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 T3 Magazine disclaim any responsibility from mishaps resulting from the construction or operation of this project.

The majority of the amateur spectrum allocation lies above 1200 MHz, yet when you read these bands, you rarely hear anything but hiss and noise. Ham sites in 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 remote and satellite TV, accessibility and availability of surplus microwave equipment commonly 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 MW television receivers: 250 Watt output and the modulation veterans have been made to "like" television movie distribution at 2156 and 2162 MHz. They have been widely sold through magazine advertisements and electronic supply houses, so there are tens-of-thousands of them in existence.**

![Waveguide short](image)

**Figure 1.** Graph showing frequency versus 1/2 for the magnetron. This shows that output frequency is (non-linearly) related to current in the magnetron.

- The basic transmitter scheme is adaptable to other emission modes, such as broadband FM, with power-tube circuitry described below.

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

First, I modified the magnetron cavity as shown in Figure 1, replacing the plug-in. I then connected a 1/2 watt 1275 MHz crystal to the oven's input. Next, I started waveguide open and with a probe (Photo A) and installed a T-band probe to couple the RF to an N-connector output jack. (Photo B shows the construction of the N-connector probe.)

Magnetron current, voltage, and frequency were measured and plotted independently to quantify performance in this modified cavity. In power output vs. magnetron current measurements, for a power range of 50-400 Watts, and a magnetron current of 33-230 mA, I found a very linear relationship. See Figure 1 for the frequency vs. current curve. This data suggests that:

1. The 2419A magnetron is a current-operated device. The modulating-cathode voltage changes only about 1 percent with a 2.1 change in cathode current.$^1$
2. Power output is a linear function of $I_p$.
3. Output frequency is a non-linear function of $I_p$, with increased current causing an operating frequency increase. The average frequency "pulling" coefficient is about 0.1 MHz/mA with a useful frequency swing of about 20 MHz.

**What Modes To Use?**
The above conclusions ruled out AM, double-sideband voice, because of the large incidental FM drift 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 tested an FM modulated signal generated 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 maximum deviation, and with video and vertical lock achieved at deviations of 100 kHz to 1.0 MHz. The best picture quality occurred at 2.2 MHz deviation.

**Modulator Circuit Description**
The modulator serves two purposes. First,
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 bleeder.

Waveguide/Cavity Operation

The waveguide circuit is deceptively simple. The oven’s TE15 waveguide feed (from tube to cavity) is shorted with a copper plate.

Figure 2: Transmitter schematic

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Figure 3. NBFM phase-lock system schematic.
(See Photo A). This is analogous to a coaxial or microstrip line, where waveforms are reflected back with a 180 degree phase inversion. At a quarter guide wavelength from the source:

$$n = \frac{\lambda}{2\pi d}$$

where $n$ = 2k guide bandwidth 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 decades rotation within the feed structure (Magnetron would not provide this data), this causes the magnetron to be pulled lower in frequency by some 25 MHz from its design frequency, ensuring linear transistor band operation.

Floating Operation

One important feature of this conversion is the modification of the high voltage power-supply for floating operation. The original power-supply had one of its main inputs grounded to the frame. This was removed and attached to a high-voltage lead wire. This modification eliminates the need to float the entire oscillator above ground, which also requires higher-bandwidth operation. Figure 2 shows twice the high voltage required to maintain the modification was reliable.

EMI Anyways?

Narrow band FM (5 kHz deviations) requires a clean RF source low in noise and narrowband FM. You can use the phase-lock or frequency discriminator, as shown in Figure 3, with the non-inverting input of $\pm 10$伏 equivalent to the variation control voltage in a conventional VCO.

The following notes discuss sections of the phase-lock circuit, and tell how to:

Photo B. E-field probe construction details.

wire this circuit into the transmitter unit.

Refer to Section A on the schematic—the envelope VCO circuit. The envelope should be tuned to a frequency center around 700 kHz by "crystal" tuning, or something similar. The oscillator drifts a total of 100 Hz per degree, causing about 1.6 kHz per degree for the frequency output unit. Stability is traded off for simplicity in this design.

Refer to the 151.87 MHz crystal in the VCO circuit. Choose this crystal after you build the vco, test the oscillator, and measure the stable operating frequency range using this unit, say, 151.85 and 151.89 MHz.

Now refer to the crystal oscillator tank coil, to the upper right of the crystal on the schematic. You fabricate this by winding six turns of #24 wire on a 3.8 kHz oscillator. Then wind one turn of neutral wire, tightly coupled, and then turn of output winding, loosely coupled.

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

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

Finally, in 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 8kHz, and the video input.

You will now connect the receiver's even transmitter to use with NBFM (4 khz voice model). Now adjust the magnetic card's probe length and 8kHz to the magnetron locks up at all times during the magnetron source warmup (5-7 minutes).

Transmitter Improvements for NBFM

• Replace DI and DI-DI7 with 0.0005 to 0.001 uF 3 kHz ceramic caps. This reduces "hum bars" in the picture and low-level audio bars in the NBFM mode.

• Place the crystal case of the 744 MHz (or U1) capacitor from ground with plastic blocks, mylar screws, or other means. This will also reduce hum bars and buzz.

• Use insulated standoffs, isolates U1 location, and frame from ground. This will further reduce hum bars and buzz, and will result in better, clearer transmission in NBFM mode.

• Disconnect the magnetic filament feedthrough from ground. Otherwise you won't get full video bandwidth, and the NBFM mode PLL filter won't work (see phase margin). See Photos C and D.

Performance

Spectrum analysis indicated the performance of the receiver. The 3khz IF resulted in a display of 30 kHz, Mod index = 1.0, Mod freq = 1000, and output level of 6-8 kHz. This 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.

Worse up drift is significant over the first ten minutes of operation, representing about...
Photo E. Microwave leakage detector—a must for any project!

13% of the available tuning range (5 MHz). Avoid magnetron “nudging” appearing on a spectrum analyzer at a point outside of a CW signal. This can be caused by a VSWR greater than 1.31, or by operation below about 50 MHz. If low power operation is desired, raise the filament voltage to 3.4–3.6 V, since internal RF components in power filaments (concrete) temperature in normal operation.

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

Small “false 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 circuit, varying the capacitance to ground at the magneto-valve's terminals. These transients are of the opposite polarity. Grounding the power supply and floating the magnetovalve at high voltage is a solution, as is floating the magnetovalve circuit. 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 transmitter is one solution, albeit an expensive one. I used a crystal line to measure the load pulling effect of a 1.5:1 VSWR over all phase angles. The frequency changed 4.6 MHz at the phase angle varied. At a design frequency of 2450 MHz, all modulating products should remain within the noise band. This is not a trivial problem, and may require line trimming or line stroke to place the phase angle in a stable region. The most possible solution is to use a VCO and the best solution to the line-pulling problem.

Remember, for this project, SAFETY IS PARAMOUNT! The transmitter has 4 KV DC and high power microwave energy present. Use a microwave leakage detector to check the integrity of the modified tank (see Photo E). You can buy an inexpensive detector suitable for the job. Also, retain the door interlocks (I installed the modulator in the non-integrated cavity). Interlocks 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, or Creative Electronics Consultants, 1812 W. Higgins Road, Sleepy Hollow, IL 60556, Telephone: (312) 425-5676.

Article materials, except the photo-block system, were drawn from the March 1980 issue of RF Design.