-to-peak volts. This is not the whole story however. The output filter of the 200-watt version of the class-e transmitter (L1 and C2) has a Q factor of 5. This means that the actual voltage across C2 is  $280 \times 5$ , or 1400 V<sub>pp</sub>. During modulation peaks, this voltage doubles to 2800 V<sub>pp</sub>. Prudence suggests a minimal rating of 5000 volts for C2.

### *Frequency:*

Class-E operation requires that final transistor switching take place during the part of the RF cycle when drain voltage is zero (see [article](#)). As frequency is increased, gate charge and discharge times become an increasingly larger fraction of the voltage-zero time. At some frequency above 2 MHz the gates of the specified IRFP350LC MOSFETs will not have time to charge and discharge sufficiently to fully turn on and off during the zero voltage window. At that point the circuit will no longer be operating in class-E mode and efficiency will begin to drop. Unfortunately for transmitter builders considering this transmitter for 80-meter operation, 200 watts in class-E mode at 3.5-4.0 MHz probably is not do-able with this circuit using the IRFP350LC. Would-be 80m builders might consider a 100-watt version, substituting type IRF740LC (lower current ratings, lower gate capacitance) for the '350LCs, or a 50-watt version using type IRF737LC. Experimentally bent builders might try different gate drive approaches, perhaps substituting high-speed MOSFET drivers, such as Microchip's TC1407, for the 2N2222/2N2907 circuits shown. [back](#)

### **Modulation**

The as-built transmitter is amplitude modulated by an external 8-ohm transformer-coupled audio power amplifier, salvaged from a public-address system, connected through the modulation input terminals shown in Figure 1. Audio amplifiers, tube or solid-state, meant for public-address service are ideal in this application since they are almost always of transformer-coupled output design. Before connecting the modulator to the transmitter, a check should be made with an

ohmmeter to make sure the output winding of the modulation amplifier is *floating* (i.e., not connected to ground). If there is a ground connection, it should be removed. Connect the terminal from which the ground connection was removed to the (-) modulation terminal on the transmitter. It may be easier to isolate the negative terminal of the power supply, in which case the modulator would be connected between the negative terminal of the power supply and ground (see Fig 3 below).

A modern solid-state linear or class-D audio power amplifier, perhaps meant for use in a high-fidelity home audio system or high-powered car stereo, can also be used as a modulator, but the amplifier output terminals must 1) be isolated from ground and 2) have very low terminal-to-terminal DC resistance (<0.5 ohm). If a check with an ohmmeter reveals that *both* of these conditions are met, the candidate amplifier can be connected directly to the transmitter modulation input terminals shown in Figure 1, otherwise it must be coupled to the transmitter through a transformer. A 500-watt (or larger) 120/120VAC isolation transformer is nearly ideal for this.

Note that the modulation transformer, be it the modulation amplifier's output transformer or the isolation/coupling transformer mentioned above, represents a DC resistance in series with the power supply and will thus subtract from the voltage presented to the final amplifier. For example, 5 amps through a 0.5-ohm transformer winding would produce a drop of 2.5 volts. Fortunately, an amplifier sufficiently rated to fully modulate the transmitter typically will have an output winding resistance low enough to produce negligible voltage drop. The output winding of the PA amplifier used with the as-built transmitter measures about 0.25 ohms.

### Core Saturation in Modulation Transformers

Core saturation occurs when the core's magnetic flux density is increased to a point where the iron in the core is fully magnetized and can support no further increase. At that point the transformer has reached the limit of its ability to transfer energy and signal clipping will occur. Modulation transformers are subject to saturation because the transformer core is being magnetized both from the alternating current (audio) flowing in the primary *and* the direct current (DC) flowing in the secondary (supplying operating DC to the RF amplifier). The problem of core saturation is avoided in modulation transformers by employing larger cores and/or cores with lower permeability.

The information needed to determine beforehand whether a given transformer will be subject to core saturation in a given transmitter - number of turns, core material, core cross-sectional area - is usually not known precisely when constructing with surplus parts, but this conservative rule of thumb seems to hold: Select a transformer weighing a minimum of 1/2 pound (0.23kg) for every 10 watts of transmitter power. For example, a 200 watt transmitter would require a transformer weighing at least 10 pounds (4.5kg). The rule applies to the modulation amplifier's output transformer, if one is in there, or to an external transformer.

