ATV Transmitter from a Microwave Oven!

Low-cost high-power microwave operation has arrived.

by David Pacholok KA9BYI

> **WARNING**
>
> ***The following construction project is not intended for novice builders! If you are not qualified to work with 5000 volts and 500 Watts of microwave power, DO NOT attempt construction of this transmitter. The above power level in the microwave region can be lethal. The author, David Pacholok, and 73 Magazine disclaim any responsibility from mishaps resulting from the construction and/or operation of this project.***

The majority of the amateur spectrum allocation lies above 1300 MHz, yet when you scan those bands, you rarely hear anything but band noise. Hams have let these regions lay fallow because of the idea that microwave equipment is complex, expensive, or just unavailable.

To be sure, there are concepts unique to microwave design, but they are not necessarily harder to grasp than those in lower frequency RF design. And, as microwave applications find a larger place in society, as with ovens, and satellite TV, affordability and availability of surplus microwave equipment constantly increases.

Project Features

The goal for this project was to provide an inexpensive, relatively simple high power microwave transmitter using a microwave oven as the foundation. This project meets the following goals:

•Low cost—less than $200.
•High power output—250 Watts minimum.
•Parts readily available from consumer electronic supply houses.
•Emission type compatible with standard low-cost B/W television receivers.
•Frequency of emission in the 2390–2450 MHz amateur band, compatible with Multipoint Distribution System (MDS) TV downconverters. (Historically, these downconverters have been misused to "pirate" television movie distribution at 2156 and 2162 MHz. They have been widely sold through magazine advertisements and electronic flea markets, so there are tens of thousands of them in existence.)

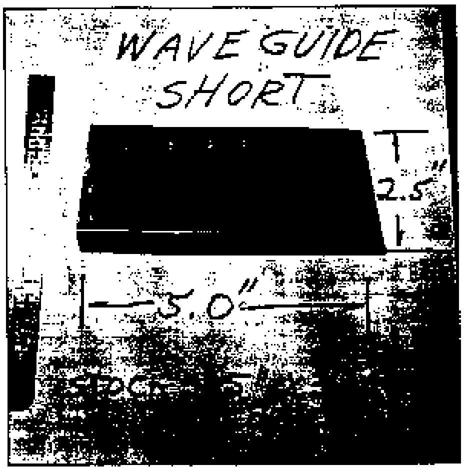


Photo A. Waveguide shorting plate, to prevent the microwave RF from entering the cooking chamber, and to reflect this energy back to an E-field probe.

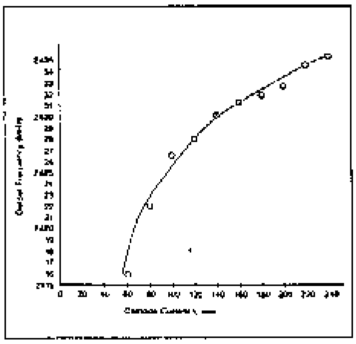


Figure 1. Graph showing frequency versus I_k for the magnetron. This shows that output frequency is (non-linearly) related to current to the magnetron.

•The basic transmitter scheme is adaptable to other emission modes, such as narrowband FM, with phase-lock circuitry described below.

Modification Description

A microwave oven magnetron is a self-contained, crossed-field power oscillator. Built-in cavities primarily determine oscillation frequency, with anode voltage and magnetic field having a secondary effect on this.

First, I modified the magnetron cavity to couple RF to a transmission line instead of to the oven compartment. I removed the interior radome/splatter cover, field stirrer blades, and magnetron output matching section. Next, I shorted the waveguide open end with a plate (Photo A) and installed an E-field probe to couple the RF to an N-connector output jack. (Photo B shows the details of the construction of the E-field probe.)

