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A Magnetically Tunable Microstrip IMPATT Oscillator

B. GLANCE

***Abstract*—Magnetically tunable resonators have been constructed in microstrip on a ferrite substrate. A large tuning range is obtained with an external magnetic field applied in the direction of the RF propagation, 17 MHz/Oe for magnetic fields from 0 to 30 Oe. A variable frequency microstrip oscillator which uses this effect is described; measurements made on an *X*-band IMPATT oscillator illustrate a tuning range from 9.4 to 10.5 GHz with an output power of 330 mW ±0.5 dB.**

I. Introduction

Solid-state microstrip oscillators are nearly fixed frequency sources which can be tuned over only a very limited frequency range by changing the dc current applied to the diode unless the resonant circuit in which they are placed is also tuned in some way. Varactor tuned oscillators [1] provide a solution to this problem but require additional microstrip circuitry and a second power supply for biasing the varator diode. YIG-tuned oscillators [2]–[6] are another solution but need large magnetic fields at microwave frequencies; at *X* band for example a highly homogeneous magnetic field of about 3500 Oe is required in order to avoid spurious modes.

A variable frequency microstrip oscillator with a ferrite substrate is described in this short paper. Such microstrip resonators can be frequency-tuned by a low magnetic field applied in the plane of the ferrite slab. A tuning range of 25 percent has been measured with a magnetic field varying from 0 to about 600 Oe.

II. Propagation in Ferrite-Filled Microstrip Line

Propagation of electromagnetic waves in gyromagnetic media has been the subject of considerable investigation. Most of the analyses have been made for ferrites magnetized at saturation. The propagating mode for wide ferrite-filled microstrip lines is a TEM mode with a scalar permeability. For ferrite substrates which are magnetized at saturation in the direction of propagation, the relative permeability is approximately [7]–[9]

$$u_r \approx 1 - \left(\frac{\omega_m}{\omega}\right)^2 - \frac{\omega_0\omega_m}{\omega^2} \qquad (1)$$

with

$$\omega_0 = |\gamma| H_0$$
$$\omega_m = |\gamma| 4\pi M$$

where H_0 is the effective dc magnetic field, $4\pi M_s$ is the saturation magnetization (equal to 2650 G for the ferrite used in this experiment), and $|\gamma|$ is the gyromagnetic constant 2.8 MHz/Oe. The frequency tuning of ferrite-filled microstrip resonators is due to the variation of the permeability with the dc magnetic field. Above saturation the frequency is found to vary about 2 MHz/Oe. This variation is mainly due to the term $\omega_0\omega_m/\omega^2$ of (1). A far more rapid change of frequency with applied magnetic field, about 17 MHz/Oe, has been measured in our experiments for magnetic fields from 0 to about 30 Oe which are far below the saturation field of about 300 Oe. This effect is due to the variation of the permeability from the demagnetized state to the saturated state [10]–[12].

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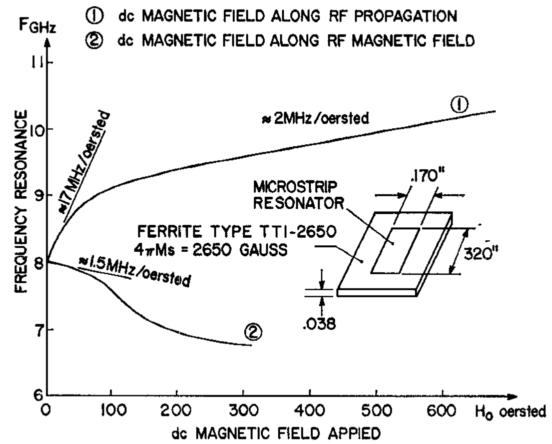

Fig. 1. Resonance frequency of a ferrite-filled microstrip resonator partially magnetized by a variable dc magnetic field directed: ① along the direction of propagation; ② along the direction of the RF magnetic field.

