COMPUTER-AIDED ANALYSIS AND IMPROVEMENT OF AN 8 TO 18 GHz YIG-TUNED FET OSCILLATOR

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ABSTRACT

Enhancing the performance of a wide-band YIG oscillator requires a comprehensive model of the circuit so that simulation accurately reflects its behavior in the laboratory. We describe how an 8 to 18 GHz FET oscillator is modeled and improved using both circuit simulation and field solving tools, along with fixtures for measuring YIG spheres and other passive networks.

SUMMARY

To gain a more complete understanding of a YIG oscillator circuit already in production (Figure 1), we constructed a comprehensive model of the circuit, drawing on both computer-aided design and network measurements and resulting in both an accurate simulation of the circuit as it exists and a point from which improvements can be made rapidly and with confidence. For simulating the circuit itself, both linear and harmonic-balance analyses were carried out with Libra[1], while a critical microstrip impedance matching network was accurately modeled with Em[2], an electromagnetic field solver. For even greater accuracy, we used measured data for the YIG sphere resonator and coupling loop combination, obtained with a Wiltron 360 network analyzer and specially-modified 3680K microstrip test fixture. We also used this fixture to measure and evaluate passive networks such as spiral inductors for bias and feedback elements in a new oscillator topology. The overriding theme of this work was to use the leverage of existing and readily-available tools to their fullest extent to improve a broadband microwave oscillator in a production environment.

HARMONIC-BALANCE CIRCUIT SIMULATION

Simulation of the circuit in Libra went along the lines of an established procedure[3]: First, the circuit, a common-gate

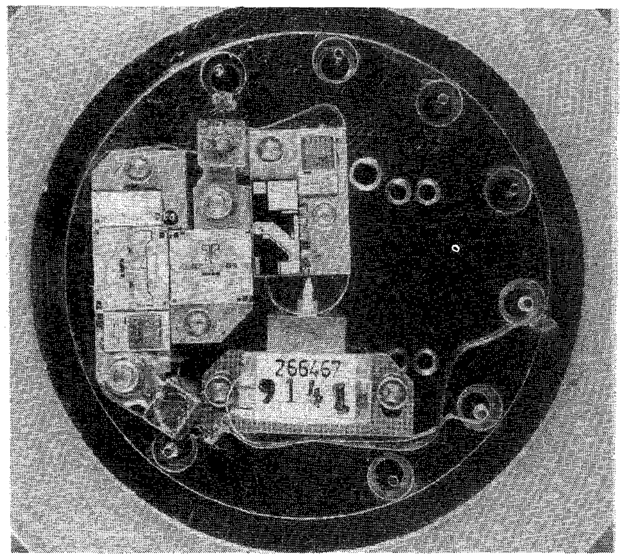

Figure 1. Photograph of Current 8 to 18 YIG Oscillator

topology with an inductive feedback element, was evaluated for negative impedance over the desired tuning range as a one-port reflection oscillator[4] using a linear simulation. We then made several one-port measurements of the YIG sphere resonator alone using the fixture described below. These measurements verified a simple equivalent-circuit model of the resonator based on the work of Carter[5]. Then a harmonic-balance power sweep was conducted with the resonator model in the circuit to determine start-up conditions for the oscillator at various frequencies throughout the observed tuning range of the oscillator. Finally, the simulation would converge on an actual operating frequency with a harmonic output spectrum which matched measured data within ±2 dB (Figure 2). Although the circuit itself used an NEC 70000, we employed the nonlinear FET model for the NEC 71000 supplied with Libra with acceptable fidelity to the observed performance of the circuit over its tuning range.