Magnetron current, voltage, and frequency were measured and plotted independently to quantify performance in this modified cavity. In power output vs. cathode current measurements, for a power out range of 50–400 Watts, and a cathode current of 50–250 mA, I found a very linear relationship. See Figure 1 for the frequency vs. current curve. This data suggests that:

1. The 2M189A magnetron is a current-operated device. The anode-to-cathode voltage changes only about 1 percent, with a 2:1 change in cathode current I_k.
2. Power output is a linear function of I_k.
3. Output frequency is a non-linear (but monotonic) function of I_k, with increased current causing an operating frequency increase. The average frequency "pushing" coefficient is about 0.1 MHz/mA, with a useful frequency swing of about 20 MHz.

What Mode To Use?

The above conclusions ruled out AM double-sideband video, because of the large incidental FM that would result. On the other hand, an FM deviation of 2 MHz would cause incidental AM of only 15–20 percent, so I investigated wideband FM video transmission.

To check compatibility with existing TV receivers, I used an FM video-modulated signal generator as a signal source for an MDS downconverter and a 5-inch monochrome receiver. I got a fair quality picture with the television adjusted for IF slope detection, and with sync and vertical lock achieved at deviations of 700 kHz to 3.0 MHz. The best picture quality occurred at 2.2 MHz deviation.

Modulator Circuit Description

The modulator serves two purposes. First, it is a high-voltage current source with high open-loop gain, setting the magnetron current to a known value, and establishing a frequency and power output. See Figure 2. U2, a 7805 5-volt regulator, establishes a reference voltage adjusted by R5 and R6. This voltage is applied to the non-inverting input of high-speed op amp U1, which drives source follower Q1. The output of Q1, plus R9 and R7, provide negative feedback to U1 in the ratio 5.7:1. At equilibrium, Q1's drain/source current produces a voltage drop across R11 that equals 5.7 times U1's non-inverting voltage.

Temporarily ignoring screen grid current, plate current equals cathode current in V1 (a,b combined). Since V1's cathode current equals Q1's drain current, V_D rises or falls until the V1 grid 1-to-cathode bias causes $I_P = I_k = I_D = I_S$. V1 is therefore a grounded-grid voltage amplifier with a current gain of unity, with enough voltage capability to drive the magnetron. However, to an input voltage at U1, a transconductance amplifier is formed, with transconductance given by:

$$\frac{\Delta I}{\Delta V} = \left(\frac{R9+R7}{R7}\right)\left(\frac{1}{R11} + \frac{1}{R9+R7}\right) = .22℧$$

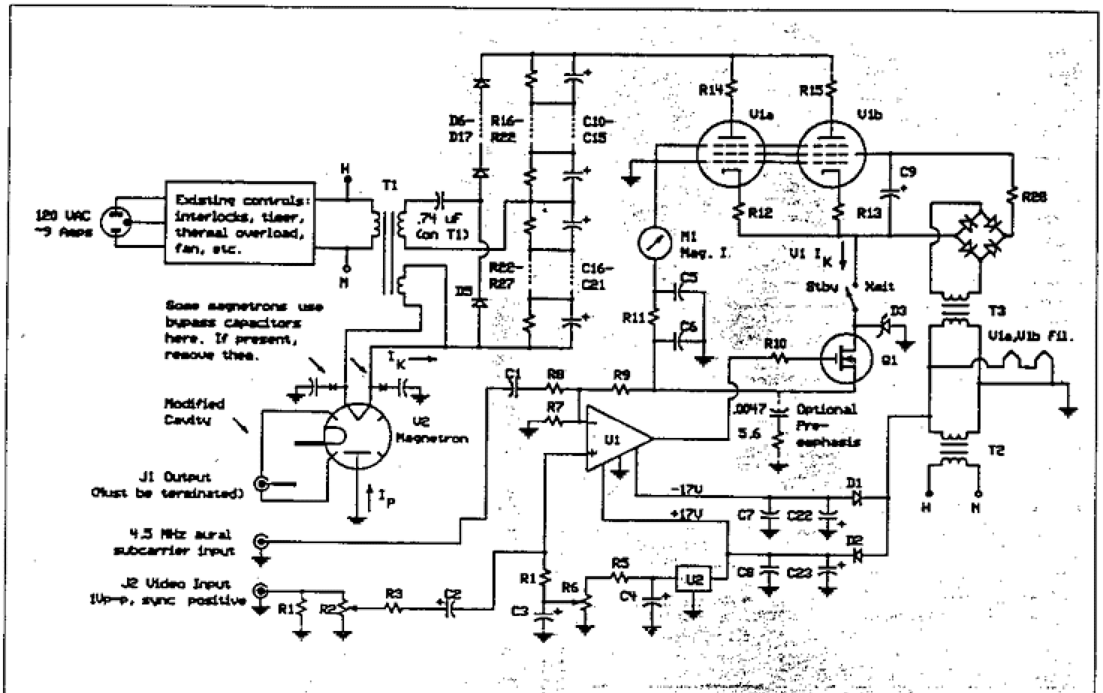
Bandwidth of this amplifier must be sufficient for the modulator's second purpose—video modulation. This must be 4.5 MHz, if you want to include the audio subcarrier. Frequency response measured with a current probe in the plate leads of V1 was down 4 dB at 4.5 MHz. Adding C6 (1200 pF) provides a pole for this frequency, flattening the response to beyond 6 MHz. C1 and R8 serve to couple an external 4.5 MHz subcarrier generator to the modulator.

