PASSIVE STABILIZATION OF SOURCES USING A DIELECTRIC RESONATOR AND A MODIFIED RING HYBRID

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ABSTRACT

A new approach for the frequency stabilization of sources[1], high power or low, vacuum tube or solid-state, is described. The method uses a high-Q dielectric resonator coupled to a three arm ring hybrid. Stabilization factors of 3 to 5 have been successfully achieved (in X- and Ku-bands) with pulsed magnetrons over an operating temperature range of -55 to +95 degrees Centigrade, and stabilization factors of 2 to 24 have been successfully achieved with X- and Ku-band pulsed IMPATT oscillators, some, but not all, operating over temperature ranges of -46 to +80 degrees Centigrade.

I. INTRODUCTION

The circuit described in this paper (referred to as the stabilizer) was first developed to improve on the frequency stability of pulsed magnetrons used as the RF power generation source in tracking radar transponders.

The useful life of magnetrons used in tracking radar transponder applications is determined by the frequency window of the tracking radar. When the magnetron drifts out of its allocated frequency window it becomes (for practical purposes) a failed magnetron.

There are four major frequency perturbation contributors associated with magnetrons which under worse case conditions sum to create a relatively large frequency deviation (on the order of 0.2%) from the desired operating frequency. This deviation increases with time (due to "ageing") and unless the magnetron is retuned (which is often not practical from a mission standpoint) the frequency variance places the MTBF of the magnetron at approximately 1000 hours.

The four major contributors to the frequency variances of magnetrons are:

1. Ageing caused by the deposition of cathode material on the anode vanes. This lowers the operational frequency due to increased capacitance as a result of the material build up. Typical ageing drift is 0.1%/1000 hours of operation.
2. Temperature Changes due to environment and pulse repetition frequency (PRF) variances. An X-band magnetron will shift in frequency by approximately 10 MHz for a 100 degree Centigrade environmental change, and approximately 5 MHz for a PRF change from 500 Hz to 5,000 Hz.
3. Filament and Anode Pushing caused by power supply changes. These changes are typically on the order of 2 MHz (X-band) for a 1 volt change in filament voltage or a 10% change in anode voltage.
4. VSWR Pulling due to a less than perfect load.

The stabilizer reduces the above first three effects by a factor 1/S [1] where S is given by:

$$S = [1+Qo/Qe(1-Po/Pa)] \quad (1)$$

Qo = unloaded Q of the stabilizing cavity
Qe = external Q of the oscillator
Po = power delivered to the useful load
Pa = power available from the oscillator into a matched load

The last effect (VSWR Pulling) is reduced an additional amount due to the insertion loss of the stabilizer [1] which is given by:

$$dF = dFo\ (Po)/(S\ Pa) \quad (2)$$

dF = frequency excursion due to the VSWR through all phases
dFo = the frequency of operation change prior to stabilization

By stabilizing the magnetron the individual frequency deviations are reduced by a factor 1/S. Thus the useful life of the magnetron is increased by the numerical value of the S factor (provided some other deleterious effect such as misfiring doesn't occur first).

II. HOW THE STABILIZER WORKS

The stabilizer uses planar microstrip as the circuit media (RT-Duriod 5800™). Figure 1 shows the topology of the circuit.

At resonance the dielectric resonator appears as a high Q open circuit at the interface of its coupling arm and the ring hybrid. Energy incident on the dielectric resonator appears 180 degrees out of phase at the input arm (delta port) and sums with the transmitted energy at the output arm (sum port).

[1] U.S. Patent No. 4843347, foreign filings in progress.

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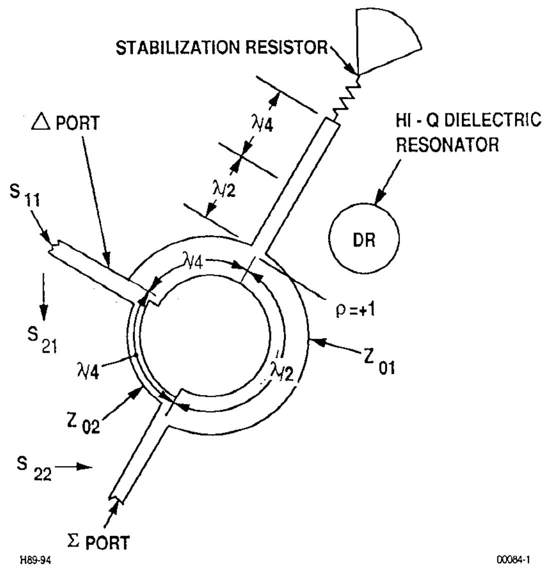

FIGURE 1: TOPOLOGY OF THE STABILIZER CIRCUIT.

Off resonance the reflection coefficient of the dielectric resonator approaches -1 and the input and output ports appear as high impedance and low impedance circuits respectively.