When considering an amplifier's suitability for modulation duty, it's usually not practical to remove the output transformer and weigh it. In that case, use the rule's corollary: Select a transformer whose *volume* (H x W x D) is 3.2 cubic inches (50cm<sup>3</sup>) or greater per 10 transmitter watts. Fortunately, an audio amplifier sufficiently powerful to fully modulate a given transmitter will usually be equipped with a transformer of sufficient size for the job. The capacitor-coupled, modified Heising modulation method shown below avoids the core saturation issue altogether.

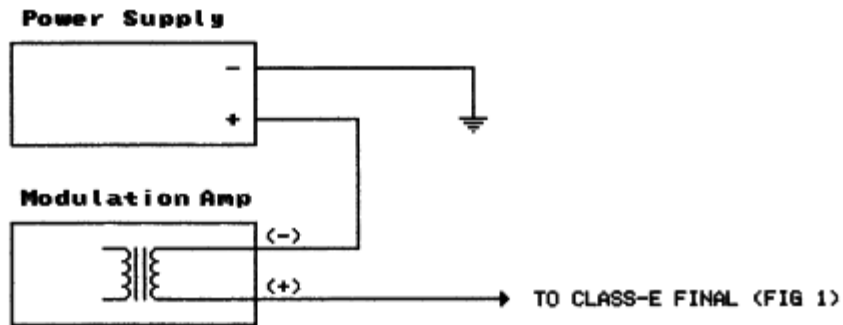
An alternate method for coupling the modulation amplifier to the transmitter is shown in Figure 5 below. Called 'modified Heising', this method does not require a floating, low-resistance amplifier output - and thus no transformer - but works only with the specific type of power supply shown in Figure 5. The options for connecting a modulation amplifier to the transmitter are summarized in Figure 3.

(Figure 3)

