TEMPERATURE COMPENSATED PERMANENT MAGNET YIG TUNED OSCILLATORS.

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ABSTRACTS

Advantages, disadvantages and areas of concern regarding the use of a permanent magnet as a means of providing the magnetic bias field for the YIG tuned oscillators are discussed. Two different types of permanent magnet YIG tuned oscillators with the temperature variation of less than 15 PPM/^{o}c are constructed. The measured characteristics of some of these devices are presented.

INTRODUCTION

Despite the advantages of low phase noise, wideband tuning capability and superb linearity of YIG Tuned Oscillators (YTO), their use has been somewhat limited, mainly due to their comparatively high DC power consumption. This power is needed to generate the magnetic bias field for the YIG resonator. Therefor, the single most important step that can be taken to make a YTO more useful would be to lower its power usage. The obvious solution that comes to everyone's mind is the use of a permanent magnet.

In the past, progress in this area was slow. Several factors contributed to this, mainly instability (time, temperature, shock,...) and the limited strength of previous permanent magnets. Advancements in the area of permanent magnet materials has lead to a renewed interest in the use of the newly developed permanent magnets for YIG tuned devices.

ADVANTAGES OF PERMANENT MAGNET YTO

In the conventional Electromagnet YIG Tuned Oscillator (EM-YTO) the YIG resonator is placed in the air gap of a closed magnetic shell. The magnetic bias field, or the tuned frequency of the YTO, is then varied by supplying the controlled DC current through the main coil.

There are two main approaches to the design of a Permanent Magnet YTO (PM-YTO). In the first approach, the permanent magnet can be used to maintain a constant bias field in the air gap for the YIG resonator. The unit can then be tuned electrically, with the aide of the main coil, to a higher or lower frequency in reference to the set center frequency. Because of the limitation imposed by the presence of the permanent magnet, the oscillator will be somewhat narrowband in comparison with the standard YTOs (approximately +/-2 GHz).

In the second case, the air gap can be varied mechanically to provide the tuning mechanism for the PM-YTO. In this case there is obviously no need for the main coil and the unit can operate continuously over several octaves (e.g. 2 to 8 GHz or 8 to 18 GHz)

Figure 1 represents a comparison of the main coil power consumption of an electromagnet versus permanent magnet narrowband YTO. In this figure, a center frequency of 12 GHz and a tuning bandwidth of +/-1 GHz for both units is considered. For the EM-YTO, the main coil will use between 3 to 4.5 Watts of DC power in order to cover the 11 to 13 GHz frequency range. By comparison, a PM-YTO with the fixed frequency of 12 GHz, needs approximately 0.5 Watts of power to operate between 11 to 13 GHz. This graph also demonstrates the usefulness of the narroband PM-YTO in even higher frequencies. For an EM-YTO operating at higher frequencies, most of the DC power is wasted by bringing the level of magnetic bias field to the start frequency. For example, a PM-YTO with the center frequency of F_0=18 GHz and tuning bandwidth of +/-1 GHz housed in a (1")^3 shell, will use less than 2 Watts for tuning. The same magnet (in

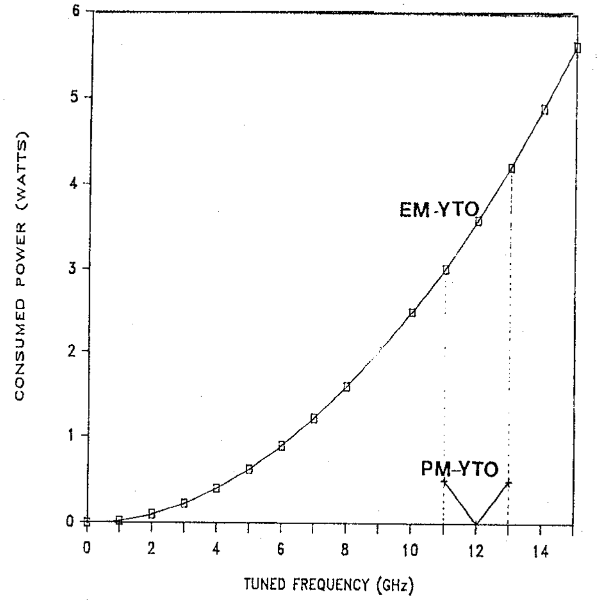


FIGURE 1: A comparison of the power consumption of an EM-YTO and a PM-YTO, both with F_0= 12 GHz and DF=+/- 1GHz.