Implementation of the stabilizer with an oscillator to be stabilized is accomplished by obtaining constant frequency contours (Rieke diagram) of the source to be stabilized and adjusting the input impedance of the stabilizer such that its resonant frequency coincides with that of the source to be stabilized and its reactance slope is normal to and of opposite sense as the source's constant frequency contours. Figure 2 graphically demonstrates the foregoing explanation.

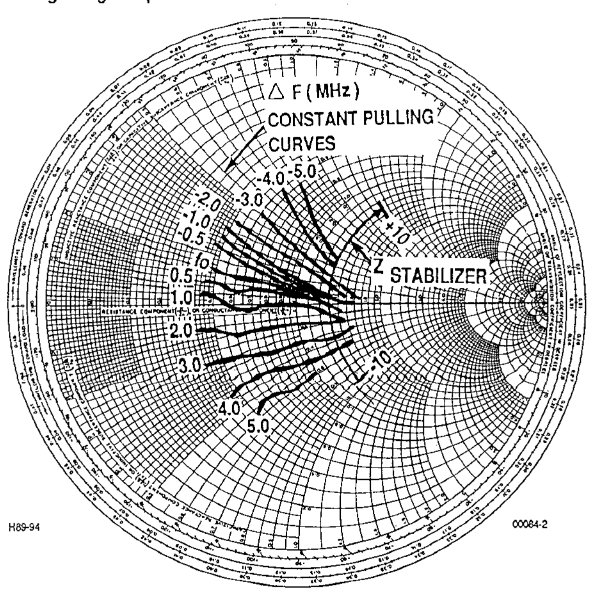

FIGURE 2: SMITH CHART PLOT OF CONSTANT PULLING CONTOURS FOR AN X-BAND MAGNETRON AND STABILIZER S11.

III. PREDICTING THE S FACTOR

A graphical prediction of the stabilization factor is achievable by plotting the reactance slope of the stabilizing frequency contours of the source to be stabilized (with the real part held constant) in X-Y coordinates. Figure 3 shows such a plot with the 25 degrees Centigrade reactance loci taken from the Smith chart of Figure 2. The -50 and +90 degrees Centigrade reactance slopes are obtained by taking the peak to peak drift of the source to be stabilized and using the knowledge that the Q of the source remains constant over temperature (therefore the reactance slopes at the temperature extremes are parallel to the 25 degree Centigrade reactance slope).

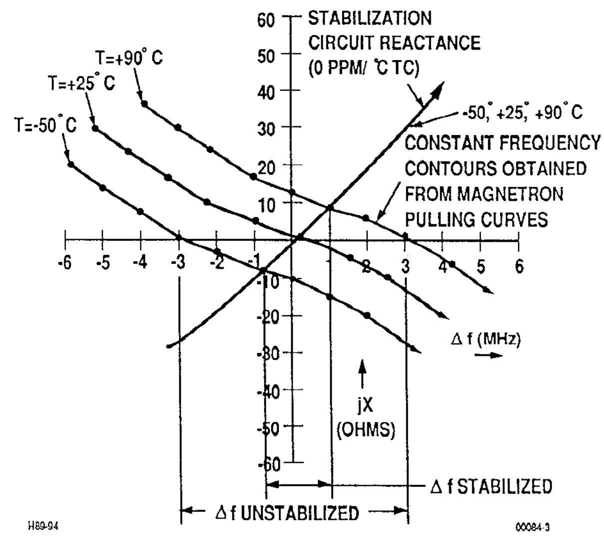

FIGURE 3: X-Y PLOT OF THE LOCUS OF CONSTANT PULLING CONTOURS (RE Z HELD CONSTANT) AND THE REACTANCE SLOPE OF THE STABILIZER'S INPUT IMPEDANCE, ALL TAKEN FROM FIGURE 2.

Inspection of Figure 3 shows that the unstabilized source drifted 6.2 MHz prior to stabilization and is predicted (and measured) to drift 1.8 MHz after stabilization.

Another observation is that in addition to the reduction of the temperature induced frequency drift by that of the S factor further improvement in the frequency vs temperature performance may be made by tailoring the temperature coefficient (TC) of the stabilizer such that it negates the residual frequency drift of the stabilized source. Figure 4 demonstrates this principle while Figure 5 shows the principle put to practice on a magnetron. In Figure 5 the before stabilization frequency drift was 3.3 MHz. Without TC'ing the stabilizer the predicted frequency vs temperature drift is 1.1 MHz (S=3) and the predicted TC'd drift is 0.7 MHz. The measured TC's frequency drift was 0.7 MHz.