A floating screen supply of about +100 volts is provided, with R28 included to limit screen dissipation. The floating supply allows only plate current (magnetron current) to be included in the control loop. Additional components with functions are:

- •R3, R14, and R15, which prevent parasitic oscillation in U1 and V1.
- •R12 and R13, which aid current sharing in V1a and V1b.
- •D3, which protects Q1 in the case of V1 arc-over.
- •Conventional power supply rectifiers, filters and bleeders.

Waveguide/Cavity Operation

The waveguide circuit is deceptively simple: The oven's TE_{10} waveguide feed (from tube to cavity) is shorted with a copper plate.



Oven	400-500 watt consumer microwave oven. Suitable models include Hotpoint RE6002, Whirlpool MW 1000XS-0 or MW 1200XS-0, Tappan 56-1007-10/02, and Goldstar ER-4020.
V1a,b	6JE6/6LQ6
V2	2M189A or 2M226A magnetron
Q1	VN66AF or similar power FET
U1	LF357 wideband op amp
U2	7805 regulator
D1, D2	1N4001
D3	1N4760, 68V, 1W zener diode
D4	1 amp, 200 PIV bridge rectifier
D5	10 kV, 250 mA diode
D6 - D17	1N4007
C1	.001 uF ceramic
C2	10 uF, 25V
C3, C4	100 uF, 10V
C5	330 uF, 6.3V
C6	1200 pF polystyrene
C7, C8	0.1 uF ceramic
C9	47 uF, 160V
C10 - C21	100 uF, 400WVDC
C22, C23	470 uF, 25V
R1	390 ohm
R2	100 ohm panel-mount potentiometer
R3, R8, R9	470 ohm
R4, R5	3.3 kohm
R6	1 kohm p.c. mount potentiometer
R7	100 ohm
R10	22 ohm
R11	27 ohm, 1 W
R12, R13	120 ohm, 1 W
R14, R15	100 ohm, 1 W
R16 - R27	470 kohm, 1/2 W
T1	Magnetron plate and filament transformer
T2	117 VAC to 12.6 VAC 3.0 A
T3	117 VAC to 12.6 VAC 450 mA
M1	0-200 mA DC
S1	SPST, 0.5 A 125 V
J1	Type "N" female panel mount connector

Figure 2. Transmitter schematic.