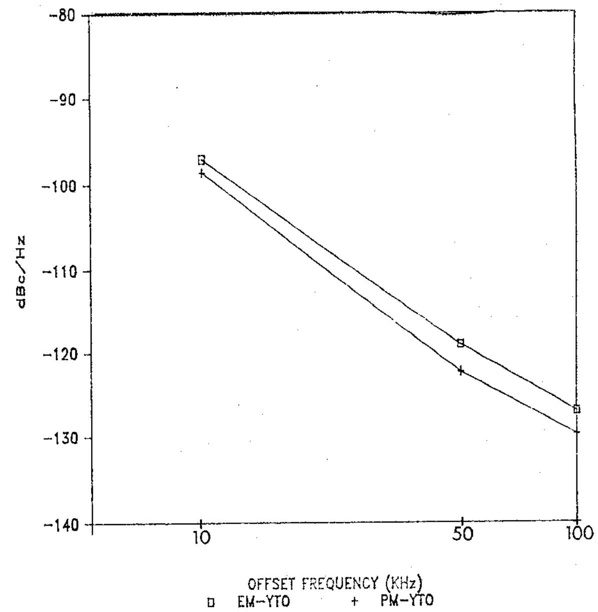


FIGURE 2: Measured phase noise of an oscillator circuit (10 GHz), biased once with an Electromagnet pole and then with a permanent magnet pole.

the same housing) using an electromagnet for magnetic biasing needs more than 20 Watts to reach 18 GHz.

For both types of PM-YTOs, fixed-narroband or mechanically tuned wideband, the reduction in size (or elimination in the the latter case) of the main coil directly translates to the reduction in the overall dimension and weight of PM-YTOs.

In addition, the absence of the main coil in the mechanically tuned PM-YTO is shown to reduce the phase noise of the oscillator. Figure 2 plots the measured phase noise of an oscillator circuit, biased once with an electromagnet pole and then with a permanent magnet pole. This reduction of phase noise in the PM-YTO is believed to be due to the elimination of noise contributing factors of the DC supply, which is needed for tuning an EM-YTO.

AREAS OF CONCERN

The most troublesome area in using any permanent magnet is the variation of magnetization with temperature. There are two types of magnetization changes, permanent and reversible, due to temperature fluctuation. The permanent change portion can be eliminated by stabilizing the permanent magnet and operating the unit well below the magnet's Curie temperature. The reversible change is then the parameter that needs to be dealt with. For example, the reversible temperature coefficient of the three widely used permanent magnets; Alnico, Samarium Cobalt and neodymium, are; .005, .05 and 0.1 %/°C, respectively[1]. If these magnets are used in a PM-YTO operating at 10 GHz, with a temperature range of -50 to +90, they will produce a 70, 700 and 1400 MHz frequency change, respectively.

The most common technique of temperature compensation is the shunting technique. In this method, a special material with negative permeability slope versus temperature is shunted across the poles of the permanent magnet[2].

It is also possible to use the temperature dependency of the YIG resonator's frequency to compensate the temperature dependency of the permanent magnet. Mizunuma et al[3] used a specially doped thin YIG film to compensate the field variation in the gap over the operating temperature range. They have been able to stabilize their 13 GHz thin film YTO to 10 MHz of variation in the temperature range of -30 to +60°C.