**Modulator Connection Options**

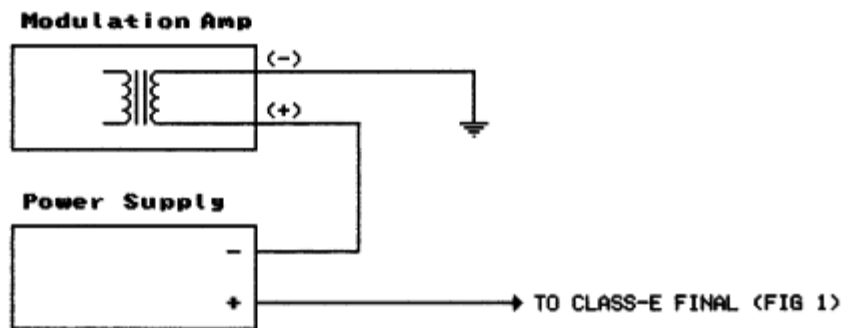
#1

**Non-Isolated Power Supply/  
Isolated Transformer-Coupled Modulation Amplifier  
(AS-BUILT CIRCUIT)**



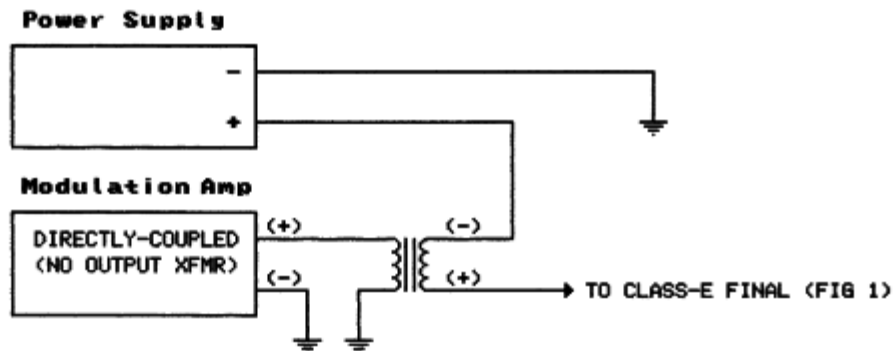
#2

**Isolated Power Supply/  
Non-Isolated Transformer-Coupled Modulation Amplifier**



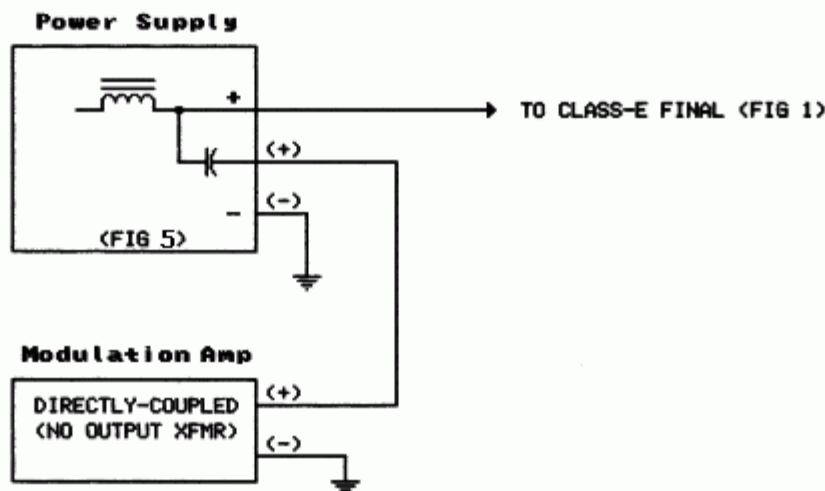
#3

**Non-Isolated Power Supply/  
Non-Isolated Transformerless Modulation Amplifier/  
External Isolation Transformer**



## 84

**Non-Isolated Transformerless Modulation Amplifier/  
Transformerless Connection (Modified Heising)**



*Modulator Power:*

As with any AM transmitter, in order to achieve 100% modulation, the modulation amplifier must be capable of RMS audio output power half that of the final RF amplifier's steady-state DC input power, and a peak (instantaneous) audio output power *twice* that value. Thus the as-built transmitter requires 110 watts RMS and/or 440 watts peak audio power from the modulation amplifier. The peak power specification is the more important of the two in determining if an amplifier is suitable for AM service at a given power level. Often the RMS power rating of an audio amplifier does not reflect the amplifier's true available peak power (which should be 4 times the RMS rating). The commercial PA amplifier used to modulate the as-built transmitter, for example, is name-plate rated at 150 watts RMS, but peaks at about 500 watts. While the amplifier will in fact deliver 150 watts as measured with a true RMS voltmeter, at the 150-watt level the output is clipped. The manufacturer has fudged the RMS rating. The "honest" RMS rating would be 125 watts. Still, the amplifier is adequate for the purpose of modulating the 200-watt transmitter.

The test for amplifier suitability can also be stated in terms of *voltage*, as follows: Peak-to-peak modulation (audio amplifier output) voltage under equivalent load must be equal to or greater than *twice* the transmitter's power supply voltage.

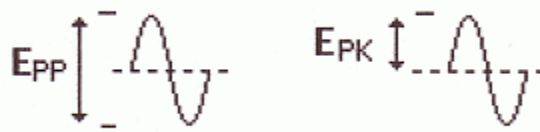
### How to Check Amplifier Power

Unless you are sure of the candidate amplifier's power rating, it should be checked under load with an oscilloscope for suitability. To check the amplifier, connect an audio tone generator (set to 1 kHz) to the amplifier's input, connect the output to a load resistor (8-ohm, 100-watt, for example), connect the oscilloscope probe across the load resistor, turn up the amplifier gain and read the scope. Set the gain to just below the clipping point and calculate amplifier output power as follows:

$$P_{\text{RMS}} = (E_{\text{pp}}/2.828)^2/R = (E_{\text{pp}})^2/8R$$

([calc](#))