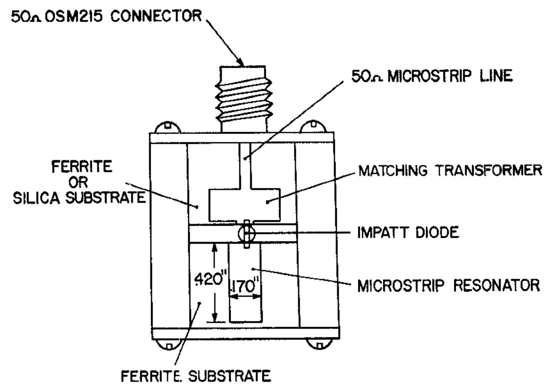

Fig. 2. Schematic drawing of the ferrite-filled microstrip IMPATT oscillator built at *X* band.

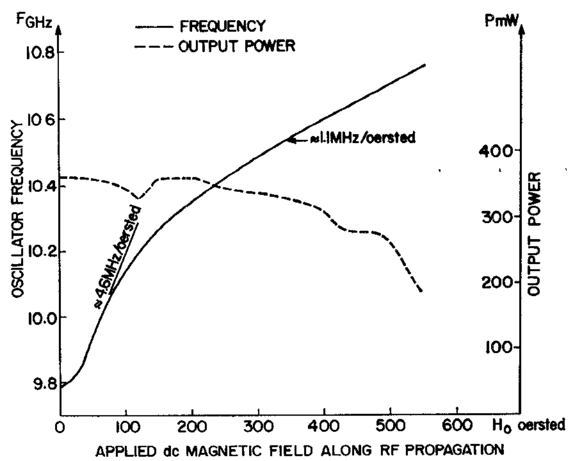

Fig. 3. Power and frequency of the oscillator versus applied dc magnetic field obtained with a microstrip circuit on a ferrite substrate.

Measurements have been made on a ferrite-filled microstrip resonator with the dimensions shown in Fig. 1, which shows also the resonance frequency versus the applied dc magnetic field for: 1) a magnetic field applied along the direction of RF propagation, and 2) a magnetic field applied along the direction of the RF magnetic field.

III. Ferrite-Filled Microstrip Oscillator

As shown in Fig. 2 the microstrip circuit of the oscillator employs two substrates. One substrate is used for the resonator and the other for a matching transformer and output circuit. The diode is mounted between the substrates as shown in Fig. 2.

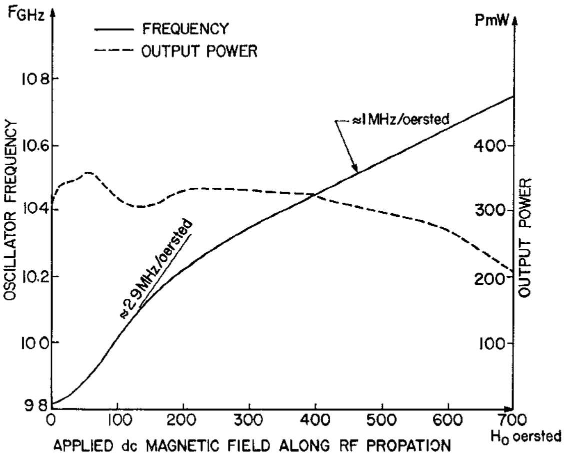

Fig. 4. Power and frequency versus applied dc magnetic field obtained with an output circuit built on a silica substrate and using a ferrite-filled resonator coupled to the diode.

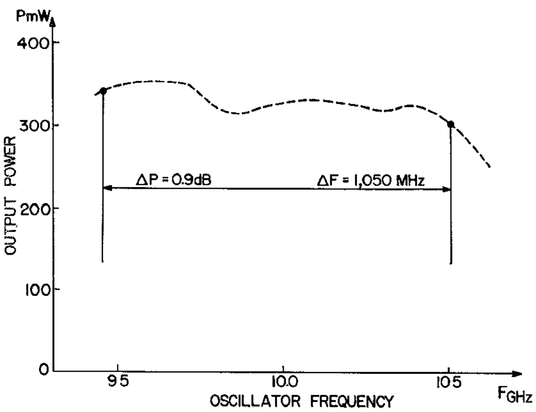

Fig. 5. Power versus frequency obtained by tuning the oscillator with a permanent magnet.

