Connecting the HP 5086-7023 YTO

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I was recently given a working YTO module from the HP 11661B FEM (Frequency Extension Module, an internal plug-in for the HP 8660C Signal Generator). While the manuals for the HP 8660C are available on-line, I had to acquire a printed manual for the FEM since none could be found in electronic form. The manual would hopefully offer information on how to connect and drive the YTO signals (so the *free* YTO cost me $15…so far).

YTO is one of those rare and elusive double acronyms we've all heard about in the news lately (or not): YTO = YIG Tuned Oscillator and YIG = Yttrium-Iron-Garnet. YIG is a very interesting microwave material with properties that can be substantially modified by the application of a strong magnetic field. The story of how YIG behaves is quite beyond the scope of this document, but it is highly interesting for anyone who delights in knowing how things work.

The manual arrived in quick order, and did contain what appeared to be sufficient information, mostly. Having a working system would make some of the investigation easier, but this is not possible at the moment (likely never), so I had to use circuit analysis and direct measurements to determine the necessary drive parameters.

Photo 1 illustrates the relevant section of the manual along with the YTO module. Since HP considered the YTO to be a non-repairable module (much like an integrated circuit), there is no more information on its internal construction contained in the FEM manual. It is highly likely that this information is considered proprietary by HP/Agilent/Keysight, so it is not likely that it will be found published by HP.

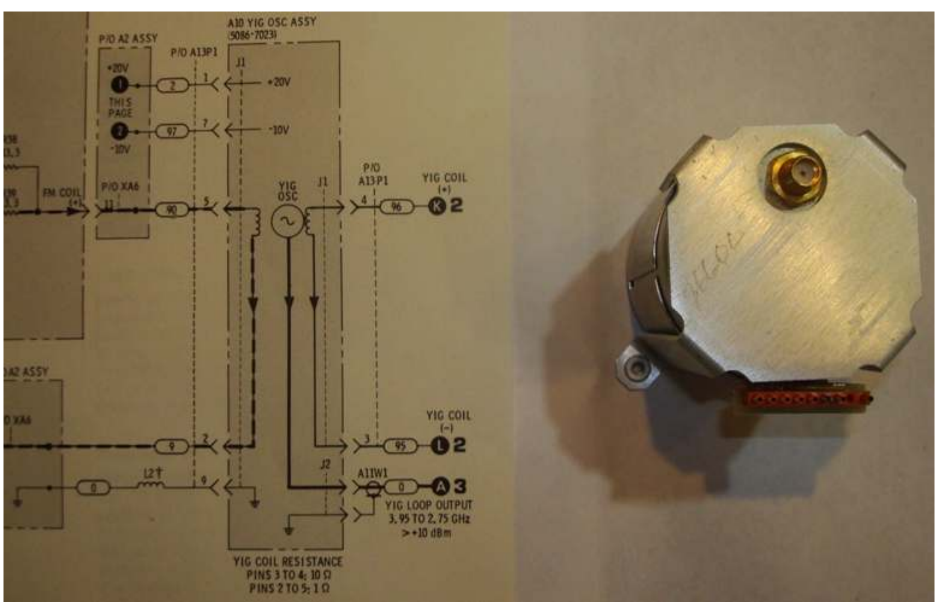

Photo 1. The 5086-7023 YTO and a section of the HP 11661B schematic showing the YTO pinout.

The HP YTO assembly consists of a YIG-tuned oscillator, YIG sphere, coupling loops, tuning coils, and heaters all contained within a cylindrical package. The YIG oscillator circuit is coupled to the YIG sphere by two quadrature coupling loops (these are not the tuning coils) and the YIG sphere is surrounded by the two tuning coils (a "large" coil, called the "pre-tune" coil at pins 3 & 4, and a "small" coil, called the "FM" coil at pins 5 & 2). Both the oscillator circuit and the YIG sphere are heated for temperature stabilization. Both tuning coils accomplish a similar task which is to tune the resonance frequency of the YIG sphere. The tuning coils have no internal connection to any other pins or to the YTO case. The +20V (pin 1) and -10V (pin 7) supplies provide power to the oscillator circuit (GND at pin 9) and heater, and the RF is output on the SMA connector shown in Photo 1. Photo 2 illustrates the pin 1 location for the device power/drive connector.