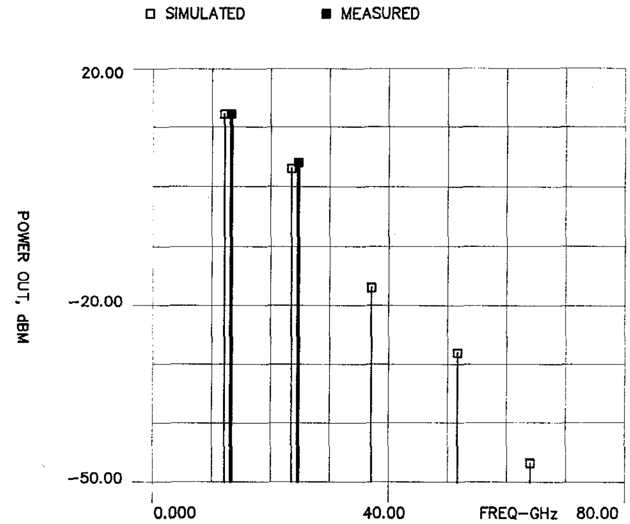

Figure 2. Simulated and Measured Output Spectrum of Oscillator at 12 GHz

ELECTROMAGNETIC CIRCUIT SIMULATION

The circuit includes an irregularly-shaped microstrip matching network with bonding points to 50 pF capacitors, used as tuning stubs. While this network is critical to the operation of the oscillator, it cannot be accurately modeled using the built-in microstrip elements offered by Libra or any other commercial simulator because of its irregular geometry. To promote accuracy in the simulation, we used an electromagnetic field analysis tool, Em, to solve for the current distribution in the metallization and then give S-parameters of the network at several frequencies of interest throughout the tuning range of the circuit[2]. The matching network was rendered accurately with Xgeom, a geometric layout tool compatible with Em, including ports for the tuning bonds (Figure 3), then simulated over the range of 7 to 20 GHz, resulting in a 5-port S-parameter file compatible with Libra 3.0.

A particular advantage of using an arbitrary-geometry electromagnetic simulator in this application came about by observing how technicians would increase tuning coverage at the low end of the band: A corner of the microstrip would be scratched away (compare Figures 3 and 4) to increase the impedance of the network. When this action was simulated with Em, we observed good correlation between the increased low-end coverage of the scratched circuit in simulations and on the bench. Additionally, the simulation showed that there was a potential "hole" (where oscillations would cease) at 12 GHz that could show up with the scratched circuit; this is reflected in reality, as well.

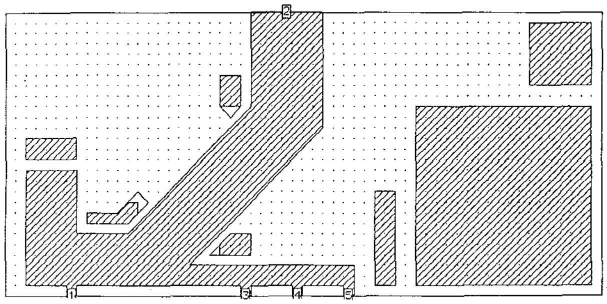

Figure 3. Oscillator Output Matching Network, Rendered in Xgeom for Simulation

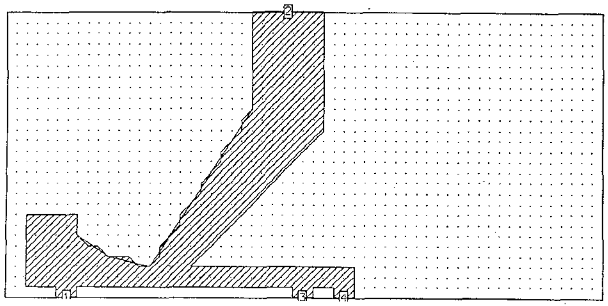

Figure 4. Simplified Output Matching Network Simulating an Empirical Modification Made to Improve Low-end Tuning of the Oscillator

With this complete simulation in hand, it was possible to adjust the oscillator circuit in much the same way as it is done on the bench: By removing or adding bond wires in the circuit simulation, different negative-resistance characteristics were produced, with the possibility of rapid optimization.

USE OF YIG SPHERE AND LOOP TEST FIXTURE

Particular difficulties limiting the tuning range in a wide-band YIG sphere oscillator often arise due to excess phase in the sphere/coupling loop resonant structure. To completely characterize the effects of changing the loop and sphere dimensions, we built a YIG sphere test fixture with a modified tuning magnet and microstrip transitions for use with a Wiltron 3680K Universal Test Fixture (Figure 5). By using identical reference and test fixtures, we could include an accurately-placed short-circuit termination (Figure 6) to set an electrical reference plane, then insert the same ribbon coupling loop circuit used in the production oscillator (Figure 7) and perform accurate measurements of the sphere/loop resonator at various frequencies. Data from these measurements were used to enhance a circuit model of the YIG sphere resonator for increased accuracy in simulation.