$$P_{\text{peak}} = (E_{\text{pk}})^2/R$$

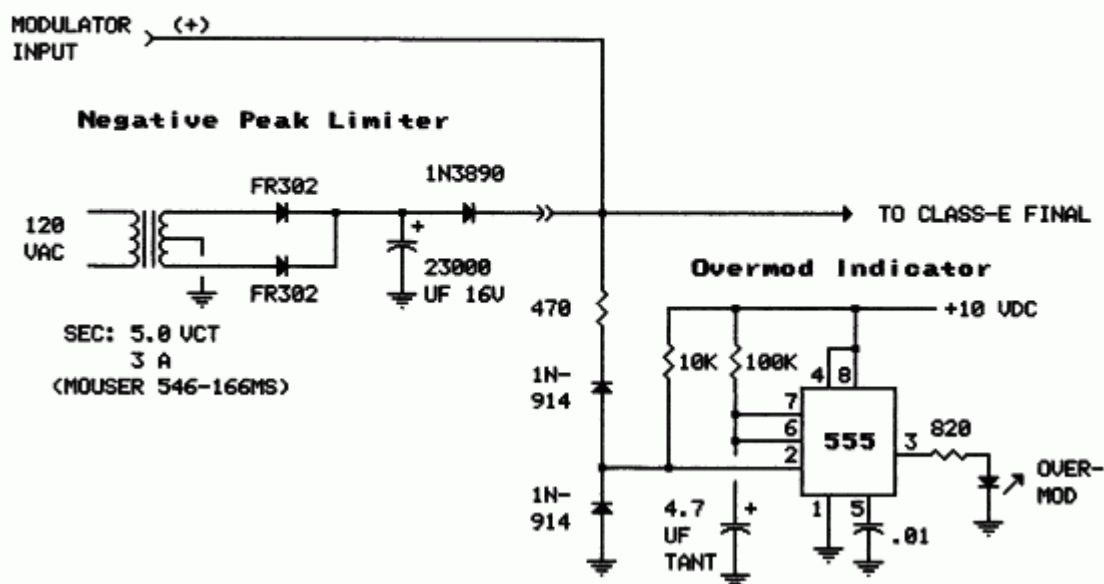


### Negative Peak Limiting:

The modulation envelope can be monitored with an oscilloscope connected to TP1 (sweep speed set to 1 mS per division). Over-modulation will be noted as a flatlining or *pinchoff* of carrier power at the envelope minimum. Pinchoff occurs when negative modulation peaks exceed the power supply voltage. At that point the instantaneous drain voltage on the output transistors drops to zero (or lower), causing instantaneous output power to drop to zero. Over-modulation produces distortion in the transmitted audio and wide-band splattering of the transmitted signal. Also, driving the drains of the output transistors negative will cause the MOSFETs' internal zener diodes to conduct in the forward direction, possibly causing failure of the output transistors.

Ideally, the modulation amplifier should be intrinsically incapable of delivering a voltage spike greater than what is needed for 100% modulation, but practically the modulator will need to be limited in some way, either in the audio stages ahead of the power amplifier or between the power amplifier and the transmitter. Over-modulation can be avoided with the indicator and negative peak limiter circuits shown in Figure 4. The circuits are independent and each can be used with or without the other.

(Figure 4)  
**Negative Peak Limiter  
 Overmod Indicator**



The negative peak limiter circuit consists of a 3-volt DC power supply connected to the positive modulation input terminal through a high-speed, high-current rectifier diode. The diode is reverse biased under normal conditions (mod input <100%). When the input voltage drops below about 2 volts, the diode conducts and supplies current to the transmitter to maintain a minimal carrier output level. Also, some of the current supplied during negative peaks is forced back into the energy storage capacitors in the main power supply, causing a slight increase in power supply voltage and subsequent increase in average carrier output power. The circuit eliminates splattering and reduces (but does not eliminate) audio distortion.

The over-mod indicator functions whenever the input voltage drops below about 2.5 volts. At this point the 555 timer is triggered and lights the LED (mounted in the transmitter's front panel). The LED will stay lit for about one-half second for each excursion of the input voltage below the trigger point. The timer will be retriggered on each input excursion and continuous over-modulation will produce a continuously lit LED.