The supply voltages likely have a nominal current draw, which can be easily measured. L2 (shown in the schematic) is an unknown. No specifications for the part (HP# 9170-0499, a.k.a. AL-2135-NH/T) could be found via internet search other than it is a torroidal coil, likely a moderate current choke intended to keep high frequencies from influencing the oscillator circuit. The remaining question is: what current levels are nominal for the tuning coils? For the FM coil, there is a 10Ω sense resistor from the YTO pin 9 to ground, along with a schematic note that reads: "UNLOCKED 2.5Vpp, LOCKED ±0.1Vdc". This would seem to indicate that the maximum FM coil current would be 250mApp, or 10mAdc.

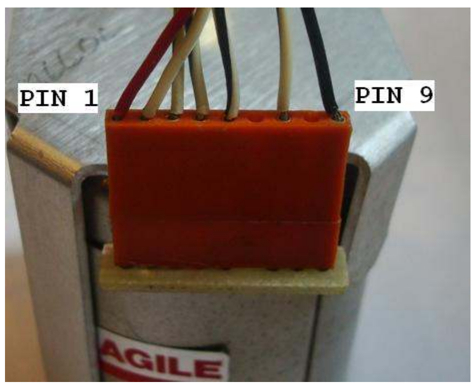

Photo 2. YTO connector close-up view.

The pre-tune coil drive circuit features two 100Ω sense resistors in parallel with a schematic note that reads: "0.0 GHz = 9.48V, 1.2GHz = 6.60V". This would seem to indicate that the pre-tune coil currents range from 190mA to 132mA. However, this YTO is rated for 2.2-4.2 GHz, so the numbers don't make sense (YTOs generally tune up with increasing current, plus the frequencies don't agree with the YTO nameplate). The sense resistors are part of an inverting amplifier, so this explains the apparent inversion of the current to frequency ratio. In addition, the HP8660 likely down converts the YTO output to achieve the 0-1.2 GHz output. If the 8660 uses the lower sideband of the mixer output, then the tuning direction will be inverted which would cancel the inversion present in the driver.

So, this is where things get interesting. The nameplate for the YTO is shown in Photo 3. Here, there are listed two resistances (Ra = 82.5Ω, Ro = 287Ω) and two currents (Ia = 60mA, Io = 22.5mA). The coil resistances are shown in the schematic as 10Ω and 1Ω (see Photo 1), and these resistances were confirmed by ohmmeter measurements. Thus, there are two, very different specifications to consider.

One might think that the coil resistances were changed during the production run of the FEM, but this contradicts the ohmmeter measurements.

Photo 3. 5086-7023 nameplate.

Since my immediate desire was to just get the unit to make microwaves, I decided to leave the FM coil alone for the moment, and just concentrate on the pre-tune coil and oscillator power. I have an electronic load that I constructed that can be used as a constant current regulator to drive the pre-tune coil, so all that remains is to cobble together a couple of power supplies to get +20V and -10V for the oscillator power.

The test setup (the RF portion of the set-up is illustrated in Photo 4) consisted of a triple output power supply configured to provide +20V and -10V, and the electronic load at the ground end of the pre-tune coil, with a 13.8V supply at the positive coil terminal. The e-load was shunted with a 0.3Ω resistor due to its limitations at current levels below about 100mA (I was later able to cobble together a 4.4 ohm shunt). A DMM was used to measure the coil current while an HP8566B spectrum analyzer (S/A) was used to spot the YTO frequency. Two attenuators were employed to provide 16 dB of attenuation at the S/A input.

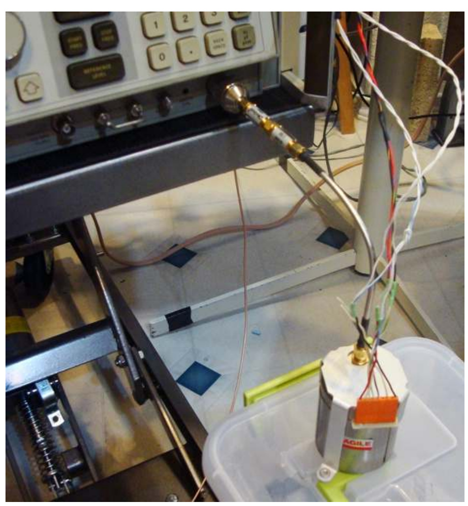

Photo 4. RF Test set-up. Note the 6dB and 10dB attenuator in line with the YTO output.

After the coil current data was taken, the S/A was placed into peak hold and the coil current was slowly adjusted across the range needed to sweep the YTO frequency between 2.00 GHz and 4.50 GHz. This "poor-man's" sweep measurement took considerable time, and required numerous up and down re-adjustments to get the plot to fill in to a reasonable degree of smoothness.