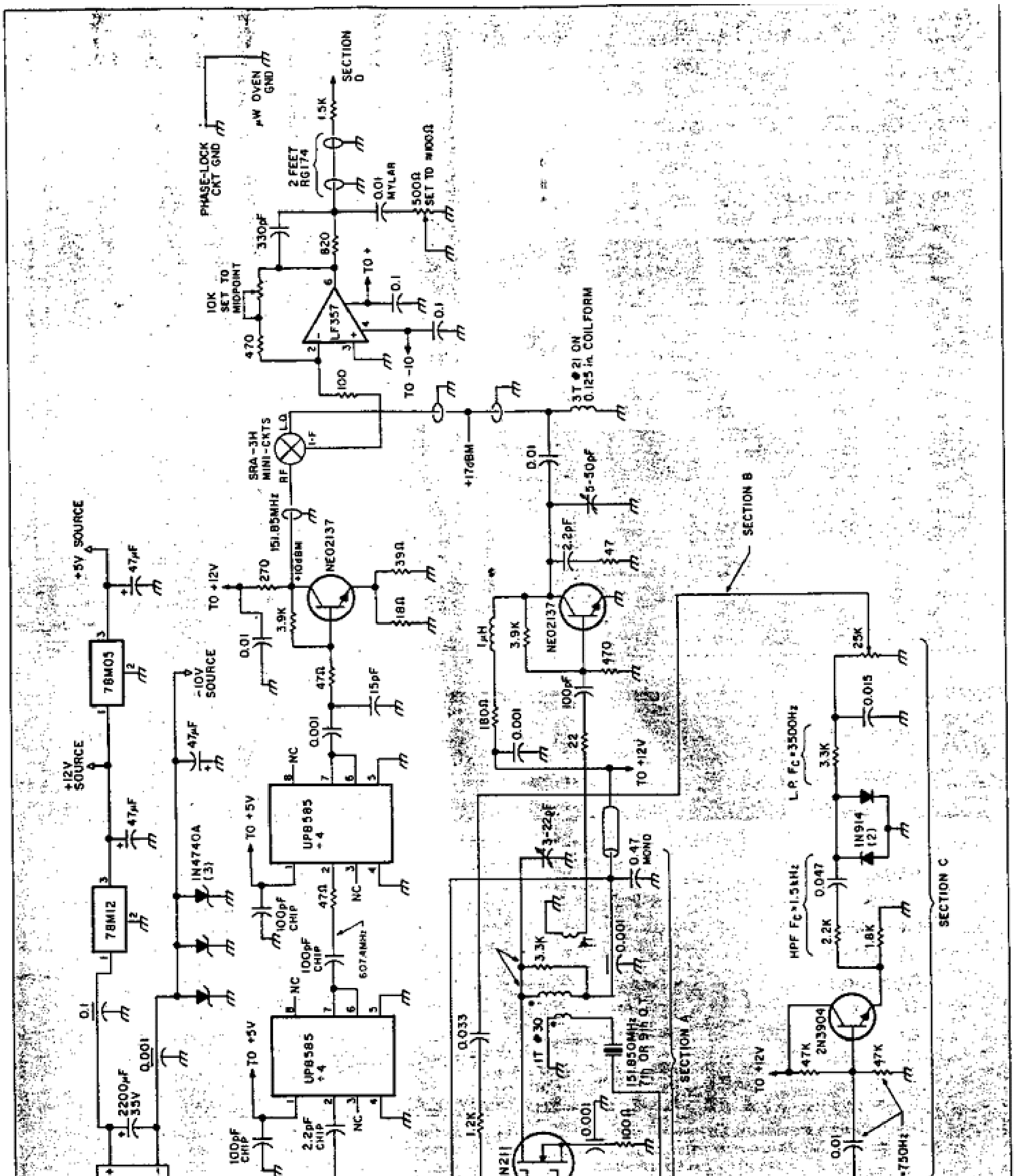


Figure 3. NBFM phase-lock system schematic.

(See Photo A). This is analogous to a coaxial or microstrip short, where wavefronts are reflected back with a 180 degree phase inversion. At a quarter guide wavelength from the short:

$$\lambda g = \frac{\lambda}{\sqrt{(\lambda/\lambda c)^2 - 1}}$$

where λc = 2X guide broadwall dimension.