A series-type pulse-width modulator (PWM) can also be used to modulate the transmitter. In that case, since the modulation power is derived from the transmitter's power supply, attention must be paid during the transmitter's design phase to issues like power supply voltage and current, as well as output stage impedance, to properly incorporate the series modulator in the overall transmitter design. As a general rule, for a given output power (full-carrier double-sideband) using a series modulator, the power supply voltage is specified at *twice* that required for CW service at the same power level and impedance, with a current capability about 150% of the CW rating. Additionally, the power supply should be capable of delivering a current surge equal to or greater than 200% of the current required for CW service. (The 200% surge requirement applies to any AM transmitter's power supply; see the power supply addendum below.) To series modulate the as-built 220-watt transmitter, for example, would require a power supply continuously rated for 84 volts at about 8 amps (10.5 amps surge). Design calculations are applied at the chosen CW operating voltage or *idle point*, the voltage the transmitter operates at with no audio input. For a series modulator adjusted to idle midway between the power supply voltage and ground (full-carrier double-sideband), the design calculations are made at 1/2 the power supply voltage, or 42 volts for the as-built, Fig-1 version of the transmitter.

One of several advantages of series modulation is that the modulator is incapable of negative over-modulation, i.e., driving the drain voltage on the transmitter's MOSFETs into

negative territory ( $<0$ ). Conversely, positive modulation is limited only by the voltage and current capability of the transmitter's power supply. These attributes can be used to generate several variations of AM: full-carrier double-sideband, "super-modulated" AM and reduced-carrier double-sideband.

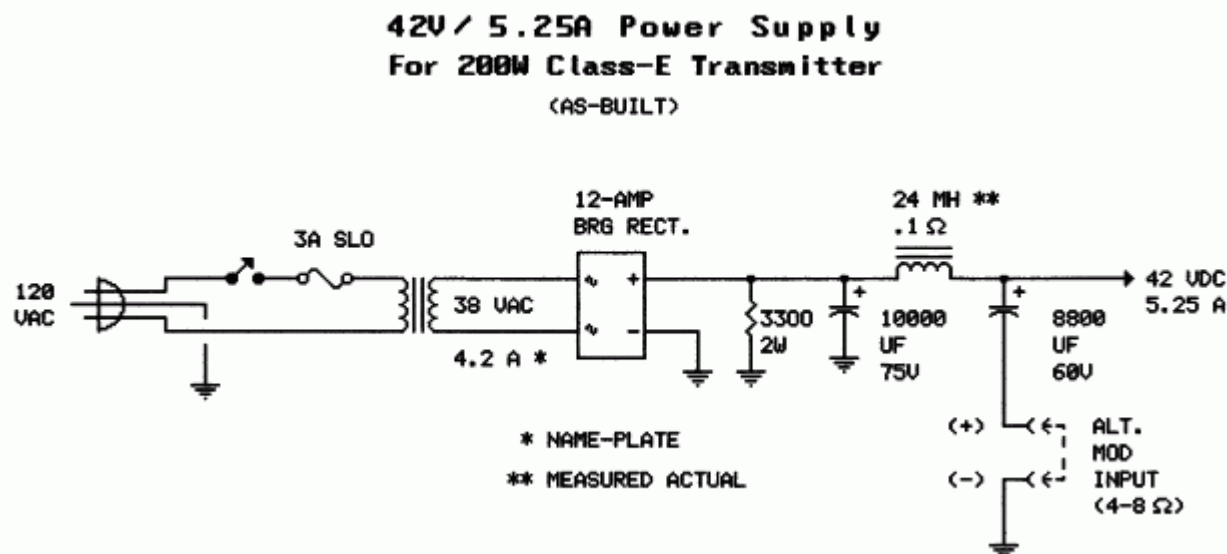
#### Shorting Jumper:

A shorting jumper should be placed across the modulation input terminals in Figure 1 (and/or Figure 5) to operate the transmitter when a modulator is not attached.

#### Power Supply

The 42-volt/5.25-amp. power supply used in the as-built 200-watt class-E transmitter is shown in Figure 5. Constructed entirely of surplus parts, it's very well behaved and operates effortlessly.

(Figure 5)



In order to achieve 100% modulation, an AM transmitter's power supply must be capable of providing, on a short-term basis, twice the current required during steady-state (CW) operation, 10.5 amps in this case. The supply in Fig. 5 uses inductive and capacitive energy storage to provide a relatively stable output voltage during and between modulation peaks. The filter/energy storage network that follows the rectifier also takes full advantage of the transformer secondary's available

voltage and current without excessive component warming. The military surplus transformer used in the as-built supply appears to be under-rated by about 20% in the circuit.