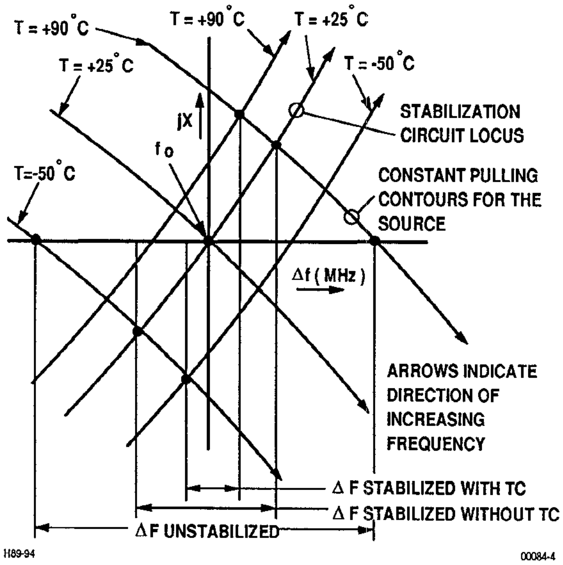

FIGURE 4: REDUCTIONS IN TEMPERTATURE INDUCED FREQUENCY CHANGES MAY BE ACHIEVED BY CHOOSING THE TEMPERATURE COEFFICIENT OF THE STABILIZING CIRCUIT SUCH THAT IT OFFSETS THE RESIDUAL FREQUENCY DRIFT AFTER STABILIZATION.

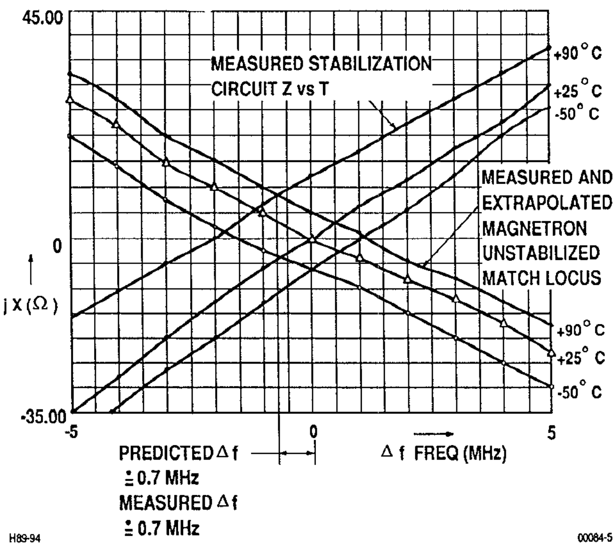

FIGURE 5: THE ABOVE GRAPH PREDICTS THE FREQUENCY DRIFT FOR MAGNETRON SN 1100. PRIOR TO STABILIZATION THE FREQUENCY DRIFT WAS 3.3 MHz, PREDICTED AND MEASURED STABILIZED DRIFT IS 0.7 MHz.

IV. MEASURED PERFORMANCE

The stabilizer has been extensively tested in X- and Ku-bands. A transponder production program experiencing 54% magnetron yields (due to poor frequency stability) increased its magnetron throughput yields to 100% after implementation of the stabilizer.

Figures 6 and 7 show the before and after stabilization performance of a Ku-band magnetron, operating at 16.3 GHz, and an X-band pulsed IMPATT oscillator (9.3 GHz), respectively. In Figure 6 the magnetron was tested over a temperature range of -55 to +95 degrees Centigrade and at each temperature data point the PRF of the magnetron was varied from 500 Hz to 5,000 Hz. The worse case frequency variation of the magnetron prior to stabilization was 13 MHz due to PRF changes and 14 MHz due to temperature effects, or a total of 27 MHz of frequency variances. After stabilization the peak to peak frequency variance, due to PRF and temperature effects, was reduced to 2.8 MHz. The S factor

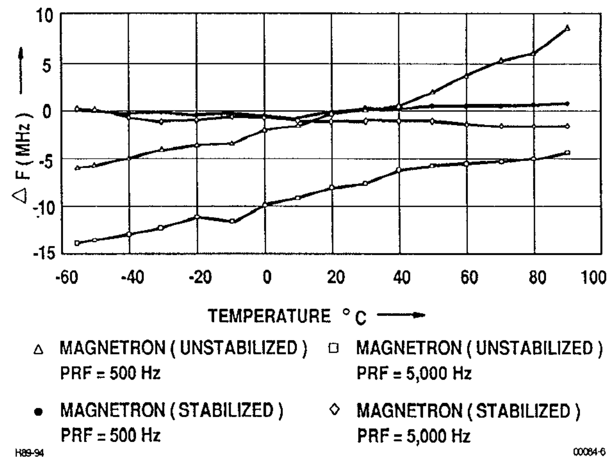

FIGURE 6: STABILIZED AND UNSTABILIZED PERFORMANCE FOR A Ku-BAND MAGNETRON. THE STABILIZATION FACTOR IS 4.5. THE APPARENT STABILIZATION FACTOR IS 10 AS A CONSEQUENCE OF TEMPERATURE COMPENSATION OF THE STABILIZER.