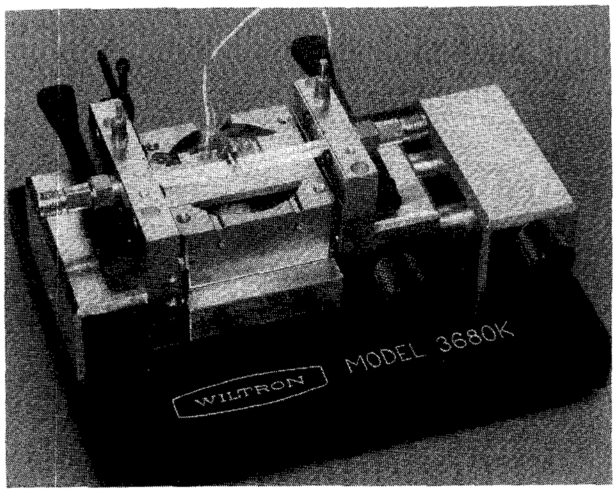

Figure 5. YIG Sphere and Coupling Loop Test Fixture, Upper Magnet Shell Removed

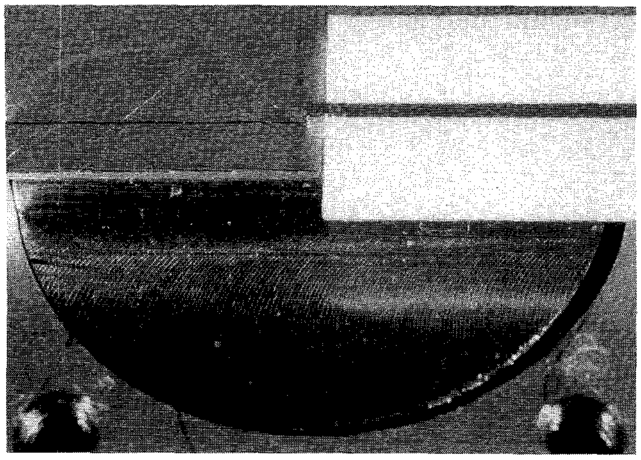

Figure 6. Detail of Microstrip Short-Circuit for Location of Reference Plane

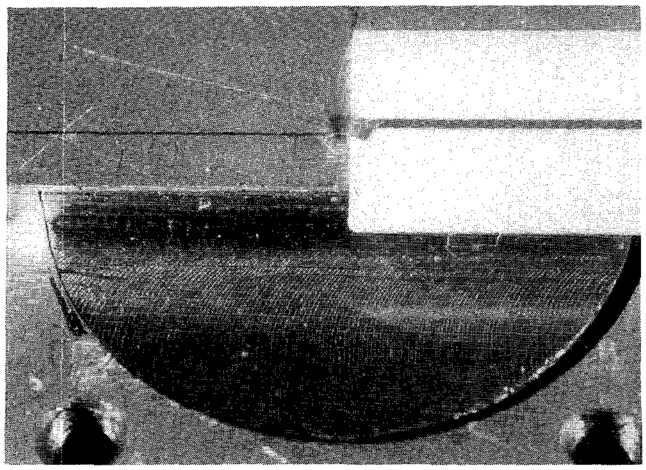

Figure 7. Detail of Ribbon Coupling Loop in Test Fixture

USE OF TEST FIXTURE FOR OTHER PASSIVE NETWORKS

This fixture also proved useful in measuring other passive networks used in these circuits. One example is the measurement of printed spiral inductors on quartz substrates, which we evaluated for use as feedback elements in a new circuit design to replace the current one. The measured data from these spiral inductors showed the presence of a > 1 pF inter-loop shunt capacitance which, when placed in the source of an NEC 71000 FET, would result in a very broadband negative resistance characteristic at the gate terminal. However, when a coupling loop of sufficient length is bonded to this terminal, a fixed oscillation usually occurs due to the resonant tank circuit formed by the feedback capacitance and the self-inductance of the loop. Simulations in Libra predicted a fixed oscillation at 9 GHz; when the circuit was built and tested, a fixed oscillation was observed at 9.2 GHz. However, with the resulting increased confidence in the simulation's accuracy, we were able to develop a phase compensation scheme to drive this oscillation out of the tuning band and hence develop an improved circuit design free of fixed oscillations.

CONCLUSION

In conclusion, we have developed a comprehensive model of a production YIG sphere oscillator using both commonly-available CAD tools and specialized measurement fixtures to enhance the accuracy of the circuit simulation. Because of this accuracy, we have achieved very close agreement between simulated and actual results over the broad tuning bandwidth of the circuit. With such correspondence as a baseline, we can then optimize the circuit model to achieve better performance in the actual circuit as well as develop new designs having close connections between simulations and reality.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Libra 3.0, EEsof, Inc., Westlake Village, CA.

[2] Em 2.1, Sonnet Software, Inc., Liverpool, NY.

[3] Libra 3.0 Procedures and Examples, pp. 8-25--8-39.

[4] Esdale, D.J. and Howes, M.J., "A Reflection Coefficient Approach to the Design of One-Port Negative Impedance Oscillators," IEEE Trans. Microwave Theory Tech., August 1981, pp. 770-776.

[5] Carter, P.S., "Equivalent Circuit of Orthogonal Loop-Coupled Magnetic Resonance Filters and Bandwidth Narrowing due to Loop Inductance," IEEE Trans. Microwave Theory Tech., February 1970, p. 100.