At MSI, using a combination of materials and/or technique we have been able to successfully compensate the PM-YTO to a remarkably low value of 15 PPM/°C over a wide temperature range. For example, a 10 GHz PM-YTO was

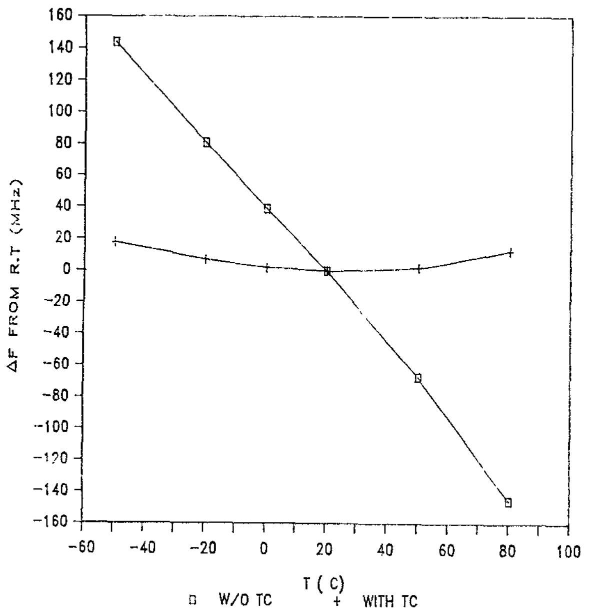


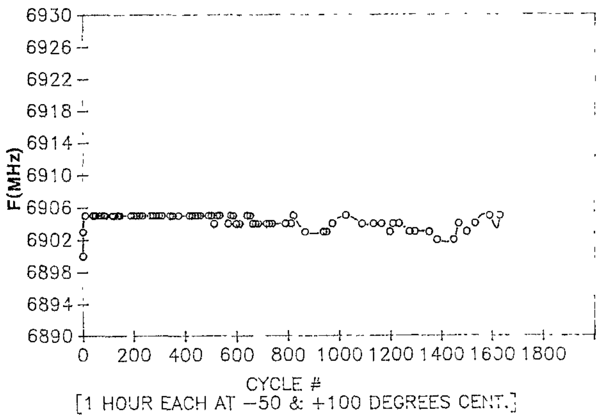
FIGURE 3: The relative frequency change of a PM-YTO, with and without temperature compensation, in reference to room temperature frequency.

temperature compensated to +/-8 MHz in the temperature range of -50°C to +90°C. In the commercial temperature range of 0 to 50°C the unit can be compensated to +/-2 MHz (approximately 10 PPM/°C). The relative frequency change of a PM-YTO, with and without temperature compensation technique is shown in figure 3. Here, the room temperature value is used as the reference frequency.

In the conventional EM-YTO a thermistor heater is used to provide a constant temperature for the YIG sphere in order to minimize the frequency variation of the unit over a wide temperature range. The power used by this heater can be as high as 1.2 Watts at low temperature. With the PM-YTO, the temperature compensation can be extended to also include the YIG sphere contribution, therefor eliminating the use of the heater.

With the elimination of the main coil and the heater in the mechanically tunable PM-YTO, the active components of the oscillator are the only source of power consumption. With the power output of approximately +14 dBm, these devices can be built with a power usage of less than 1 Watt.

Another concern regarding the use of permanent magnets is aging. Traditionally, permanent magnets have been considered unstable when used over a long period of time. The new permanent magnets, after stabilization, show a remarkable degree of insensitivity to aging. Ongoing testing at MSI on aging has shown no detectable loss of magnetization until present time (approximately 6 months). testing is conducted with live units for two different conditions. One in a constant high temperature (+75°C) and the other in a 1 hour cyclically varying temperature of -50°C and +100°C. The