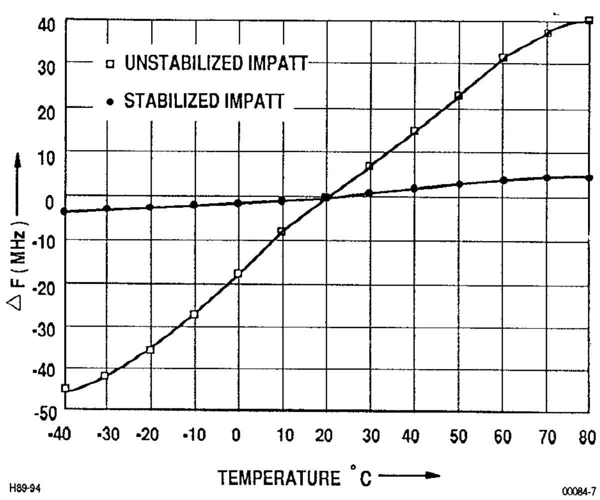

FIGURE 7: STABILIZED AND UNSTABILIZED PERFORMANCE FOR AN X-BAND PULSED IMPATT SOURCE.

for this test was 4.5. The additional frequency stability was achieved by the offsetting temperature compensation of the stabilizer circuit. Figure 6 shows an approximate 10:1 frequency stability improvement on a free running IMPATT oscillator. The free running frequency drift of the IMPATT oscillator was too great to use offsetting TC by the stabilizer and the frequency drift reduction is almost totally due to the S factor of the stabilizer.

V. THEORETICAL LIMITATIONS

Classic stabilization theory predicts that passive stabilization of magnetrons by an S factor greater than 3 gives rise to the probability of operation in modes other than the principle mode of operation [2]. However, the stabilizer circuit has been tested with magnetrons operating in X- and Ku-bands and with stabilization factors ranging from 3 to 5 without any sign of modeing.

The pulsed IMPATT oscillator stabilization experiments did show difficulty in stabilization with S factors greater than 4 (S factors of 2 to 24 were evaluated); by incorporation of the stabilization resistor depicted in Figure 1 stabilization at all evaluated S factors was achieved without frequency hopping.

The role the stabilization resistor plays in excluding unwanted stable operating points is covered by Collins [2] in Section 16.4. Stable and unstable operating points are explained by Kurokawa [3].

VI. OTHER ASPECTS OF THE STABILIZER

In addition to the reduction in frequency variations induced by the aforementioned perturbations the fm (1/f) noise of the source is also reduced by 1/S.

The frequency of operation of the system formed by the source to be stabilized and the stabilizer is given by equation (3) [1].

$$F = Fc+(Fo-Fc)/S \qquad (3)$$

F = frequency of operation
Fc = stabilizer resonate frequency
Fo = resonate frequency of the source to be stabilized
S = stabilization factor

Differentiation of equation (3) gives the basic properties of the stabilizer:

$$dF = (1-1/S)dFc+(1/S)dFo \qquad (4)$$

Setting (4) equal to zero will yield the TC needed from the stabilizer to realize offsetting temperature compensation for the source/stabilizer system.

The stabilization resistor shown in Figure 1 suppresses off-resonance, unwanted frequencies of oscillation. On resonance the real part of the dielectric resonator's impedance overshadows the stabilization resistor's value (typically 50 ohms) and very little power is lost in the stabilization resistor.

VII. CONCLUSIONS

A modern day approach to an old technique has been presented. Passive stabilization of sources (magnetrons) date back to the Second World War and is covered in impressive detail in the MIT Radiation Laboratory Series, Volume 6, Microwave Magnetrons, edited by G.B. Collins [2].

The approach presented realizes a small, compact, and inexpensive method of achieving frequency stabilization of free running sources. The technique is not limited to magnetrons, but applies equally well to other types of sources.

The author would like to thank the supporting contributions of Mr. Lawrence Schumacher (who is co-inventor of the described stabilization technique) and performed the X-band magnetron and IMPATT oscillator stabilization experiments, and Mr. Steve Maziarz who performed most of the Ku-band magnetron stabilization experiments.

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REFERENCES

[1] MITEC Corp., "Stabilizing Cavity Operating Instructions", Microwave Electronics Corporation, Technical Bulletin #10.

[2] Collins, G.B., Editor, Microwave Magnetrons, Vol. 6 of Radiation Laboratory Series, McGraw-Hill, 1948.

[3] Kurokawa, K., "Injection Locking of Microwave Solid-State Oscillators", Proceedings of the IEEE, Vol. G1, No. 10, October 1973, pp. 1386-1410.