While the as-built power supply is well matched to the task of powering the transmitter, almost any power supply design with a full-time steady-state rating sufficient to achieve the desired CW output level can be used. A grossly over-rated supply should be avoided, however. The power supply should be electronically regulated or intrinsically current-limited to 150% or less of calculated transmitter final input current. (The supply in Fig 5 is intrinsically limited.)

Power supplies with limited short-term output current capability can be easily upgraded for AM service by adding a storage capacitor (minimum 1000 uF per peak amp) across the output terminals. Actively regulated supplies, however, usually can NOT be modulated through the negative terminal of the storage capacitor, as shown in Fig 5. In that case, a high-current choke having a reactance equal to or greater than about 8 ohms at 50 Hz must be placed in series with the power supply output, ahead of the storage capacitor.

The power supply should be provided with a slow-blow fuse sized at about 150% of transmitter DC input power

$$I_{\text{fuse}} = 1.5(P_{\text{DC input}}/E_{\text{line}}),$$

placed in the primary/line side circuit only. Do not fuse the DC circuit between the power supply output and the transmitter. This configuration provides a softer shutdown in case an arcing fault occurs in the transmitter output filter or antenna system. Bitter experience has shown that MOSFETs are much more likely to survive such a fault when the fuse is on the line side of the power supply.



output circuit. A switch is provided to reverse the phase of the current sample, allowing power flow reflected from the load to be read. True (real) power delivered to the load is the difference between the forward and reflected readings.

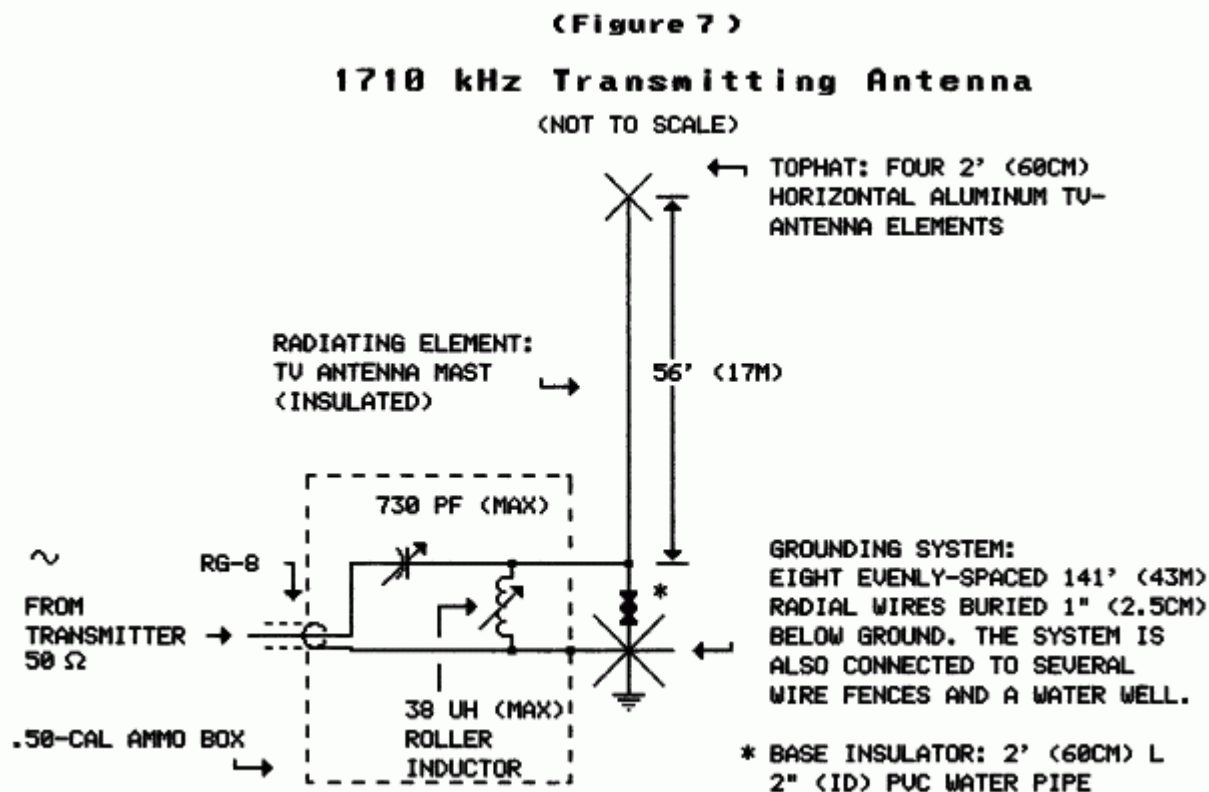
Calibration: Connect a 50-ohm resistive load to the transmitter output; connect an oscilloscope to the output connector (TP1) through a 10x probe; power the transmitter; set the FWD/REV switch to REV; adjust the NULL control for a reading of zero on the panel meter; calculate the forward power as follows:

$$P = (V_{pp}/2.828)^2/50 \text{ (calc);}$$

set the FWD/REV switch to FWD and adjust the SCALE control for a meter reading equal to the calculated power.

### Addendum: Antenna

Readers may be interested in the antenna system used with the as-built 1710 kHz transmitter. The schematic is shown in Figure 7.



The antenna system consists of three parts: 1) the radiating element, 2) the grounding system, sometimes called the *counterpoise*, and 3) the transmission line/matching network. During planning and construction of the antenna, these general guidelines were followed:

- The radiating element should be constructed vertically and made as tall and "fat" as possible. If the length of the radiating element falls short of being a full quarter wavelength at the operating frequency, a capacitive "hat" should be added. This makes the antenna look longer electrically and thus improves radiation efficiency.
- The grounding system should be built to have the lowest resistance possible. This minimizes ground heating. Transmitter power dissipated in the ground is lost power.
- The transmission line and matching network components should be chosen to be as free of losses as possible. (Not usually a problem at 1.71 MHz.)

The transmission line is type RG-8 (though smaller RG-58 would work nearly as well), the roller inductor is a silver-plated type (almost all are) and the capacitor is a transmitting-type air variable ([photo](#)).

Adjustment of antennas and tuners is typically made with an inline directional wattmeter (Bird ThruLine) or reflectometer (VSWR meter). The preferred method for adjusting this antenna/tuner is with a 50-ohm signal generator and 2-channel oscilloscope as follows:

1. Connect the signal generator to the oscilloscope; adjust it to the operating frequency and to a convenient output voltage such as  $2V_{pp}$  (this adjustment should be made with the signal generator *un-terminated*, i.e., with no load connected).
2. Connect the signal generator to the coax feedline at the feedpoint (the near end of the coax) where the transmitter would normally be connected.
3. Connect the oscilloscope, through 10x probes, to the coax center conductor where it connects to the antenna tuner (at the far end of the coax) and to the base of the antenna; alternately adjust the tuner components for maximum voltage on the base of the antenna and for a dip in the voltage at the end of the coax; fine tune the coupling capacitor for a  $90^\circ$  phase shift between the two voltages. When the tuner is correctly adjusted, the voltage on the base of the antenna will be at maximum and the voltage at the coax/tuner connection point will be *one-half* the signal generator voltage set in step 1.

4. Disconnect the test equipment; connect and power the transmitter; verify minimal reflected power on the transmitter's directional wattmeter.

The matching network component values shown in Figure 7 should be usable over a fairly wide range of radiating element lengths. Optimal adjustment of the as-built antenna occurs with the tuning capacitor about half meshed and the roller inductor tap located about midway on the roller coil. Longer radiating element lengths require less inductance and more capacitance; shorter lengths require more inductance and less capacitance.

Would-be builders of a transmitting antenna for 1710 kHz need not follow the particulars of the circuit in Figure 7, however, the guidelines should be followed. The challenge will be to radiate as much of the transmitter's output power as possible so as to produce the strongest on-air signal possible. A random length of wire connected to the transmitter's output connector will *not* achieve that goal.

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Building and tuning the 200-Watt Push-Pull Class-E AM Transmitter should be hassle-free for an experienced constructor as long as the design steps and construction notes are followed. The builder should also expect and be willing to expend equal time and energy constructing and tuning the antenna.

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