The reflection is in phase with the incident wave from the magnetron, and an E-field probe (see Photo B) is inserted at this voltage maximum. Ordinarily, maximum power transfer occurs when this probe is $\lambda/4$ in length. Deliberately shortening the probe introduces a reactive mismatch at the magnetron output port. After an unknown number of degrees rotation within the feed structure (Matsushita would not provide tube data), this causes the magnetron to be pulled lower in frequency by some 25 MHz from its design frequency, ensuring legal amateur band operation.

Photo B. E-field probe construction details.

Floating Operation

One important feature of this conversion is the modification of the high voltage power supply for floating operation. The original power transformer had one end of the secondary grounded to the frame. I lifted this end and attached it to a high-voltage lead wire. This modification eliminates the need to float the entire modulator above ground, which also requires video-bandwidth opto-isolators. Hi-pot tests at twice the rated voltage confirmed that the modification was reliable.

EME Anyone?

Narrow band FM (±5 kHz deviation) requires a clean RF source low in noise and incidental FM. You can use the phase-lock or frequency-lock loop, as shown in Figure 3, with the non-inverting input of U1 equivalent to the varactor control voltage in a conventional VCO.

The following notes discuss sections of the phase-lock circuit, and tell how to wire this circuit into the transmitter unit.

Refer to Section A on the schematic—the overtone VXO circuit. The entire unit should be temperature controlled at 70°C by "crystal ovens," or something similar. The oscillator drifts at around 100 Hz per degree, causing about 1.6 kHz per degree for the frequency out drift. Stability is traded off for simplicity in this design.

Refer to the 151.85 MHz crystal in the VXO circuit. Choose this crystal after you build the oven video transmitter and measure the stable operating frequency range using one UBP585 and a 600 MHz counter.

Now refer to the crystal oscillator tank coils, to the upper right of the crystal on the schematic. You fabricate this by winding six turns of #24 wire on a 3.3 k ½W carbon resistor. Then, wind one turn of feedback winding, tightly coupled, and one turn of output winding, loosely coupled.

Now look at Section B, the connection between the VXO and the IOC. There is about 0.6V PEP for 300 Hz VXO deviation, which results in about 5 kHz of magnetron deviation. The VXO deviation is linear up to about ±10 kHz output (magnetron) deviation.

In Section C, the IOC is cheap 'n' dirty, but plenty effective. The *Handbook* has a better—and more complicated—version of this.

Finally, at Section D, find the two-foot lead of RG-174 that comes off pin 6 of the LF357 IC. Attach this to pin 2 of U1 in the transmitter circuit (Figure 2). Before doing this, however, be sure to remove the 4.5 MHz audio subcarrier at R8, and the video input.

You have now converted the microwave oven transmitter to use with NBFM (±5 kHz) voice mode! Now adjust the magnetron cavity probe length and R6 until the magnetron locks up at all times during the magnetron anode warmup (5–7 minutes).

Transmitter Improvements for NBFM

- Bypass D5 and D6–D17 with 0.0005 to 0.001 µF 3kV minimum caps. This reduces "hum bars" in the picture and low-level audio buzz in the NBFM mode.
- Isolate the metal case of the 0.74 µF (on T1) capacitor from ground with plastic blocks, nylon screws, or other means. This will also reduce hum bars and buzz.
- Using insulated standoffs, isolate T1 laminations, and frame from ground. This will further reduce hum bars and buzz, and will result in better insulation in T1 after mods.
- Disconnect the magnetron filament feedthrough from ground! Otherwise you won't get full video bandwidth, and the NBFM mode PLL filter won't work (no phase margin). See Photos C and D.