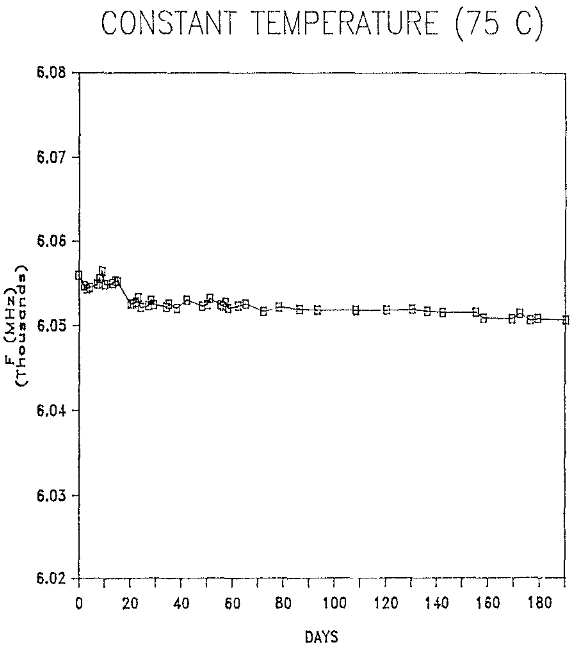


Figure 4: TOP: stability of PM-YTO in the cyclic temperature variation.
BOTTOM: variation of frequency over time for PM-YTO at a constant high temperature.

results of these tests are shown in figure 4.

Finally, the popular belief that a permanent magnet loses its magnetization in a shock is no longer a concern for the new powerful rare earth permanent magnets. The high coercive force of these magnets makes them virtually unaffected by shock.

A photograph of several PM-YTOs, both electrically tunable and mechanically tunable, are shown in figure 5. The measured characteristics of these units are summarized in table 1.

CONCLUSIONS

In this paper the capability of the newly developed powerful permanent magnet as a means of supplying the magnetic biasing field for the design of various YIG tuned oscillators is demonstrated. The biggest obstacle, temperature variation, can be overcome to a remarkably low value of 15 PPM/^{o}C in the full military temperature range. The PMs, when stabilized, show no deterioration of strength due to aging or repeated electrical and mechanical demagnetization.

In conclusion, The highest frequency attainable by the PM-YTO, and its usefulness for the other microwave applications is only limited by the imagination of its designer.

TABLE 1: Measured characteristics of some of the PM-YTOs.

: ELECTRICALLY TUNABLE PM-YTO

	PMO#1	PMO#2	PMO#3
DIMENSIONS	1X1X.5	1X1X1	1X1X1
FREQUENCY (GHz)	6.5	8.5	17.5
TUNING RANGE (MHz)	+/- 500	+/- 500	+/-1000
LINEARITY ERROR (MHz)	.25	.3	.4
HYST. LOSS (MHz)	.8	.8	.6
F VARIATION OF T (MHz) IN 0 TO 50^{o}C	+/-3	+/-3	+/-3
RF POWER OUT	+17	+12	+16
PHASE NOISE (dBC)			
10KHz OFFSET	-100	-98	-
100KHz OFFSET	-128	-128	-

: MECHANICALLY TUNABLE PM-YTO

DIMENSION (INCH)	0.7 Diagonal 0.60 Height
FREQUENCY (GHz)	2 TO 8
F VARIATION OF T (MHz) IN 0 TO 50 ^{o}C	15PPM/^{o}C
RF POWER OUT (dBM)	+14 dBM Minimum
PHASE NOISE (dBC):	
10KHz OFFSET	-100
100KHz OFFSET	-128

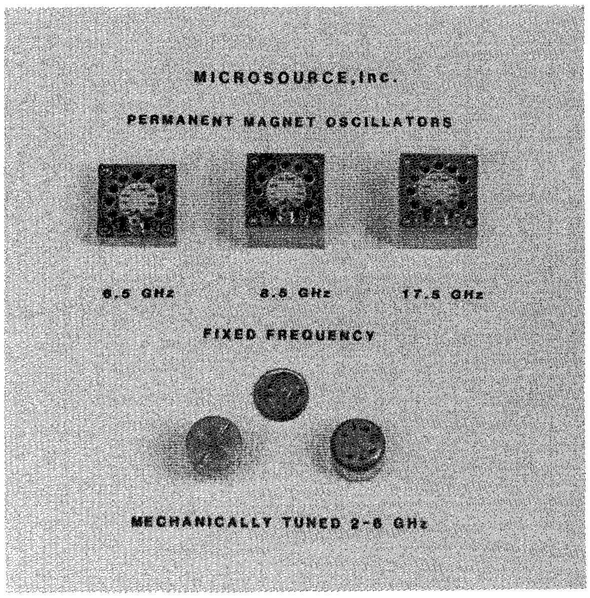


FIGURE 5: Photograph of the two types of PM-YTOs developed at MSI.

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