Table 1 lists the YTO frequency vs. I_{coil} data, with this data presented in plot-form in Figure 1. As can be seen from the plot of Figure 2, the frequency linearity is very good. *Note: In regards to the notes that are found in the pre-tune drive circuit, the voltages noted therein would seem to indicate that the actual YTO tuning range called for by the HP 8660 is from about 2.8 to 4.1 GHz.*

Icoil (mA)	Fyto (GHz)
77.9	1.71
101.1	2.19
101.7	2.20
111.2	2.40
121.0	2.60
130.7	2.80
140.2	3.00
149.8	3.20
159.4	3.40
168.9	3.60
178.5	3.80
188.1	4.00
198.0	4.20
207.7	4.40

Table 1. F_{yto} vs. I_{coil}

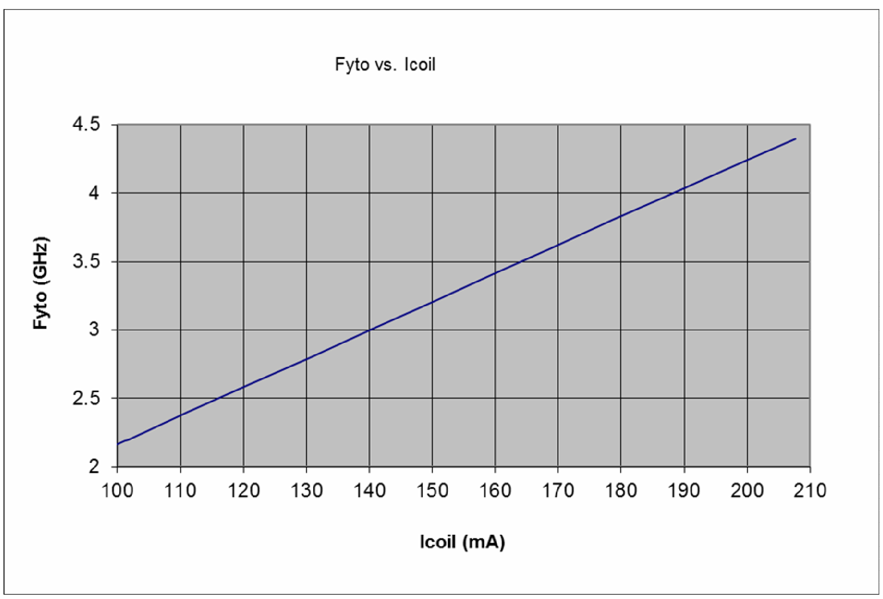

Figure 1. YTO F_{out} vs. I_{coil}

Figure 2 illustrates the output flatness plot (with the fixed attenuation values removed from the data). With the exceptions at each end of the span, the flatness looks somewhat reasonable.

The data tabulated from the S/A in the specified frequency span of 2.2 – 4.2 GHz (the nameplate specification for this YTO) shows that the average output level is +10.6dBm, while the min/max is +7.3/+12.3 dBm, with a min/max center of +9.8 dBm. This gives a flatness of ±2.5 dB. If one repeats this analysis in the frequency span of 2.4 – 4.0 GHz, the average becomes +10.9dBm, with a min/max of +9.0/+12.3 dBm with a center of +10.65 dBm. This range has a flatness of ±1.65 dB, an improvement of almost a dB over that observed in the specified span.

Examining the plot of Figure 2, it is easy to observe that the low-end of the frequency span is the greatest contributor to the amplitude ripple, and most of the deviation appears to occur in the first couple of MHz of the low end of the span.

The aforementioned data was taken with the YTO relatively cold as it was at 25C when the measurements were started. The spectrum sweep was repeated after a 2 hour warm-up and this plot appears in Figure 3. It is largely unremarkable. The careful observer will note that the plot line appears to be slightly higher in amplitude, and in fact it is. The normalized amplitude median was +11.1 dBm for the warm YTO vs. +10.65 dBm for the relatively cold sweep. The flatness over the 2.2 – 4.2 GHz span was slightly worse for the warm sweep at ±1.9 dB.