Fig. 3 shows the results obtained with the oscillator biased by an electromagnet; the magnetic field was applied in the direction of the propagation.

Fig. 4 shows similar results obtained with the 50-Ω line and quarter-wavelength transformer made on a silica substrate. The diode is coupled to the same ferrite-filled microstrip resonator as previously described.

Frequency tuning has also been achieved with a small cylindrical permanent magnet 0.500 in wide and 0.500 in long. The fringing field of the magnet has a maximum value of about 2000 Oe. Frequency tuning is obtained by sliding the magnet across the shielded end of the ferrite-filled microstrip resonator. Part of the frequency tuning, at the low end, is obtained by the transverse component of the magnetic field. Fig. 5 shows the results which have been obtained by this method.

Conclusion

A variable frequency microstrip resonator using a partially magnetized ferrite substrate has been used for tuning an X-band IMPATT oscillator. Frequency tuning with a slope of about 4.6 MHz/Oe has been achieved with a magnetic field of 30 to 80 Oe applied in the direction of the RF propagation. Frequency tuning has also been obtained by displacement of a small magnet across the shielded end of the resonator. In this way a tuning range of about 10 percent was obtained with an output power of 330 mW ±0.5 dB.

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Double-Amplification Mode Maser

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***Abstract*—A chromium-doped rutile traveling-wave maser utilizing simultaneously two signal frequency transitions has been designed and a prototype section tested.**

The use of a chromium-doped rutile as an active medium for a paramagnetic maser is governed by the following properties of the material [1].

1) The ground state of the Cr^{3+} ion is split in a magnetic field into four levels (designated 1, 2, 3, and 4, in the order of increasing energy).

2) The ion can be located in one of two magnetically inequivalent sites.

3) For a magnetic field inclined at the angle of 54°44′ ($=\cos^{-1} 1/\sqrt{3}$) to the c axis and lying in the (010) or (100) planes, the energy levels of the two sets of inequivalent ions are identical and the frequencies of the 1–2 and 3–4 transitions are equal. The lowest frequency of the 2–3 transition is 21.7 GHz.

The choice of the direction of the magnetic field specified above results in an efficient use of the active medium in that all chromium ions participate in the gain mechanism, and all four level populations contribute to the establishment of population inversion. For signal frequencies above 21.7 GHz, this can be achieved by employing the push–pull pumping scheme. For signal frequencies below 21.7 GHz, 1–2 and 3–4 are utilized as the signal and 1–4 as the pump transitions; this mode of operation has been designated the double-amplification mode [2].

Following the guidelines sketched above, a prototype test section of a 15.7 GHz traveling-wave maser has been built and tested. The high values of permittivity of rutile (250 and 150 in the directions parallel and perpendicular, respectively, to the c axis) allow one to obtain a slowing factor of about 15 by employing dominant-mode rectangular waveguides filled with rutile. The waveguide dimensions chosen were 0.07×0.14 cm². The need to eliminate gaps between metallic walls and the dielectric for structures of this size precluded the use of machined parts, and electrolytic deposition methods had to be employed.

The observed electronic gain of a 12-mm-long test section at 4.2 K was 2.5 dB with a 3-dB bandwidth of 25 G. For the low value of gain observed, the amplifier bandwidth is approximately equal to the combined linewidth of the two signal frequency transitions involved. Thus, with the incremental gyromagnetic ratio of 4.6 MHz/G, the effective value of linewidth was approximately 115 MHz. When not pumped, the electronic loss of the structure was 2.5 dB/cm at 4.2 K. Due to different filling factors of the two signal frequency transitions, the ratio of gain to loss, 2.5/2.5 dB = 1, can be equated to the inversion ratio only if one assumes the same spin temperature (negative) for the two transitions.

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