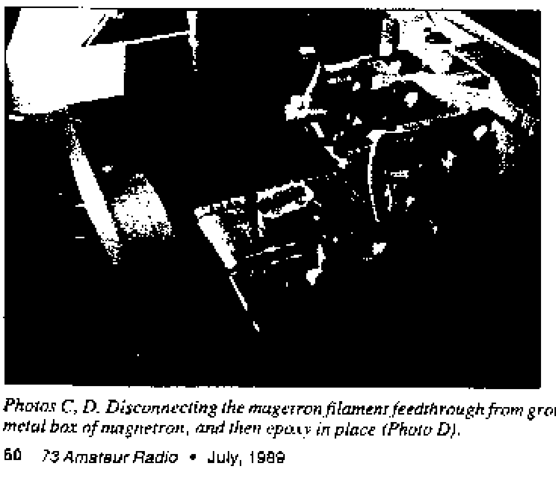
Performance

Spectrum analysis indicated the performance of the transmitter. The 1st Bessel null display (I_k = 160 mA, V_p = 3500V, Mod. index = 2.4, Mod. freq. = 1 MHz, and center freq. of 2.431 GHz) shows that the modulation is primarily FM.

Additional Comments and Observations

The following notes may or may not apply to the system if the NBFM phase-lock system is installed.

Warm-up drift is significant over the first ten minutes of operation, representing about



Photos C, D. Disconnecting the magetron filament feedthrough from ground. Drill out the rivets (Photo C) and push feedthrough 3/16" into sheet metal box of magnetron, and then epoxy in place (Photo D).

Photo E. Microwave leakage detector—a must for this project!

15% of the available tuning range (2.5 MHz).

Avoid magnetron "moding," appearing on a spectrum analyzer as a comb instead of a CW signal. This can be caused by a VSWR greater than 1.5:1, or by operation below about 50 mA. If low power operation is desired, raise the filament voltage to 3.4 – 3.6 V, since internal RF contributes to proper filament (cathode) temperature in normal operation.

If used with a true FM television receiver, such as a modified satellite TVRO unit, the simple pre-emphasis network shown on the schematic diagram will improve video S/N by up to 10 dB. Also, TVRO receivers use greater than 20 MHz IF bandwidth, greatly reducing the effects of warm-up drift.

Small "hum bars" are visible in the picture, due to the floating high voltage power supply. This effect is caused by the 60 Hz switching of the diodes, varying the capacitance to ground at the magnetron cathode. These transients are out of the control loop. Grounding the power supply and floating the modulator at high voltage is a solution, as is floating the magnetron and cavity. Either would increase circuit complexity and increase exposure to hazardous voltages.

As with any non-locked oscillator, a change in system load impedance will change the frequency of operation. A high power isolator is one solution, albeit an expensive one. I used a stretch line to measure the load pulling effects of a 1.5:1 VSWR over all phase angles. The frequency changed ±6 MHz as the phase angle varied. At the design frequency of 2430 MHz, all modulating products should remain within the amateur band. This is not a trivial problem, and may require line trimming or line stretchers to place the phase angle in a stable region. The lowest possible antenna VSWR is the best solution to the line-pulling problem.

Beware!

Remember, for this project, SAFETY IS PARAMOUNT! This transmitter has 4 kV DC and high power microwave energy present. Use a microwave leakage detector to check the integrity of the modified unit (see Photo E). You can buy an inexpensive detector suitable for the job. Also, retain the door interlocks (I installed the modulator in the now-unused cooking cavity.) Antennas can easily have high gain at this frequency—DO NOT POINT THEM AT PEOPLE OR OTHER LIVING BEINGS!

Although this is not a "high performance" television transmitter, it represents a low-cost effort to achieve significant power output at microwave frequencies.

Readers interested in finding out more about this project can contact the author for details, at *Creative Electronics Consultants, 1815 W. Higgins Road, Sleepy Hollow, IL 60118, Telephone: (312) 428-5676.* ■

Article materials, except the phase-lock system, were drawn from the March 1989 issue of RF Design.

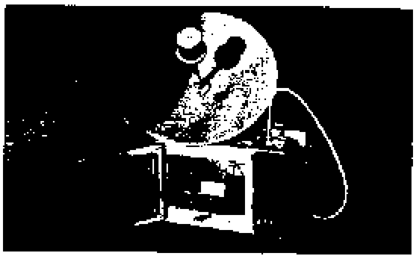


Photo F. The complete microwave oven ATV transmitter unit. The transmitter circuit is located in the oven's cooking chamber.