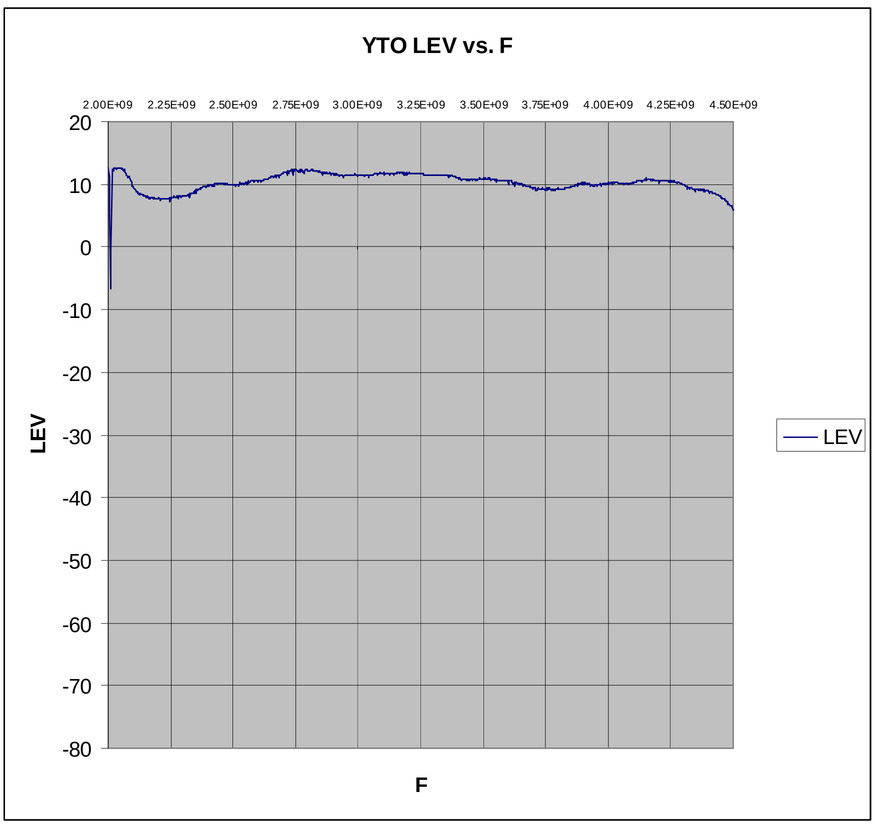

Figure 2. YTO Output (dBm) vs. Frequency (Hz)

The current from the +20V supply was measured at 80mA dc while the -10V supply was measured at 84mA dc, making the total power dissipation about 2.44W, not including power lost in the coils. One of these supplies is suspected of powering the YIG heater. Returning to Photo 3 and the issue of the conflicting nameplate values, the "-10 VDC" nomenclature may offer a clue. The stamped values for Io and Ia add up to 82.5 mA, which is in very good agreement with the 84 mA value measured for the -10 Vdc supply. Ra and Ro apparently refer to the two internal heaters (likely Ro for the oscillator, and Ra for the YIG sphere). This would seem to indicate that the majority of the -10 Vdc supply power is used to power the internal heaters. However, it is unknown if this supply provides any bias to the oscillator, so it is possible that the additional 1.5mA drawn from the -10V supply is used by the oscillator circuit.

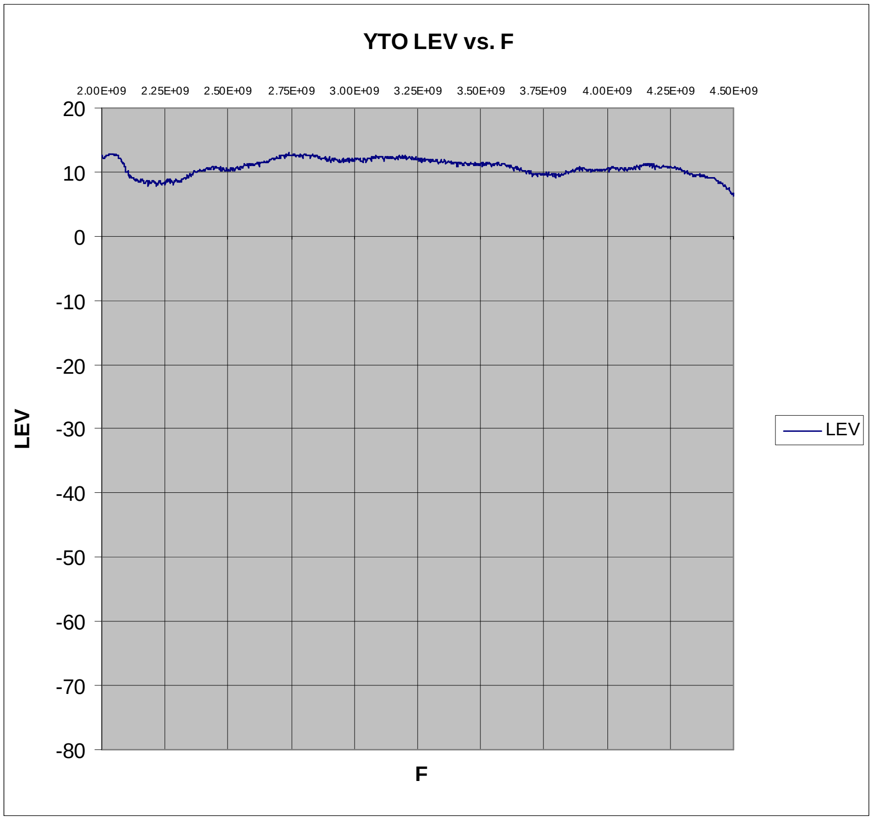

Figure 3. YTO output vs. frequency after 2 hour warm-up.

A drive circuit for the pre-tune coil could be nothing more than an NPN pass transistor operated as an emitter follower with its collector connected to a regulated supply and Vb fed by a 10K potentiometer. This is the essence of a traditional, pass-transistor linear regulator. A series resistor from the emitter to the (+) coil pin, and the (-) coil pin to ground would complete the drive circuit. The resistor value would be determined by the regulated power supply to allow about 220 mA(max) to flow into the coil:

$$\text{Re} = ((\text{Vreg} - \text{Vbe})/\text{Imax}) - \text{Rcoil}$$

$$= ((\text{Vreg} - 0.7)/0.22) - 10\ (\Omega)$$

The resistor power would be given as $\text{Icoil}^2 * \text{Re}$. For a 5V supply, Re = 9.01 Ω, P(re) = 0.43W. P(q) would be Vbe * Icoil = 0.15W. Two 1W, 20 ohm resistors in parallel would offer plenty of power margin for this simple drive circuit. Conversely, a 4 Ω resistor would dissipate about half the power of the larger resistance (0.19W) at the expense of an increase in the transistor power dissipation (0.42W). The effect is to essentially swap the power from the resistor to the transistor. This would allow an efficient heat sink for the transistor, and for smaller wattage (e.g., two 8 ohm, 1/4W) resistors to be used.

A microcontroller DAC or PLL phase-frequency comparator could also replace the potentiometer to allow tuning control by one of these circuits. Of course, any open-loop control would result in considerable drift in the YTO frequency.

A circuit similar to the one employed in the FEM would feature a current feedback into an op-amp circuit to provide a current regulator. This is the principal employed in the e-load that was used to control the YTO during these tests. Such a feedback loop is not terribly difficult to design or construct, but would be more complex that the emitter follower described above. The choice would be driven by application. In an application where the YTO might be used to sweep across a frequency range with little regard for precise start or stop frequencies, the emitter follower would likely suffice. For applications where the YTO would need to maintain a relatively precise fixed frequency, the current-feedback method would be preferable.

Of course, the FM coil was not considered in the above investigation. However, as a fine-tune mechanism, this input to the YTO is not to be out-done. As a case-in-point, the YTO in question was needed as a sweep oscillator to perform a front-to-back loss plot of a microwave isolator. The e-load script capability was employed to step the YTO pre-tune coil current across the desired tuning range. However, the step-size of the e-load current changes are limited by the 12-bit DAC used in the e-load, resulting in considerable piece-wise frequency steps in the YTO output.

To combat this, a frequency generator was connected to the FM coil and operated at 600 Hz and about 8Vpp (unloaded). This resulted in enough delta-F in the YTO output that the resulting plot on the S/A was reasonably smooth. Figure 4 illustrates the normalized plot of the isolator performance. The plot took several minutes to complete, but required no operator intervention. An improvement would be to increase the drive level to the FM coil to allow a higher frequency FM sweep which would allow the pre-tune sweep rate to be increased thus reducing the overall sweep time.

Figure 4. Swept YTO plot of a microwave isolator using the FM and pre-tune coils.
Note: the coarse plot results at the extreme right side are noise remnants due to the YTO output dropping out at about 4.6 GHz

The results of this quick-look show that this YTO does, in fact, function, has a somewhat reasonable output flatness, and considerable output level. The device can serve as a poor-man's sweep oscillator or be slaved to a stable reference with a microwave PLL – the addition of a microcontroller (to drive the coil and PLL), a mixer, and an un-correlated 2.2 GHz source would allow sweeps from DC (or very near) to around 1.5 GHz or so.

Bibliography:

Operating and Service Manual, HP Model 11661B Frequency Extension Module, 11661-90025, August, 1981

Design of a YIG-Tuned Oscillator (A Thesis), by Tien Liang Jin, New Jersey Institute of Technology, 1975 (http://archives.njit.edu/vol01/etd/1970s/1975/njit-etd1975-001/njit-etd1975-001.pdf)

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